Carpathian Journal of Earth and Environmental Sciences, August 2019, Vol. 14, No. 2, p. 385 - 398; DOI:10.26471/cjees/2019/014/088

FIRST ANALYSIS RESULTS OF IN SITU MEASUREMENTS FOR ALGAE MONITORING IN LAKE NAPLÁS (HUNGARY)

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Abstract: Accurate knowledge about the quality of water bodies is crucial for natural resource management. A significant part of the biological water quality is related to the chlorophyll-a content of the phytoplankton. Their spatial distribution is very inhomogeneous in the water bodies, depending on several influencing factors such as nutrient availability, water temperature, wind and underwater light conditions. To study this complex system, a long-term observation and sampling experiment was carried out on Lake Naplás, Hungary. As the first step, a database was developed of the actual vertical distribution of algae together with the most important influencing factors: underwater light conditions measured from ultra-violet (UV) to infrared (IR), water temperature and a number of selected chemical parameters. During the observation period, 34 campaigns were carried out at three observation points, and more than 1020 samples and in situ measurement data were collected. The measured parameters included water temperature, UV radiation, underwater light conditions (350-800 nm), chemical parameters (Fe, NO_2^-, NO_3^- NH_4^+, PO_4^{3-}, pH, hardness) and chlorophyll-a content. The results showed that the main influencing parameters of the vertical distribution of chlorophyll-a were the water temperature, UV radiation and the available light.

Keywords: algae, underwater light condition, chlorophyll-a, UV radiation, water temperature

1. INTRODUCTION

Water is one of the most important and most vulnerable natural resources. Information about its quantity and quality is inevitable for proper resource management from the local to the international river basin levels. The European Union's Water Framework Directive (European Community 2000) states that the Member States of the European Union should aim to achieve at least good water quality status of their water resources or, where good water quality status already exists, it should be maintained. For this, it is inevitable to monitor the relevant parameters of the water bodies.

A large number of small and shallow lakes and wetlands can be found in Hungary. These areas encompass complex ecosystems, which are in the focus of the European Union's regulations, since the state of such water bodies is critical in the Member States, including Hungary. These areas provide important ecosystem services for the nearby residents, who strongly depend on the chemical and biological properties of the water.

Water quality is a complex concept, that refers to the hydrological, chemical, physical and biological characteristics of water (Padisák 2005; Chapman 1996). A significant part of this concept is the biological water quality (Allaby et al., 2008), that is associated mainly with the presence and distribution of algae, frequently characterised by the chlorophyll-a (Chl-a) concentration, that can influence the water quality in many different ways (Jindal et al., 2015).

Spatial distribution of the algae is inhomogeneous, depending on several influencing factors, widely studied by researchers. For example, the role of vertical mixing on the algae distribution was examined in a stratified reservoir by Serra et al., (2007). They showed that in a stratified water body, in case of weak surface forcing, i.e. weak winds or low surface energy dissipation, algae form distinct layers during the day which are dissolved at night or when surface forcing is increasing. Moreno-Ostos et al., (2006) investigated the vertical distribution of different algae species in a thermally stratified reservoir. They found that the maximum concentrations of the two examined algae species were formed in two different depths, i.e., the different species reacted on environmental factors differently.

Several authors studied the vertical distribution of algae with in situ methods, for example, using submersible fluorescence spectrometers (e.g. Bazzain et al., 1992; Poryvkina et al., 2000 and Gregor & Maršálek 2004; Parésys et al., 2015). The reliability of the method was examined with different phytoplankton species which belonged to divisions of *Chlorophyta*, *Dinophyta* and *Heteroconthopyta* (Moreno-Ostos et al., 2006). Researchers can easily get a large amount of data about the vertical distribution of algae at one point with this technique, but the financial costs are very high, especially when larger areas have to be covered.

Remote sensing provides a synoptic overview of a large area and has many application opportunities in water research (Campbell 2006). It can be used for quantifying those water quality constituents, which influence the reflectance of water, among which the Chl-a, suspended solids and dissolved organic matter are the most important ones (Budhiman et al., 2012). Furthermore, material covering the surface, for instance, oil spills can be detected, as well as physical property that is related to the energy emitted by the water body, i.e., the water surface temperature can be quantified (Dekker et al., 2001). Maybe the most widely observed parameter is the Chl-a, both with dedicated sensors as the Envisat MERIS (Doerffer and Schiller 2007) and Sentinel-3 OLCI (Toming et al., 2017) with more generic sensors like the Landsat-8 OLI (Yang & Anderson 2016) or the Sentinel-2 MSI (Toming et al., 2016). A shortcoming of this technology is that with the available processing methods we get a concentration value for each location (pixel), but it is not known how the vertical distribution of Chl-a influences this value.

Phytoplankton ecology was widely examined in freshwater lakes, e.g., by Giripunje et al., (2013). They found that the most important influencing factors of the vertical distribution of phytoplankton are the light, transparency, pH, nutrient concentration, prey-predator relationship, fish population, the structure of the lake, seasonal variations of sunshine, wind, and water temperature. One of the most important parameters related to photosynthesis is the distribution of underwater light. The photosynthesising organisms need appropriate wavelengths of light (Kirk 2011), so they actively adapt to the available light field, but the other parameters mentioned above also influence the actual vertical distribution. Based on our antecedent experience, the vertical distribution of underwater light – including the UV radiation – and the water temperature can be of considerable impact on the vertical distribution of the phytoplankton.

Linking the vertical distribution of algae to the signal measured by remote sensing sensors is an ultimate challenge. As the first step in this direction, the present study aims at building a database of the actual vertical distribution of the algae together with the data of the most important influencing factors: underwater light condition measured from ultra-violet (UV) to infrared (IR) and water temperature. This provides the basis for achieving our later objective: defining how these factors influence the vertical distribution of the phytoplankton.

The database is built upon a complex and long-term in situ sampling and measurement series in a study area in Hungary. This article introduces the first one-year time series of parameters describing the annual cycle of the environment and its influence on the values of the physical, chemical and biological parameters related to the distribution of algae. To achieve this main objective, we took the following steps:

- First of all, we designed and carried out a systematic in situ measurement and sampling series of Chl-a concentrations and other selected physical and spectral properties of water.
- We determined the relationship between the ultra-violet radiation and the algae distribution.
- Finally, we analysed the effect of water temperature on the vertical distribution of the algae.

