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# Variability of bio-optical parameters in Lake Jasień Północny and Lake Jasień Południowy

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**Abstract:** Bio-optical properties of water in two lakes from the Bytow district, Jasień Południowy (JS) and Jasień Północny (JN), were measured between 2007 and 2010. These lakes were chosen as reference for research in the Regional Environment Monitoring System (Wojewódzki Program Monitoringu Środowiska) between 2007 and 2009. The research concerned mainly OSCs (Optically Significant Constituents) such as chlorophyl *a*, SPM (Suspended Particulate Matter), CDOM (Colored Dissolved Organic Matter) and optical parameters of water (Secchi depth $z_{SD}$, diffuse light attenuation coefficient $K_{d,PAR}$). The aim of this article is to present temporal variability of OSC and optical properties in the investigated lakes as well as the relation between OSCs and the optical properties of water. The research has shown that the variability in the properties of water of these lakes is quite significant: concentration of chlorophyl $C_{Chl}$ varied from 1.3 to 32.3 mg $m^{-3}$ and the $K_{d,PAR}$ coefficient from 0.42 to 1.05 $m^{-1}$. The obtained results were compared with the same parameters from other lakes in this region. The variability in the optical properties depend on the season and the biological activity of phytoplankton. Regression analyses showed a high correlation of optical properties of water with $C_{Chl}$ and $C_{SPM}$ , and no correlation with CDOM concentration. The highest determination coefficient was obtained for the optical parameters correlated with the three OSCs. The presented results show not only annual variability and variability between the years but also an influence of OSC elements on the optical properties of lakes.

**Key words:** Underwater light field, Optically significant substances

## Introduction

Optical properties of water are important for the ecological structure and function of lakes. They are also very sensitive to global climate change and local environmental changes in the lakes vicinity (Kirk 1996; Sheffer 2004). Changes in the environment usually lead to increased lake trophicity, decreased transparency and a change in the waters colour. Thus, optical methods are frequently used for lake monitoring. Information on the type and quantity of OSC are used in creating algorithms for remote sensing of optically complex water (Arst 2003; Zhang 2008). The data taken in situ are used for the parameterization and validation of these models (Shalles 2006; Darecki et al. 2008).

The analyses of data found in literature show that a lakes concentration of OSC and optical properties such as Secchi depth $z_{SD}$ and diffuse light attenuation coefficient $K_{d,PAR}$ can increase even by three times and more (Arst 2003; Paavel 2008). It is connected with the variability of three main OSC elements such as: chlorophyl *a*, which is an indication of phytoplankton concentration, suspended matter (SPM) and dissolved organic matter (CDOM) (Woźniak and Dera 2007). The relation between their concentration is responsible for the water colour. High diversity of lakes on Earth is the reason for insufficient data that would allow an effective description of their properties and variability. There are regions where measurements have been taken with modern equipment for a number of years thus contributing to a large number of articles (e.g. Arst 2003; Reinart et al. 2004, 2005). Lack of data also prevents from e.g. developing satellite algorithms that would allow spacial and time analysis of the variability of properties from a given regions lakes. Remote sensing is successfully applied to measurements taken in oceans, seas and coastal

waters (Miller et al. 2007). Using these methods for lakes, due to their above mentioned regional diversity, requires relevant data measured directly in the water. As a result, the remotely received signal can be compared with the real characteristics of the environment. Although some progress has been made with respect to Polish lake waters, the number of articles on this topic is still insufficient. This article is an attempt to fill this gap by presenting the variability and relations between bio-optical parameters of two Pomeranian lakes, Jasień Północny and Jasień Południowy.

The lakes were chosen for this study because they are reference points for research in the Regional Environment Monitoring System. Research presented in this article incorporates studies carried out between 2007 and 2010. The obtained results were compared with results from one of the most transparent waters in the Pomeranian region, Lake Jeleń (Ficek et al. 2008; Ficek and Zapadka 2008). The article presents range of variability and seasonal cycle of OSC and relation relationships between the OSC and apparent optical properties of investigated lake waters.

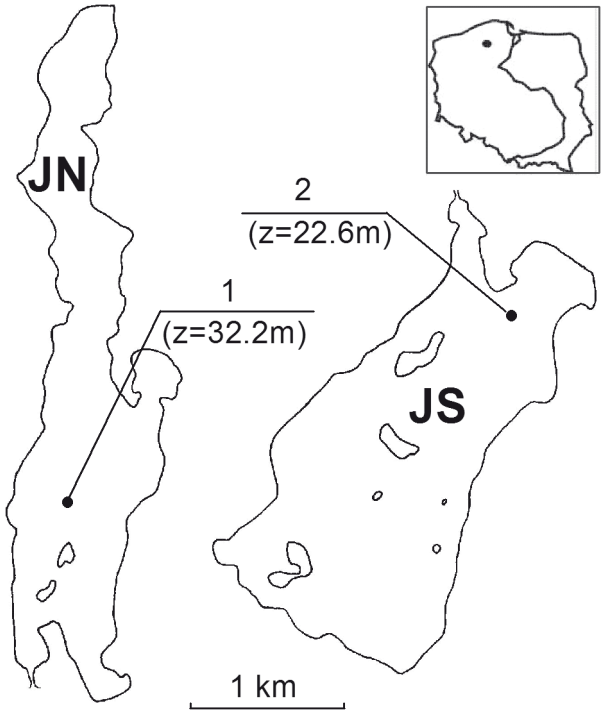



Fig. 1. Location of measurement stations in Jasień Północny (JN) and Jasień Południowy (JS)

