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Distribution of epiphytic algae on macrophytes of various ecological groups (the case study of water bodies in the Dnieper River basin)

by

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Abstract

The generalization and analysis of original data have shown that the nature of epiphytic algae distribution on higher aquatic plants, representing different ecological groups, is very similar in various types of numerous water bodies in the Dnieper River basin. Their species richness and values of quantitative indices were mostly higher on submerged plants compared to plants of other ecological groups. The number of epiphytic algae species was 1.1-1.7 times higher on submerged plants compared to that on half-submerged plants and 1.6-3.1 times higher compared to plants with floating leaves. The taxonomic structure and species composition of epiphyton were very similar on half-submerged and submerged plants and moderately similar on plants with floating leaves compared to macrophytes of other ecological groups. It is emphasized that the specificity of epiphytic algae distribution on macrophytes of various ecological groups should be taken into account when performing monitoring and assessment of the ecological status of water bodies by the bioindication method.

Key words: epiphytic algae, species composition and richness, taxonomic structure, algal cell counts, biomass, higher aquatic plants, ecological groups, water bodies of various types

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Introduction

The bioindication method is mostly used to assess the ecological status of water bodies exposed to anthropogenic load. Phytobenthos (in a broad sense, including periphyton and epiphyton) is classified into the so-called biological elements of water quality. The indices of the structure and abundance of hydrobionts' communities, including their species richness, taxonomic, ecological, and morphological structure, are indicative of the ecological status of water bodies and its changes under the influence of anthropogenic factors (The Directive… 2000).

Epiphytic algae attract attention of many scientists. The following characteristics of epiphyton are investigated: species composition, taxonomic structure, complex of dominants, quantitative indices (Makarevich 2003; Sysova 2007; Sudnitsyna 2008; Rodriguez et al. 2001; Shevchenko 2013; Tunca et al. 2014), seasonal dynamics (Rychkova 2003; Karosiené & Kasperovičhené 2008; Toporowska et al. 2008), features of vertical distribution (Sharipova 2012), ecological characteristics (Klochenko et al. 2014a), the functional role (Belyayeva 2013; Meteleva 2013), etc.

Data on epiphytic algae are used to assess the ecological status of various types of water bodies (Komulaynen 2002; 2006; Stenina 2003; Ács et al. 2004; Bauer et al. 2007; Karosiené 2007; Glushchenko 2010; Rusanov et al. 2012; Klochenko et al. 2014b).

At the same time, literature data suggest that the structure and abundance of epiphyton on macrophytes of various ecological groups is varied (Laugaste et al. 2003; Kasperovichene & Karosene 2005; Meteleva 2008; Leonova 2012; Stanislavskaya 2012).

The objective of the presented work was to reveal the regularities in the distribution of epiphytic algae on macrophytes, representing various ecological groups and occurring in various water bodies of the Dnieper River basin, based on original published and unpublished data.

Materials and methods

Description of the study site

Sampling was carried out in the reservoirs of the Dnieper cascade, including Kiev – 50°54′N, 30°29′E, Kanev – 49°58′N, 31°14′E, and Kremenchug reservoirs – 49°17′N, 32°34′E (Fig. 1), in 13 lakes (Almaznoye – 50°50′N, 30°65′E, Goluboye – 50°50′N, 30°41′E, Iordanskoye – 50°49′N, 30°50′E, Lugovoye – 50°51′N, 30°47′E, Pidbirna – 50°37′N, 30°60′E, Raduzhnoye – 50°48′N, 30°58′E, Redkino – 50°53′N, 30°48′E, Sineye – 50°30′N, 30°24′E, Solnechnoye – 50°41′N, 30°63′E, Telbin – 50°25′N, 30°36′E, Tsentralnoye – 50°51′N, 30°50′E, Verbnoye – 50°29′N, 30°31′E, and Vyrlitsa – 50°24′N, 30°40′E) and in 12 ponds of the "Goloseyevo" National Nature Park – 50°17′N, 30°33′E (including Didorovka, Kitayevo and Orekhovatka ponds), located within the territory of Kiev (Fig. 2).