2. STUDY AREA

The study area is the Lake Naplás, a small reservoir on the Szilas Creek in the outskirts of Budapest (Fig. 1). Nowadays, this shallow artificial lake is utilised primarily for sport angling. The average depth of it is 3m. With its 520m length and 320 m width, Lake Naplás is the biggest open-surface urban lake in Central Europe (Bognár 2005), located in the middle reach of the Szilas creek, which flows from the Gödöllő hills to the Danube along a 27km long route. The lake and its direct surroundings are under environmental protection since 1997, and provide habitat for unique wildlife in the urban region, giving shelter to migratory birds and other animals and plants, like the common spadefoot toad (*Pelobates fuscus*) and the pond turtle (*Emys orbicularis*). The latter is the only native tortoise species in Hungary. There were 150 different bird

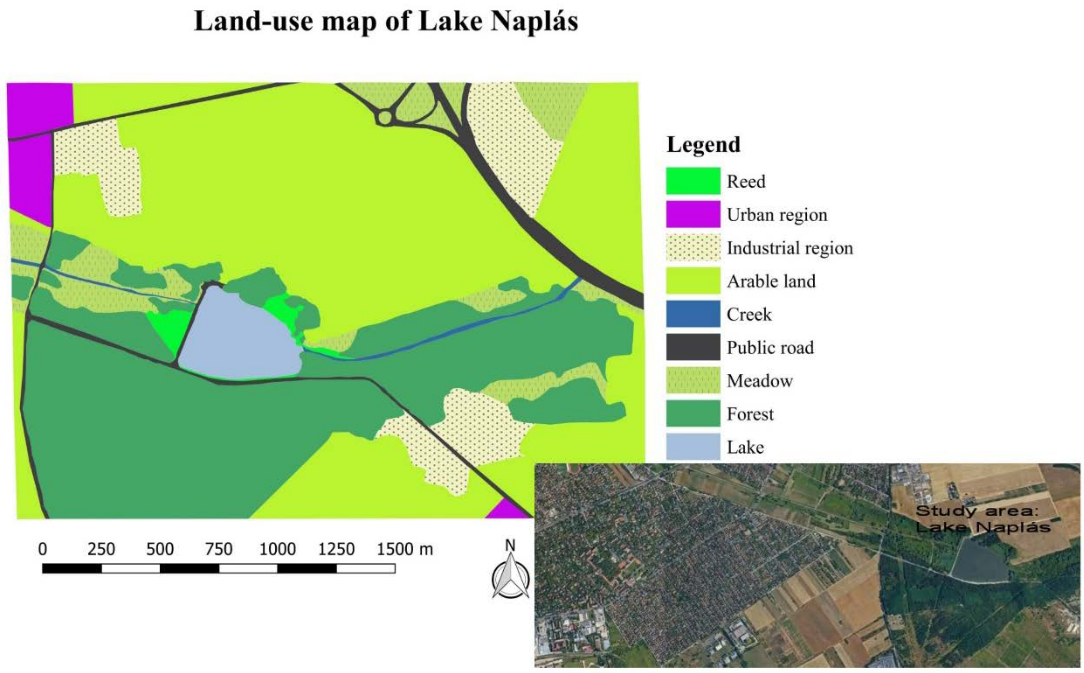

Figure 1. Land use map of the surroundings of Lake Naplás and its location (Source of satellite image: Google Earth, CNES/Airbus Digital Globe, 7th October 2016)

species observed around the lake. The fish fauna is managed by fish planting to meet the needs of the sport anglers. As part of the management measures, in case of algal blooms, occasional chemical treatment is used for the suppression of the algae concentration in the water. Furthermore, many protected plant species can be found around the lake, for instance, the Siberian iris (*Iris sibirica*) and the cream pincushions (*Scabiosa ochroleuca*). A remarkable landmark is a swamp willow in the northern side of the lake, which stands in a strictly protected area.

3. METHODS

3.1. Data collection

For setting up the database, an in-situ data collection campaign was carried out to record the following parameters throughout at least one vegetative period:

- vertical distribution of phytoplankton (investigated parameter: Chl-a) by taking water samples for laboratory analysis, and
- vertical distribution of selected environmental parameters (UV radiation, water temperature and underwater light conditions), partly analysed from the water samples in the laboratory and partly recorded by in situ measurements.

Due to practical reasons, the measurements could not start at the beginning of the vegetative period in 2015, only in June. Nevertheless, the recently available data set allows some conclusions on the first completed twelve months. With this analysis, we aim at drawing the first conclusions on the vertical distribution of the algae in Lake Naplás, but the measurements are continued beyond the here-discussed period, that will enable us to carry out a more detailed analysis in the near future. The analysis is focusing on the location N1 (N2 and N3 were used only in extreme circumstances, Fig. 2), so in the following, this is the referred observation location when it is not indicated differently.

The collected data have been analysed for the three main measured parameters over 34 sampling campaigns, covering one year.

3.2. Locations of water sampling and in situ measurements

The sampling and measurement process started in June 2016, so the first year ended in June 2017. During this observation period, 34 campaigns were carried out, and more than 1020 samples were collected at three observation locations (Fig. 2, and Table 1). The number of samples collected at the different sampling points was the following: 690 samples from N1, 180 samples from N2 and 150 samples from N3. A submerging sampler was used for water sampling, specifically developed for this experiment. It was operated from a boat that was navigated to the predetermined sampling locations using a GPS.

The first observation location (N1) was on the northern side of the lake, where currents are moderate, and anglers hardly disturb the water.

We collected water samples at two times of the day to document the extremities of the daily phytoplankton migration. We used this sampling point throughout almost the whole year, except for the winter season when the lake is frozen and walking on the ice is not permitted.

The N2 observation location was selected on the southern side of the lake to provide continuity in the measurements for the winter period. It was at a landing point with a small pier for boats, so it is accessible in the winter. Unfortunately, here, the water is frequently disturbed in the summer period. Therefore, this location was used only in the winter, when N1 was not approachable, and the pier was not used for landing.

Figure 2. Observation locations on the lake

The third observation location (N3) was close to the inflow of the Szilas creek. This area of the lake is shallower than the others, and it is partly covered with reed along the coast. In this region, due to the vicinity of the inflow, the concentration of the nutrients is higher, and due to the shallow depth, the water temperature is also higher than at the other parts of the lake. These influencing factors cause algal blooms in this region frequently.

The N3 location was used during the algal blooms to capture the higher concentrations of Chl-a. At each location, samples were taken, and measurements were made (Table 1). In the following, the positions where measurements and samples were taken at different depths at the observation locations are referred to as sampling points.

3.3. In situ measurements

Underwater light condition data, UV radiation and water temperature values were collected in the field. Furthermore, water samples were collected in the sampling points for laboratory analysis. A cooler box was used for preserving the samples during the sampling process and transportation. Other measures were not necessary since the chemical laboratory analyses were performed latest within 2 hours after the collection. The main objectives of the in situ measurements were to quantify the most important influencing parameters which affect the vertical distribution of phytoplankton and to determine how the vertical distribution of algae affects the underwater light conditions, including the subsurface irradiance reflectance. The measured parameters are listed in Table 2.