## Materials and methods

The presented water reservoirs are typical postglacial channel lakes located in the Pomeranian region (**Jasień Południowy** 54°16.7'N; 17°35.8'E; **Jasień Północny** 54°18.5'N; 17°37.3'E). The River Łupawa with the estuary to the Baltic Sea runs through both lakes. They are surrounded by woods and cultivated fields. Morphometric parameters of both lakes are presented in Table 1. The empirical material presented in this article was gathered between April 2007 and February 2010. The measurements were taken once a month in the growing season. The measurements were only taken once during winter in February 2010. The localisation of measurement points is presented in Fig 1. Measurements in JS and JN were taken on the same days.

The surface water samples were taken at the depth of 20cm under the surface. Samples from deeper layers were taken by a bathometer. The reason for choosing the depth from which samples were taken was the thermal and fluorescent profile. The samples were taken from four depths: from the surface, from the depth with maximal phytoplankton fluorescence, from the level just over the thermocline, and just above the bottom of the lake. Due to the fact that one of the aims of this study was to analyse optical properties of water, the results presented only relate to the euphotic layer.

Chlorophyll-*a* concentration measurements ($C_{Chl}$) of the water were taken using the standard spectrophotometric method (Jeffrey and Humpreys 1975). The samples were filtered through Whatmans filters GF/F at the underpressure up to 35kPa. The amount of filtered water depended on the amount of chlorophyl and was 0.3÷2.5 l. The extraction was carried out in 90% acetone water solution. The pigments were extracted after storing the samples for 24h in darkness in the refrigerator. The extract was centrifuged (2320xg, 20 min). The measurements of absorbance were carried out by means of a Hitachi U 2810 spectrophotometer.

Table 1. Morphometric data of investigated lakes (Jańczak 1997)

| Lake | Symbol | Area [ha] | Maximum depth [m] | Mean depth [m] |
|---|---|---|---|---|
| Jasień Południowy | JS | 336.7 | 22.6 | 7.8 |
| Jasień Północny | JN | 240.5 | 32.2 | 9.7 |

Due to the fact that determining individual organic elements of the CDOM mixture is expensive and requires advanced analytical techniques, the optical method was used to analyse absorption spectra of the filtered water. It is commonly assumed that CDOM absorption, and particularly the absorption coefficient $a_{CDOM}$, can be used as an indicator of CDOM concentration (e.g. Paavel 2008; Arst 2003; Woźniak and Dera 2007). The analysed samples of water were filtered twice. First, through Whatman GF/F filters, then through cellulose acetate membrane (diameter 0.2μm). Absorbance of the filtered water samples was measured in the laboratory using a double-beam Hitachi U2810 spectrophotometer with 5 cm quartz cell in the spectral range 200-700 nm with the 1 nm spectral resolution. A quartz cell with twice distilled water was used as the reference for all samples. The absorption coefficient $a_{CDOM}$ for each wavelength (λ) was calculated according to Kirks formula (1994):

$$a_{CDOM}(\lambda) = 2.303\ A(\lambda)/l \qquad (1)$$

where: $A(\lambda)$ is the measured absorbance for a given wave length, $l$ is the length of the cuvette in metres.

The concentration of total suspended particular matter $C_{SPM}$ was determined as a mass of the dried matter retained of the filter after filtration of the volume water sample through the a glass filter GF/F (diameter 47mm; Whatman). The isolation of the organic part POM (Particulate Organic Matter) from all the suspensions was carried out by another weighting of the filter after 30min in the temperature of 550°C. Then the mass of the filter with what remained of the suspended matter after heating was subtracted from the total mass of the filter together with the suspended matter (Van der Linde, 1998).

Vertical profiles of the chlorophyll *a* fluorescence in lake waters were performed with use of the Pump Probe submersible fluorometer equipped with a depth gauge and a quantometer. The fluorometer is constructed for measuring chlorophyl concentration and is based on the technique developed by professor Falkowski (Falkowski et al. 1985; Matorin et al. 2004). This instrument was submerged in water and lowered steadily to the bottom of the water reservoir. The integrated quantometer that measured downwelling solar irradiance $E_{d,PAR}$ in the spectral range from 400 to 700nm (photosynthetically active radiation PAR) was used for the measurements of underwater light. The instrument took the measurements at 1s time interval. It allowed to register approximately 10÷20 measurements at a depth of 1m depending on the velocity of submerging the instrument. The measurements were taken in as similar weather conditions as possible (clear sky or stable overcast). During the analyses, the obtained data were checked for any anomalies that could have taken place during the measurements (identified as disturbances in depth profiles) caused by waves on the surface of the water reservoir or overcast. These sporadic anomalies were discarded or eliminated by means of interpolation and calculating average values. A mean $K_{d,PAR}$ light attenuation coefficient for particular layers was established by means of nonlinear regression. Mean coefficient values for the layers of water of $z_2$-$z_1$ thickness were established by means of the following formula (Kirk 1994):

$$K_{d,PAR}(z_1 \div z_2) = \frac{1}{z_2 - z_1} \ln \frac{E_{d,PAR}(z_1)}{E_{d,PAR}(z_2)} \qquad (2)$$

