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MINERALIZATION OF PHYCODETRITUS IN WATER COLUMN OF THE SUBMOUNTAIN DAM RESERVOIR (SOUTHERN POLAND): SIMULATED EXPERIMENTS

ABSTRACT: The mineralization (expressed as O_2 consumption and CO_2 release) of *Scenedesmus quadricauda* detritus was investigated in homothermal (spring, autumn) and stratified (summer, winter) conditions, using the Micro-Oxymax respirometer. In experiments, the rate of O_2 consumption and CO_2 release, sedimentation rate and time of mineralization of phycodetritus in water from 2.5, 7.5 and >17 m depth were determined. It was found that 41% and 100% of detritus carbon (31.4 mg C dm^{-3}) added to the water could be mineralized in whole water column in time 28 days during spring and 37 days during autumn homothermal conditions. In summer stratification periods 61% of the detritus carbon during 29 days, and in winter 100% during 35 days, could be mineralised down to the depth 18 m. The rate of mineralization of phycodetritus depends on temperature and activity of microflora. The differences in the rate of O_2 consumption and CO_2 release between particular layers of water and seasons were statistically significant in the majority of cases.

KEY WORDS: algal detritus, mineralization, respiration, sedimentation

1. INTRODUCTION

The state of surface water quality, and particularly the effect of uncontrolled growth of productivity (eutrophication) are still in centre of attention of freshwater ecologists. The water bloom formation and the phenomena accompanying them, as production of toxins, activity of microorganisms, and others, are the most frequently subjects of investigations (Chróst 1977, Andersen and Jacobsen 1979, Alhgreen 1984, Hansen *et al.* 1986, Fulton and Pearl 1987, Weisse *et al.* 1990, Christoffersen *et al.* 1990, Sarazin *et al.* 1995, Bucka and Wilk-Woźniak 1998, Mallet and Debroas 1999). However, the greet part of algal biomass and its mineralization in situ as well as sedimentation rate is not frequently represented in publications (Poremba 1994, Burssaard *et al.* 1996). These observations mainly refer to marine environments (Poremba 1994, Burssaard *et al.* 1996, Chen and Wangersky 1996, Duineveld *et al.* 1997, Kunnis 1998, Boon *et al.* 1999, Grossard 2001, Fujii *et al.* 2002, Moodley *et al.* 2002), and in much smaller degree to the freshwaters (Afi *et al.* 1996, Wehr *et al.* 1999). It is believed that the mineralization of the biomass created during water bloom undergoes mainly in water column. Only a part of the produced mass, or the remnants refractory to the decomposition are settled on the bottom (Amblard *et al.* 1992, Lampert and Sommer 1996).

The aims of our work were: the determination of the mineralization rate of phycodetritus in the water column of the submountain dam reservoir, the evaluation of phycodetritus quantities that could be mineralized on the bottom and the prediction of the time, when after a collapse of water bloom a decline of oxygen content and an increase in mineral salts concentration in the near bottom water could be expected.

2. STUDY AREA

Samples of water were taken up from the submountain Dobczyce dam reservoir (49°57'N, 20°02'E, 270 m a. s. l), being a source of drinking water for Cracow city, located at 60 km of the Raba River course, in middle part of the river, about 25 km south-east of Cracow, (Fig. 1). The Dobczyce dam-reservoir lies on terrain of the Wieliczka Plateau that is built of Silesian flysch of various ages and mosaic-like distribution. The surrounding area of the reservoir is chiefly in agricultural use (Pasternak 1969). The Raba River brings 88.6% of the total water inflow, and the remaining water (11.4%) is supplied by the drainage basin and by atmospheric precipitation on the surface of the reservoir. The capacity of the reservoir is 120 million m^3, surface – 1000 ha, maximum depth – 28 m, mean depth – 16 m and the average frequency of water exchange is 3.6 times a year. It has hypolimnial release outlet. The reservoir is thermally stratified and its water is mixed twice a year during homothermal conditions, usually in April and in October (Mazurkiewicz-Boroń 2000).

3. MATERIAL AND METHODS

Samples (5 dm^3 in volume) of the water of the reservoir were collected 4 times during the years 2001 and 2002, from 2.5, 7.5 and >17 m depth, in spring homothermal conditions (April), thermal stratification period (July), autumn homothermal condition (October) and in the winter thermal stratification (January), at the station localized in the deep part of the Dobczyce Reservoir (Fig. 1).

Temperature of water in all the investigated water layers was measured in situ, with accuracy of 0.1°C. The content of organic carbon in the water was determined, using the wet combustion method, according to APHA (1992) (Table 1).

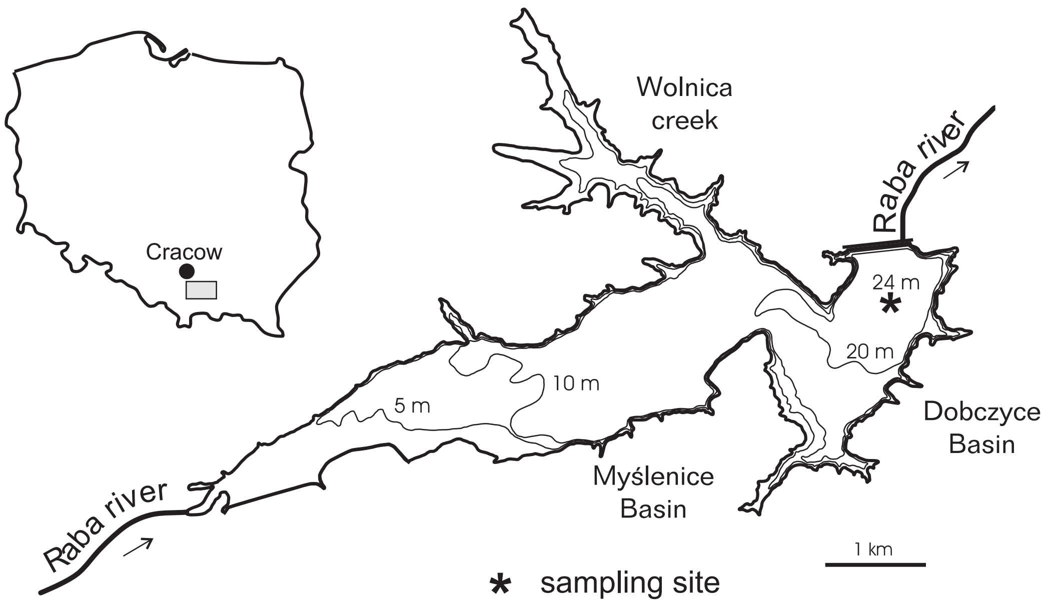

Fig. 1. Dobczyce dam reservoir (near Cracow, southern Poland) – location plan and study area.

Table 1. Organic carbon content (mg C dm^{-3}) and temperatures (°C) in Dobczyce Reservoir water (see Fig. 1) in SP(ring), SU(mmer), AU(tumn) and W(inter).