Underwater light conditions were measured parallel to the water sampling. Two different types of Ocean Optic STS spectrometers were used for the experiment. Together, the sensing range of the two spectrometers is 190-800 nm. The view angle of the optical fibre is 180° as a cosine corrector was used during the measurements. A supporting structure was constructed for the sensors to exclude any shielding effect that could confuse the measurements.

3.4. Water sample analysis

The objectives of the laboratory analysis were to determine the concentration of the most important chemical components, which can influence the distribution of phytoplankton, and to quantify the abundance of algae in the samples. Thus, the laboratory-measured parameters were the following: concentration of Chl-a and some other selected chemical components, i.e., Fe, NO_2^-, NO_3^- NH_4^+, PO_4^{3-} content as well as hardness and pH. Table 3 lists the analysed chemical parameters and the used instruments.

A reliable technique of phytoplankton concentration determination, the Felföldy method (Felföldy 1987) was applied, which uses methanol to extract Chl-a pigments from the cells (Kiss Keve 1998). A laboratory spectrometer (Jenway 6405 UV/VIS Spectrophotometer) was used to determine the Chl-a content of the collected water samples. The chemical parameters (Table 3) were measured with the laboratory photometer from the samples of 250ml collected at the measurement points. For the Fe, NO_2^-, NO_3^-, NH_4^+ and PO_4^{3-} measurements, the water samples were treated with the prescribed reagent (determined and composed by the manufacturer) and were analysed in the photometer. The pH and the hardness were measured on the site by in situ measuring instruments.

Table 1. Vertical distribution of sampling points at the three observation locations

Obs. Location	Coordinates	Water depth	Sampling depth 0-1 m	Sampling depth 1 m - bottom	Number of sampling depths	Sampling times
N1	47°30'36.17" N; 19°14'50.66" E	1.8 m	By 0.1 m	By 0.2 m	15	In spring, summer and fall, 14:00 h and 19:00 h
N2	47°30'30.38" N; 19°14'38.14" E	1.8 m	By 0.1 m	By 0.2 m	15	In winter 14:00 h
N3	47°30'34.23" N; 19°14'59.84" E	0.7 m	By 0.1 m	n.a.	8	During algal blooms, 15:00 h

Table 2. Measured parameters and the applied instruments

Investigated parameters	Instruments	Measurement points	Measurement time
Water temperature	Mares Icon HD professional dive computer	by every 10 cm depth	together with water sampling
Wind speed	Voltcraft BL-30 AN	1 m above the water	3 times during sampling
Ultra-violet radiation	Reena UV Master & Ocean Optics STS-UV (190-650 nm) modular spectrometer	1 m above water and every 0.1 m between 0-1 m underwater	together with water sampling.
Underwater light conditions	Ocean Optics STS-VIS (350-800 nm) modular spectrometer	every 0.1 m between 0-1.8 m underwater	together with water sampling.

Table 3. Water sample analysis: parameters and equipment

Investigated parameters	Instruments	Number of the measured samples
Chemical parameters: Fe, NO_2^-, NO_3^- NH_4^+, PO_4^{3-}, pH, hardness	Hanna Instrument HI 83200 photometer	510
Chlorophyll-a content	Jenway 6405 UV/VIS spectrometer	510

3.5. Analysis steps

Based on the in situ and laboratory measurements, the analysis steps were the following:

- Statistical characterisation of the vertical and temporal distribution of the algae.
- Analysis of the suspended particulate matter to define the proportion of the algae in it.
- Combined analysis of the Chl-a and underwater light distributions.
- Multivariate analysis of the measured parameters (UV, radiation index, water temperature, etc.) and the Chl-a concentrations to define the relative importance of each factor influencing the distribution of algae, using the R software.
- Final analysis and conclusions about the dependence of the at-surface reflectance on the vertical distribution of algae.

4. RESULTS

4.1. Overall descriptors of the algae distribution

For setting the scene, the vertical distribution of the Chl-a content was defined from the water samples. The overall statistics of the Chl-a concentrations is presented in Figure 3. The mean Chl-a content in the analysed period was 31.17 $\mu g\,l^{-1}$, with the highest value in July 2016. The Chl-a concentration rose sharply between 23rd June 2016 and 31st July 2016 then fell to a much lower level on 8th August 2016. A similar drop was observed in the maximum values, i.e., the maxima of the vertical sections (166.7 $\mu g\,l^{-1}$ on 31st July 2016 and 55.7$\mu g l^{-1}$ on 8th August 2016.). This concentration decline between two sampling dates was due to water quality management measures by the supervisory staff of the lake to prevent algal bloom. They used chlorine to suppress algae growth in the lake three times in the monitored period (Fig. 3). The mean values do not reflect the sharp drop of the maximum on 26th April 2017, since an intense wind-driven mixing of the water eliminated the formation of a sharp maximum peak.

Based on the Chl-a and nutrient content values, using the OECD criteria (Zurlini 1996), the overall trophic level of the lake is eutrophic. In the summers the Chl-a content belongs, with a very high probability, to the hypertrophic category.

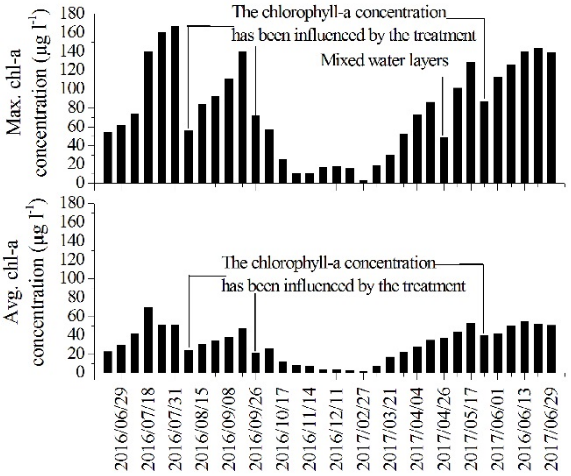

Figure 3. Maximum and average Chl-a concentrations of Lake Naplás at the observation points during the first year of sampling

During algal blooms, the observation point N3 was also monitored. This location showed high surface concentrations of algae, proving to be an ideal place for characterising this extreme environmental situation. The highest Chl-a concentration on the surface, 441.5 µgl^{-1}, was measured on 18th September 2016. It is interesting to note, that under this “green cover”, relatively low Chl-a concentrations were found (Fig. 4). This uneven vertical distribution is mainly attributed to the shading effect of the surface concentration of algae.