Figure 1

Location of the reservoirs of the Dnieper cascade

Figure 2

Location of the studied ponds and lakes of Kiev (according to the specialist in ecohydrology S.V. Batog)

Sampling and laboratory studies

The study was carried out in 2003-2014, mainly in summertime. A total of 606 samples of epiphytic algae were collected and processed. In this case, 75 samples were collected in the Kiev Reservoir, 89 and 84 – in the river and lake sections of the Kanev Reservoir, 94 – in its bays, 72 – in the Kremenchug Reservoir, and 75 and 117 – in the ponds and lakes of Kiev.

Epiphyton samples were collected from 26 species of higher aquatic plants belonging to three ecological groups: half-submerged (*Alisma plantago-aquatica* L., *Butomus umbellatus* L., *Glyceria maxima* (C. Hartm.) Holmb., *Phragmites australis* (Cav.) Trin. ex Steud., *Sagittaria sagittifolia* L., *Scirpus lacustris* L., *S. sylvaticus* L., *Sparganium erectum* L., *Typha angustifolia* L., and *T. latifolia* L.), with floating leaves (*Nuphar lutea* (L.) Smith, *Nymphaea alba* L., *Trapa natans* L., *Polygonum amphibium* L., and *Potamogeton natans* L.), and submerged (*Batrachium foeniculaceum* (Gilib.) V. Krecz., *Elodea canadensis* Michx., *Ceratophyllum demersum* L., *Myriophyllum spicatum* L., *Najas marina* L., *Potamogeton crispus* L., *P. gramineus* L., *P. pectinatus* L., *P. perfoliatus* L., *P. praelongus* Wulf., and *Stratiotes aloides* L.).

The samples of epiphyton were collected and processed following the commonly accepted hydrobiological procedures (Topachevskiy & Masyuk 1984; Arsan et al. 2006). The species composition of algae found on higher aquatic plants, representing various ecological groups, was compared using the Sorensen coefficient of community similarity (Vasilevich 1969) and the overlap method (Mirkin & Rozenberg 1983). Taxonomic analysis was carried out using the methods accepted for the comparison of floras (Shmidt 1980). The frequency of occurrence was determined as the ratio of the total number of samples in which the species was found to the total number of samples collected from higher aquatic plants of a certain ecological group. The algal cell counts (the number of algal cells) and biomass of epiphytic algae were calculated per 1 g of air-dry mass of plant substrate. In addition, the algal cell counts and biomass of epiphyton found in the fouling of *Phragmites australis*, *Typha angustifolia*, *Nuphar lutea*, *Trapa natans*, *Potamogeton gramineus*, *P. perfoliatus*, and *P. praelongus*, occurring in the Dnieper reservoirs, were calculated per 1 cm^2 of plant substrate. The following manuals were used to identify algal taxa (Ettl 1978; 1983; 1988; Komarek & Fott 1983; Starmach 1985; Krammer & Lange-Bertalot 1986; 1988; 1991a,b; Popovský & Pfiester 1990; Komarek & Anagnostidis 1999; 2005; Vetrova 2002; Palamar-Mordvintseva 2003; Palamar-Mordvyntseva 2005; John et al. 2011). The Latin names and the volume of algal taxa are given in accordance with the classification systems (Blümel 2003; Calisová & Gabka 2009; Tsarenko et al. 2006; 2015).

Results

The study has shown that the distribution of epiphyton on macrophytes of various ecological groups is varied. The largest number of epiphytic algae species was found on submerged plants (144-253), the smaller number – on half-submerged plants (99-184), and the smallest number – on plants with floating leaves (60-119). Thus, the number of species on submerged plants was 1.1-1.7 times higher than on half-submerged plants and 1.6-3.1 times higher than on plants with floating leaves. Such pattern of distribution was observed in studies of epiphyton occurring in the Kiev Reservoir, in different sections of the Kanev Reservoir, in the Kremenchug Reservoir, and in lakes and ponds of Kiev (Table 1).

Bacillariophyta, Chlorophyta, and Charophyta were highly diverse in their species composition on higher aquatic plants of all ecological groups.

