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A regulated river ecosystem in a polluted section of the Upper Vistula*

5. Seston

Teresa Bednarz, Roman Żurek

Polish Academy of Sciences, Institute of Freshwater Biology, ul. Sławkowska 17, 31-016 Kraków, Poland

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Abstract — Abioseston comprised 90 percent of the seston, the bioseston consisting of algae, planktonic, and non-planktonic animals. Owing to high salinity, species of brackish waters appeared in the bioseston. 210 taxa of algae and 83 of animals were distinguished. The destruction of organic matter by the zooseston was assessed. The water stage modified these processes of destruction, its physical action and the hydrographic character of the river affecting the processes of self-purification.

Key words: regulated river, pollution, zooseston, phytoseston.

1. Introduction

Since the 19th century, the River Vistula in its upper course has been affected by municipal, industrial, and mining pollution. The first investigations of the bioseston of the Vistula, made half a century ago by Starmach (1938), characterized the river from the sanitary aspect according to the system of Kolkowitz and Marsson. Later studies on the seston were made by Turoboyski (1956, 1962), Kyselowa and Kysela (1966), and more recently by Starzykowa (1972), Hanak-Schmager (1974), and Turoboyski, Pudo (1979).

These studies did not describe the role of the elements of the biocenoses in the processes of the self-purification of the river. The aim of the present work, besides the biological description of the seston, was to estimate the degradation of organic matter by the zooseston. Moreover, in association with the existing and prospective hydrotechnical construc-

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tions on the river, the need arose to find out how this building would affect the self-purification processes and the quality of the water in the Vistula.

2. Study area, material, and methods

The studies were conducted at 6 stations localized between kilometres 33 and 58 of the river course (fig. 1). A detailed description of the study area has been given by Dumnicka, Kownacki (1988a).

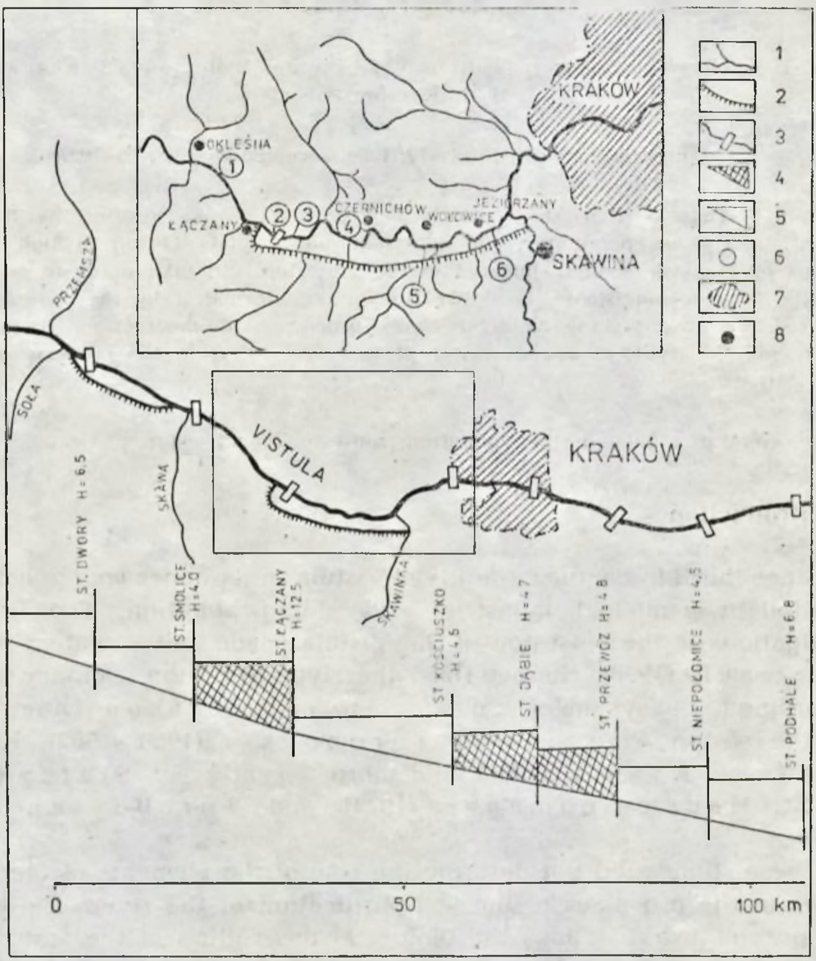

Fig. 1. The Upper Vistula, showing cascade building and stations on the investigated river section. 1 — rivers; 2 — canal; 3 — water stages, dams; 4 — water stages built; 5 — water stages under construction and planned; 6 — stations; 7 — cities; 8 — towns and villages

