

FACTORS AFFECTING RANGE OF PHOTOSYNTHETICALLY ACTIVE LIGHT IN THREE LAKES OF WIELKOPOLSKI NATIONAL PARK

Tomasz Joniak

Department of Water Protection, Adam Mickiewicz University,
Umultowska str. 89, 61–614 Poznań, tjoniak@amu.edu.pl

Summary. Vertical variability and the maximum range of the photosynthetically active radiation, as well as the impact of components affecting light availability on them were researched in three lakes characterised each by a different water trophy and type of mixis. Sampling and field measurements were conducted on three consecutive days in July 2009 in identical weather conditions. The hypereutrophic lake was characterised by a strong scattering of light in the shallow subsurface layer and by a thin euphotic zone that constituted only 1/6 of depth. In the mesotrophic lakes, the range of light penetration was comparatively larger. The analysis revealed significant statistical dependencies between the optical features of water and the vertical gradient of light intensity.

Key words: lake, Secchi disc, photosynthetically active radiation, suspensoids, trophy

INTRODUCTION

The behaviour of light in water, particularly its attenuation with depth, has important ecological and water quality implications. Besides, optical properties of natural waters are important for many factors such as the heat budget of water bodies, the depth distribution of submerged macrophytes, productivity and species composition of phytoplankton [Kirk 1994]. Light attenuation is regulated by the composition and concentration of various attenuating constituents, which include water itself, yellow substances, tripton and phytoplankton [Reinart *et al.* 2003]. As a result of eutrophication and the connected degradation of lake waters, the natural optic features of water change, which leads to numerous changes in the environment. A key consequence of this is acceleration of the primary production of algae and, as its effect, a considerable decrease of the penetration depth of solar radiation which is mostly absorbed in the shallow epilimnion

[Joniak 2009]. The aim of the study presented in this paper was to characterise the light climate and the factors affecting the range of photosynthetically active radiation in three lakes of Wielkopolski National Park.

STUDY AREA, MATERIAL AND METHODS

The object of this study were three lakes with different surface area and morphology of the basins, especially depth – dimictic Lake Góreckie, GL (surface area of 104 ha, max. depth 17.2 m), Lake Kociołek, KL (4.3 ha, 7.8 m), and the polymictic Lake Wielkowiejskie, WL (13.3 ha, 4.3 m), located in the area of the Wielkopolski National Park. Because of the strong anthropogenic pollution, Lake Góreckie is strongly degraded and periodically hypereutrophic [Sobczyński and Joniak 2008]. Lakes Kociołek and Wielkowiejskie are actually mesotrophic. Specific of the latter is an extensive cover of various macrophyte associations, especially underwater meadows built by *Characeae phytocoenoses* [Kuczyńska-Kippen and Nagengast 2002]. All the lakes are supplied with underground springs and surface inflow.

Sampling and field measurements were conducted on three consecutive days in July 2009 (between 12 pm and 1 pm). Secchi disc visibility (SDV) was measured with a 30 cm-diameter white disk. Underwater measurements for the photosynthetically active radiation (PAR) wavelength interval (400–700 nm) were made using a spherical quantum sensor (LI-COR 193SA) with data logger LI-1400. Irradiance readings were made in air over surface of water, then shallow under surface (at the depth of circa 0.02 cm), and later in the water column at 10 cm intervals to below the level of 1% (Z1%), and usually to the total loss of radiation (below 0.001 mol m⁻²). Water samples for laboratory analysis were collected, using peristaltic pump, at 0.5 m intervals from subsurface layer to the depth with minimal value of PAR and additionally at the level of SDV and Z1%. Four parameters were taken into consideration to characterise the optical regimes of the lakes: total suspended sediments TSS (after filtration through GF/F filter, gravimetrically), turbidity T_n (nephelometrically), inherent water colour (spectrophotometrically at 420 nm), and OAS (optically active substances, characterised by beam attenuation coefficient at 380 nm). The chlorophyll *a* (Chl) was determined after extraction with ethanol. Statistical analysis was made using Statistica 7.

RESULTS AND DISCUSSION

Although atmospheric conditions (lack of clouds and wind) were identical, the value of energy PAR reflected by water surface differed in the case of each lake. The highest value (30%) was registered in Lake Wielkowiejskie, while those registered in Lakes Góreckie (18%) and Kociołek (13%) were significantly

lower. Therefore, it seems that it is not the weather and wave-motion that have a determining impact on this value, but the chemical composition of the surface water layer. The most favourable light conditions existed in KL, where the value of SDV was 2.7 m. In WL the range of light was more limited (2.5 m), yet the worst light conditions were registered in the hypereutrophic GL (1.1 m). The optical features of water in each lake shaped the light regime differently. In GL the euphotic zone (Z_{eu}) made up only 1/6 of the entire depth (down to 2.7 m) and the total loss of PAR was registered at the depth of 4.2 m. In both mesotrophic lakes, on the other hand, the light conditions were significantly better, though very different from each other. In KL the euphotic zone reached down to almost 5 m and the total loss of radiation was registered at the depth of about 6 m. In the shallowest WL the light conditions were the most favourable and Z_{eu} reached down to the bottom (Fig. 1).

