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## The impact of aeration on ecological state of lake Telbyn in Kyiv

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**Abstract.** Lake Telbyn is considered to be one of the largest lakes located in the eastern part of Kyiv. The artificial aeration of this lake was started at the end of 2016 by using of 8 aerators, which has been continuing so far. The main purpose of this measure is improving the ecological state of the lake mostly for recreational use. There were carried out a field study of the lake and the analysis of remote sensing data. Physical and chemical characteristics of water, phytoplankton biomass, chlorophyll *a* concentration and some other parameters at the different depths were studied. It was found out that artificial aeration has a positive effect on the ecological state of the lake. The water aeration causes the blur of thermocline whereas the impact on its depth is not essential. Under impact of aeration the concentration of dissolved oxygen become larger, mostly in the bottom layer. The highest concentration of ammonium nitrogen in a warm period is observed in the bottom layer of the lake. The deep location of aerators causes the increasing of concentration in bottom layer. At the same time there is not visible impact on concentration near the surface. The similar result was obtained for the concentration of inorganic phosphorus. The impact of aeration on algal bloom is not such essential as on hydrochemical characteristics. The artificial aeration causes negative impact on the phytoplankton abundance and less effect on their biomass. It means the larger effect on the algae with small cells. In other words the aeration has larger impact on green algae than on blue-green ones. The use of remote sensing data showed that ecological state of Lake Telbyn during the aeration period improved comparably with other lakes of Kyiv. As a result of aeration, the view of water surface of the lake became more similar to water surface of the Dnipro River, which flows through the city.

**Keywords:** aeration, lake, thermocline, nutrients, phytoplankton, remote sensing data

## Вплив аерації на екологічний стан озера Тельбін у Києві

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**Анотація.** Озеро Тельбін вважається одним із найбільших озер, розташованих у східній частині Києва. Наприкінці 2016 р. було розпочато штучну аерацію цього озера за допомогою 8 аераторів, що триває і досі. Основна мета цього заходу – поліпшення екологічного стану озера – передусім для рекреаційного використання. Виконано польові дослідження озера та аналіз даних дистанційного зондування Землі. Вивчено фізико-хімічні характеристики води, біомасу фітопланктону, концентрацію хлорофілу та деякі інші параметри на різних глибинах. З'ясовано, що штучна аерація позитивно впливає на екологічний стан озера. Аерація води зумовлює розмивання термокліну, водночас її вплив на його глибину неістотний. Під впливом аерації концентрація розчиненого кисню стає більшою, насамперед у придонному шарі. У теплий період року найвища концентрація азоту амонійного спостерігається у придонному шарі озера. Глибоке розташування аераторів зумовлює підвищення концентрації в нижньому шарі. При цьому не спостерігається видимого впливу на концентрацію біля поверхні. Аналогічний результат отримано щодо концентрації неорганічного фосфору. Вплив аерації на “цвітіння” водоростей не настільки значний, як на гідрохімічні характеристики. Штучна аерація спричиняє негативний вплив на кількість фітопланктону та менший вплив на їх біомасу. Це означає більший вплив на водорості з дрібними клітинами. Іншими словами, аерація має більший вплив на зелені водорості, ніж на синьо-зелені. Використання даних дистанційного зондування показало, що екологічний стан озера Тельбін за період аерації покращився, порівняно з іншими озерами Києва. Внаслідок аерації вигляд водної поверхні озера наблизився до вигляду водної поверхні Дніпра, що тече через місто.

**Ключові слова:** аерація, озеро, термоклін, біогени, фітопланктон, дані дистанційного зондування Землі

## Introduction.

Artificial aeration of water bodies is a well-known and widespread method aimed at improving their ecological state. Accordingly, there is a significant amount of scientific works (Ashley 1983, Beutel, Horne 1999, Gasi et al 2009, Heo, Bomchul 2004, Imteaz, Asaeda 2000, Osuch, Podsiadłowski 2012, Riabov, Sirenko 1982) devoted to this activity. In Ukraine, such measures are also carried out, but mainly in small water bodies and in order to improve the living conditions of fish. Until recently, the aeration of rather large lakes to improve their ecological state for recreational purposes was not performed. It was first started on Lake Telbyn (sometimes Telbin), which is located in Kyiv.

The Lake Telbyn is located in the eastern part of the city. Its geographical coordinates are: 50°25'33" N, 30°36'10" E. The lake originates from the old channel of the Dnipro River and by the mid of the 19<sup>th</sup> century it had been much larger than it is now. In 1868–1869 it was divided by the railway on two parts. The northern part known nowadays as the Lake Telbyn was gradually built up around. The southern part during the next decades was transformed to the Lake Koroliok. The hydraulic connection of these lakes with other water bodies is almost absent.

The current area of the Lake Telbyn is 13.6 hectares, perimeter is 2.1 km and the maximum depth is 13 m. There are two beach areas that are rather popular with the local people for recreation.

Besides the Lake Telbyn there are many other water bodies in the eastern part of Kyiv. Some data as to these objects, obtained from satellites images, were used for the study as well (fig. 1).

an hour, but at the beginning of aeration it was much less – about 100 m<sup>3</sup> per hour. Actually the operation of the aerators was irregular. At first the depth of aerator installation was rather small – 1.5–2.5 m from the water surface. Gradually some aerators were moved from small depth deeper – up to 5 m (fig. 2).