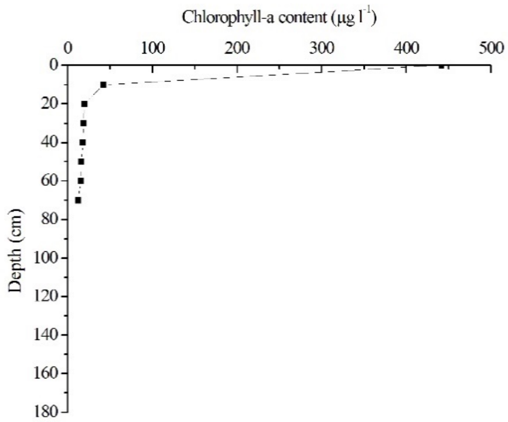

Figure 4. Chlorophyll-a concentration at N3 during the algal bloom (18th September 2016)

The phytoplankton measurements showed a changing pattern throughout the day (Fig. 5). Under general circumstances, we experienced that the maximum Chl-a content has migrated to the deeper layers in the afternoon. Our observations reviled a migration pattern as follows: the maximum Chl-a concentration occurred in the deeper layer at around dawn then ascended to the surface layer till midday. After sunset, and throughout the night, it was found in the deeper layers again.

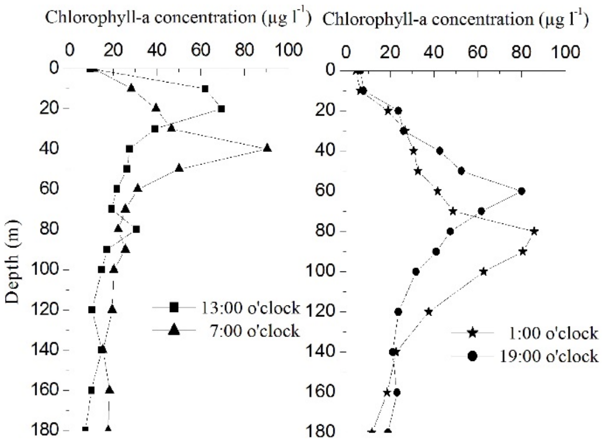

Figure 5. Daily migration pattern of phytoplankton at N1 (18th September 2016)

4.2. Light conditions in the water column

The accessibility of underwater light is influenced by the amount of suspended particulate matter (SPM), that is, in Lake Naplás, primarily formed by phytoplankton, since 91% of the SPM consisted of algae on 18th September 2016. The underwater light conditions during this algal bloom are shown in Figure 6. The diagram depicts the spectra of underwater light measured at different depths. There was a significant difference between the total downwelling light (direct sunlight and sky radiance) at the surface and the light intensity measured at 1cm depth. The highest intensities of the incident light occurred around 550 nm, with a maximum of 15839 counts (expressed in the units of the spectrometer), whilst 1cm under the water surface the maximum was 3761 counts, exhibiting some shift of the peak towards the blue. The data reveals that the algae bloom affected the distribution of the underwater light strongly. Below the very high Chl-a concentrations at the surface (more than 400µgl^{-1}), already in the depth of 10 cm, the Chl-a concentration was only around 9 µg l^{-1}, due to the low intensity of light available for phytoplankton. Under normal circumstances, light attenuation was much more gradual.

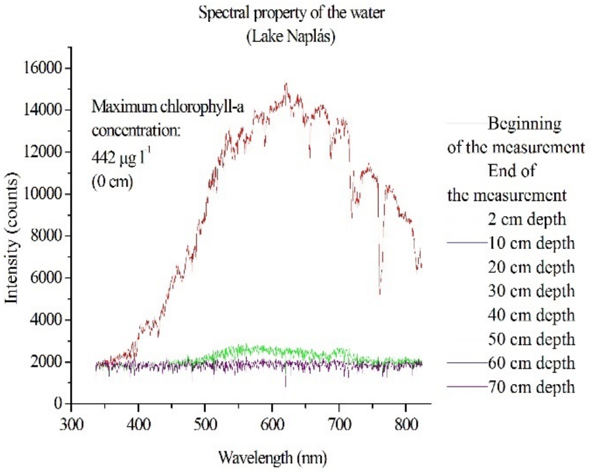

Figure 6. Spectral property of the water, Lake Naplás (18th July 2016.)

Algae are highly dependent on light, but due to their absorption and scattering, the distribution of the light is influenced by their presence; compare Figure 6 and Figure 7. The latter shows a situation where the light attenuation was more evenly distributed.

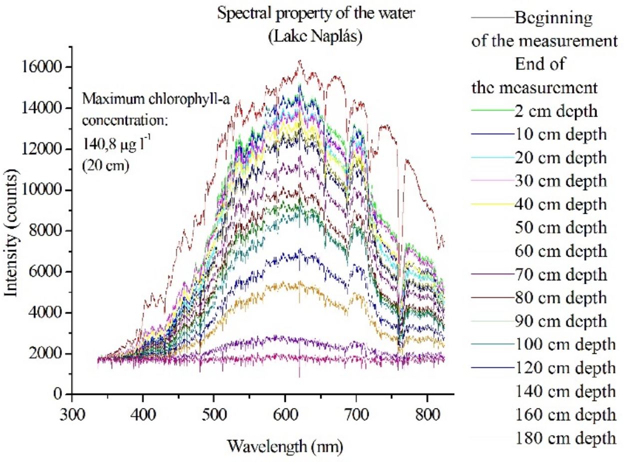

Figure 7. Downwelling light intensities in the water at N3 during the algae bloom (18th September 2016.)

Figure 8 introduces the situation on 4th August 2017, when the Chl-a maximum was at 50 cm, that coincided with a strong decline of the downwelling light intensity at the same depth. The almost linear dependence of the attenuation coefficient on the Chl-a content (Fig. 8/b) proves that the distribution of the inorganic part of TSM was distributed almost homogeneously.

