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Characteristics of the phytobentos communities in the Goczałkowice Reservoir (southern Poland)

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A b s t r a c t - The structure and distribution of phytobenthic communities are presented and the effect of the depth gradient on the development dynamics of the bottom algae in the Goczałkowice Reservoir described. The investigations revealed the existence of qualitative and quantitative differences in the algal communities between the littoral and the central part of the reservoir. In the backwater part an intermediate type of community of riverine-lake character has developed. Along the depth gradient changes were observed in the algal communities. Active phytobenthos developed in the photic zone tc a depth of about 2 m.

K e y w o r d s : dam reservoirs, phytobenthos community, depth gradient, numbers, variety, chlorophyll *a*.

1. Introduction

The present paper gives a synthesis of the results of investigations carried out in the Goczałkowice Reservoir during 1987-1988 on the structure and distribution of the phytobenthic communities. The aim of the study was also to define the tendencies in the changes occurring in the communities of bottom algae along the depth gradient.

It is well known that in lakes and dam reservoirs the planktonic algae are the most important of the primary producers. Nevertheless, in some parts, a significant role in the production of the organic matter is played by the sessile algae, associated with the

substratum in various ways (Pieczyńska 1976). In comparison with phytoplankton, the communities of sessile algae, and among these the phytobenthos in particular, have been less investigated or simply neglected as was the case with the dam reservoirs of southern Poland. A number of data referring to phytobenthic communities can be found in general floristic studies or in limnological monographs (Round 1964, 1984, Pieczyńska 1971, 1976, Kajak, Hillbricht- -Illkowska 1972, Wetzel 1975, Reynolds et al. 1981). Investigations of phytobenthos in dam reservoirs have been carried out by, among others, Vladimirova (1968, 1972, 1978), Gak et al. (1972), Skorik (1972), Zhdanova et al. (1989).

2. Study area, material, and methods

The dam reservoir in Goczałkowice was built in 1955, on the river Vistula, 67 km from its source, as water intake for the Upper Silesian Industrial District and for the purpose of retention. A detailed description of the reservoir and its waters can be found in a study by Kownacki and Krzyżanek (1986), while the microbiological and hydrochemical characteristics of the sediments have been given by Petrycka et al. (1990).

The material was sampled at monthly intervals, from June to November 1987 and from June to September 1988 at 6 stations: Station I - close to the dam (about 7-9 m deep, muddy bottom), Station II - in the central part (about 6-8 m deep, muddy bottom), Station III - in the backwater of the reservoir (about 2-2.5 m deep, muddy bottom), in the littoral zone, along the southern bank of the reservoir: Station IV (0.5-1.0 m deep, muddy-sandy bottom), Station V (about 0.5 m deep, sandy bottom) and Station VI (about 0.5 m deep, muddy bottom, partly overgrown by macrophytes).

In order to determine the effect of the differentiated light conditions on the development of bottom communities, along the depth gradient (section between Stations II-IV) 5 or 6 additional stations were set up, depending on the water level, at which double samples were collected from the depths of 0.5, 1, 2, 3, 4-5 and 7-9 m, at monthly intervals, during the period June-September 1988. The water transparency measured by the visibility of a Secchi disc was determined at the stations each time. The location of all stations is shown in fig. 1.

The subject of investigation was a 0.5 cm thick surface layer of the sediment collected from the bottom by means of a tube sampler.