Secchi depth $z_{SD}$ was also measured for all samples.

## Results

### Temporal variation of bio-optical parameters

During three years of regular research large empirical data was collected that allowed comparison of JS and JS lakes according to their bio-optical parameters. Table 2 presents the variablity range, mean values and standard deviation of OSCs and optical parameters of water. The waters of both lakes vary with regard to OSC and optical properties. JS, which is more shallow and of bigger surface, has greater mean concentrations of all three OSCs: $C_{Chl}$ approx. 55%, $C_{SPM}$ approx. 33% and CDOM approx. 39% higher than JN. It is reflected in the optical properties of the water: mean $z_{SD}$ is 21% smaller, whereas $K_{d,PAR}$ is approx. 24% bigger than in JN.

A comparison of OSC concentration of the more transparent water in JN with those observed in Lake Jeleń shows that the mean $C_{Chl}$ values are the same in both lakes. However, both $C_{SPM}$ and absorption through CDOM are higher by respectively 50% and 64%. Still greater differences are observed in the maximal OSC values. Chlorophyl concentration $C_{Chl}$ is higher by 27%, $C_{SPM}$ by 104% and absorption through CDOM by 73% in comparison with Lake Jeleń.

Table 2. Summary of optical property determinators based on measurements in Lake Jasień Północny, Jasień Południowy and Jeleń (N – number of measurements)

| Parameter | Range of variability | Average | Standard deviation | N |
|---|---|---|---|---|
| Jasień Południowy | | | | |
| $C_{Chl}$ , mg m$^{-3}$ | 2.1-32.3 | 9.9 | 9.1 | 75 |
| $C_{SPM}$ , g m$^{-3}$ | 1.1-6.8 | 3.2 | 1.4 | 56 |
| $a_{CDOM}(380)$ , m$^{-1}$ | 1.7-3.4 | 2.5 | 0.37 | 45 |
| $z_{SD}$ , m | 1.7-4.8 | 2.7 | 0.8 | 25 |
| $K_{d,PAR}$ , m$^{-1}$ | 0.55-1.05 | 0.78 | 0.15 | 25 |
| $C_{POM}/C_{SPM}$ , % | 35÷94 | 69 | 16 | 50 |
| Jasień Północny | | | | |
| $C_{Chl}$ , mg m$^{-3}$ | 1.3-23.8 | 6.4 | 5.4 | 60 |
| $C_{SPM}$ , g m$^{-3}$ | 1.0-5.9 | 2.4 | 1.3 | 51 |
| $a_{CDOM}(380)$ , m$^{-1}$ | 1.2-2.6 | 1.8 | 0.31 | 40 |
| $z_{SD}$ , m | 2.4-5.5 | 3.4 | 0.9 | 28 |
| $K_{d,PAR}$ , m$^{-1}$ | 0.42-0.76 | 0.63 | 0.08 | 27 |
| $C_{POM}/C_{SPM}$ , % | 62-92 | 77 | 10 | 50 |
| Jeleń | | | | |
| $C_{Chl}$ , mg m$^{-3}$ | 2.0-18.8 | 6.4 | 3.7 | 101 |
| $C_{SPM}$ , g m$^{-3}$ | 0.8-2.9 | 1.6 | 0.6 | 48 |
| $a_{CDOM}(380)$ , m$^{-1}$ | 0.9-1.5 | 1.1 | 0.16 | 43 |
| $z_{SD}$ , m | 2.8-7.0 | 4.7 | 1.0 | 31 |
| $K_{d,PAR}$ , m$^{-1}$ | 0.38-0.80 | 0.50 | 0.10 | 24 |
| $C_{POM}/C_{SPM}$ , % | 79-97 | 91 | 5 | 39 |

The measurements allowed to track seasonal variations in all three OSC elements (Fig. 2a and 3a) together with all the values characteristic of water transparency (Fig. 2b and 3b). The amount of suspensions present in the pelagic layers of the lakes is mainly determined by abiotic and biotic factors that regulate the size of the phytoplankton. Annual changes in the biomass of the phytoplankton reflect to a great extent seasonal changes in light, temperature and biogene availability (Kawecka and Eloranta 1994; Willen E. 2000; Longhi and Beisner 2009; Sheffer 2004). During the 3-year study, seasonal changes in the phytoplankton in JN showed classical development with two clear maxima related to algae bloom peaks: one in spring, the other late summer and early autumn. A third maximum taking place in the beginning of summer was observed in JS. Naturally, these cycles vary slightly from year to year mainly due to different weather conditions. Changes in OSC are reflected in changes in water transparency. The growth of each OSC element results in a decrease of the Secchi $z_{SD}$ disk visibility and an increase of the $K_{d,PAR}$ coefficient.