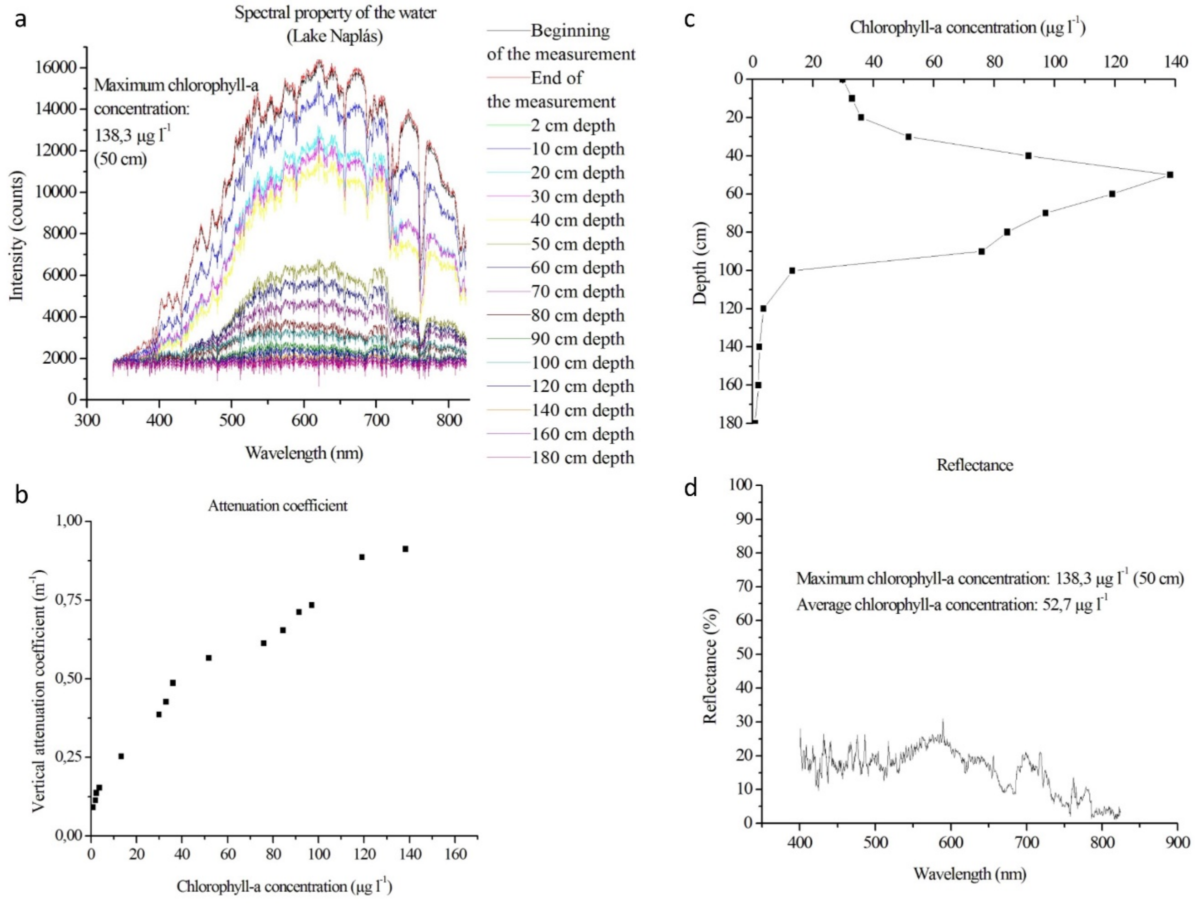

Figure 8. Context between the placement depth of the maximum Chl-a concentration and the reflection (4th August 2017.)

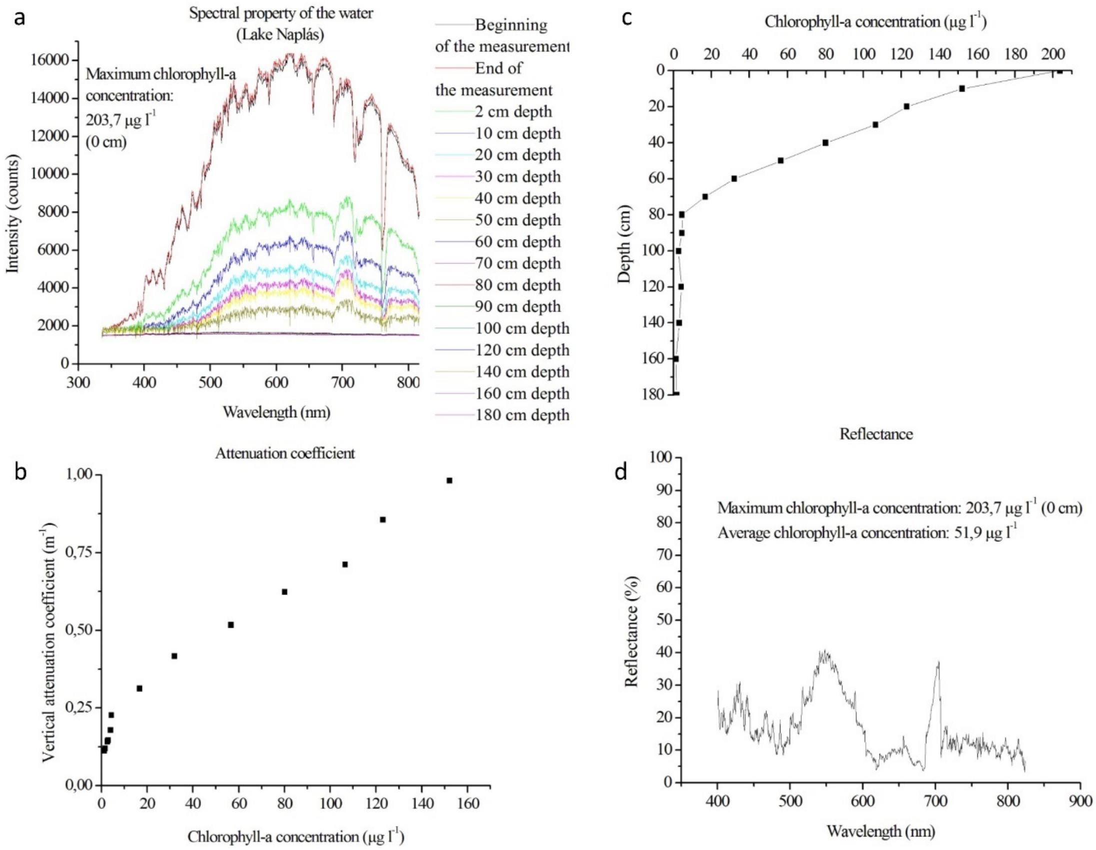

Figure 9. Context between the placement depth of the maximum Chl-a concentration and the reflection (16th August 2017)

An algal bloom of medium intensity is depicted in Figure . The average Chl-a concentration of the illuminated top layer (0 to 100 cm in these compared cases) is the same as of the situation shown in Figure , i.e., it was 52.7 µgl^{-1} on 4th August 2017 and 51.9 µg l^{-1} on 16th August 2017. On these days, the meteorological boundary conditions and the sun angles were similar, but the vertical algae distributions were different. The difference between the two measured spectra can be seen in the “d” sections of the figures. Both the green peak (around 550nm) and the red absorption (around 650nm) are more pronounced during the algal bloom when the maximum of the Chl-a concentration is at the surface than in the other case.

A decline of the Chl-a concentration was experienced in all sections under the depth where the maximum of the downwelling light intensity dropped to the value of around 3000 counts of the spectrometer. The depth of this point varies, depending on the vertical distribution of the algae (Fig. 10 and Fig. 11), meanwhile, the chemical components and water temperature have not shown any changes in these depths.