Seston samples were collected between December 1982 and December 1983, at roughly monthly intervals. When the samples were taken, the temperature of the river water was also measured, using a mercury thermometer. At each station, 50 dm^3 of water was strained through a No 25 plankton net with 50 μm mesh. The samples from the river were taken from the 0.7 m deep zone near the bank and in the case of the Łączany Reservoir from a platform. The collected material was preserved using formalin. In the samples, the abundance and species composition of the bioseston were determined while the proportion of the bio- and abioseston was also estimated and expressed as a percentage of the area it occupied on the microscope slide. In order to distinguish the dominating species in the bioseston, the criterion applied was a share of over 10% in the total numbers.

The abundance of the algae was determined using the drop method (Pringsheim 1946) and their biomass according to that of Javornicky and Komarkova (1973).

The number of the zooseston was determined in 1 cm^3 subsamples. Depending on the number of animals, they were counted in 5 to 50% of the volume of the sample. Also the size of individuals was measured, being required for subsequent calculations of their mass from appropriate regression equations. For most species, the dry weight was calculated using the coefficients of regression equations compiled in the papers of Bottrell et al. (1976), Jørgensen (1979), and Dumont et al. (1975). The dry weight of the Chironomidae was calculated according to the equation of Kamler and Srokosz (1973). For those animals for which no suitable coefficients could be found, the weights were calculated by comparing their bodies to a configuration of the appropriate geometric solids, assuming the dry weight to constitute 10% of the wet weight.

The individual weights of animals were the basic parameter in the equations used to calculate respiration. The process of combustion of organic matter by way of respiration is treated here as that of destruction of organic matter. Its quantity will further be expressed in $dm^3\ O_2\ m^{-3}$ of water d^{-1}. Respiration of the rotifers was calculated according to the data of Pourriot, Deluzarches (1970), and Pourriot (1973), assuming after Lavrovskaya (cit. Erman 1962) that protein constitutes 41.2% of rotifers' dry weight. Respiration of the chironomid larvae was calculated using the equation of Kamler, Srokosz (1973); Oligochaeta according to Berg, Jonasson (1965); Nematoda according to Klekowski and Fischer (1975), that of the remaining groups being calculated according to the appropriate equations, given after various authors by Jørgensen (1979). The calculated values of respiration were referred to the real temperatures using Krogh's curve. For crustaceans, factors correcting the metabolism for temperature according to S h u s c h y e n y a (1972) were used, and for the remaining animals those given by V i n b y e r g (1956).

3. Results

3.1. Composition of the seston

The seston of the Vistula consisted chiefly of abioseston: coal dust, sand, clay, and detritus fragments were found and also bioseston: algae, planktonic animals (mainly cladocerans and protozoans) and, from other habitats, Nematoda, Oligochaeta, Tardigrada, and Chironomidae. At all the stations, mineral particles and detritus covered 85—95% of the area of the microscope slides, bioseston comprising 5—15%. In the abioseston collected above the water stage in Łączany, coarse-grained coal dust prevailed, the proportion of fine mineral particles increasing below it.