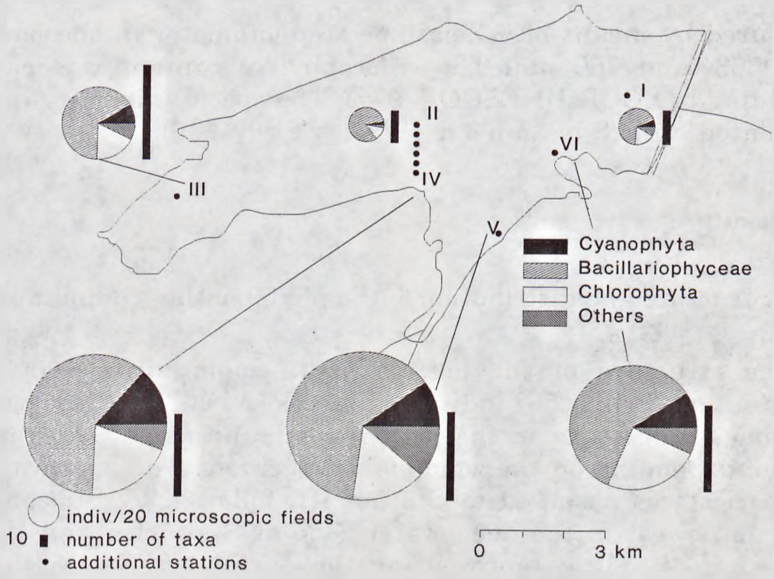

Fig. 1. Spatial distribution of density and taxonomic structure of phytobenthos in the Goczałkowice Reservoir

The qualitative and quantitative composition of the algal communities were analysed and the concentration of chlorophyll *a* measured. The qualitative evaluation was partly carried out on live material, partly on material preserved in 4% formalin solution. The diatoms were determined on the basis of solid preparations fixed in pleurax. To determine the quantitative relations the modified method of S t a r m a c h (1969) was applied, this having also been used in the investigations of the bottom algae by K r z e c z k o w s k a - W o ł o s z y n and B u c k a (1969), K y s e l o w a and K r z e c z k o w s k a - W o ł o s z y n (1974), and B u c k a (1978, unpubl.). From each sample appropriately dissolved sediment was obtained from which two 0.05 cm^3 preparations were made. In these preparations the algae were counted in 10 microscopic fields of vision, limited by the graticule. A single cell, filament, and colony was treated as an individual. The results were expressed in percentage figures, the species attaining more than a 20% share in the community being regarded as dominants.

Samples to be used for evaluation of the chlorophyll a content were each obtained from the same volume of sediment and expressed in micrograms in 1 g of dry weight (K y s e l o w a 1977). Extinction of chlorophyll solutions extracted by 90% acetone was

measured by means of a Zeiss spectrophotometer in the bands 630, 645, 663, and 750 nm. The chlorophyll *a* content was calculated according to SCOR-UNESCO (1971). The species diversity index was calculated after Shannon-Weaver (1949).

3. Results

3.1. Structure and distribution of the phytobenthos communities

The structure of the bottom algal communities was strongly differentiated in the individual sections of the reservoir. The number of alga taxa in the bottom communities varied over a wide range, depending on the zone of the reservoir. The greatest number of species was observed at Station III, followed by Stations IV-VI, and the lowest in the deep water zone at Stations I and II (fig. 1). The share of algae representing the particular systematic groups changed little. The main role was played by the diatoms, which at all stations showed a many times greater number of taxa than the other systematic groups. Green algae appeared in greater and blue-green algae in smaller numbers, while other groups, such as euglenoids (genera *Euglena* and *Trachelomonas*), Chrysophyta (genera *Dinobryon* and *Synura*), and cryptomonads (genus *Cryptomonas*) played no major role (fig. 1).

At Stations I and II the phytocoenoses were composed almost exclusively of dead, sedimentating, plankton organisms, represented by a small number of individuals. These were mainly diatoms with a prevailing number of *Cyclotella comta, C. catenata, Asterionella formosa*, besides *Stephanodiscus hantzschii, S. astrea* var. *minutulus, Melosira varians* var. *angustissima, M. distans* var *alpigena*, species from the genus *Synedra*, and less numerous chlorococcous green algae from the genera *Scenedesmus* and *Pediastrum*.

At Station III in the populations of algae the number of live individuals rose, as well as that of species and their numbers. The communities of algae did not represent an ecologically uniform group. Both the plankton diatoms and the typically bottom forms, i.e., *Navcula viridula, N. cryptocephala, Cymbella ventricosa*, and *Fragilaria capucina* var. *vaucheriae* occurred very numerously without any distinct numerical prevalence of one of these forms. At this station the presence of many rheophile species, such as *Ceratoneis arcus*, species from genera *Surirella, Nitzschia*, and *Gomphonema*, was also noted. Most of these species occurred in

small numbers; their presence, however, was an indication of the different character of the communities from those discussed previously. Besides the diatoms, the chlorococcous green algae developed in abundance with the genus *Scenedesmus* prevailing. In some periods increased amounts of filamentous blue-green algae with the domination of *Oscillatoria* were observed.