The suspended substances in the examined lakes are mainly related to phytoplankton. The fact that there exists a strong relationship between the concentration of phytoplankton and SPM is confirmed by a high $R^2$ determination coefficient presented in Table 3 (see positions 1 and 8) and Figure 4 a. Due to the fact that phytoplankton is only related to the organic part of the suspended matter, the relationship between $C_{Chl}$ and $C_{POM}$ produces a significantly higher $R^2$ determination coefficient, which is illustrated in Figure 4b and presented in Table 3 (see positions 2 and 9).

### Correlation analysis

Lakes constitute very complex systems and usually all three OSC elements influence the optical properies of their waters. Literature provides examples of appriopriate regression equations developed for many different water reservoirs or different trophic types of water reservoirs where significant variation of OSC is found. An analysis of correlations between different values using separate data from two particular water reservoirs would be of great interest. This

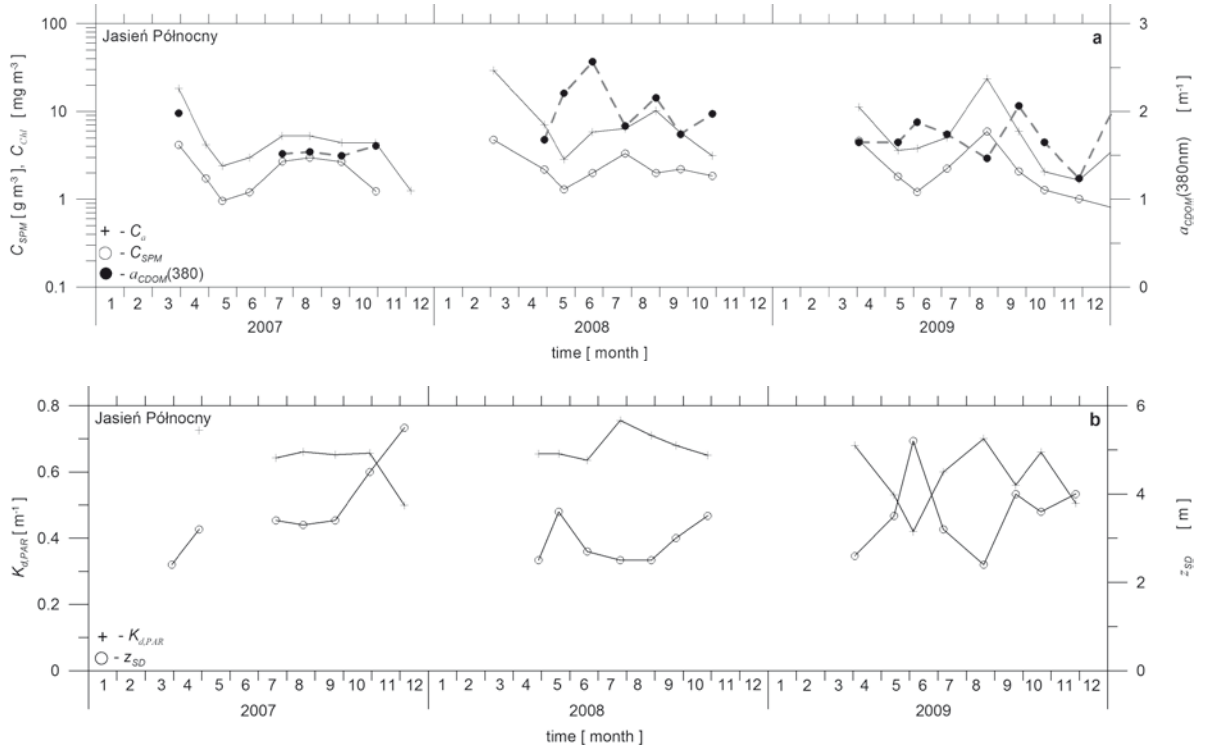



Fig. 2. Temporal distribution of bio-optical parameters in Jasień Północny Lake during 2007÷2009: (a) elements of OSC, (b) Secchi depth $z_{SD}$ and diffuse attenuation coefficient of light $K_{d,PAR}$