The study of the ecological state of the Lake Telbyn was started in early 2000s (Morozova, 2008; Morozova, 2009). It was defined the anaerobic conditions in the bottom layer of the lake, mainly during the warmest period. It was found out great differences in the concentration of inorganic phosphorus and total iron in the surface and bottom layers – up to 20 times.

According to the results of hydrochemical study carried out in 2007–2008, the Lake Telbyn was exposed to eutrophication. The pH values varied within 6.75–9.40, the concentration of dissolved oxygen amounted to 0.0–16.5 mg/dm<sup>3</sup>, ammonium nitrogen – 0.32–13.9 mg/dm<sup>3</sup>, total iron – 0–2.65 mg/dm<sup>3</sup>. When having the direct temperature stratification it was recorded the essential increase in ammonia nitrogen and iron concentrations in the bottom layer and the deficit of dissolved oxygen at the same time. The high concentration of suspended solids in the surface layer, which reached 80 mg/dm<sup>3</sup>, indicated an intense algal bloom (Morozova, 2008; Morozova, 2009).

The study, carried out by authors of this article in the warm period of 2009, revealed the existence of thermocline at the depth of about 3 m.

It is possible to evaluate the ecological state of this waterbody using phytoplankton data, which was successfully proven in previous works (Bilous et al., 2014; Bilous et al., 2016). In turn, there were some studies on the ecological state of the water bodies lo-



**Fig. 1.** Water bodies of Kyiv under study: 1 – Lake Telbyn, 2 – Lake Almazne, 3 – Lake Koroliok, 4 – Lake Soniachne, 5 – Berkivshchyna bay, 6 – Lake Lebedyne, 7 – Lake Tiagle

The air for the aeration purpose is supplied by a compressor to 8 aerators, which were installed uniformly on the Lake Telbyn at the end of 2016. The total productivity of the aerators makes 360 m<sup>3</sup> per

hour within the urban area of Kyiv, based on remote sensing data (Vyshnevskiy and Shevchuk, 2018). It was obtained a rather close correlation in warm period between the water transparency, measured with



Fig. 2. Satellite image of the Lake Telbyn with the location of installed aerators

Secchi Disk, and the values of the spectral band B3 of the Landsat 8 satellite, which correspond to green colour. The stronger correlation between the water transparency and the satellite data was obtained for the expression  $SD = (B4 - B2)/B3$ .

### Materials and methods.

The current investigation of the ecological state of the Lake Telbyn, regarding the impact of artificial aeration, included field study and analysis of remote sensing data.

The field study was carried out during warm period of 2017–2018 with the focus on hydrochemical measurements and characteristics of phytoplankton. The most complete study, including samplings of phytoplankton, was carried out 06.07.2017, 02.08.2017, 08.08.2017, 13.09.2017, 10.07.2018, 09.08.2018, 16.08.2018 and 30.08.2018. Some additional measurements on hydrochemical characteristics were carried out on 24.07.2018, 21.11.2018 and 11.03.2020 as well. The study was carried out in the different parts of the lake with various conditions: very close and far away from the working aerators and also near aerators installed at different depths.

The following hydrochemical characteristics were studied: water temperature, concentration of dissolved oxygen, mineralization, nitrogen compounds, inorganic phosphorus and pH. The concentration of dissolved oxygen, mineralization, pH were determined using the multifunctional device AZ-86031. The concentration of dissolved oxygen was deter-

mined by Winkler's method as well. Water clarity was measured by use of the Secchi Disk with diameter of 30 cm. The water clarity was measured in the Dnipro River in the point closed to the Lake Telbyn as well. Seignette salt with Nessler's reagent was used to determine ammonium nitrogen ( $N-NH_4^+$ ), the Grisse reagent – to determine nitrite ions ( $N-NO_2^-$ ), sodium salicylate for nitrate ions ( $N-NO_3^-$ ), and ammonium molybdate with ascorbic acid for dissolved inorganic phosphorus ( $P-PO_4^{3-}$ ) or soluble reactive phosphorus (SRP) (Nabivanets et al., 2007).

The algological samples in alive state were investigated using Zeiss and PZO microscopes under magnification  $\times 400$ –1000. The quantitative analysis of plankton was carried out using a Nageotte Chamber ( $0.2\text{ cm}^3$ ). No less than 800 cells from each sample were calculated. The biomass of phytoplankton was determined by studied cells in particular volume of water. Dominant species were considered those, the share of which exceeded 10 % of the total biomass.

For the identification of the taxonomic algae species the following sources were used: *Süsswasserflora ...* (1998, 2005, 2013), Asaul (1975), Tsarenko (1990), Lange-Bertalot et al. (2017). The taxonomic system of algae, accepted in the monograph series *Algae...* (2006, 2009, 2011, 2014) and nomenclature changes to *Algae Base* (Gury and Gury, 2020) were determined on the base of common system derived from T. Cavalier-Smith (2004).

The concentration of chlorophyll *a* in phytoplankton was determined using the standard spectro-



photometry method and calculated using Jeffrey and Humphrey equation (Jeffrey and Humphrey, 1975).