The littoral zone was characterized by rich microflora and great differentiation of community types. At Stations IV , V, in an area where macrophytes were absent, the blue-green algae-diatom complex developed in masses. The main component of this group was the blue-green alga *Oscillatoria tenuis* with the concomitant species *O. limosa* and bottom diatoms from the genus *Navicula*, the most numerous being *N. cryptocephala*. The plankton forms from the genus *Cyclotella*, *Stephanodiscus* and *Melosira*, developed less intensively, except for the species *Melosira granulata* var. *angustissima*. Its proportion exceeded 10%, similarly as that of the chlorococcous green algae. At Station VI, in the neighbourhood of the macrophytes the main role was played by the ephyphitic diatoms and green algae. Among the diatoms the dominants were *Gomphonema angustum*, *G. angustatum*, *Cymbella ventricosa*, and at times also *Fragilaria capucina* var. *vaucheriae*. The green algae were represented by the filamentous forms *Oedogonium* sp., *Chaetophora elegans*, *Stigeoclonium tenue*, desmids (mainly the genera *Closterium* and *Cosmarium*) and chlorococcous algae.

During the investigation cycle the differences in the structure of the communities in the particular months were small, being determined rather by the conditions existing in the reservoir than by the biology of the dominating groups and taxa. The differences referred to changes in the numbers while the essential structure of the domination was preserved. In the absence of any regularities these differences were most distinctly marked in the littoral phytobenthos and were connected with the dynamics of water movement.

The differences in the chlorophyll *a* content during the examined period revealed similar tendencies in various parts of the reservoir. In June 1988, just before the period of intensified growth of the plankton algae, maximum amounts of chlorophyll *a* were observed in the surface layer of the sediment, 140 $\mu g\ g^{-1}$ d.w. at Station IV and 52 $\mu g\ g^{-1}$ d.w. at Station II. A similar content of chlorophyll *a* was recorded in the last decade of July. In August, after the water had been subjected to copper treatment at the end of July, the amount of chlorophyll *a* decreased to a value of 57 $\mu g\ g^{-1}$ d.w. at Station IV, and to 20 $\mu g\ g^{-1}$ d.w. at Station II. After renewal of the

population of the bottom algae in September, an increase in chlorophyll *a* took place successively at the above stations reaching 77 and 44 μg g^{-1} d.w., respectively.

3.2. Development of phytobenthic communities and changes in chlorophyll *a* content at various depths

Along the depth gradient considerable differences were observed in the structure of algal communities and in the amount of chlorophyll *a* at the bottom (figs 2, 3, Table I).

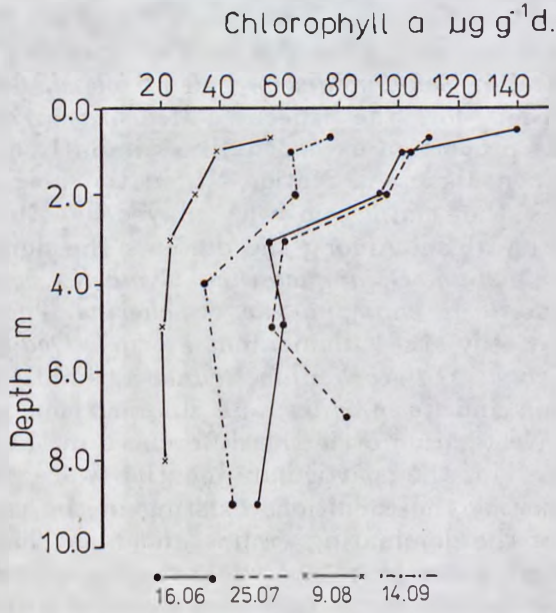

Fig. 2. Chlorophyll *a* content in the bottom sediment at various depths of the Goczałkowice Reservoir

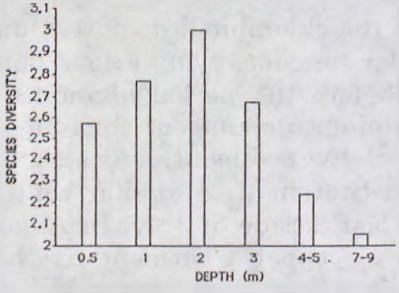

Fig. 3. Range of values of the species diversity index at various depths in the Goczałkowice Reservoir