	Organic carbon				Temperature			
Depth	SP	SU	AU	W	SP	SU	AU	W
2.5 m	3	3.7	30	3.8	6	20	15	2.5
7.5 m	2.6	4.13	27	3.4	6	15	15	2.8
>17 m	2.6	5.25	27.75	3.4	6	10	15	3.8

Measurements of respiration (O_2 consumption detected by Pb-O fuel cell and CO_2 release detection by infrared adsorption) of the water samples were carried out at the laboratory during 24 hours exposition at 3-hour intervals, with accuracy of 1 μg O_2 or CO_2 cm^{-3} of water, using Micro-Oxymax Columbus Instruments, Columbus, Ohio, USA. The apparatus, besides measuring parallelly the rate of consumption of oxygen and carbon dioxide release, permits also to define the sum of oxygen consumed and sum of carbon dioxide released during experiment. The measurements were carried out at the same temperature, like in the water column of the reservoir, keeping the samples in thermostatized water-bath. After 24 h exposition of water samples (150 cm^3 of water samples in chambers, volume 250 cm^3), the algal detritus into the samples of water was added, in the concentration of 31.4 mg C dm^{-3} (appointed by wet combustion method, according to APHA (1992)) that corresponds to 63 μ dm^{-3} of chlorophyll *a*, i.e. the value often appearing during water blooms. Algal material added was originated from laboratory cultures of *Scenedesmus quadricauda* (Turp.) Breb., and was previously thermally killed (80°C). Respiration of water samples with algal detritus added was measured during 48 h of the exposition with the same accuracy and the same intervals and the temperatures the same as in samples water alone. All the experiments were carried out in parallel three repetitions.

The differences in the rate and the accumulation of O_2 consumption and CO_2 release between water samples with phycodetritus and water samples without the algal material addition (considered as a blank) were treated as mineralization of phycodetritus added. The mean (± SD) and maximal rates of phycodetritus mineralization (expressed in O_2 and in CO_2 mg dm^{-3} of water h^{-1}) were calculated.

The rate of sedimentation of the algal detritus suspended in the water taking up from particular layers of the reservoir water column was determined at laboratory conditions using cylinders (40 cm high), kept at the same temperature as it was in the reservoir; the rate was expressed in cm h^{-1}. A height of the column of clear water above the green suspension was estimated. It permitted to assess the time of residence of algal detritus in water column of the reservoir. The time of residence of algal detritus in water column and amount of phycodetritus mineralised during 48 hours (recalculated as mg C dm^{-3}) were used to calculate the quantities of phycodetritus mineralized in the water column.

The significance of differences in the rate of the respiration between the particular water column layers and the periods of year were statistically tested (t-test).

4. RESULTS

4.1. Organic carbon content in the water of the dam reservoir

Organic carbon content in the Dobczyce Reservoir water varied from 3 mg C dm^{-3} in spring to 30 mg C dm^{-3} in autumn. The concentration of carbon in autumn prevailed over 5–7 times the carbon concentration found in the water of other periods. In particular layers of water concentration of carbon varied between 0.4 and 3 mg C m^{-3} and was greater in the surface layer than that near the bottom, with the exception of summer period, when it was the greatest in the deepest layer of water (>17 m). In autumn homothermal period temperature was 2.5 times greater than in spring homothermal conditions. In summer stratification period temperature of water varied from 10°C in hypolimnion (>17 m depth) to 15°C in metalimnion and 20°C in epilimnion. In winter stratification period the greatest temperature was noted near the bottom (3.8°C) and the smallest one (2.5°C) in surface water (Table 1).

4.2. Mineralization rate of phycodetritus

The rate of mineralization of phycodetritus added to samples of water taken up from 2.5, 7.5 and >17m depth, that is the measured quantities of oxygen consumed and carbon dioxide released during one hour, was the most differentiated in summer and in autumn, and the smallest in winter period (Figs 2 and 3).

The greatest mean rate of oxygen consumption in all the investigated water layers was found in summer, and the smallest in winter, especially in the water sampled from 7.5 m depth (Fig. 4). In spring homothermal conditions, similarly as in summer thermal stratification, the differences in oxygen consumption between particular water layers were statistically insignificant