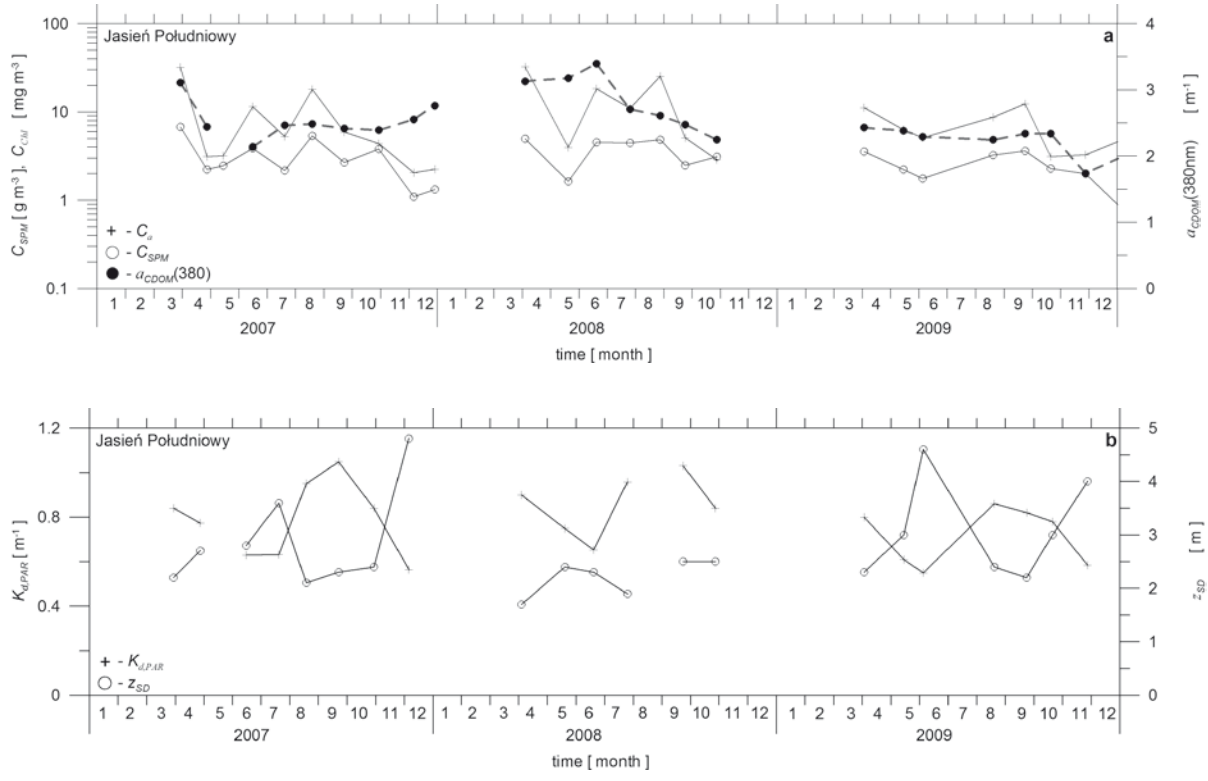



Fig. 3. Temporal distribution of bio-optical parameters in Jasień Południowy Lake during 2007÷2009: (a) elements of OSC, (b) Secchi depth $z_{SD}$ and diffuse attenuation coefficient of light $K_{d,PAR}$

article provides different determination coefficients and regression equations between $z_{SD}$ and each OSC element. The above mentioned regression equations are presented in Table 3. Determination coefficients were not particularly high in most cases. As shown in the table, $z_{SD}$ in JN correlates highly with chlorophyll *a* concentration and weakly with suspended matter. There is no correlation with $a_{CDOM}(380)$. However, in JS determination coefficients are highest with suspended matter, lower with chlorophyll *a* concentration and very low with $a_{CDOM}(380)$.

Due to the fact that all three OSC elements influence water transparency simultaneously, the relationship between $z_{SD}$ and all OSC elements was measured by means of nonlinear regression. The obtained regression formulas are presented below:

Taking into consideration in equation (3) main OSC elements increases determination coefficient ($R^2$=0.69). These equations allow to indicate any parameter when the other three are known. The verification of the obtained relationships is shown in Fig. 5.

The relationships between Secchi depth $z_{SD}$ and the light diffuse attenuation coefficient $K_{d,PAR}$ and the appriopriate regression formula are presented in Fig. 6. The analysis was carried out on the basis of 46 measurements from both lakes. As expected, an increase in $z_{SD}$ results in a decrease in $K_{d,PAR}$, whereas the determination coefficient between the two values is relatively high $R^2$=0.68. The distribution of the points around

$$z_{SD} = 3.405(C_{SPM})^{-0.7614} + 22.01(C_{Chl})^{0.0029} - 0.3478(a_{CDOM}(380)) - 20.15 \quad (3)$$

(N=40, $R^2$=0.69)

where: $C_{SPM}$ is measured in g m$^{-3}$, $C_{Chl}$ mg m$^{-3}$ and $a_{CDOM}(380)$ m$^{-1}$.