3.2. Phytoseston

In the phycological aspect the seston of the investigated section of the Vistula can be considered as varied. 211 taxa were determined, 200

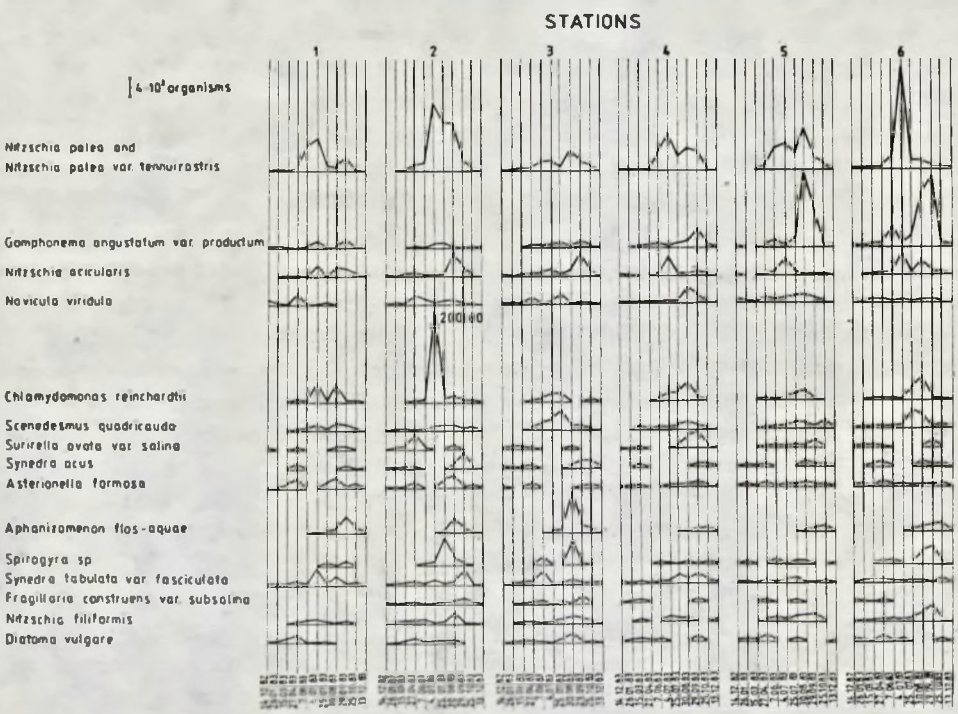

Fig. 2. Dynamics of the development of species dominating in the phytoseston at Stations 1—6 in one year

being identified down to species. Particular stations had similar taxonomic composition, the greatest variety of species being noted in the water from Station 5 (136 species), and the smallest at Station 3 (120 species). In the water of the remaining stations the same number of algal species (132) were distinguished. In over 90% of the microscopic slides, besides the 15 dominating species of alga (fig. 2), the following were usually present: *Phormidium autumnale, Oscillatoria sp., Euglena sp., Cyclotella comta, C. meneghiniana, Melosira granulata, M. varians, Thalasiosira fluviatilis, Fragillaria crotonensis, Synedra tabulata, Cymbella ventricosa, Gomphonema olivaceum, Navicula cryptocephala, N. cryptocephala var. veneta, Surirella ovata,* and *Scenedesmus acutus.* At Stations 1—4 constantly present were also *Crucigenia rectangularis* and *C. apiculata,* and at Stations 5 and 6 *Cladophora glomerata.* Most of the taxa identified in the seston came from periphytes. Typically planktonic algae were less frequent, occurring chiefly at the water stage (Station 2).