4.3. Analysis of the chemical and physical parameters

In the top layers, the vertical distribution of nutrients was negatively correlated with the distribution of phytoplankton. Actually, at the depth where the Chl-a concentration reached its maximum value, the measured nutrient concentrations were at their minimum (Fig. 12). In the deeper layers, where little algal activity occurs, this relation could not be recognised.

In the next step, we qualitatively analysed the relationship of the UV radiation and the placement depth of the maximum Chl-a concentration. Three basic cases could be identified. The first one is characterised with high downwelling UV radiation like, for example, on 23rd June 2016, when the UV index was 8 to 10, and the maximum Chl-a concentration was in the deeper layers (from 50 cm to 70 cm). The second case occurred, e.g., on 18th July 2016, when the UV radiation was low (from UV index 0 to UV index 3), and the maximum Chl-a concentration was in the upper layers (from 0 cm to 10 cm). There were no significant differences between the other environmental circumstances on these two mentioned dates. The third case occurred, for example, on 25th July 2016: although the UV radiation was low, the maximum Chl-a concentration remained in the deeper layers. In this case, the water temperature of the top layers was the limiting factor, ranging from 27.7°C to 28.5°C.

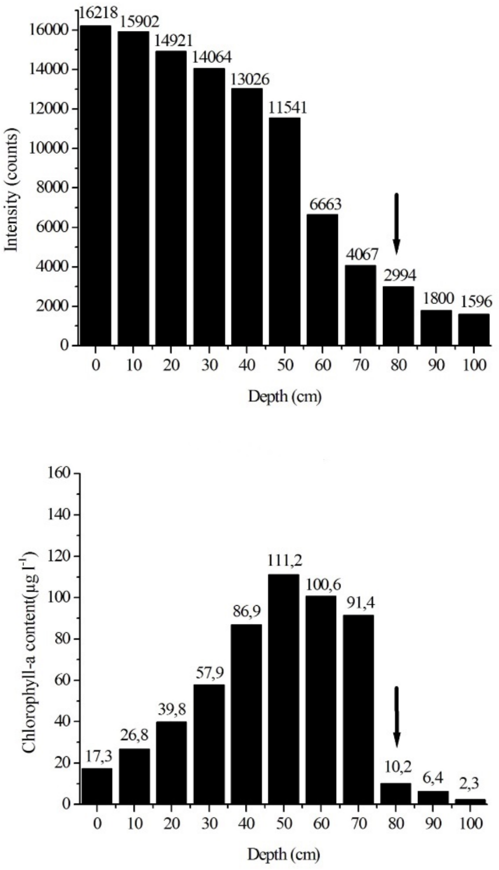

Figure 10. Context of the light intensity and chlorophyll-a concentration (18th September 2016.)

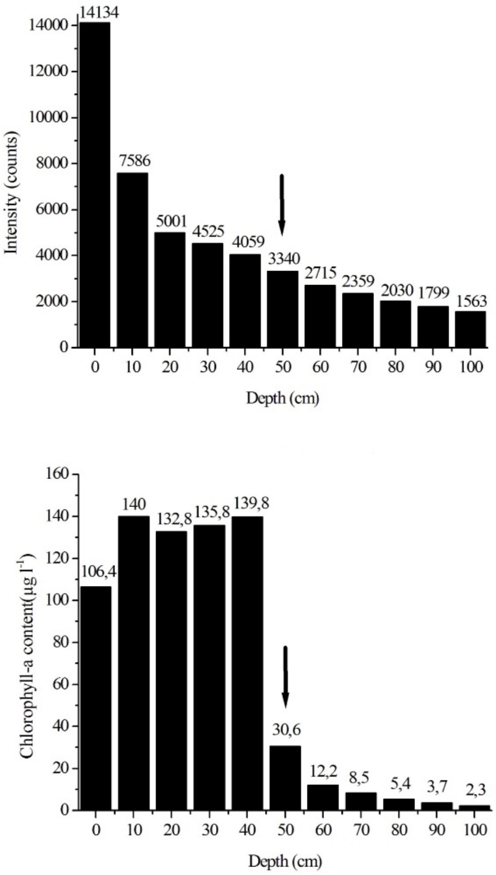

Figure 11. Context of the light intensity and chlorophyll-a concentration (8th September 2016.)

The examples above are not individual occurrences, as it is proved by Figure 13 and Figure 14. The former one shows clearly that the maximum of the algae concentrations occurred close to or at the water surface when the UV radiation was low, or in other words, the high UV radiation is not favourable for the occurrence of algae. Figure 14 documents that the algae did not rise to the surface for long in the summer of 2016 when the surface layers were warmer than about 26 °C. From the analysis, we had to omit the cases when no layering occurred due to the mixing effect of wind. To quantify the strength of dependencies among the examined parameters, we used multiple regression analysis between the maximum Chl-a content, the water temperature, the UV radiation and the placement depth of the maximum Chl-a concentration, with the maximum Chl-a content as the dependent variable. The results showed that the maximum Chl-a content was strongly influenced by the water temperature and the UV radiation (with a correlation coefficient of 0.78 and 0.50, respectively). The multiple determination coefficient was 0.72, in other words, the maximum Chl-a content primarily depends on these independent variables (Table 4).

Under general circumstances, the majority of the algae stayed in the depth where the water temperature ranged between 23 C and 26°C. In case of higher surface water temperatures, the maximum Chl-a content migrated to the deeper layers.

In general, the results showed that algae tend to occur close to the surface of the water, but two major limiting factors were found statistically: the UV radiation, and the higher than optimal water temperature.

5. DISCUSSION AND CONCLUSIONS

This study presents the results of a one-year systematic sampling campaign on Lake Naplás, Hungary, that contained more than 1020 evaluated samples to define the relationships between environmental variables and the vertical distribution of algae. The distribution of algae affects the underwater light conditions and consequently, the optical properties of the water, which define the at-surface reflectance, a crucial parameter of water quality remote sensing. Based on the Chl-a concentrations, the trophic level of the study area is eutrophic.