Table 1

The number of species (infraspecific taxa) of epiphytic algae on macrophytes of various ecological groups

Water bodies	Ecological groups of plants		
	half-submerged	with floating leaves	submerged
Kiev Reservoir	184 (187)	118 (121)	238 (243)
Kanev Reservoir			
river section	114 (119)	89 (92)	151 (159)
bays	128 (133)	99 (104)	184 (191)
lake section	113 (116)	60 (61)	188 (194)
Kremenchug Reservoir	99 (102)	88 (89)	144 (153)
Ponds of Kiev	151 (156)	94 (97)	160 (167)
Lakes of Kiev	175 (182)	119 (123)	253 (271)

Their contribution to the total number of species on half-submerged plants accounted for 85.9-94.0%, on plants with floating leaves – 83.9-91.7%, and on submerged plants – 83.8-88.9%. The contribution of other divisions was only 6.0-16.7%.

The taxonomic spectra of epiphyton on macrophytes of various ecological groups were very similar. Bacillariophyta (36.7-71.7% of the total number of species), followed by Chlorophyta (13.3-32.6%) and Charophyta (2.3-19.3%), were represented by the largest number of species on higher aquatic plants of all the studied ecological groups. However, the contribution of Bacillariophyta to the total number of species on plants with floating leaves was higher – 40.3-71.7% (on average 58.9%), whereas the contribution of Chlorophyta was lower – 13.3-31.0% (on average 22.2%) compared to plants of other ecological groups. At the same time, the contribution of Charophyta was higher on submerged plants – 7.3-19.3% (on average 13.7%), with the lower contribution of Bacillariophyta – 36.7-57.0% (on average 46.2%).

The taxonomic spectra of epiphyton were also very similar at the level of classes. The classes Bacillariophyceae (28.9-57.4% of the total number of species) and Chlorophyceae (11.5-26.7%) were represented by the largest number of species on macrophytes of all ecological groups. They were followed by the classes of Zygnematophyceae (2.2-18.4%) and Fragilariophyceae (4.1-12.0%). In this case, the maximum contribution of Bacillariophyceae and Fragilariophyceae to the total number of species was observed on plants with floating leaves, whereas the maximum contribution of Chlorophyceae and Zygnematophyceae – on submerged plants.

On macrophytes of all ecological groups in the spectra of leading taxa, Bacillariophyta were represented by the largest number of orders, families, and genera. Chlorophyta and Charophyta occupied higher rank places and were represented by the largest number of taxa on submerged plants, while they occupied lower rank places and were represented by a smaller number of taxa on plants with floating leaves compared to plants of other ecological groups. This regularity was observed in studies of the taxonomic structure of epiphyton in the Kiev Reservoir (Klochenko & Shevchenko 2016), different sections of the Kanev Reservoir (Tarashchuk et al. 2011a; 2012; Klochenko et al. 2016), the Kremenchug Reservoir, as well as in the lakes (Klochenko et al. 2012b) and ponds (Lynnyk et al. 2015) of Kiev.

The taxonomic structure of epiphyton on higher aquatic plants of all the studied ecological groups was very similar, which is supported by high values of the Kendall rank correlation coefficient calculated in terms of the leading families ($\tau = 0.67$-0.91) and leading genera ($\tau = 0.58$-0.82). In this case, the highest values of the coefficient were observed when comparing the taxonomic structure of epiphyton on half-submerged and submerged plants, whereas lower values – when comparing the taxonomic structure of epiphyton on plants with floating leaves and plants of other ecological groups.

The species composition of epiphytic algae was very similar on half-submerged and submerged plants (Sorensen's coefficient of community similarity was 60-77%, on average 70%) and on half-submerged plants and plants with floating leaves (59-72%, on average 67%). It was rather similar (45-67%, on average 58%) on submerged plants and plants with floating leaves.

As evidenced by the overlap method, many algal species found on plants with floating leaves were recorded on half-submerged (K = 79-88%) and submerged plants (K = 83-97%). In this case, many algal species observed on half-submerged plants were found on submerged plants (K = 79-87%). At the same time, a much smaller number of epiphytic algae species occurring on half-submerged plants was determined in the fouling of plants with floating leaves (K = 53-65%). The same applies to epiphyton of submerged plants found in the fouling of half-submerged plants (K = 49-63%) and plants with floating leaves (K = 31-49%).

Diatoms were most frequent species on macrophytes of all ecological groups, whereas representatives of Bacillariophyta, Chlorophyta, and Charophyta – on submerged plants. This regularity was observed in studies of epiphyton of the Kiev Reservoir (Klochenko & Shevchenko 2016), different sections of the Kanev Reservoir (Tarashchuk et al. 2011a, Klochenko et al. 2016), the Kremenchug Reservoir, as well as lakes (Shevchenko et al 2010, Klochenko et al. 2012a) and ponds of Kiev.