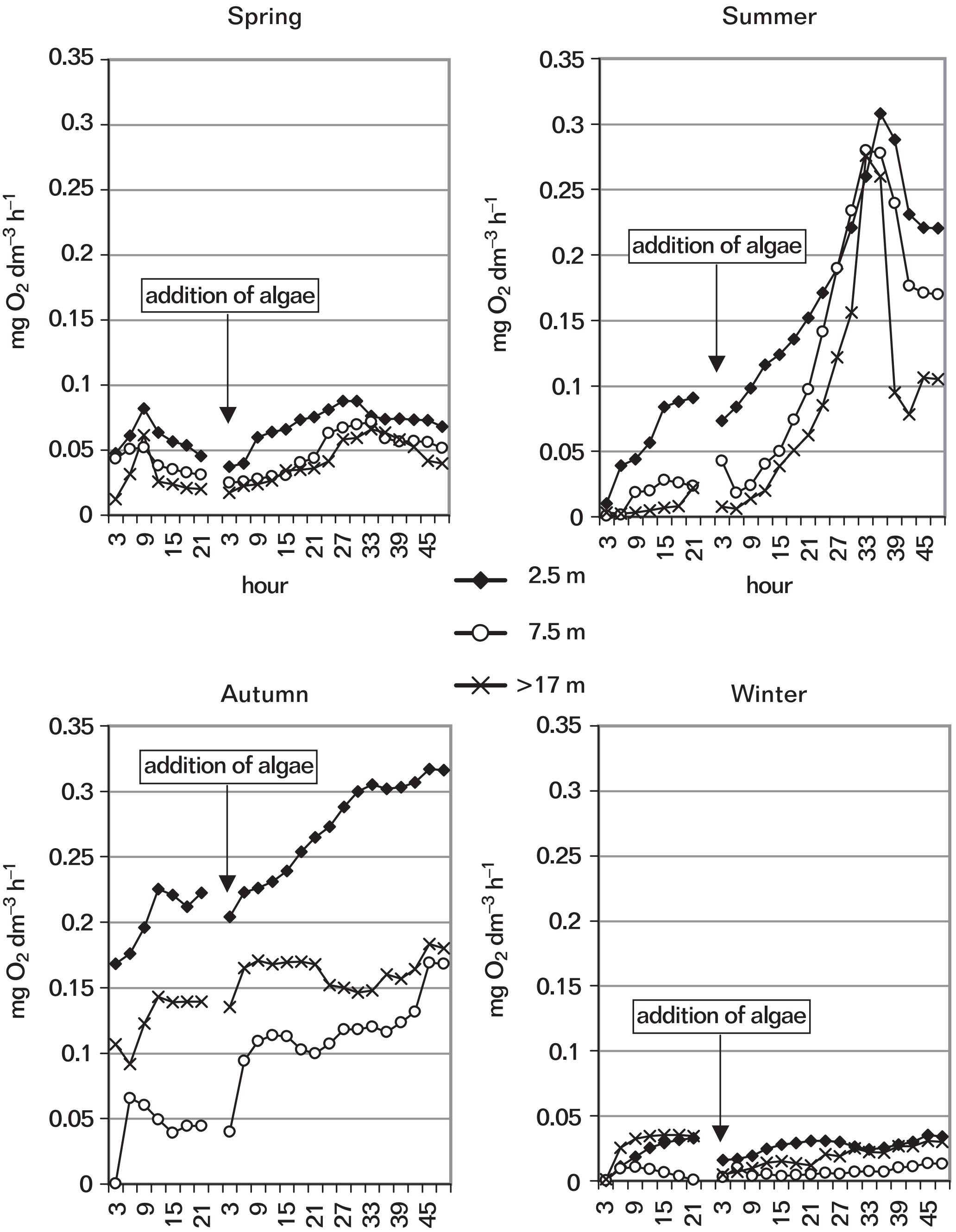

Fig. 2. Mineralization rate of *Scenedesmus quadricauda* detritus as oxygen consumption in water taken up from three depths of water column, during 48 hours at different (as *in situ*) temperatures (see Table 2).

(t-test). However, in autumn homothermal conditions the differences between the deepest and surface layers of the water and between both deep layers of water were significant, at $P \leq 0.05$.

The greatest mean rate of carbon dioxide released was found in summer period in surface layer of water and the smallest one in spring in water taken up from the deepest layer (Fig. 5). Statistically significant differences in rate of CO_2 release were found in spring between surface and both deeper layers of water, as well as in summer between surface and 7.5 m deep

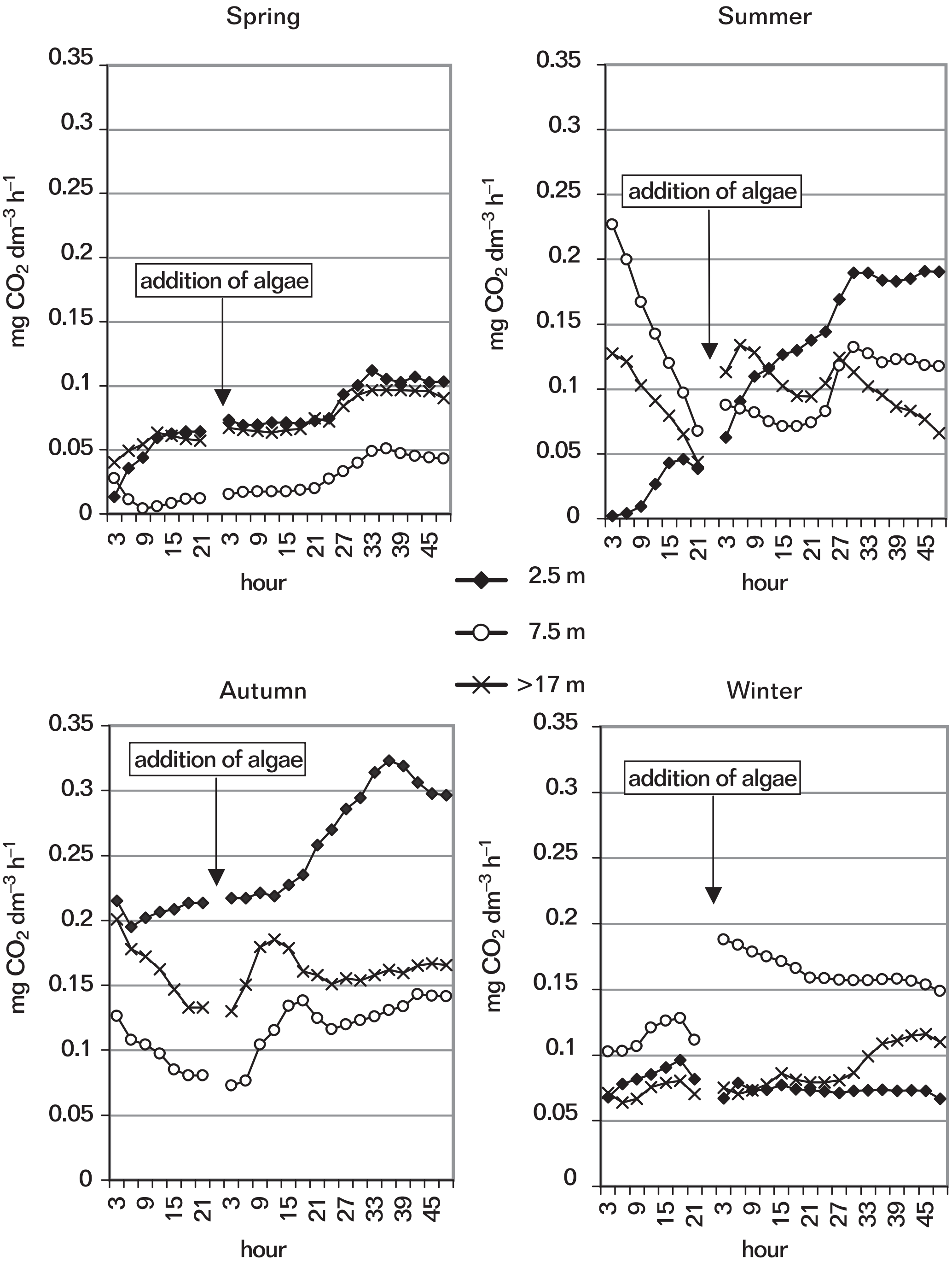

Fig. 3. Mineralization rate of *Scenedesmus quadricauda* detritus as carbon dioxide released in water taken up from three depths of water column, during 48 hours at different (as *in situ*) temperatures (see Table 2).

layer of the water. In autumn, significant differences appeared only between surface and the deepest layer of water, whereas in winter they appeared between all the investigated layers of water column.

When comparing the mean rate of the phycodetritus mineralization in the water taken up from the same layers of the water column in particular periods it was found that the differences in the rate of oxygen consumption were statistically significant in all periods. However, the insignificant differences were found in values of the rate of carbon dioxide released between winter and summer and winter and autumn periods (Figs 4 and 5).