Table 3. Relationship between OSC and optical parameters in two Pomeranians lakes JN and JS (N –number of measurements)

| Relationship | Regression formula | $R^2$ | N |
|---|---|---|---|
| Jasień Północny | | | |
| $C_{Chl}$ vs. $C_{SPM}$ | $C_{Chl} = 1.62\ (C_{SPM})^{1.32}$ | 0.64 | 51 |
| $C_{Chl}$ vs. $C_{POM}$ | $C_{Chl} = 2.41\ (C_{POM})^{1.39}$ | 0.77 | 50 |
| $z_{SD}$ vs. $C_{Chl}$ | $z_{SD} = 5.28\ (C_{Chl})^{-0.28}$ | 0.64 | 28 |
| $z_{SD}$ vs. $C_{SPM}$ | $z_{SD} = 4.34\ (C_{SPM})^{-0.37}$ | 0.55 | 28 |
| $z_{SD}$ vs. $a_{CDOM}(380)$ | $z_{SD} = -0.373\ (a_{CDOM}(380))+3.96$ | 0.02 | 28 |
| $K_{d,PAR}$ vs. $z_{SD}$ | $K_{d,PAR} = 1.06\ (z_{SD})^{-0.43}$ | 0.56 | 21 |
| $z_{SD}$ vs. $K_{d,PAR}$ | $z_{SD} = 1.86\ (K_{d,PAR})^{-1.31}$ | 0.56 | 21 |
| Jasień Południowy | | | |
| $C_{Chl}$ vs. $C_{SPM}$ | $C_{Chl} = 1.04\ (C_{SPM})^{1.74}$ | 0.72 | 56 |
| $C_{Chl}$ vs. $C_{POM}$ | $C_{Chl} = 2.34\ (C_{POM})^{1.55}$ | 0.76 | 50 |
| $z_{SD}$ vs. $C_{Chl}$ | $z_{SD} = 4.12\ (C_{Chl})^{-0.22}$ | 0.46 | 25 |
| $z_{SD}$ vs. $C_{SPM}$ | $z_{SD} = 4.31\ (C_{SPM})^{-0.46}$ | 0.65 | 25 |
| $z_{SD}$ vs. $a_{CDOM}(380)$ | $z_{SD} = -0.918\ (a_{CDOM}(380))+5.06$ | 0.18 | 25 |
| $K_{d,PAR}$ vs. $z_{SD}$ | $K_{d,PAR} = 1.34\ (z_{SD})^{-0.61}$ | 0.62 | 25 |
| $z_{SD}$ vs. $K_{d,PAR}$ | $z_{SD} = 2.01\ (K_{d,PAR})^{-1.08}$ | 0.62 | 25 |

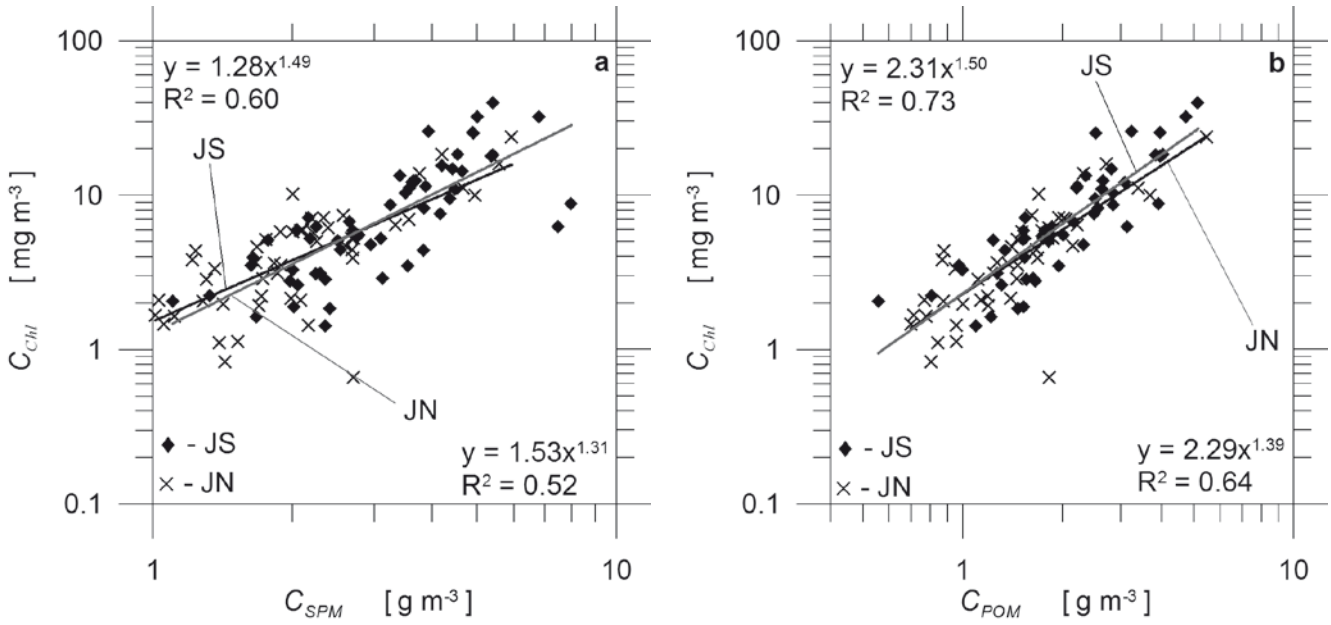



Fig. 4. Relationship: (a) $C_{Chl}$ vs. $C_{SPM}$, (b) $C_{Chl}$ vs. $C_{POM}$ in euphotic depth for lakes JN and JS