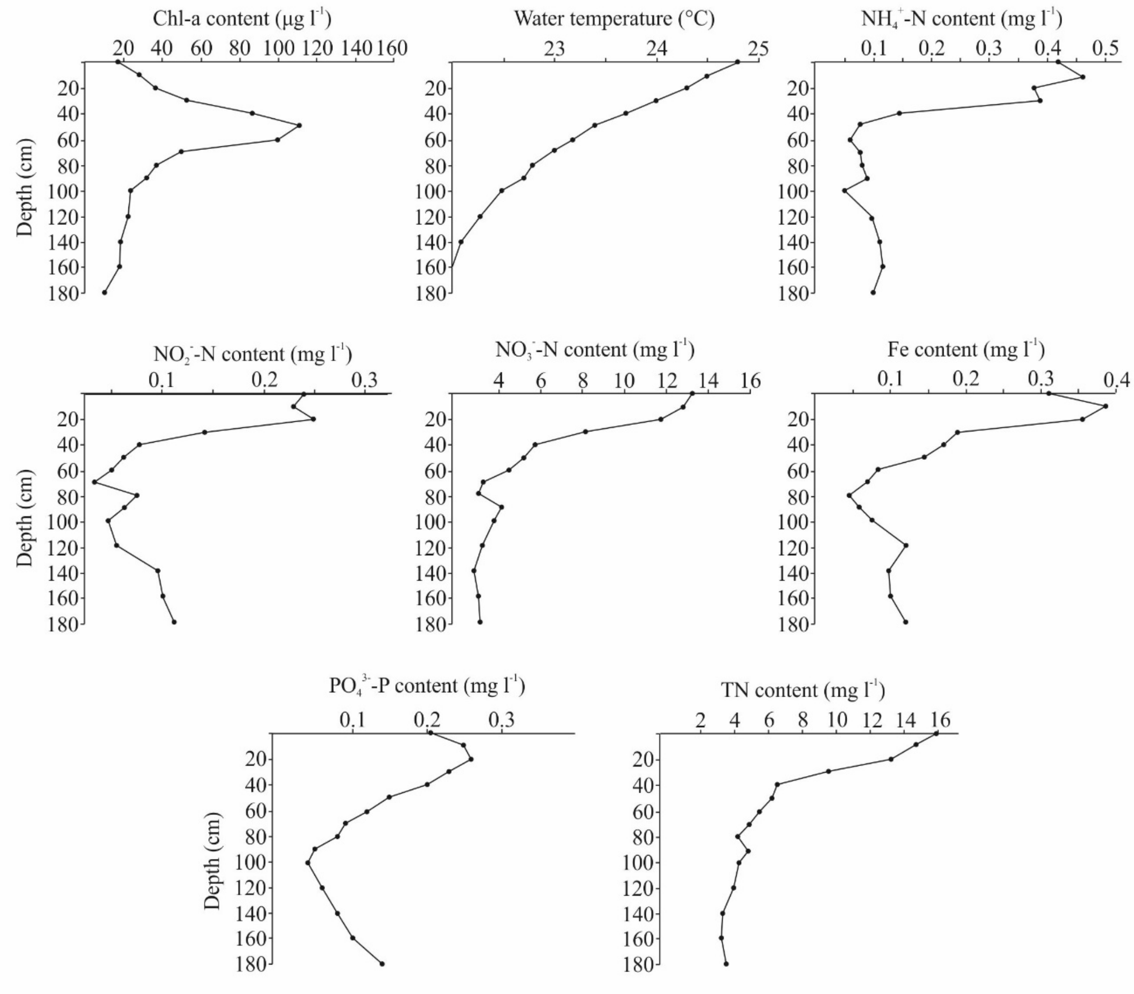

Figure 12. Distribution of Chl-a, temperature and nutrients at N1 (8th September 2016.)

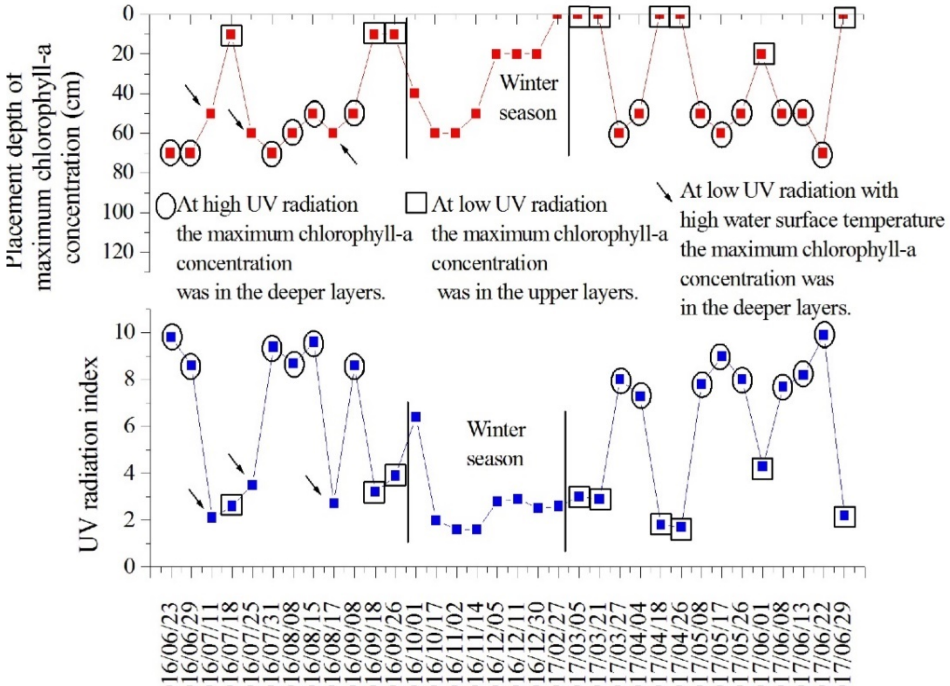

Figure 13. The context of the UV radiation and the placement depth of maximum Chl-a concentration

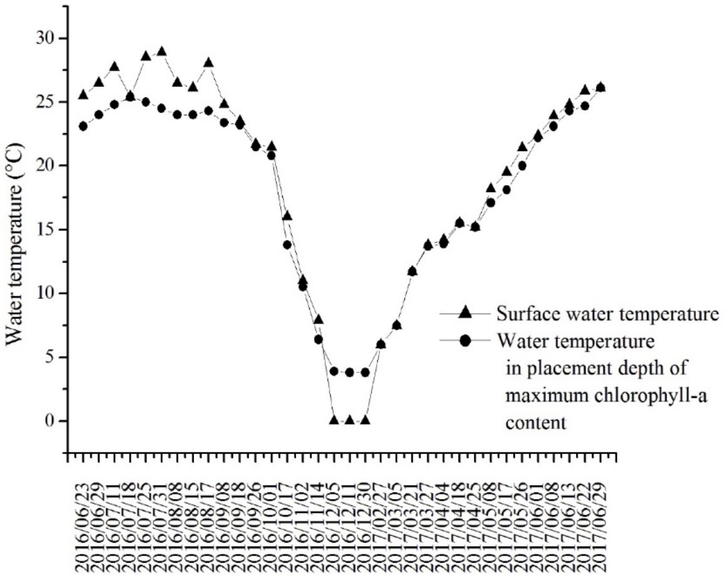

Figure 14. The context of the surface water temperature and water temperature in placement depth of the maximum Chl-a concentration

Table 4. Multivariate analysis details of the main parameters

ANOVA[a]

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	203 07.9	3	67 692.0	62.552	.000[b]
Residual	77 915.9	72	1 082.1		
Total	280 991.9	75			

a. Dependent Variable: Maximum Chl-a content

b. Predictors: (Constant). UV radiation. Water temperature. Placement depth of the maximum Chl-a