4.3. Accumulation of oxygen consumption and carbon dioxide release

After 48 hours of phycodetritus mineralization the greatest accumulation of oxygen consumed was found in the all samples of

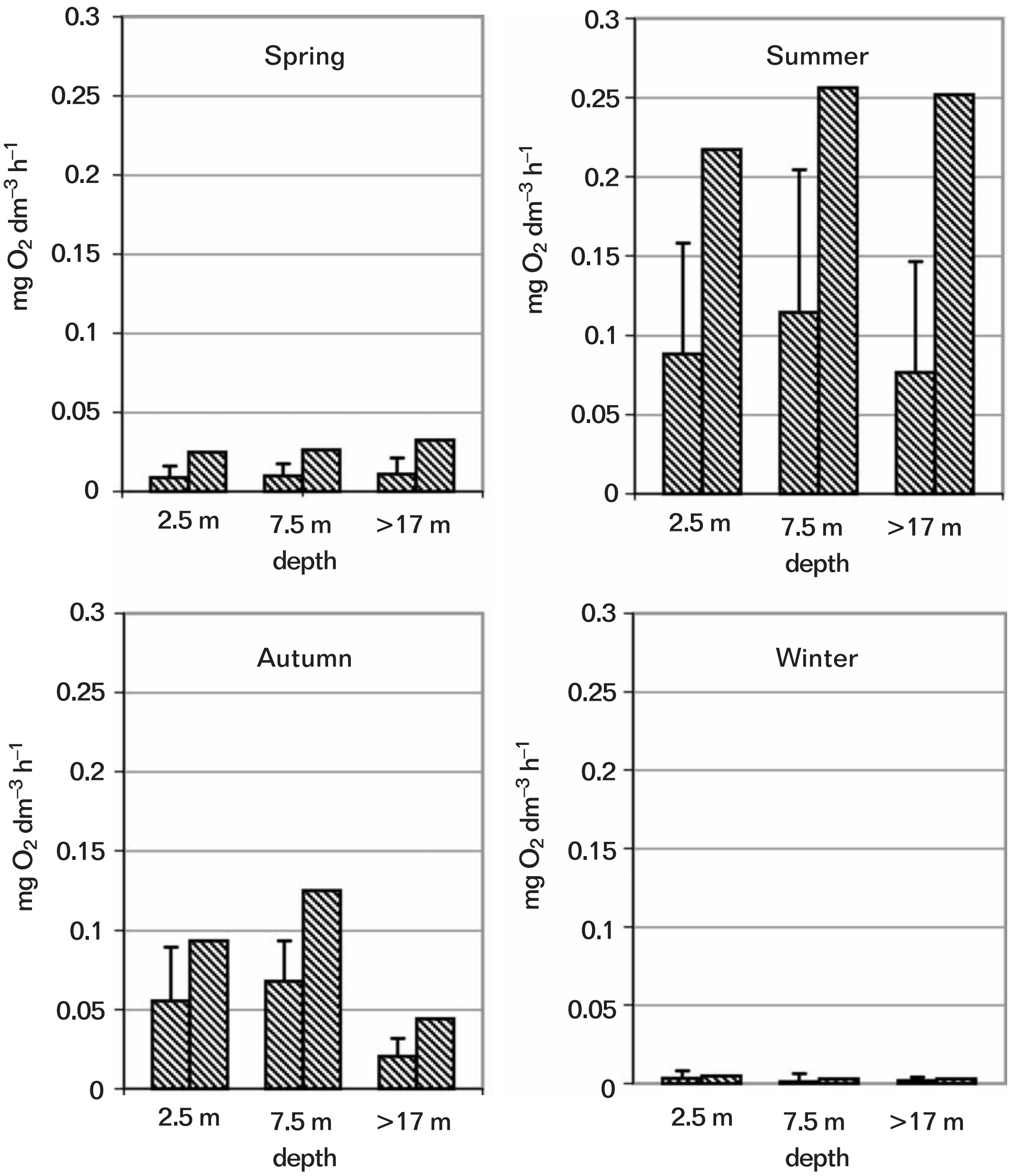

Fig. 4. Mean (±SD) and maximal rate of mineralization of *Scenedesmus quadricauda* detritus expressed as oxygen consumption in water from different depths (temperatures like *in situ*, Table 2).

water taken up in autumn, and the smallest one in winter. In summer thermal stratification period and in autumn homothermal conditions, the accumulation of oxygen consumption in surface water decidedly prevailed over oxygen consumption in both deep layers of water (Fig. 6). However, the accumulation of carbon dioxide release was the greatest in autumn in the surface and deepest layers of water and also in winter in water taken up from 7.5 m depth (Fig. 7).

The quantities of carbon dioxide released from detritus added to the water taken up from all layers of water column usually was greater than quantities of oxygen consumed, with the exception of autumn homothermal conditions, when these values were similar (Figs 6 and 7).

4.4. Sedimentation of phycodetritus

The sedimentation rate of *Scenedesmus quadricauda* detritus in reservoir water was differentiated and dependent on the water temperature (Table 2).