The search of high-quality satellite images was the first stage in the study of the Lake Telbyn using the remote sensing data. It is focused on the data of the Landsat 8 satellite. Data processing of satellite images was carried out using the ArcMap 10 program. The obtained data were analyzed along with making images in pseudo-natural colours and using some indices, which were the ratio of satellite images spectral bands. The study was carried out for the Lake Telbyn and some other water bodies located nearby. The values of the bands B2, B3 and B4 in some points of their water area were measured. The average values were used for further comparison. In total, 14 images of the Landsat 8 satellite, obtained in a warm period during 2014–2020, were used in the research process: 6 – in 2014–2016 and 8 – in 2017–2020. The last processed image was obtained on 16.08.2020.

## Results and Discussion.

### *Hydrometeorological conditions*

During the some last years, the air temperature in Kyiv, likewise over the world, was warmer than usual. According to the observations of a local meteorological station in Kyiv the annual air temperature in 2016–2020 was two or even more degrees higher compared to the period of 1961–1990 (table 1).

**Table 1.** Mean monthly air temperature (°C) at the meteorological station in Kyiv

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean
2016	-5.7	2.0	3.9	12.4	15.5	20.6	22.4	21.1	16.1	6.5	1.2	-1.5	9.5
2017	-4.9	-2.8	6.2	10.4	15.3	20.0	20.9	22.4	16.4	8.4	3.3	1.6	9.8
2018	-2.4	-3.8	-1.9	13.1	18.8	20.6	21.4	22.5	17.3	10.7	0.3	-2.2	9.5
2019	-4.5	0.6	5.1	10.6	17.0	23.6	19.8	20.7	15.9	11.1	4.6	2.7	10.6
2020	0.8	2.5	6.5	9.9	12.4	21.7	21.9	21.4	18.4	12.5	2.1	3.8	10.9
Norm	-5.6	-4.2	0.7	8.7	15.2	18.2	19.3	18.6	13.9	8.1	2.1	-2.3	7.7

Under these circumstances, the ecological state of the Lake Telbyn, even having artificial aeration, can be worse than in the years with lower water temperature. Hydrometeorological conditions before and during the field studies play the important role as well.

Due to the evaporation of water from the surface of the lake (especially in the warm period) its level was decreasing. Thus, from 04.05.2018 until 21.11.2018 it decreased by 35 cm.

### *Water clarity*

The water clarity in the Lake Telbyn was measured in 2018 using the Secchi Disk with the intervals of about 10 days. The lowest water clarity was observed in the beginning of August (table 2).

The water clarity in the Dnipro River at this time was much larger. During 2018 it was as follows: 10.07 – 151 cm, 22.07 – 153 cm, 09.08 – 131 cm, 16.08 – 156 cm, 28.08 – 143 cm.

### *Water temperature*

The water temperature was permanently recorded during the field studies. On all dates of measurements, except 21.11.2018 and 11.03.2020, a thermocline phenomenon occurred. In the summer period of 2017 it was observed at the depth of 5–5.5 m, in summer of 2018 it was about 6 m.

The carried out study proves the positive impact of aeration on the distribution of water temperature. Distribution of water temperature near the working aerators by depth was more even comparably with the cases without aeration (fig. 3).

It is important to note that the change of the depth of aerator does not influence on the depth of thermocline, but aerator, which is installed deeper, causes more visible blurring of the thermocline.

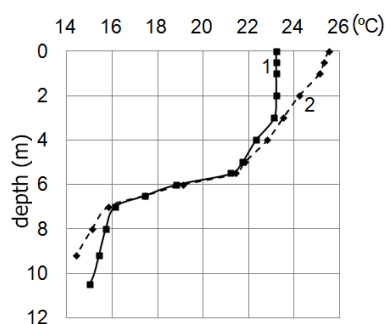
### *Concentration of dissolved oxygen*

The concentration of dissolved oxygen significantly depends on the season. In summer period under the effect of algal bloom the highest concentration of

dissolved oxygen is observed in the surface layer. In some cases the oxygen saturation exceeds 100 % and reaches 150–155 %. First of all, it should be noted that the changes in the concentration of dissolved oxygen in depth in the area with aeration are more uniform than in the area without aeration. It is very important the positive impact of aeration on the concentration in the bottom layer. Thus, on July 10, 2018, in the zone with aeration it was 2.9, and in the zone without aeration – only 1.1 mg/dm<sup>3</sup> (fig. 4).

**Table 2.** Water clarity (cm) of the Lake Telbyn during 2018

04.05	17.05	29.05	09.06	20.06	10.07	22.07	09.08	16.08	28.08	21.11
74	70	75	75	74	54	54	49	61	62	165



**Fig. 3.** Distribution of water temperature by depth in the Lake Telbyn on 10.07.2018:

1 – close to the aerator No 3 installed at the depth of 1.5 m, 2 – without aeration near unoperated aerator No 7

The increasing of the depth of aerators causes the increasing of dissolved oxygen concentration in the bottom layer.

In the last summer days and in September the concentration of dissolved oxygen in the surface layer becomes less. This time the maximum values of dissolved oxygen are observed at the depth of several meters. In the spring, in particular on 11.03.2020, the concentration of dissolved oxygen in the surface and bottom layers was almost the same – 9.5–10.3 mg/dm<sup>3</sup>, the saturation level was 78.5–87.2 %.