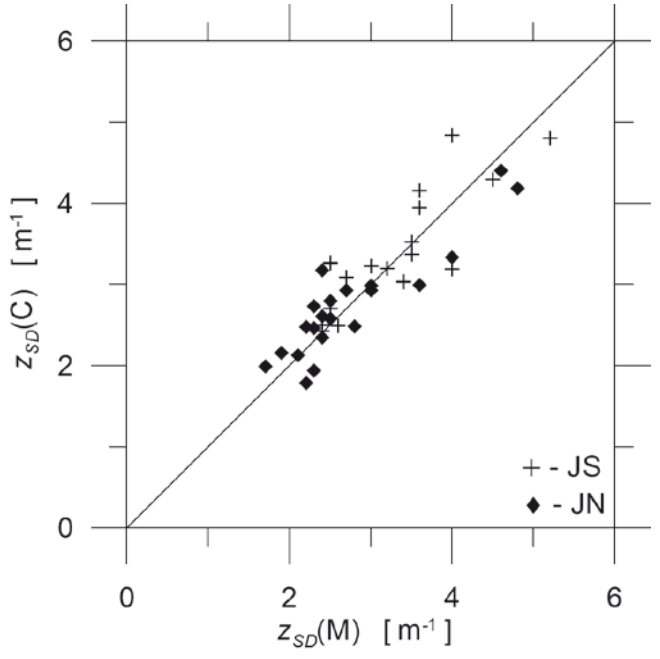



Fig. 5. Relationship between measured $z_{SD}$(M) and calculated $z_{SD}$(C) (from multiple regression analysis equation 3) diffuse attenuation coefficient values in JN and JS (N=40)

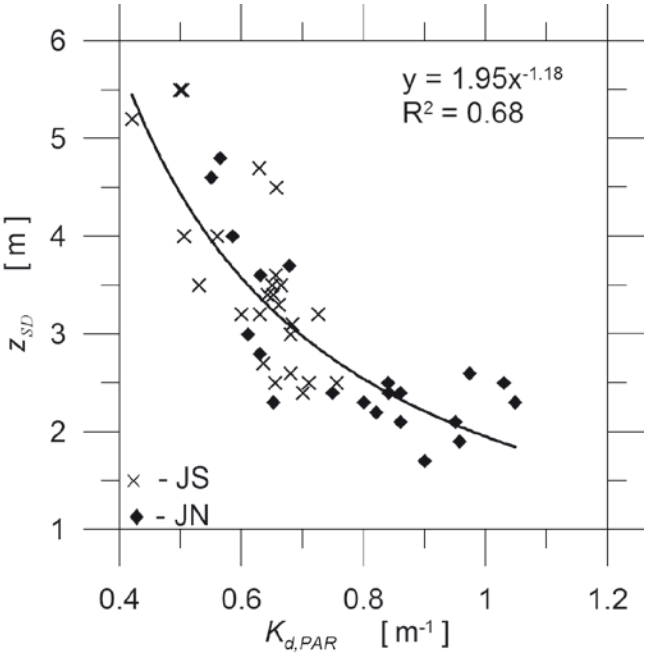



Fig. 6. Relationships between the values of Secchi disk depth $z_{sd}$ and diffuse attenuation coefficient $K_{d,PAR}$ in two Pomeranians lakes (all data from JN and JS are included, N=46)

the trend line both for low and high values is similar. The obtained results show that the relationship between $z_{SD}$ and $K_{d,PAR}$ can be described by means of a power function in which the exponent equals 1.18. A similar relationship calculated for Scandinavian lakes gives an exponent that equals 1.38 (Paavel et al. 2008). Apart from presenting the above mentioned relationships between $z_{SD}$ and $K_{d,PAR}$ , Table 3 also shows an inverse relation between $K_{d,PAR}$ and $z_{SD}$. The formulas given in this article allow a quick calculation of the above mentioned values and euphotic depth $z_{eu}$. Euphotic depth is the depth where 1% from subsurface irradiance reach is related to $K_{d,PAR}$:

$$z_{eu} = \frac{\ln(100)}{K_{d,PAR}} \cong \frac{4.6}{K_{d,PAR}} \qquad (4)$$

From equation (4) and equations presented in Table 3 (see positions 6 and 13) we get an approximate relationship between euphotic depth and $z_{SD}$.