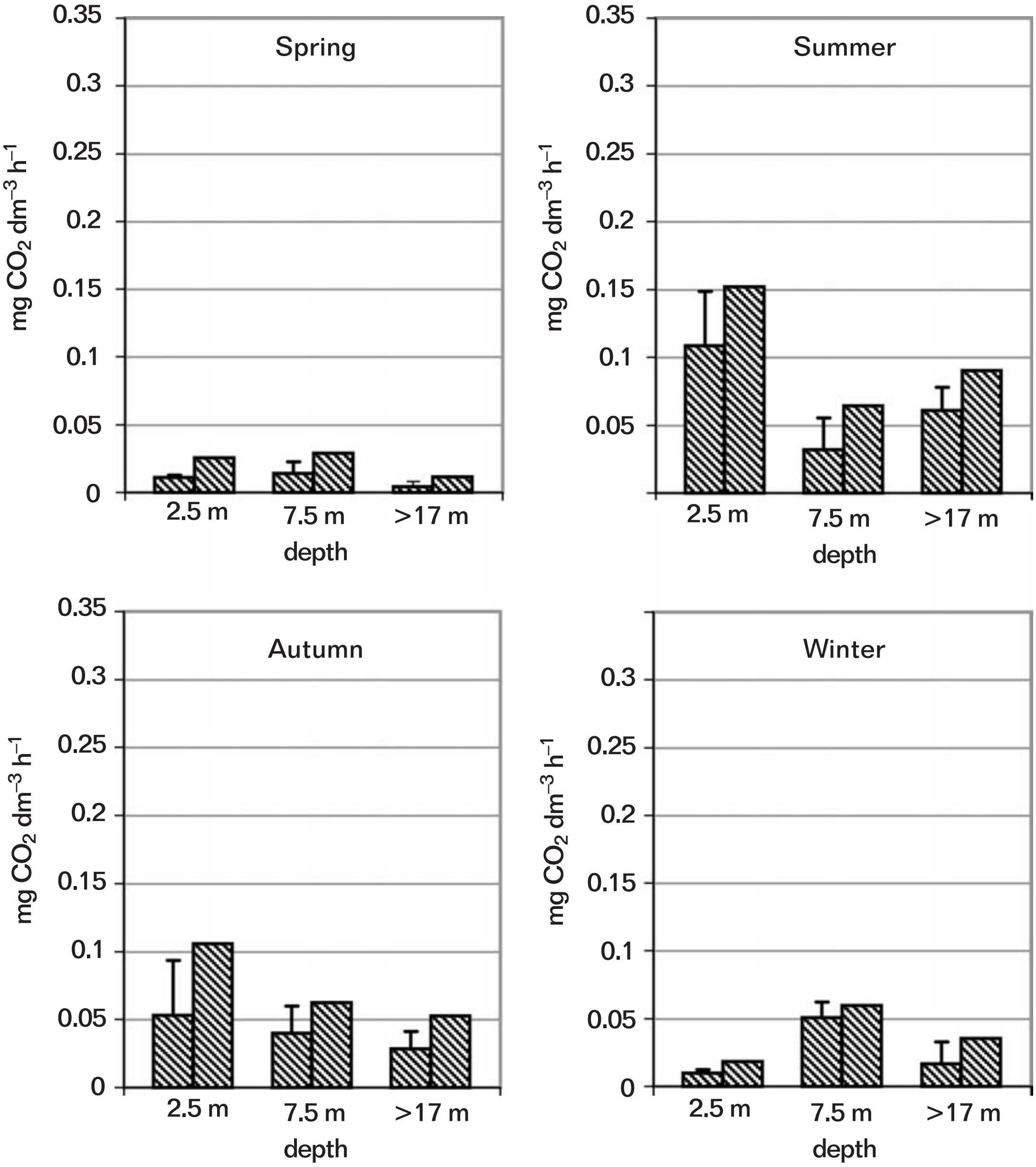

Fig. 5. Mean (±SD) and maximal rate of mineralization of *Scenedesmus quadricauda* detritus expressed as carbon dioxide released in water from different depths (temperatures like *in situ*, Table 2).

During spring homothermal conditions, at 2.5 times lower temperature of water and slower sedimentation rate than during autumn homothermal condition, phycodetritus could be settled on bottom during 37 days i.e. in time longer by 9 days than in autumn. During winter thermal stratification, at about 3–8 times lower temperature of water and thereby smaller sedimentation rate than during summer thermal stratification, phycodetritus could be settled on the bottom after 47 days, i.e. in time longer by 17.6 days (Table 2).

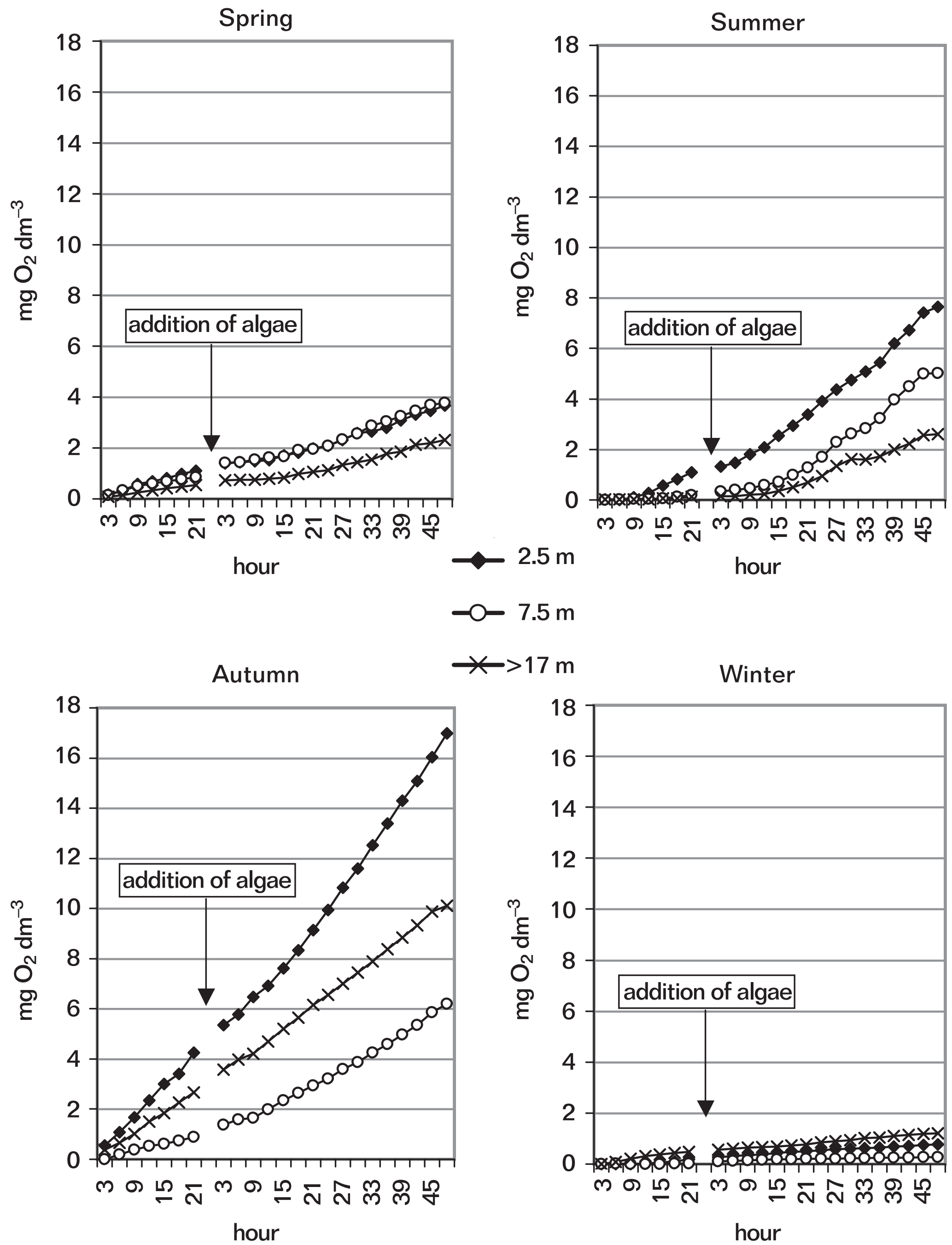

Fig. 6. Accumulation of oxygen consumed during mineralization of *Scenedesmus quadricauda* detritus after 48 hours in water from different depths (temperatures like *in situ*, Table 2).

4.5. Mineralization of phycodetritus in the water column

Based on the data of carbon dioxide accumulated during 48 hours period of phycodetritus mineralization (Fig. 7) and recalculated as carbon, and the time of phycodetritus sedimentation in water from particular layers of water column at different periods (Table 2), the amount of phycodetritus carbon mineralized in water column was calculated. During spring homothermal condition in the whole water column 12.75 mg C dm^{-3} and in autumn 32.27 mg C dm^{-3} could be mineralized that corresponded to 41% and 100% of the car-