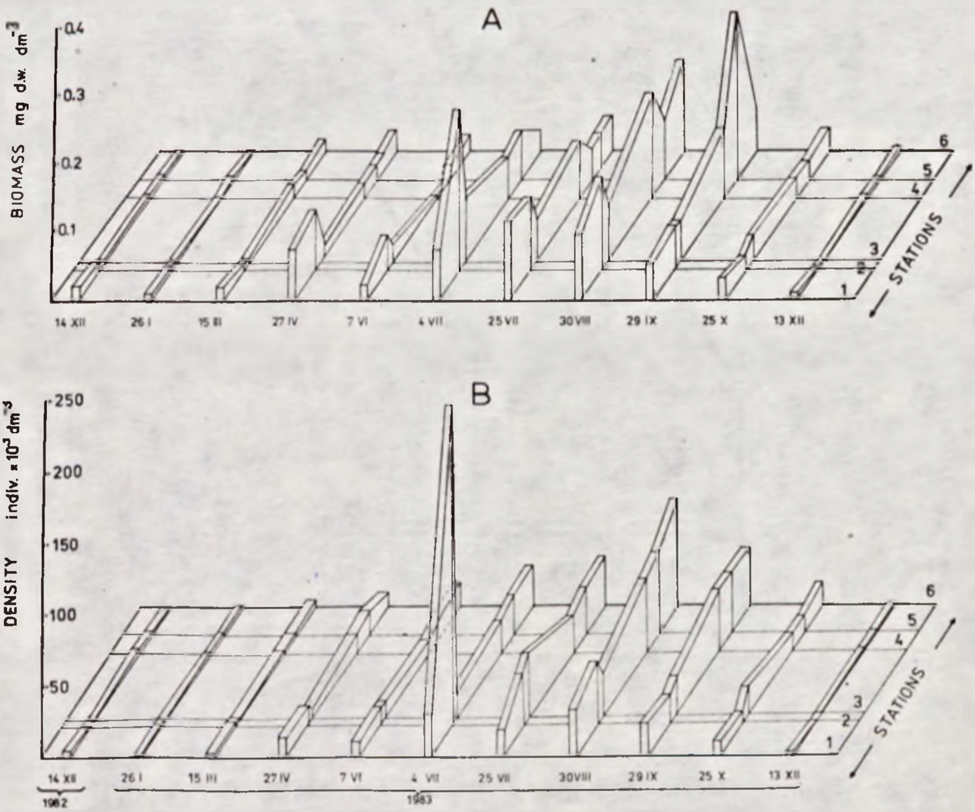

Fig. 3. Dynamics of the development of seston algae at Stations 1—6 in one year.
A — biomass; B — numbers

At Stations 1 and 4, and frequently also at Station 2 the numerous occurrence of bacteria of the *Zoogloea* type was noted, though they occurred only sporadically at further stations.

During the period of study, changes were observed in the number and biomass of the seston algae at particular stations (fig. 3), though an increase in their number was not always accompanied by an increase in their biomass. The abundance of the algae varied from 1160 in winter to 227 000 indiv. dm^{-3} in summer, biomass varying from 0.003 to 0.23 mg

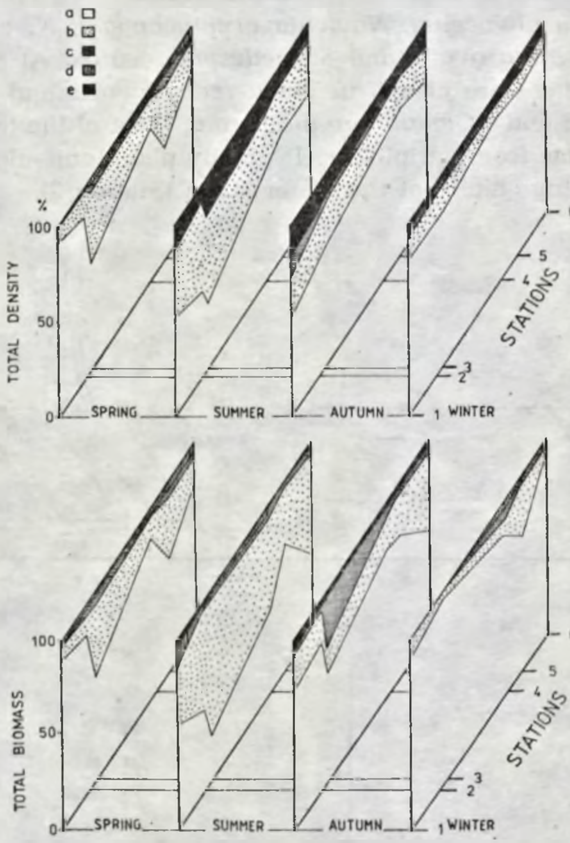

Fig. 4. Percentage of the systematic groups of alga in the total numbers and biomass in the vegetation seasons. a — diatoms; b — green algae; c — euglenins; d — chrysophites; e — blue-green algae

dry weight dm^{-3} (fig. 3). The latter values were associated with the summer bloom of *Chlamydomonas reinchardtii* at Station 2 (fig. 2). If this station and also Station 3 are omitted it will be seen that, going downriver, there was usually an increase in the number and biomass of algae (fig. 3). Stations 2 and 3 disrupted this pattern, because at Station 2 the