The number of epiphytic algae species on higher aquatic plants of the same species, on plants belonging to the same ecological group and plants of various ecological groups varied over a wide range (Tarashchuk et al. 2011b; Klochenko et al. 2012a; 2015b; 2016; Lynnyk et al. 2015). The average number of epiphytic algae species on half-submerged plants varied from 9 to 26, on plants with floating leaves – from 14 to 21, and on submerged plants – from 21 to 38. The average number of epiphytic algae species recorded on submerged plants was 1.5-1.9 times higher than that on plants with floating leaves and 1.2-2.3 times higher than that on half-submerged plants (Table 2).

At the same site, the species richness of epiphytic algae was higher on submerged plants than that on plants of other ecological groups. For example, epiphyton was represented by 33 species in the fouling of submerged plants (*Ceratophyllum demersum*) in the Kiev Reservoir, by 12 – on plants with floating leaves (*Nuphar lutea*), and by 8 species – on half-submerged plants (*Typha angustifolia*) (Klochenko & Shevchenko 2016).

It should be noted that the number of epiphytic algae species was significantly lower in the dense beds of half-submerged plants compared to loose half-submerged vegetation or on individual plants. In the Kiev Reservoir, for example, epiphyton was represented by 5 species in the dense *Phragmites australis* beds and by 32 species – on individual reed specimens (Klochenko & Shevchenko 2016). In the dense beds of half-submerged plants in the lakes of Kiev, epiphyton was relatively often represented by one species (mainly by *Cocconeis placentula* Ehrenb.) (Klochenko et al. 2012a).

The quantitative indices of epiphyton development on higher aquatic plants of various ecological groups, calculated per 1 g of air-dry mass of plant substrate, were significantly different. The average algal cell counts and biomass of epiphyton on submerged plants were mostly one to two orders of magnitude higher than those on half-submerged plants and plants with floating leaves (Table 3).

A slightly different pattern of the distribution of epiphytic algae on macrophytes of various ecological groups was observed when calculating their average algal cell counts and biomass per 1 cm^2. In most cases, higher quantitative indices of epiphyton development were determined on submerged plants, while lower values – on plants of other ecological groups. In this case, the difference between the quantitative indices of epiphyton development on macrophytes of various ecological groups was not so significant compared to average epiphyton algal cell counts and biomass per 1 g of air-dry mass of plant substrate (Table 4).

In terms of their algal cell counts and biomass, Bacillariophyta and Chlorophyta dominated on macrophytes of all ecological groups. The contribution of Bacillariophyta to the total algal cell counts and biomass of epiphyton accounted for 41.9-94.3 and 41.8-98.4%, whereas that of Chlorophyta – 3.2-38.9 and 1.4-46.3%, respectively. Cyanoprokaryota ranked 3rd in terms of their algal cell counts (0.9-28.5%), while Charophyta – in terms of their biomass (0.1-37.6%). In this case, the maximum contribution of Bacillariophyta to the total algal cell counts and biomass was observed on plants with floating leaves, whereas the maximum contribution of Chlorophyta and Charophyta – on submerged plants.

Table 2

Average number of species of epiphytic algae on macrophytes of various ecological groups

Water bodies	Ecological groups of plants		
	half-submerged	with floating leaves	submerged
Kiev Reservoir	23 ± 8.2**	21 ± 3.8*	38 ± 7.3**
Kanev Reservoir			
river section	22 ± 4.2*	18 ± 5.0*	27 ± 3.7**
bays	26 ± 6.0**	19 ± 1.5*	35 ± 4.6**
lake section	24 ± 7.4*	17 ± 4.7*	31 ± 6.3*
Kremenchug Reservoir	17 ± 4.5**	15 ± 1.1*	29 ± 3.9*
Ponds of Kiev	19 ± 3.0**	20 ± 4.6*	30 ± 7.1*
Lakes of Kiev	9 ± 5.0**	14 ± 8.4*	21 ± 5.2*

Note: Median ± SD (standard deviation); * – $p \leq 0.05$, ** – $p \leq 0.01$.