Table I. The percentage frequencies of the more frequent species in the phytobenthos at different detphs. Main habitat: P - planctonic; B - benthic; P/B - both habitats

TAXON	Depth (m)						Main habitat
	0.5	1	2	3	4-5	7-9	
Oscillatoria tenuis Ag.	35.6	25.1	8.2	3.0	1.8	0.9	B
Asterionella formosa Hass.	1.6	3.1	7.2	17.4	10.5	20.8	P
Cyclotella comta (Ehr.) Kütz. *C. catenata* Brun.	4.8	6.3	15.0	20.4	28.1	35.9	P
Cymbella ventricosa Kütz.	10.0	12.2	11.5	9.0	1.8	0.9	B
Melosira granulata var. *angustissima* (O. Müll.) Hust.	5.6	10.0	11.0	7.5	15.8	10.5	P/B
Navicula cryptocephala Kütz. *N. viridula* Kütz.	23.4	20.7	11.5	7.0	2.6	1.8	B
Stephanodiscus astrea var. *minutulus* (Kütz.) Grun.	2.0	3.5	7.7	11.5	23.7	17.0	P
Genera: *Scenedesmus* *Pediastrum*	6.5	9.8	16.1	17.9	13.2	7.6	P/B

At a water transparency equal to 0.6-0.9 m the active, photosynthetizing phytobenthos developed mainly in the littoral zone. The richest, typical bottom phytocoenosis with mass occurrence of the blue-green algae *Oscillatoria tenuis* and numerous diatoms, species from the genus *Navicula* being the dominants developed starting from a depth of 0.5-1 m, and attaining their optimum at 1 m. This zone was characterized by a large number of species and the greatest amount of chlorophyll *a*, from 40 to 140 μg g^{-1}d.w. depending on the season (fig. 2). The values of the species diversity index varied from about 2.6 at a depth of 0.5 m to 2.8 at about 1 m (fig. 3).

At a depth of about 2 m, with a decrease in the total numbers of the algae, a great number of species and the highest value of the species diversity index (fig. 3), there developed a community composed of almost equal numbers of the algal species. These were forms belonging to plankton such as *Cyclotella comta, C. catenata, Stephanodiscus astrea* var. *minutulus*, and *Asterionella formosa*, and forms representative of the bottom, i.e. *Oscillatoria tenuis, Cymbella*

ventricosa, *Navicula cryptocephala*, and *N. viridula*. In addition, this zone was characterized by the presence of the more numerous species both at the bottom and in the water depths. These were the diatom *Melosira granulata* var. *angustissima* and green algae from the genera *Scenedesmus* and *Pediastrum* (Table I). A decrease in the amount of chlorophyll *a* in comparison with the first zone was noted (fig. 2), its concentration varying from 31 to 96 $\mu g\ g^{-1}$ d.w.

At a depth of 3 m and deeper, besides a reduction in the number of taxa and the numbers of the cells, with a high species diversity index value (fig. 3), a change in the species composition was observed. The bottom forms had been replaced by the plankton diatoms, accompanied by the chlorococcous green algae present on the bottom (Table I). Simultaneously there took place a decrease in the vitality of the cells which increased with depth. The content of chlorophyll *a* ranged from 22 to 61 $\mu g\ g^{-1}$ d.w., showing a tendency to maintain these values also below 3 m (in the deepest parts the amount of chlorophyll *a* ranged from 20 to 53 $\mu g\ g^{-1}$ d.w.; fig. 2).

In deeper parts of the reservoir the assimilation activity became greatly reduced. The phytobenthos was no more than a complex of dead, sedimenting, plankton organisms. The live component of the community were mainly the plankton diatom and occasionally chlorococcous green algae. This zone was characterized by small population numbers and the lowest species diversity index value (fig. 3).

4. Discussion

The structure of phytobenthos inhabiting the bottom of the Goczałkowice Reservoir with the dominance of diatoms, blue-green, and chlorococcous green algae, was characteristic of epipelic communities (Wetzel 1975, Round 1984) and conformed with investigation results from other dam reservoirs (Skorik 1972, Vladimirova 1972, 1978, Zhdanova et al. 1989).

In the surface layer of the bottom sediments of the reservoir the species composition, the numbers of the algae population, the diversity and activity of their cells, and the amount of chlorophyll *a* were greatly differentiated in the particular sections. Among the many factors which determine the distribution and the development dynamics of algae the importance of light and nutrients as well as the interdependence of these organisms have been strongly emphasized (Vladimirova 1978, Stevenson, Stoermer 1981, Reynolds 1984, Oleksowicz 1988).