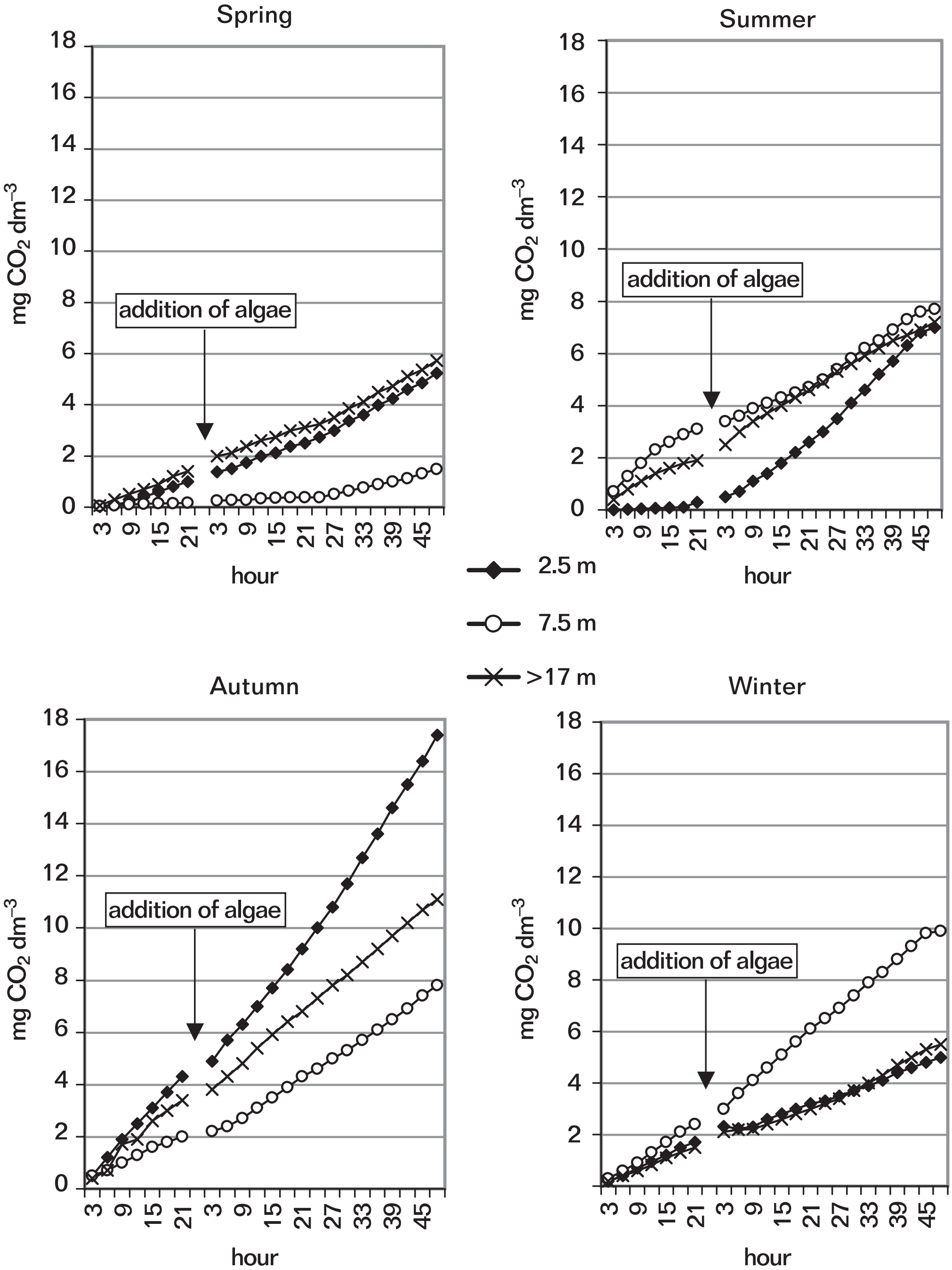

Fig. 7. Accumulation of carbon dioxide released during mineralization of *Scenedesmus quadricauda* detritus after 48 hours in water from different depths (temperatures like *in situ*, Table 2).

Table 2. Sedimentation rate of phycodetritus in particular layers of water and sedimentation time calculated for whole water column in seasons.

Period of year	Depth (m)	Temperature of water (°C)	Sedimentation rate (cm h^{-1})	Time of sedimentation (day)	Sedimentation time from whole column of water (day)
Spring homothermal condition	24	>6	2.66	37.1	37.1
Summer thermal stratification	2.5	20	3.90	8	29.4
	7.5	15	3.48	5.4	
	>17	10	2.99	16	
Autumn homothermal condition	24	15	3.48	28.1	28.1
Winter thermal stratification	2.5	2.5	2.18	14.3	47
	7.5	2.8	2.13	8.8	
	>17	3.8	2.09	23.9	

bon in phycodetritus added, in time 37.1 days and 28.1 days, respectively.

In summer thermal stratification period 5.92 mg C dm^{-3} could be mineralized in epilimnion; 2.8 mg C dm^{-3} – in metalimnion and 10.4 mg C dm^{-3} – in hypolimnion. However, in winter thermal stratification 13.62, 3.78 and 26.79 mg C dm^{-3} could be mineralized from analogical layers of water. It means that in summer period phycodetritus in water column could be mineralized in 61% during 29.4 days, and 39% of it was settled on the bottom. In winter period phycodetritus could be completely mineralized during 35 days in water column 18 m deep.

5. DISCUSSION

In the Dobczyce Reservoir periodically appearances of algal and cyanobacterial water blooms were found especially in spring and in autumn periods (Bucka and Wilk-Woźniak 1998, Wilk-Woźniak 2000). The mineralization of produced blooming mass and its settlement on the bottom caused distinctly the decrease of oxygen content and the increase in mineral salts concentration in water near the bottom. In the deepest places of the reservoir the content of oxygen dissolved in water usually varied between 6 and 12 mg O_2 dm^{-3}, but it decreased to 0.6 mg dm^{-3} during water bloom (Mazurkiewicz-Boroń 2000).

Data presented by us suggest that in all the investigated periods (spring homothermal conditions, summer thermal stratification, autumn homothermal conditions and winter thermal stratification), the time of sedimentation of algal material in the Dobczyce Reservoir water exceeded 28 days, and in winter even 47 days. In this time 41–100 % of algal material could be mineralized in water column, and 0–39% of blooming material could penetrate into the bottom sediments. Total mineralization of phycodetritus in water column occurred in the periods of autumn homothermal conditions and winter thermal stratification. For this reason, especially dangerous for the reservoir are bloomings that appear during spring homothermal conditions and in summer thermal stratification, when the mineralization of phycodetritus in water column is incomplete.

In general, the opinion prevails that mineralization of blooming mass proceeds in water column (Amblard *et al.* 1992, Burssaard *et al.* 1996), and only a little of its part is settled on the bottom, or it rests refractory to mineralization (Amblard *et al.* 1992, Lampert and Sommer 1996). The similar opinion was given by Starzecka and Bednarz (1998) who investigated the sediments of deep zone of Dobczyce Reservoir. The authors found 3 times smaller carbon content in sediments of deep part of the reservoir than in shallower ones. However, in other investigations it was showed that during spring water bloom, caused by diatom *Nitzschia palea*, dead or decayed algal mass was settled in profundal and was mineralized there. In consequence, the content of oxygen dissolved decreased in water near the bottom (Bednarz and Starzecka 1998, Starzecka and Bednarz 2000, Bednarz *et al.* (in press).