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error
1	.850[a]	.723	.711	32.90

a. Predictors: (Constant). UV radiation. Water temperature. Placement depth of the maximum Chl-a

Correlations

		Max. Chl-a content	Placement depth of the maximum Chl-a	Water temperature
Pearson Correlation	Maximum Chl-a content	1.000	.121	.783
	Placement depth of the maximum Chl-a	.121	1.000	.436
	Water temperature	.783	.436	1.000
	UV radiation	.503	.586	.550
Sig. (1-tailed)	Maximum Chl-a content	.	.148	.000
	Placement depth of the maximum Chl-a	.148	.	.000
	Water temperature	.000	.000	.
	UV radiation	.000	.000	.000
N	Maximum Chl-a content	76	76	76
	Placement depth of the maximum Chl-a	76	76	76
	Water temperature	76	76	76
	UV radiation	76	76	76

Our measurements were taken with higher spatial and temporal detail than many previous studies. For example, Reynolds and Rogers (1976) proved temperature-induced seasonal vertical migration of cyanobacteria, which frequently cause harmful algal blooms in eutrophic waters, but did not analyse daily movements.

The measurements showed a changing distribution pattern of algae during the day when external forces (wind, heat dissipation) do not start strong convection in the water body: the maximum Chl-a concentration migrated from the surface to the deeper layers during the afternoon. This migration pattern is similar to what was published by, e.g., Klaveness et al., (1988); and Serra et al., (2007) in their studies. Both publications described environmental parameters as influencing factors of this changing pattern.

Our multiple regression analysis of the Chl-a occurrence and the affecting factors showed that the strongest correlation occurs with water temperature and UV radiation.

Analysing the vertical distribution pattern of the algae, we have found three basic cases. From these, the first two cases were connected to the intensity of the UV radiation, and the third one was more influenced by the water temperature. In the first case, the UV radiation was high, and the maximum Chl-a concentration was in the deeper layers. In the second case, the UV radiation was low; the maximum Chl-a concentration was in the upper layers. In the third case, the water temperature had a limiting effect, and despite low UV radiation intensities, the maximum Chl-a concentration was formed in the lower layers. In this case, the surface water temperature was higher than in general circumstances. We can conclude, that in optimal temperature ranges (up to about 26°C) the vertical distribution of the algae is driven by the intensity of UV irradiation, whilst too high surface temperatures (>26°C) can block the algae from moving to the surface even though low UV irradiation would allow it.

In Lake Naplás more than 90% of the suspended particulate matter (SPM) is formed by algae, especially at higher algal concentrations. Thus, the underwater light conditions are strongly related to the Chl-a distribution. Algal blooms result in very high Chl-a concentrations at the surface. It was beyond our objectives to analyse the reasons for their occurrence, but our observations coincide with the results of Michalak et al., (2013), who found that agricultural activity and meteorological circumstances are significant factors. During this phenomenon, when very high algal concentrations occur on the surface, there is not enough light available for the phytoplankton in the deeper water layers. We found very little Chl-a concentrations even a few centimetres below the surface.

It is a well-known fact that in case of insufficient amount of nutrients, phytoplankton cannot thrive (Lampert & Sommer, 2007). Nutrients are important influencing factors of the algae concentration. Nutrient uptake and assimilation in phytoplankton were measured by Usher et al.. (2006), who found that the nitrogen and phosphorus limitations were the most significant influencing factors for algal growth. In our experiments, we did not find situations of lack of nutrients. Within the framework of the recent study, we measured the main nutrients and some other chemical parameters. The available nutrient and the distribution of algae were influenced by each other in the top layers. The data reveals that the vertical distribution of main nutrients was negatively correlated to the vertical distribution of algae. Ganf and Oliver (1982) have found that especially the available nutrients (nitrogen and phosphorus) caused vertical replacement of green algae, but they also pointed out the importance of light.

The first results of our underwater spectral measurements, on the one hand, proved the limiting effect of the short waves (UV) as was discussed above but also showed that there is a serious drop of Chl-a content below a certain light intensity (3000 counts on the radiometer). This result adds to the findings of Usher et al., (2006), who investigated the phytoplankton motion in aquatic environments and found that algae sinking and rising depended on the wavelength of the available light. We also found that the available light defined basically the distribution of algae. However, we also quantified that underwater light conditions are influenced by the vertical distribution of phytoplankton.

Our analysis showed that the water temperature, UV radiation, and available light affected the vertical distribution of phytoplankton the most. Furthermore, we found that in the top layers, nutrients were inversely correlated to the abundance of algae. This is virtually not in line with the findings of Giripunje et al., (2013), who investigated the phytoplankton ecology in freshwater lakes and found that the nutrient concentrations, among others, were the significant positively correlated influencing factors. Nevertheless, in our observations, the inverse relation with the nutrient content is the result of the algae activity and not the reason of it.

The results of the present study showed that, with equal total chlorophyll contents of the analysed zone and close to identical meteorological and light conditions, different placement depths of the maximum Chl-a concentration resulted in different integrated at-surface reflectance values. Two cases were compared: in the first case, the maximum concentration of Chl-a was formed in the surface layer. By contrast, in the second case, the maximum Chl-a content was in a lower layer, at around 50 cm depth. The at-surface reflectances of the two cases were significantly different (Figs 8a and 9d) especially in two ranges: from 500 to 600 nm and between 680-720 nm. During the analysis, we measured 30% higher surface reflectance in these two ranges when the Chl-a maximum was close to the surface. This issue will require further detailed research in the future since this shows how significant influence the vertical distribution of the algae can have on the accuracy of the bio-optical model inversions based on remote sensing data.

In this study, the objective was to collect data about the influencing factors of the vertical distribution of algae in a shallow lake and to create a database sufficient for the evaluation of the complex effects of the factors. The first results give an interesting insight into the dependencies and provide a sound basis for further studies. For example, a possibility is opened for the comparison of the field data with remote sensing data to examine the relationship between the remote sensing reflectance and the placement depth of maximum Chl-a concentration for improving the bio-optical models and their inversions for water quality remote sensing.

Acknowledgements

This publication was supported by the EFOP-3.6.1-16 -2016-0016 project: Improvement of the research and training profile of the SZIU Campus in Szarvas in the themes of water management, hydroculture, precision mechanical engineering, alternative crop production.

The underlying research was supported by the Higher Education Institutional Excellence Program (1783-3/2018/FEKUTSRAT) awarded by the Ministry of Human Resources in the framework of water-related research of the Szent István University, Gödöllő (Hungary).

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Received at: 17. 12. 2018
Revised at: 30. 04. 2019
Accepted for publication at: 16. 05. 2019