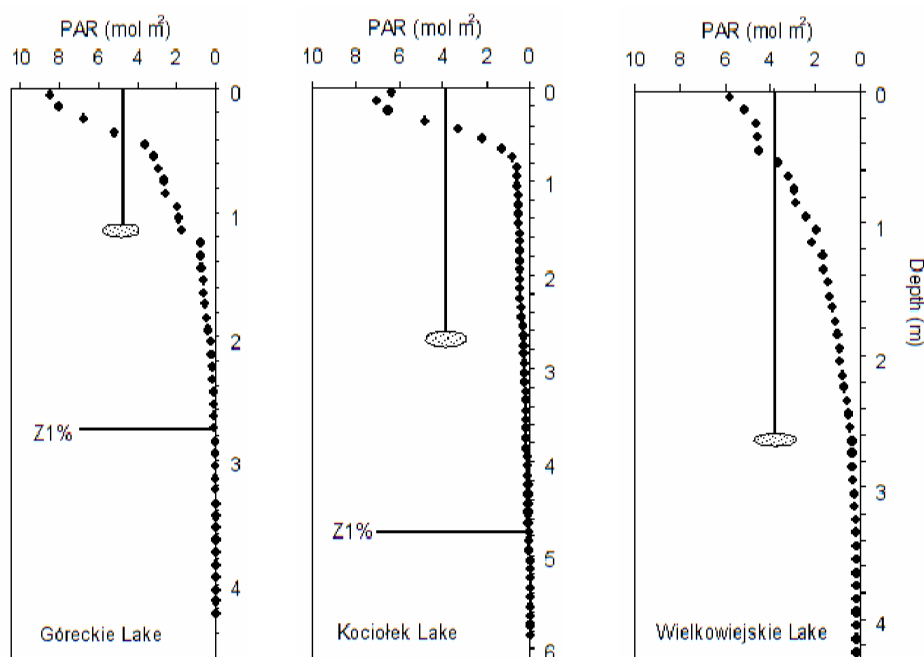


Fig. 1. Vertical characteristics of photosynthetically active radiation (PAR) of researched lakes in relation to Secchi disc visibility (grey ellipse) and range of euphotic zone ($Z_{1\%}$)

Transformation of light energy flux under the influence of optically active substances may cause its strong absorption or the transmission to larger depths as scattered light. The analysis of optical features of water revealed that in each of the lakes a specific composition of substances is responsible for the quality of light in the light zone. In the hypereutrophic lake, in the layer above the SDV limit, strong diffusion of light and lightening of water was observed. The main

reason for that was a high concentration of phytoplankton and the accompanying turbidity and opalescence of water which increased with the depth. The two latter were caused by a large release of dissolved organic substances (in a form of secretion and excretion) from organic compounds into the water [Tilzer *et al.* 1975]. The composition of substances causing the turbidity depends on the structure of planktonic biocenosis and the quality of organic matter supplied by rainfalls and surface run-off from the catchment area [Joniak 2009a]. However, with regards to the total range of PAR in the lake, statistically significant impact was registered in the case of chlorophyll *a*, water colour and OAS (Tab. 2). The characteristic feature of the light regime in Lake Góreckie, compared to the other lakes, was that more than 20% of the PAR energy gathered at the depth of SDV (1.1 m). The concentration of photosynthetically active water components in this layer, particularly suspensions, turbidity and the chlorophyll *a* (Tab. 1), resulted in the abrupt decrease of PAR only 10 cm deeper – from 1.8 mol m² to 0.8 mol m². In the other two lakes the value of PAR in the SDV layer was much lower – 8% in WL and 5% in KL. This resulted in a higher vertical balance of optical properties of water and in a weaker attenuation and absorption of solar light with the growing depth (Fig. 1).