Simulated laboratory investigations carried out by other authors (e.g. Poremba 1994, Burssaard *et al.* 1996, Kunnis 1998) and by us indicated that mineralization of blooming material in water column could be incomplete and depended on its sedimentation rate. The activity of microflora and longer presence of the material in the water column promoted the complete mineralization of phycodetritus. On the other hand, as showed in present investigations, the high rate of sedimentation occurring especially in summer period, caused that even 40% of non-mineralized blooming material could be transported into the sediments.

Microbial degradation of detritus, originated from *Skeletonema costatum* thermally killed culture (the analogical method used in present work), as a substratum for marine microbial community, was studied experimentally by Kunnis (1998) during 11 days at the summer water temperature (20°C). The author calculated that the detritus could be completely utilized by pelagic microbial community within a period of 8–11 days. In our investigations, the summer mineralization of *Scenedesmus quadricauda* detritus in the water column was calculated as 61% of organic carbon in the original mass at time 29.4 days, i.e. during the time of sinking of detritus towards the bottom.

Biodegradability of DOC in three different layers of deep Soyang Lake, Korea, during thermal stratification season was investigated by Choi *et al.* (2001). In their opinion relatively labile compounds, which might originated from phytoplankton, are characteristic for dissolved organic carbon in epilimnion. In metalimnion, DOC was variable in its composition (possibly affected by turbid water inputs to the reservoir during the summer monsoon season). In the hypolimnion DOC always showed refractory character, with low decomposition rate. In our experiment the rate of the decomposition of *Scenedesmus quadricauda* detritus as O_2 consumption and O_2 accumulation in summer stratification period were higher in epilimnion and distinctly lower in metalimnion and in particular in hypolimnion. It indicated that in these layers of water the activity of microflora was distinctly discriminated. Probably the type of organic matter presented there affected the composition of microflora and its activity.

Based on the DOC concentration and assuming bacterial growth yield as 20% in the River Danube, Berger *et al.* (1995) calculated mean DOC turnover times of around 69 days in winter and less than 8 days during summer. In our work, we calculated the time of total mineralization of *Scenedesmus quadricauda* phycodetritus around 35 days in winter and in 61% during 29 days in summer. Despite that above data refer to two different environments (river, reservoir) they indicate that the seasonally changed conditions similarly affected the length of the time of mineralization of organic matter.

Decomposition experiments were conduced by Fujii *et al.* (2002) on cultured *Skeletonema costatum* in seawater containing decomposers and consumers. During experiment the decomposition was equal to 2.4–71 mg C dm^{-3} and the decomposition rate estimated at 20°C was 0.008 and 0.13 mg C day^{-1}. In our experiments mean decomposition rate estimated for temperature range 2.5–20°C was 0.028–0.349 mg C day^{-1} (data recalculated from CO_2).

The rate of biological degradation of organic matter was usually positively correlated with biological activity of water. The maximum values in freshwaters occurred in the autumn (Thomas 1997). Similar observations were found in presented investigations.

The data mentioned above indicated that mineralization rate of phycodetritus is strongly connected with temperature. High temperature of water accelerates the decomposition rate. However, in presented materials we found the higher rate of mineralization of phycodetritus in autumn period than in the summer, despite of lower temperature of water. The results obtained were probably an effect of high activity of water bacterioflora, which accompanied the autumnal water bloom with *Cryptomonas* share (Wilk-Woźniak, personal communication). The presence of water blooming in this time caused that the concentration of organic carbon in water was 5–7 times higher than that found in spring, summer and winter (Table 1).

It is generally known that among many factors the concentration of dissolved phosphorus affects the metabolic activity of aquatic organisms. Bacteria and algae usually very quickly uptake dissolved phosphorus and utilized it to produce their biomass. In situation of deficit of mineral forms of phosphorus in water, bacteria and algae synthesize phosphoesterases, which deliver PO_4 from organophosphorus compounds. Among other parameters, the deficit of phosphorus in the water, especially in the summer stratified period, could affect the decrease of respiratory activity of microorganisms, despite that the phycodetritus added was for them the source of both the carbon and phosphorus. The question whether phycodetritus addition can affect the phosphatases activity, will be the subject to further work.

6. SUMMARY

Mineralization (expressed as O_2 consumption and CO_2 release rate) of *Scenedesmus quadricauda* phycodetritus added to the water taken up from the depths 2.5, 7.5 and >17 m of the Dobczyce dam reservoir (southern Poland) during 2001 and 2002 years (Fig. 1) was investigated in simulated laboratory experiments, using the Micro-Oxymax respirometer. Organic carbon content in the water of the reservoir varied from 3 to 30 mg C dm^{-3} (Table 1).

The rate of mineralization of phycodetritus added was more differentiated in summer and in autumn, and smaller one in winter (Figs 2 and 3). The greatest mean rate of O_2 consumption in all the investigated layers of the water column was found in summer and the smallest one in winter (Fig. 4). The greatest rate of CO_2 release in surface layer of water and the smallest one in the deepest layer was found in spring (Fig. 5). The differences in the rate of O_2 consumption or CO_2 release between the particular layers of water and seasons were statistically significant in the majority of cases.

In summer and in autumn the accumulation of O_2 consumption in surface water prevailed over O_2 consumption in both deep layers of water column (Fig. 6). Accumulation of CO_2 released was the greatest in autumn in surface and the deepest layer of water and in winter at 7.5 m depth (Fig. 7). The sedimentation rate of *Scenedesmus quadricauda* detritus in the reservoir water was differentiated and depended on the temperature of water (Table 2). We calculated that in summer and winter stratification periods about 61% and 100% of detritus added could be mineralized during 29 and 35 days in water column. During homothermal conditions 41% of detritus through 37 days in spring and 100% – through 28 days in autumn could be mineralized (Table 2).

7. REFERENCES

Afi L., Metzger P., Largeau C., Connan J., Berkaloff C., Rousseau B. 1996 – Bacterial degradation of green microalgae: Incubation of *Chlorella emersonii* and *Chlorella vulgaris* with *Pseudomonas oleovorans* and *Flavobacterium aquatile* – Organic Geochem. 25: 117–130.

Ahlgreen I. 1984 – Sedimentation and respiration loss rates during the decline of a blue-green algae bloom – Verh. Internat. Verein. Limnol. 22: 736–742.

Amblard C., Rachiq S., Bourdier G. 1992 – Photolithotrophy, photoheterotrophy and chemoheterotrophy during spring phytoplankton development (Lake Pavin) – Microb. Ecol. 24: 109–123.

Andersen J. M., Jacobsen O. S. 1979 – Production and decomposition of organic matter in eutrophic Frederiksborg Slotss?, Denmark – Arch. Hydrobiol. 85: 511–542.

APHA 1992 – Standard methods for the examination of water and wastewater – 18th ed. Amecican Public Health Association, Washington.

Bednarz T., Starzecka A. 1998 – Microbiological processes taking place in Dobczyce Reservoir during spring water bloom – Oceanol. Stud. 27 (2): 13–21.

Bednarz T., Mazurkiewicz-Boroń G., Starzecka A. in press – *Nitzschia palea* (Kütz.) W. Sm. water bloom in submountain dam reservoir and microbiological processes associated with them – Algol. Stud.