Table 3

Average algal cell counts and biomass of epiphytic algae on macrophytes of various ecological groups calculated per 1 g of air-dry mass of plant substrate

Water bodies	Ecological groups of plants		
	half-submerged	with floating leaves	submerged
The algal cell counts (millions of cells g^{-1})			
Kiev Reservoir	0.208 ± 0.177**	0.835 ± 1.048*	5.501 ± 2.778*
Kanev Reservoir			
river section	0.382 ± 0.273**	2.669 ± 2.586*	14.755 ± 9.922*
bays	1.602 ± 1.324**	5.380 ± 4.215*	57.400 ± 26.172**
lake section	1.574 ± 1.849*	3.649 ± 2.575*	68.935 ± 49.722*
Kremenchug Reservoir	0.621 ± 0.779*	0.917 ± 0.612*	19.080 ± 19.949*
Ponds of Kiev	0.811 ± 0.574**	2.259 ± 2.527*	10.609 ± 8.344*
Lakes of Kiev	3.218 ± 3.814**	15.654 ± 11.227**	44.211 ± 27.358*
Biomass (mg g^{-1})			
Kiev Reservoir	0.51 ± 0.40**	1.89 ± 1.98*	13.36 ± 8.19*
Kanev Reservoir			
river section	0.79 ± 0.81**	2.32 ± 1.45*	23.76 ± 17.659*
bays	1.80 ± 1.33**	9.33 ± 3.21**	125.48 ± 92.57*
lake section	1.75 ± 2.15**	5.35 ± 4.08*	73.73 ± 44.82*
Kremenchug Reservoir	1.97 ± 2.60*	2.12 ± 1.30*	84.72 ± 127.00*
Ponds of Kiev	0.94 ± 0.66**	2.14 ± 1.96*	9.49 ± 7.65*
Lakes of Kiev	4.17 ± 4.68**	36.90 ± 16.98**	137.13 ± 80.77*

Note: Median ± SD (standard deviation); * – $p \leq 0.05$, ** – $p \leq 0.01$.

Table 4

Average algal cell counts and biomass of epiphytic algae on macrophytes of various ecological groups calculated per 1 cm^2 of plant substrate

Water bodies	Ecological groups of plants		
	half-submerged	with floating leaves	submerged
The algal cell counts (millions of cells cm^{-2})			
Kiev Reservoir	0.112 ± 0.041*	0.108 ± 0.084*	0.066 ± 0.053*
Kanev Reservoir			
river section	0.115 ± 0.099**	0.047 ± 0.026*	0.085 ± 0.054*
bays	0.402 ± 0.346**	0.252 ± 0.182**	0.520 ± 0.476*
lake section	0.140 ± 0.079*	0.180 ± 0.071*	0.264 ± 0.178**
Kremenchug Reservoir	0.091 ± 0.080*	0.069 ± 0.055*	0.116 ± 0.112*
Biomass (mg cm^{-2})			
Kiev Reservoir	0.32 ± 0.18**	0.20 ± 0.12*	0.20 ± 0.15**
Kanev Reservoir			
river section	0.17 ± 0.23**	0.10 ± 0.08*	0.25 ± 0.22**
bays	1.13 ± 0.76**	0.41 ± 0.34**	1.27 ± 1.18*
lake section	0.56 ± 0.46**	0.34 ± 0.22**	0.68 ± 0.54*
Kremenchug Reservoir	0.24 ± 0.10*	0.22 ± 0.19*	0.33 ± 0.26*

Note: Median ± SD (standard deviation); * – $p \leq 0.05$, ** – $p \leq 0.01$.

Discussion

The study has shown that the distribution of epiphyton on higher aquatic plants of different ecological groups is irregular in various types of many water bodies of the Dnieper River basin. The largest number of epiphytic algae species was found on submerged plants, while the lower number – on half-submerged plants, and the lowest number – on plants with floating leaves, which was observed in the Kiev, Kanev, and Kremenchug reservoirs, as well as in the lakes and ponds of Kiev. The obtained results are consistent with literature data. The same pattern of distribution was observed in studies of epiphytic algae in lakes of the middle reaches of the Lena River (Russia). Epiphyton on submerged plants was represented by 254 species, on half-submerged plants – by 232 species, and on plants with floating leaves – 192 species (Kopyrina 2003). In Lake Peipsi/Pinkva (Russia), the largest number of epiphytic algae species (99) was found also in the fouling of submerged plants (*Stratiotes aloides*) (Leonova 2012).