#### **Water mineralization**

In general, the Lake Telbyn is characterized by rather small mineralization. To some extent, it depends on the season: the smallest values are observed in the spring period while in autumn mineralization becomes higher. The highest values (353–355 mg/dm<sup>3</sup>) were observed on 21.11.2018.

#### **Water pH**

The water pH in a whole corresponds to the concentration of dissolved oxygen distribution by depth and to some extent to the distribution of phytoplankton. The highest value (up to 8.5–9.0) in warm period was observed near water surface. In March 2020 the pH of the water was 8.2–8.3. The noticeable effect of aeration on the water pH was not recorded.

#### **Concentration of nutrients**

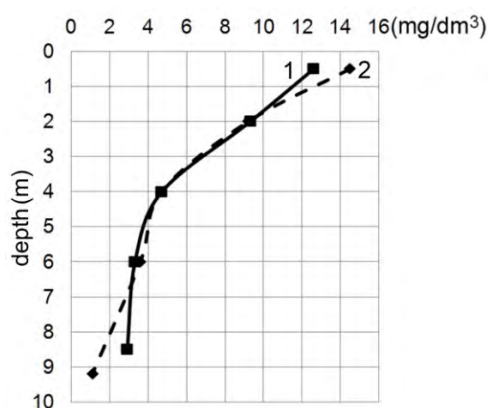
The concentration of ammonium nitrogen, nitrate ions and inorganic phosphorus were the key points of field study.

The concentration of ammonium nitrogen in the warm period greatly changes by depth: in the surface layer it is significantly less than near the bottom. The largest changes in the ammonium nitrogen concentration correspond to the depth of thermocline. In the summer of 2017 the largest changes in ammonium nitrogen were observed at a depth of 5–5.5 m. On 13.09.2017, the zone of the largest changes moved a little deeper at the depth of about 6 m. In 2018, the largest changes of ammonium nitrogen concentration were observed at the same depth of about 6 m.

The aerators, installed at a rather small depth, do not have any essential effect on NH<sub>4</sub><sup>+</sup> ions distribution. The increasing the depth of aerators causes the rise of NH<sub>4</sub><sup>+</sup> concentration in the bottom layer (fig. 5).

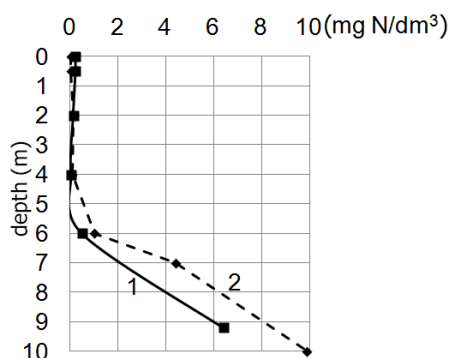
The concentration of nitrite nitrogen by depth and water area is approximately the same. In different periods it was 0.004–0.035 mg N/dm<sup>3</sup>. The effect of aeration on this chemical compound is not essential.

The concentration of nitrate nitrogen by depth is generally the opposite of the concentration of ammonium nitrogen. The highest concentration (0.8–1.0



**Fig. 4.** The concentration of dissolved oxygen by depth in the Lake Telbyn on 10.07.2018:

1 – close to the aerator № 3 installed at a depth of 1.5 m, 2 – without aeration close to the unoperated aerator No 7



**Fig. 5.** Concentration of ammonium nitrogen by depth in Lake Telbyn on 16.08.2018:

1 – close to the aerator № 4 installed at the depth of 1.5 m, 2 – close to the aerator № 5 installed at the depth of 5 m

mgN/dm<sup>3</sup>) in warm period is observed in the surface water layer. In March 2020 the distribution of all forms of nitrogen by depth was approximately equal.

The concentration of inorganic phosphorus by depth is distributed similarly to NH<sub>4</sub><sup>+</sup> concentration. The largest concentrations are recorded in the bottom layer. The increasing of the depth of installed aerators causes a rather small rise of inorganic phosphorus concentration in the bottom layer. The effect of aeration on the surface layer is absent (fig. 6).

In our opinion, the aeration of the lake should be performed carefully, because the rise of water from the bottom layer, which is rich in nutrients, can cause an increase their concentration near the surface and the corresponding growth of phytoplankton under favorable conditions. About negative effects of aeration are mentioned in (Gafsi et al 2009).

### Phytoplankton

There were five stages of the investigation on phytoplankton in the Lake Telbyn during 2017–2018: threefold in 2017 (06.07, 02.08 and 13.09) and twice in 2018 (10.07 and 16.08).

On 06.07.2017, the abundance of cells in the surface layer was 10–13 × 10<sup>6</sup> per dm<sup>3</sup>, in water layer it was 11–19 × 10<sup>6</sup> per dm<sup>3</sup> and at the bottom 5–8 × 10<sup>6</sup> per dm<sup>3</sup>. Correspondingly, the biomass of phytoplankton was the following: in the surface layer – 2–5

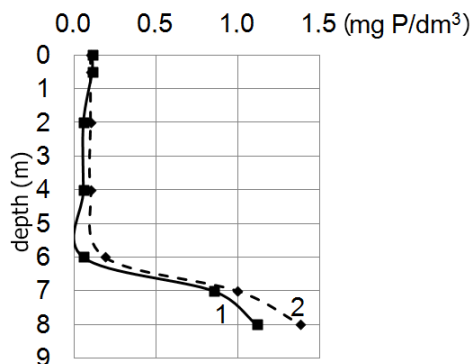
mg/dm<sup>3</sup>, in water layer – 5–8 mg/dm<sup>3</sup>, at the bottom – 1.5–2.9 mg/dm<sup>3</sup>.