Berger B., Hoch B., Kavka G., Herndl G. J. 1995 – Bacterial metabolism in the River Danube: Parameters influencing bacterial production – Freshwater Biology, 34: 601–616.

Boon A. R., Duineveld G. C. A., Kok A. 1999 – Benthic organic matter supply and metabolism at depositional and non-depositional areas in the North Sea – Estuarine Coastal and Shelf Science, 49: 747–761.

Bucka H., Wilk-Woźniak E. 1998 – Dynamic of algae and cyanophytes developing in mass in dam reservoir: the Wisła Czarne reservoir and the Dobczyce reservoir (southern Poland) – Fragm. Flor. et Geobot. Ser. Polonica, 5: 269–277.

Burssaard C. P. D., Gast G. J., van Duyl F. C., Riegman R. 1996 – Impact of phytoplankton bloom magnitude on a pelagic microbial food web – Mar. Ecol. Progr. Ser. 144: 211–221.

Chen W. H., Wangersky P. J. 1996 – Rates of microbial degradation of dissolved organic carbon from phytoplankton cultures – J. Plankton Res. 18: 1521–1533.
Choi K., Kim B., Lee U. H. 2001 – Characteristic of dissolved organic carbon in three layers of deep reservoir, Lake Soyang, Korea – Internat. Rev. Hydrobiol. 86: 63–76.
Christoffersen K., Riemann B., Hansen L. R., Klysner A., Sørensen H. B. 1990 – Qualitative importance of the microbial loop and plankton community structure in a eutrophic lake during a bloom of cyanobacteria – Microb. Ecol. 20: 253–272.
Chróst R. J. 1977 – O niektórych współzależnościach pomiędzy glonami i bakteriami w środowiskach wodnych [Some relationships between algae and bacteria in water environments] – Wiad. Ekol. 23: 343–358.
Duineveld G. C. A., Lavaleye M. S. S., Berghuis E. M., de Wilde P. A. W. J., van der Weele J., Kok A., Batten S. D., de Leeuw J. W. 1997 – Patterns of benthic fauna and benthic respiration in the Celtic continental margin in relation to the distribution of phytodetritus – Int. Rev. Ges. Hydrobiol. 82: 395–424.
Fujii M., Murashige S., Ohnishi Y., Yuzawa A. Miyasaka H., Suzuki Y., Komiyama H. 2002 – Decomposition of phytoplankton in seawater. Part 1. Kinetic analysis of the effect of organic matter concentration – J. Oceanogr. 58: 433–438.
Fulton R. S., Pearl H. W. 1987 – Toxic and inhibitory effects of the blue-green algae *Microcystis aeruginosa* on herbivorous zooplankton – J. Plankton Res. 9: 837–855.
Grossard H. P., Riemann L., Azam F. 2001 – Bacterial motility in the sea and its ecological implications – Aquat. Microb. Ecol. 25: 247–258.
Hansen L., Krogh G. F., Søndergaard M. 1986 – Decomposition of lake phytoplankton. 1. Dynamics of short term decomposition – Oikos, 46: 37–44.
Kunnis K. 1998 – Development of microbial community during Skeletonema costatum detritus degradation – Hydrobiologia, 363: 253–260.
Lampert W., Sommer U. 1996 – Ekologia Wód Śródlądowych [Ecology of inland water] – Warszawa, Państwowe Wydawnictwo Naukowe, 390 pp. (in Polish).
Mallet C., Debroas D.1999 – Relations between organic matter and bacterial proteolytic activity in sediment surface layers of a eutrophic lake (Lake Aydat, Puy de Dôme, France) – Arch. Hydrobiol. 145: 39–56.
Mazurkiewicz-Boroń G. 2000 – Parametry siedliskowe i troficzne [Habitat and trophic parameters] (In: Zbiornik Dobczycki – Ekologia – Eutrofizacja – Ochrona. [Dobczyce Reservoir – Ecology – Eutrophication – Protection] Eds. J. Starmach, G. Mazurkiewicz-Boroń) – Publ. Karol Starmach Institute of Freshwater Biology PAS, Kraków, pp. 63–80.
Moodley L., Middelburg J. J., Boschker H. T. S., Duineveld G. C. A., Pel R., Hetrman M. P. J., Heip C. H. R. 2002 – Bacteria and Foraminifera: key players in a short-term deep-sea benthic response to phytodetritus – Mar. Ecol. Progr. Ser. 236: 23–29.
Pasternak K. 1969 – Szkic geologiczno-gleboznawczy zlewni rzeki Raby [A geological and pedological sketch of the Raba River catchment basin] – Acta Hydrobiol. 11: 407–422.
Poremba K. 1994 – Simulated degradation of phytodetritus in deep sea sediments – Mar. Ecol. Prog. Ser. 105: 291–299.
Sarazin G., Gaillard J. F., Philippe L., Rabouille C. 1995 – Organic matter mineralization in the pore water of a eutrophic lake (Aydat Lake, Puy de Dôme) – Hydrobiologia, 315: 95–118.
Starzecka A., Bednarz T. 1998 – Comparison of microbiological activity in bottom sediments of littoral and profundal zones of a submontaine dam reservoir – Acta Hydrobiol. 40: 293–300.
Starzecka A., Bednarz T. 2000 – III. 15. Mikrobiologiczne procesy zachodzące w Zbiorniku Dobczyckim i rzece Rabie powyżej i poniżej zbiornika [Microbiological processes taking place in Dobczyce Reservoir and in the Raba River above and below the Reservoir] (In: Zbiornik Dobczycki – Ekologia – Eutrofizacja – Ochrona [Dobczyce Reservoir – Ecology – Eutrophication – Protection] Eds. J. Starmach, G. Mazurkiewicz-Boroń) – Publ. Karol Starmach Institute of Freshwater Biology PAS, Kraków, pp. 163–176.
Thomas J. D. 1997 – The role of dissolved organic matter, particularly free amino-acids and humic substances, in freshwater ecosystems – Freshwater Biology, 38: 1–36.
Wehr J. D., Petersen J., Findlay S. 1999 – Influence of three contrasting detrital carbon sources on planktonic bacterial metabolism in a mesotrophic lake – Microbial Ecology, 37: 23–35.
Weisse T., Müller H., Pinto-Coelho R. M., Schweizer A., Springmann D., Baldringer G. 1990 – Response of the microbial loop to the phytoplankton spring bloom in a large prealpine lake – Limnol. Oceanogr. 35: 781–794.
Wilk-Woźniak E. 2000 – III. 10. Fitoplankton [III. 10. Phytoplankton] (In: Zbiornik Dobczycki – Ekologia – Eutrofizacja – Ochrona [Dobczyce Reservoir – Ecology – Eutrophication – Protection] Eds. J. Starmach, G. Mazurkiewicz-Boroń) – Publ. Karol Starmach Institute of Freshwater Biology PAS, Kraków, pp. 95–112.

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