At the same time, literature data on the quantitative indices of epiphyton development on macrophytes of various ecological groups are rather contradictory. For example, the algal cell counts and biomass of epiphyton on half-submerged plants in Lake Spera (Lithuania) were essentially higher than those on plants with floating leaves (Kasperovichene & Karosene 2005). In Lake Nero (Russia), the highest intensity of epiphyton development was observed on *Nuphar lutea*, and the lowest one – on *Scirpus lacustris*. In the fouling of *Nuphar lutea*, epiphyton biomass was eight times higher compared to *Phragmites australis* and four times higher compared to *Typha angustifolia* (Meteleva 2013). In lakes of Estonia, high quantitative indices of epiphyton development, in terms of chlorophyll *a* content, were determined on half-submerged and submerged plants, while the lowest ones – on plants with floating leaves (Laugaste et al. 2003). In lakes of Lithuania, the maximum algal cell counts of epiphyton were recorded on half-submerged plants (*Phragmites australis*), the lower algal cell counts – on plants with floating leaves (*Nuphar lutea*), and the lowest algal cell counts – on submerged plants (*Potamogeton lucens* L.) (Mokhamad & Kasperovichene 2001). In Lake Ladoga (Russia), epiphyton biomass on submerged plants (species of the genus *Potamogeton* L.) was almost twice as high as that on half-submerged plants (*Phragmites australis*) (Rychkova 2003). Based on the original data, the average algal cell counts and biomass of epiphyton on submerged plants, calculated per 1 cm^2 of plant substrate, were in most cases several times (1.1-3.1) higher than those recorded on half-submerged plants and plants with floating leaves. In this case, the average algal cell counts and biomass of epiphyton on submerged plants, calculated per 1 g of air-dry mass of plant substrate, were mostly one to two orders of magnitude higher than those on half-submerged plants and plants with floating leaves, which is consistent with literature data (Sudnitsina 2008).

It is likely that the difference in light intensity is the main reason of irregular distribution of epiphytic algae on macrophytes of various ecological groups. It has been found (Klochenko et al. 2015a) that the intensity of light in the dense beds of half-submerged plants and plants with floating leaves was on average 12 times and 8 times lower (respectively) compared to the open sections of water bodies.

In this case, the position of plant substrate in space is of considerable importance. In the case of half-submerged plants, epiphytic algae occur on their vertical stems, plants with floating leaves – mainly on the back side of their leaves, and in the case of submerged plants – on their horizontal or located at an angle leaves, receiving the largest portion of solar radiation. Therefore, the contribution of shade-tolerant Bacillariophyta (Hill 1996; Reynolds et al. 1994; Wunsam et al. 2002; Korneva 2009) on half-submerged plants and plants with floating leaves to the total number of species as well as to the total algal cell counts and biomass of epiphyton is higher, while the contribution of photophilous Chlorophyta and Charophyta (Hill 1996; Komulaynen 2004) is lower compared to submerged plants. The influence of plant substrate architecture on epiphytic algae development is emphasized by many authors (Cattaneo et al. 1998; Toporowska et al. 2008). It has been found (Cattaneo et al. 1998) that the most favorable light conditions for epiphyton occur in beds of submerged plants, whereas considerable shading prevails in beds of plants with floating leaves. In the dense beds of half-submerged plants, shading of plant substrate has an adverse effect on epiphyton (Liboriussen & Jeppesen 2003; Rychkova 2003). For this reason, the largest number of species of epiphytic algae occurs on submerged plants.

Thus, epiphyton occurring on macrophytes of various ecological groups is characterized by special features, which should be taken into account in monitoring and assessment of the ecological status of water bodies according to the provisions of the Water Framework Directive (The Directive… 2000). Epiphyton occurring at different sites should be compared on the same plant species or on plants belonging to the same ecological group. The most reliable and valid results can be obtained when comparing epiphytic algae occurring in the fouling of submerged plants, where their species composition is highly diverse. On half-submerged plants and plants with floating leaves, the low intensity of light inhibits the development of many algal species, primarily representatives of Chlorophyta and Charophyta, including diagnostic and indicator species.

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