On 02.08.2017, the quantitative characteristics of phytoplankton were almost the same as in previous measurements. In surface layer, the abundance was 14–16 × 10<sup>6</sup> cells/dm<sup>3</sup>, in water layer it was 10–11 × 10<sup>6</sup> cells/dm<sup>3</sup> and at the bottom – 9–15 × 10<sup>6</sup> cells/dm<sup>3</sup>. The biomass in the surface layer was 4–5 mg/dm<sup>3</sup>, in water layer it was about 4 mg/dm<sup>3</sup> and at the bottom – 3–5 mg/dm<sup>3</sup>.

On 13.09.2017, the number of cells in the surface layer was 10–13 × 10<sup>6</sup> cells/dm<sup>3</sup>, in water layer 7–8 × 10<sup>6</sup> cells/dm<sup>3</sup> and at the bottom about 6 × 10<sup>6</sup> cells/dm<sup>3</sup>. The biomass of phytoplankton in the surface and water layer was about 1 mg/dm<sup>3</sup> and at the bottom – 0.7–0.8 mg/dm<sup>3</sup>.

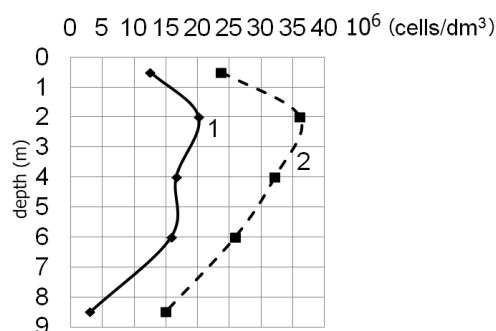
In 2018, phytoplankton samples were taken in the zones with essentially different conditions as to water aeration. On 10.07.2018, one area close to the working aerators and another area without aeration were investigated. In the second case (16.08.2018) one sampling point was located near working aerator, installed at the small depth, and another one was located close to the aerator, installed at the depth of 5 m.

On 10.07.2018, the abundance of phytoplankton in the zone without aeration reached 35 × 10<sup>6</sup> cells/dm<sup>3</sup>, simultaneously in the aeration zone it was less



**Fig. 6.** Concentration of inorganic phosphorus by depth in the Lake Telbyn on 30.08.2018:

1 – close to the aerator No 4 at the depth of 1.5 m, 2 – close to the aerator No 7 installed at the depth of 4 m



**Fig. 7.** The distribution of abundance by depth in the Lake Telbyn on 10.07.2018:

1 – close to the aerator No 3 installed at the depth of 1.5 m, 2 – in zone without aeration near unoperated aerator No 7

almost twice. In both cases the largest abundance was recorded at the depth of about 2 m (fig. 7).

As it can be seen on the fig. 7, the abundance of phytoplankton in the zone with aeration is significantly less than in the zone without it. At the same time the difference in biomass of phytoplankton along the water column is not so essential. It can be explained by the effect of aeration mostly on small-sized species. The similar results were obtained in (Ashley, Nordin 1999, Beutel, Horne 2009) and other researches.

The largest abundance of phytoplankton was recorded on 16.08.2018. In the 2 m layer from the surface it reached  $75\text{--}80 \times 10^6$  per  $\text{dm}^3$ . At the same time the zone of maximum biomass was observed at the depth of 2–4 m. The largest biomass (about  $34 \text{ mg/dm}^3$ ) was recorded in this depth in the zone close to the aerator, installed near surface.

The share of blue-green algae (Cyanoprokaryota) on 06.07.2017 was 71 % and for green algae 24 %. In three weeks (on 02.08.2017) the value changed somewhat, the share of blue-green increased to 77 % and green algae decreased to 17 %. On 13.09.2017, the share of blue-green algae reached 79 % and green one decreased to 15 %. As can be seen, during June–September 2017, the share of blue-green algae increased and green algae decreased.

In 2018, the study was carried out in the zones with different conditions of aeration. On 10.07.2018, in the zone with aeration the share of blue-green algae in total by depth equalled 91 %, whereas without aeration 94 %. A more noticeable difference was obtained for the abundance of green algae. In the first case, its share was 7.7 %, in another 5.5 %. It can be added that in surface layer the difference in abundance of green algae was larger: in the zone with aeration it was 10.5 % whereas without aeration 6.0 %.

On 16.08.2018, the share of blue-green algae abundance in the zone with aerator on small depth was 97 % and in the zone with the aerator on the depth 5 m 94 %. Accordingly, the share of green algae equalled 2 % and 4 %.