## Discussion

Seasonal cycle of OSCs drives the variability of optical properties of lake waters. It is connected both with seasonal variability resulting from changes in phytoplankton activity and changes in CDOM concentration. We can see that the bio-optical properties of water in JN and JS differ from the ones observed in Lake Jeleń. Maximal concentrations of all three OSC elements are much greater which has an effect on the transparency of water. Maximal Secchi depths $z_{SD}$ reach 4.8 m in JS and 5.5m in JN, whereas in Lake Jeleń even 7m. Concentraions of all OSC elements also differ in the investigated lakes. The measurements show that chlorophyl concentration is high during phytoplankton blooms which appears in early spring and early autumn, which is typical for mesotrophic lakes of the temperate zone (Kawecka and Eloranta 1994; Willen E. 2000; Sheffer 2004). As shown in Fig.2, the greatest concentrations are 32 mg $m^{-3}$ in JS and 24 mg $m^{-3}$ in JN. They can appear both in early spring and early autumn.

CDOM concentrations show a typical annual cycle with high values for spring and autumn during which there is a higher CDOM concentration in comparison with summer. Thus, it can be concluded that in the Pomeranian lakes spring and autumn are periods of increased CDOM in the surface waters. A high value of the $a_{CDOM}$(380 nm) coefficient in early spring suggests that during this period there is a high CDOM concentration probably rinsed into the lake by the spring thaws and precipitation. Relatively high increases in $a_{CDOM}$(380 nm) values observed in autumn are related to an increase in CDOM concentration in the water of the investigated lakes which is a result of leaching substances into the investigated lakes by autumnal precipitation. Also, the surface water is fed by the more CDOM rich layers, that is meta- and hypolimnium, during gradual water circulation of the summer epilimnion. In different months during summer, smaller maxima connected with the enriching of the water reservoirs with CDOM from land and precipitation are also observed.

Temporal changes in the value of the light diffuse attenuation coefficient $K_{d,PAR}$ are strictly connected with changes in OSC. The lowest $K_{d,PAR}$ values are observed under the ice. In the growing season, the changes are mainly observed during summer and autumn after the phytoplankton bloom ceases. The values can even be up to 0.55 $m^{-1}$ in JS and 0.42 $m^{-1}$ in JN. These periods are short and the values increase quickly when phytoplankton activity is greater and can reach 1.05 $m^{-1}$ in JS and 0.76 $m^{-1}$ in JN. In general, due to small annual fluctuations in CDOM and a high correlation of suspended matter with phytoplankton, seasonal changes in $K_{d,PAR}$ reflect the seasonal dynamics of phytoplankton. Similarly, Secchi depth, which is the other parameter of water transparency, varies in JS from 1.7 to 4.8 m, and 2.4-5.5 m in JN.

When comparing the obtained $K_{d,PAR}$ values with those from Lake Jeleń, we can see that minimal $K_{d,PAR}$ is 11% higher in JN and 31% higher in JS. Similarly, Secchi depth maximal values are 5.5 m for JN and 4.8 m for JS, whereas in Lake Jeleń they are up to 7m. The range of variations for JN and JS is not so big. $K_{d,PAR}$ varies from 0.42 to 0.76 $m^{-1}$ in JN and from 0.55 to 1.05 $m^{-1}$ in JS while $z_{SD}$ varies from 2.4 to 5.5 m in JN and from 1.7 to 4.8 m in JS. It varies from 2.8 to 7.0 m in Lake Jeleń. It indicates great variation of underwater light in these lakes.

Table 3 shows that correlations between $z_{SD}$ and each OSC element are the highest with $C_{Chl}$ in JN and with $C_{SPM}$ in JS. It is probably related to the differences in the surface and depth of these lakes. Bigger surface and smaller mean depth in JS facilitate enriching the suspensions with minerals due to resuspension. Additionally, JS waters are more influenced by river waters that bring suspensions rich in minerals to the

water reservoir. JN is significantly smaller but has a greater mean depth. The suspensions that are present in it are much more connected with phytoplankton which results in a greater amount of organic matter in suspensions in this lake (see $C_{POM}$ / $C_{SPM}$ in Table 2). The correlation between $z_{SD}$ and $a_{CDOM}(380)$ is weak in both lakes. It results from the fact that relative seasonal changes in $a_{CDOM}(380)$ are much smaller than the variation of phytoplankton and suspended matter in these lakes.

The $R^2$ determination coefficient between $z_{SD}$ and each OSC separately (Table 3) is smaller than the result obtained by means of multilevel regression (equation 3). Regression formulas of $z_{SD}$ and $K_{d,PAR}$ obtained for both lakes have higher determination coefficient for JS. The value of this coefficient is $R^2$=0.62 for JS and $R^2$=0.57 for JN.

## Conclusions

The article shows differences between optical properties of water and optical characteristics of the investigated lakes, and the most transparent Pomeranian Lake Jeleń. Seasonal variations of OSC elements and optical parameters of water are shown. As presented, it is mostly connected with the variations in seasonal biological activity. All three OSC elements influence the bio-optical properties of water in these lakes. However, due to little CDOM variation correlations between optical parameters (e.g. $z_{SD}$) and each OSC element separately are high with $C_{SPM}$ and $C_{Chl}$, and weak with $a_{CDOM}(380)$. The determination coefficient obtained by means of multilevel analysis between all three OSCs and $z_{SD}$ shows higher values. This proves that all OSCs influence the optical properties of water.

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