An analysis of the spatial distribution of phytobenthic communities revealed distinct qualitative and quantitative differences between the littoral zone of the reservoir, where a complex with sessile forms as dominants has been established, and the zone of deep water. Within the latter the phytobenthos, characterized by the presence of plankton algae, small numbers, and low vitality of the cells of the algae did not play any major role.

An intermediate type of community of riverine-lake character developed in the upper part of the reservoir (backwater). A characteristic feature of this complex was the large number of species and diversity of the ecological groups of algae, without any distinct domination and with smaller total numbers of individuals than at the littoral stations. The diversity of this community was associated with the specific conditions existing in the zone. The slower current of the Vistula within the reservoir created favourable conditions for the development of plankton including the rapidly proliferating green algae from the order Chlorococcales and the diatoms, among others from the genera *Cyclotella* and *Melosira*. The diatoms, particularly those from the genus *Melosira*, are unable to float in the water and require strong mixing or depth gradient to be supported in the water (S i m m 1990). In sedimenting, the algae enrich the bottom phytocoenosis. At the same time, the rapid development of the plankton deteriorated the light conditions, thereby inhibiting a more intensive development of numerous river algae carried into the reservoir by the current of the Vistula or of the littoral species displaced into this region owing to undulation. It should be noted that in the last few years a progressive eutrophication process has been observed in the Goczałkowice Reservoir, manifested by the mass occurrence of the plankton algae (B u c k a , Ż u r e k 1992).

The interaction between the communities of phytoplankton and phytobenthos consists chiefly in the competition for food and light, though under certain conditions these communities also become a source of mutual feeding (R o u n d , H a p p e y 1965, V l a d i m i r o v a 1968, 1978, R e y n o l d s et al. 1981, R e y n o l d s 1984).

Investigations of the phytobenthos in the Goczałkowice Reservoir have shown that in the formation of bottom complexes there participate the representatives of two ecological groups of algae - phytoplankton and phytobenthos. Among these groups, the presence has been reported of species of wide ecological tolerance, occurring in greater numbers both in the water depths and on the bottom and referred to as a group of facultative-planktonic (S k o r i k 1962) or

planktonic-benthic species (Vladimirova 1978). Here belonged mainly the green algae of the order of Chlorococcales with the genus *Scendesmus* and *Pediastrum* as dominants and the diatom *Melosira granulata* var. *angustissma*. The numerical participation of the representatives of the various life forms of the algae depended primarily on the zone and on the depth. The effect of depth on the development of bottom algae in the lakes has been discussed by, among others, Round (1961), Stańczykowska and Przytocka-Jusiak (1968), Stevenson and Stoermer (1981), and Kigston et al. (1983).

In the Goczałkowice Reservoir, along the depth gradient, changes have been observed in the structure of the communities and in the chlorophyll *a* content in the bottom sediments. Active phythobenthos developed mainly in the littoral zone to a depth of about 2 m. However, greater amounts of chlorophyll *a* and the richest, typically bottom phytocoenoses occurred at about 1 m. The range of photic zone and the degree of algal development at various depths may vary greatly according to the type and trophic condition of the lake as well as to the season. The degree of development and the differences in species composition of the communities occurring along the depth gradient are due to cooperative factors, mainly such as the amount and quality of light reaching the bottom, the mechanical effect of undulation of the water, which causes disturbances in the substratum, and the character of the substratum (Vladimirova 1978, Stavenson, Stoermer 1981).

The results of investigations of the phytobenthos in the eutrophic dam reservoirs of the Dnieper cascade (Skoric 1972, Vladimirova 1972, 1978) showed that the most productive zone was the littoral one at a depth of about 2 m. At greater depth the production of bottom algae was reduced, although the potential ability for photosynthesis was still retained at a depth of 3-5 m and was closely associated with seasonal changes in the plankton communities (Vladimirova 1978).