In the first year of aeration, on 06.07.2017 the dominant complex of blue-green algae (Cyanoprokaryota) representatives was the following: *Dolichospermum flosaquae* (Lyngb.) Wacklin, Hoffmann et Komarek, *Aphanizomenon flosaquae* (L.) Ralfs ex Bornet et Flahault, *Anagnostidinema amphibium* (C. Agardh ex Gomont) Strunecký, Bohunická, J.R. Johansen et al., *Oscillatoria tenuis* J. Agardh ex Gomont, as for green algae it should be mentioned *Acutodesmus pectinatus* (Meyen) P. Tsarenko. On 02.08.2017, the dominant species from this group's representatives were the following: *Anagnostidinema amphibium*, *Dolichospermum flosaquae* and *Spirulina subtilissima* Kütz. ex Gomont observed in all depths. On 13.09.2017, the dominant complex was formed by blue-green algae *Aphanizomenon flosaquae*, *Spirulina subtilissima*, *Merismopedia tranquilla* (Ehrenberg) Trevisan (= *Merismopedia punctata* Meyen) and *Anagnostidinema amphibium*. The abundance of phytoplankton was in the range of  $1\text{--}8 \times 10^6$  cells per  $\text{dm}^3$  and the biomass varied from less than 1 to  $4 \text{ mg/dm}^3$ .

In the year 2018 the dominant complex of species changed somewhat. On 10.07.2018, the dominant species from Cyanoprokaryota representatives were the following: *Aphanizomenon flosaquae* and *Anagnostidinema amphibium*. Its abundance varied from  $3$  to  $11 \times 10^6$  cells per  $\text{dm}^3$ . The dominant species regarding biomass was presented by *Ceratium hirundinella* (O.F. Müller) Dujardin, with the values from 1.8 to  $4.23 \text{ mg/dm}^3$ . On 16.08.2018, abundance was presented mostly by *Anagnostidinema amphibium* and *Merismopedia warmingiana* (Lagerheim). Their abundance had the range of  $9.5$  to  $75 \times 10^6$  cells per  $\text{dm}^3$ . The biomass at this period was presented mostly by *Ceratium hirundinella* and *Parvodinium umbo-natum* (F. Stein) Carty with values varied from 1.4 to  $23.8 \text{ mg/dm}^3$ .

#### **Concentration of chlorophyll a**

There were 5 measurements of chlorophyll a concentration on the Lake Telbyn during 2017–2018: threefold in 2017 (06.07, 02.08 and 13.09) and twice



in 2018 (10.07 and 16.08). The concentration of chlorophyll *a* on 06.07.2017 varied from 60  $\mu\text{g}/\text{dm}^3$  at the depth 0.5–4 m to 25–30  $\mu\text{g}/\text{dm}^3$  at depth 6–9 m. On 02.08.2017, the concentration of chlorophyll *a* somewhat increased: 80–85  $\mu\text{g}/\text{dm}^3$  in surface layer, 100–105 at the depth of 2 m, 60–67 at the depth of 4 m and 45–46  $\mu\text{g}$  at the bottom. The highest values were observed on 13.09.2017: 188–218  $\mu\text{g}/\text{dm}^3$  in surface layer, 103–107  $\mu\text{g}/\text{dm}^3$  at the depth of 4 m and 45–50  $\mu\text{g}/\text{dm}^3$  near the bottom. Such larger values than in previous cases may be explained by the known fact, that concentration of chlorophyll *a* depends on not only on the abundance of algae but also on the concentration of nutrients and water temperature as well (Kureyshevich et al., 2016). The high temperature has negative impact on biosynthesis of algae. As the result, inspite less abundance of algae, the concentration of chlorophyll *a* on 13.09.2017 was larger than in summer.

The concentration of chlorophyll *a* in 2018 was similar to the previous year. The aeration makes the concentration of chlorophyll *a* by depth more uniform. The highest concentration becomes less (Fig. 8).

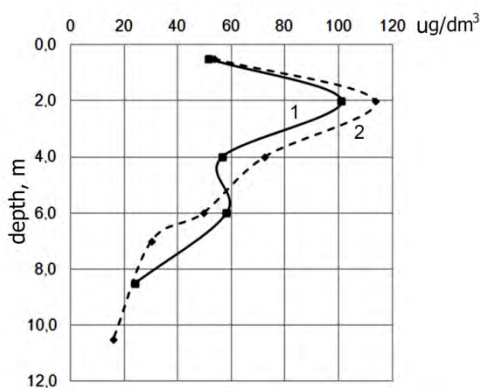


Fig. 8. Vertical distribution of chlorophyll *a* concentration in the Lake Telbyn on 16.08.2018:

1 – close to the aerator No 4 installed at the depth of 1.5 m, 2 – close to the aerator No 5 installed at the depth of 5 m

In general, the effect of aeration on the concentration of chlorophyll *a* is relatively small. A similar result was obtained in (Ashley, Nordin 1999).

#### Remote sensing data

The carried out field studies showed the large differences in water quality from one measurement to another. It can be explained by the impact of seasonal features and hydrometeorological factors. Under these circumstances, it is hard to identify the impact of artificial aeration among other influencing factors. For this purpose, the remote sensing data were used. The main idea was to compare the ecological state of Lake Telbyn with other water bodies before and under the impact of aeration. Accordingly, it was treated

data before aeration, i.e. in 2014–2016 and with aeration in 2017–2020 (Fig. 9).