Table 1. The concentration of physical and chemical parameters of lakes water in subsurface layer (Subs), on depth of Secchi disc visibility (SDV) and the mean values in euphotic zone (Zeu)

Lake	Layer	Parameter				
		TSS mg dm ⁻³	T _n NTU	Chl µg dm ⁻³	Colour mg Pt dm ⁻³	OAS m ⁻¹
Góreckie	Subs	5.2	4.7	11	5	0.5
	SDV	12	38.8	53	5	0.8
	Zeu	12	25.9	47.7	6	0.8
Kociołek	Subs	3.1	0.8	4.4	5	1.34
	SDV	3.4	3	7.7	12	2.62
	Zeu	4.5	2.3	9.2	10	2.3
Wielkowiejskie	Subs	3	0.5	9.3	25	0.57
	SDV	2.5	2.9	32	25	2.26
	Zeu	2.9	2.2	17.3	24	2.13

In the mesotrophic Lake Kociołek, the water was crystal clear down to the depth of 0.5 m. An untypical phenomenon was registered at the depth of 10–20 cm, where the value of PAR was about 10% higher than in the subsurface layer at the depth of 0.02 cm (Fig. 1). Below the depth of 0.5 m, the light was gradually absorbed by the growing turbidity and the growing concentrations of chlorophyll and OAS (Tab. 1). Because the water bloom did not take place, it was not possible to study the water opalescence. From the observations on the site, it seems that the steep forested slopes of the catchment area which protect the lake from the winds and thus hinder the wind-induced mixing of water contributed greatly to the formation of stable light conditions in the lake. It appears that the long-term stability of the

vertical physical gradients and the chemical properties of water were the main reason for the formation of these specific light conditions. The statistical analysis confirmed that the range of penetration of PAR was significantly affected by the water colour and OAS, and to a lesser degree also by TSS (Tab. 2).

Table 2. Statistical correlations between vertical gradient of PAR and optical features of water

Lake	n	Parameter				
		TSS	T _n	Chl	Colour	OAS
Góreckie	10	–	–	-0.71*	-0.68*	-0.78*
Kociołek	11	-0.61*	–	–	-0.77**	-0.82**
Wielkowiejskie	10	–	-0.91**	–	–	-0.94**

* $p < 0.05$, ** $p < 0.001$, – not significant

In the polymictic Lake Wielkowiejskie, the dissolved optically active substances – which influence light absorbency – as well as turbidity were the key determinants of the light quality. It is probable that low concentrations of most of the optically active substances, including suspensions, were equally important for the slower attenuation of PAR with depth (Tab. 1). In order to compare the light conditions in both mesotrophic lakes a PAR range value of $> 10\%$ ($\pm 0.6 \text{ mol m}^{-2}$) was used. The comparison demonstrated that while in WL this value referred to a water layer that was almost 2.5 m deep, in KL this layer had a maximum of 1 m (Fig. 1). Despite the typical polymictic character of WL, the concentration of the TSS in water was lower than in other lakes (Tab. 1) due to, most prominently, dense underwater meadows built by *Characeae* phytocoenoses. Those covered the lake bottom and were effectively blocking the resuspension of bottom sediments [James *et al.* 2004].

CONCLUSIONS

The results of the investigations suggest that the eutrophication of the examined water bodies had some modifying effect on their water quality and the transmission of photosynthetically active radiation. The analysis of the physical features of water in the euphotic zone permitted the identification of characteristic substances blocking the penetration of PAR in each of the lakes. In the hypereutrophic lake those substances included the chlorophyll *a* and dissolved optically active substances. A very high light scattering in shallow subsurface layer caused by high turbidity and opalescence of water (a type of microstratification) related to a strong blooming of algae were of key significance for the general range of PAR. In mesotrophic lakes, the range of PAR depended mainly on the turbidity of water and the content of dissolved organic compounds.

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CZYNNIKI KSZTAŁTUJĄCE ZASIĘG ŚWIATŁA FOTOSYNTETYCZNIE AKTYWNEGO
W TRZECZ JEZIORACH WIELKOPOLSKIEGO PARKU NARODOWEGO

Streszczenie. Analizowano pionową zmienność i maksymalny zasięg promieniowania fotosyntetycznie aktywnego w trzech jeziorach o różnej trofii i mikcji wód na tle wpływu składników kształtujących dostępność światła. Badania prowadzono w ciągu 3 dni lipca 2009 r., w jednakowych warunkach pogodowych. Cechą jeziora hipereutroficznego było bardzo silne rozproszenie światła w płytkiej warstwie powierzchniowej i miąższość strefy eufotycznej stanowiąca zaledwie 1/6 część głębokości. W jeziorach mezotroficznych zasięg światła był relatywnie większy. Wykazano istotne statystycznie zależności cech optycznych wody od pionowego gradientu natężenia światła.

Słowa kluczowe: jezioro, krążek Secchiego, promieniowanie fotosyntetycznie aktywne, zawiesiny, trofia