Stevenson and Stoermer (1981), in their investigations of the role of benthic algae and of the factors affecting their development at various depths, izolated in the deep Lake Michigan three characteristic zones (shallow, with a depth of 6.5 m; intermediate: 9 m and 14.6 m; and deep: 22.6 and 27.4 m), in which the distribution and composition of the phytobenthos were differed extremely. The greatest variety of species, large numbers, and domination of the benthos algae were characteristic of the intermediate zone on account of sufficient light and minimal disturbances caused by water movement.

The competitive prevalence of some groups or species of alga at greater depths was due to their ecological adaptation to the light conditions. The occurrence of bottom species at great depths may also be connected with the possible change to a heterotrophic method of feeding (Stevenson, Stoermer 1981). Admiral and Peletier (1979), cited by the mentioned authors (1981), described the development rate of benthos diatoms of the genera *Navicula* and *Nitzschia*, supplemented by the heterotrophic method of feeding at levels with an insufficient amount of light. It is probable that the benthos population of *Microcystis aeruginosa*, which represents the "inoculum" for the plankton, is also supported by photoheterotrophic increase (Reynolds 1984).

Nevertheless, from among all the types of environment occurring in a lake the optimal zone for the development of bottom communities is the littoral one. Frequent and mass appearances of sessile algae in the eulittoral and littoral zones bring about a total primary production during some periods that is very high (Pieczyńska 1971, 1976).

Considering the great extent of the photic zone of the littoral in the Goczałkowice Reservoir, reaching 40% of the whole surface of the reservoir at low water (Kownacki, Krzyżanek 1986), it should be stressed that the intensively developing phytobenthos communities in the reservoir play a significant role in the circulation of nutrients and organic matter, thus contributing to an increase in the primary production in the whole reservoir.

5. Polish summary

Charakterystyka zbiorowisk fitobentosu w Zbiorniku Goczałkowickim (Polska południowa)

W pracy przedstawiono wyniki badań prowadzonych w latach 1987-1988. Podstawę badań stanowiła powierzchniowa warstwa osadu pobieranego z dna. Analizowano skład jakościowy i ilościowy oraz mierzono koncentrację chlorofilu *a*. Określono również wpływ gradientu głębokości na zborowiska glonów dennych.

Analiza przestrzennego rozmieszczenia fitobentosu w Zbiorniku Goczałkowickim wykazała istotne różnice między strefą przybrzeżną zbiornika, gdzie rozwijały się zespoły litoralowe z dominacją form osiadłych, a strefą przyzaporową i centralną. W ich obrębie fitobentos z udziałem form planktonowych, przy niewielkich liczebnościach i słabej aktywności życiowej komórek glonów, nie odgrywał większej roli (ryc. 1). Pośredni typ zbiorowiska, o charakterze rzeczno-jeziornym, ukształtował się w cofkowej części zbiornika. Cechą tego zespołu była duża liczba gatunków i duża różnorodność grup ekologicznych glonów.

Wzdłuż gradientu głębokości obserwowano różnice w stopniu rozwoju fitobentosu i zawartości chlorofilu *a* w osadach dennych (ryc. 2, 3, tabela I). Aktywny fotosyntezujący fitobentos rozwijał się od głębokości 0.5 do ok. 2 m. Jednakże największe ilości chlorofilu *a* i najbogatsze liczebnościowo, typowo denne fitocenozy, z dominacją sinicy *Oscillatoria tenuis* i okrzemkami z rodzaju *Navicula*, obserwowano na głębokości 1 m. Na głębokości około 2 m przy największej różnorodności gatunkowej i obecności gatunków dennych, pojawiły się równorzędne liczebnościowo okrzemki planktonowe z rodzajów *Cyclotella, Stephanodiscus, Asterionella, i Melosira*, oraz zielenice chlorokokkowe. Jednocześnie notowano zmniejszenie liczebności populacji i tendencję spadkową w ilości chlorofilu *a* w osadach. Poniżej tej granicy gatunki planktonowe wypierały typowych przedstawicieli dna, obniżała się aktywność komórek glonów, jak również zawartość chlorofilu *a*. W najgłębszych partiach zbiornika aktywność fotosyntetyczna glonów redukowała się nieomal do zera, gdyż fitobentos był raczej zgrupowaniem organizmów w większości martwych.

Należy podkreślić, iż rozwijające się intensywnie w obrębie litoralu zbiorowiska fitobentosu, odgrywają istotną rolę w produkcji materii organicznej, przyczyniając się do jej wzrostu w skali całego zbiornika.

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