It is evident from the image obtained on 29.07.2016, that the colour of water in the Lake Telbyn essentially differs from the colour of water in the Dnipro River and it is close to the water colour in the neighbouring lakes. In the second case, namely, on 04.08.2018, the water colour of the Lake Telbyn became almost the same as in the Dnipro River. A similar result was obtained for other images of 2019–2020.

These differences become more evident in case of use images in larger scale and created on the base of NDTI index, which is the ratio:  $\text{NDTI} = (B4 - B3) / (B4 + B3)$ . By this ratio the band B3 corresponds to the green colour of the spectrum, B4 – to the red one (fig. 10).

The comparison of optical images has an element of subjectivity. Therefore, the ecological state of water bodies was analyzed on the base of digital values of the B3 band of the Landsat 8 satellite. The meaning of B3 depends on phytoplankton abundance: larger quantity corresponds to the larger B3 and vice versa. In particular, it concerns the blue-green and

green algae which dominate in warm period. There is an opposite correlation between water clarity and B3 as well (Vyshnevskiy, Shevchuk 2018).

During the year, the greatest value of the B3 of the Landsat 8 satellite is observed in the period with the largest algal abundance – usually in August when the water clarity is the lowest. Thus, according to the data of the B3 band it is possible to estimate not only water transparency of lakes but their ecological state as well. The same it is concerned for lakes located nearby: Almazne, Koroliok, Lebedyne, Soniachne, Tiagle and Berkivshchyna bay (see the fig. 1).

For this aim it were analyzed 14 satellite images, from which 6 ones were obtained for 2014–2016 and



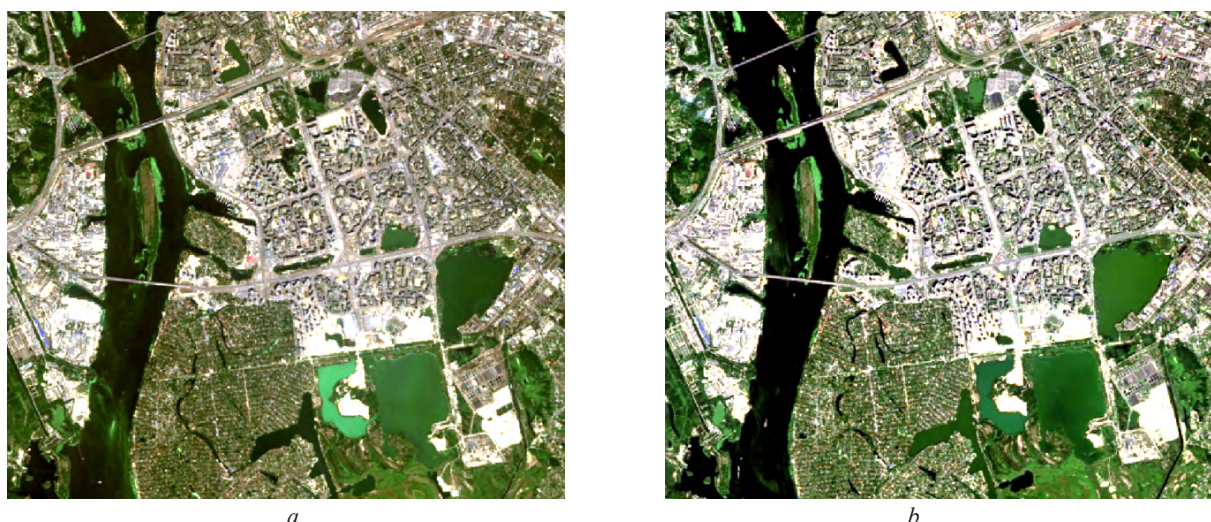


Fig. 9. The satellite images of the south-eastern part of Kyiv in pseudo-natural colours: *a* – on 29.07.2016, *b* – on 04.08.2018

8 ones for 2017–2020. Before the start of aeration the Lake Telbyn had the average position with value of B3 among other water bodies. Under impact of aeration, the position of the lake in 2017–2020 by the B3 value was essentially improved. It took the second position after Berkivshchyna bay which belongs to the Dnipro River (the fig. 11).

The same result was obtained for the ratio  $(B3-B2) / (B3+B2)$ . As in previous case this ratio for the Lake Telbyn in 2017–2020 became the lowest except for the Berkivshchyna bay (fig. 12).

The essential growth of the ratio  $(b2-B4) / B3$  in the Lake Telbyn during aeration period was observed as well. Thus, it means the larger decreasing of the B3 value comparably with the other spectral bands.

### Conclusion.

The Lake Telbyn is the first rather large lake in Ukraine, for which the artificial aeration of water was started to improve its ecological state mostly for recreational use. For this aim 8 aerators with air supply

from the compressor were installed at the end of 2016.

The water aeration causes the blur of thermocline whereas the impact on its depth is not essential.

The concentration of dissolved oxygen by depth mostly depends on algal bloom and the water temperature. The highest value is observed in surface layer when the algal bloom is the highest.

The operation of aerators causes a slight decrease in the concentration of dissolved oxygen in the surface layer and an increase in concentrations in the bottom layer. In the end of summer period the depth of zone with the highest concentration of dissolved oxygen goes down. This time the impact of aeration is rather small.

The impact of aeration on pH parameter is not essential. There is direct correlation of this parameter with the distribution by depth of dissolved oxygen.

The highest concentration of ammonium nitrogen in warm period is observed in the bottom layer. The deep location of aerators causes the increasing of concentration in bottom layer. At the same time there

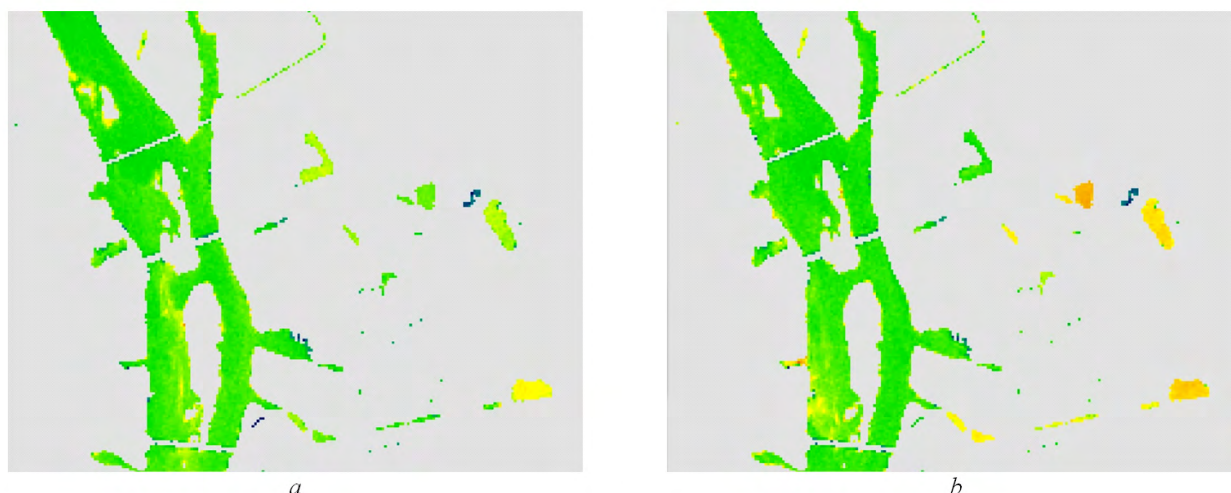
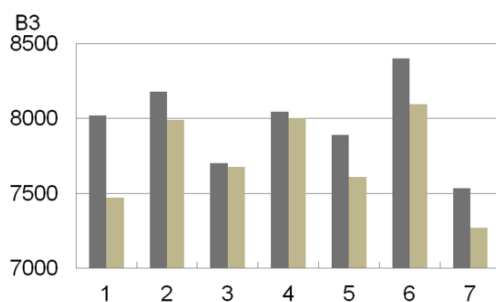


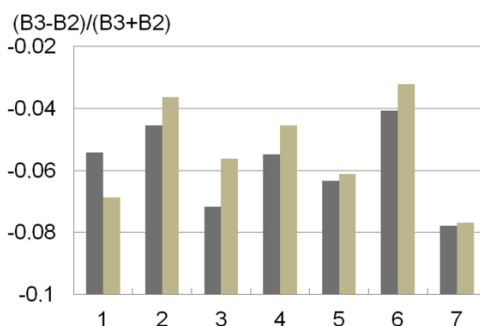
Fig. 10. The images of the Lake Telbyn and adjacent water bodies created on the base of the NDTI index:

*a* – on 29.07.2016, *b* – on 04.08.2018



**Fig. 11.** The B3 value of the Landsat 8 satellite for some water bodies of Kyiv during warm period:

1 – the Lake Telbyn, 2 – the Lake Almazne, 3 – the Lake Koroliok, 4 – the Lake Lebedyne, 5 – the Lake Soniachne, 6 – the Lake Tiagle, 7 – the Berkivshchyna bay (left columns correspond to 2014–2016, right columns – to 2017–2020)



**Fig. 12.** The value of  $(B3-B2)/(B3+B2)$  the Landsat 8 satellite for some water bodies of Kyiv during warm period:

1 – the Lake Telbyn, 2 – the Lake Almazne, 3 – the Lake Koroliok, 4 – the Lake Lebedyne, 5 – the Lake Soniachne, 6 – the Lake Tiagle, 7 – the Berkivshchyna bay (left columns – 2014–2016, right columns – 2017–2020)

is not visible impact on concentration near the surface. The similar result was obtained for the concentration of inorganic phosphorus.

The impact of aeration on phytoplankton biomass as well as on its composition is not such essential as on hydrochemical characteristics. The artificial aeration causes negative impact on the phytoplankton abundance and less effect on their biomass. It means the larger effect on the algae with small cells. In other words the aeration has larger impact on green algae than on blue-green algae. The water aeration has some impact on the vertical distribution of chlorophyll *a* concentration. In the zone with aeration its concentration is somewhat less than without aeration.

Comparison of the ecological state of the Lake Telbyn with other lakes, carried out on the base of satellite data, showed a positive effect of aeration. Nowadays, the color of water surface of the lake has become closer to the Dnipro River than it was before aeration.

In general, there is positive effect of aeration on the ecological state of the Lake Telbyn.

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