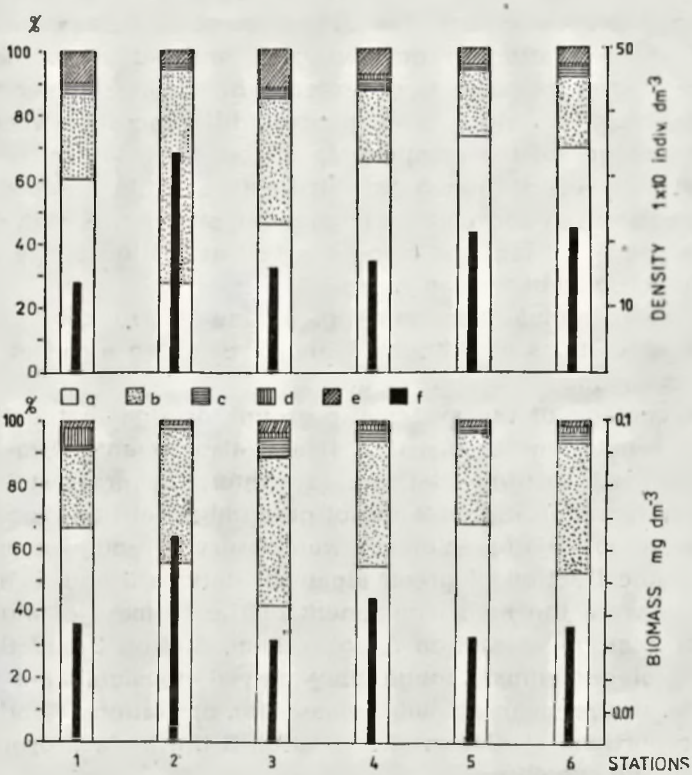

Fig. 5. Mean annual changes in the percentage of systematic groups of algae in numbers and biomass, at Stations 1—6. a — diatoms; b — green algae; c — euglenins; d — chrysophites; e — blue-green algae; f — mean biomass or mean numbers

development of algae (even a bloom) was greatest, while at Station 3 there was a distinct decrease in their number and biomass.

The dynamics of the development of the species dominating in the phytoseston usually followed a similar pattern (fig. 2). This is evident in the development of *Nitzschia palea* together with its *tennuirostris* variety, *Chlamydomonas reinchardtii*, *Scenedesmus quadricauda*, and *Nitzschia filiformis*. *Gomphonema angustatum* var. *productum* is an example of a species whose increase in abundance continued along the whole studied section of the river. An opposite phenomenon was observed in the development of *Aphanizomenon flos-aquae*, *Asterionella formosa*, and *Synedra tabulata* including its *fasciculata variety*. The development of these species was stronger in the upper stretches of the river, that of the remaining dominant species of the phytoseston showing no pattern associated with its course.

Taking into account the seasonal changes in the numbers of particular systematic groups of alga (fig. 4) it can be seen that winter was the period when diatoms preponderated. The development of these organisms was similar at all the stations. From spring till summer an increase in the percentage of green algae was observed, while from summer to autumn in that of blue-green algae. The greatest differences between stations in the percentages of the components of the phytoseston occurred in spring and summer. Station 3 was distinctive in its greatest share of green algae in spring and blue-green algae in summer. A high proportion of green algae in spring was also observed at Station 5, the highest in summer being noted at Station 2.

In the mean annual numbers (fig. 5) one is struck by the highest proportion of diatoms at Stations 1 and 5, of green algae at Station 2, and blue-green algae at Stations 1 and 3.

The percentage of the systematic groups of alga in the biomass in successive vegetation seasons (fig. 4) and also its annual mean (fig. 5) varied somewhat between stations. In winter, the greatest biomass of diatoms was found at Station 2 and of green algae at Station 5. In spring a decrease in the diatom biomass was observed, and concurrently an increase in the fraction of green algae at Stations 3 and 5. In summer, green algae were the main component of the biomass of algae at Station 3, and diatoms at Station 5. In autumn, Station 3 had the highest percentage of euglenins, though they played no significant numerical role (fig. 4). In the mean annual biomass (fig. 5) Stations 1 and 5 had the highest proportions of diatoms and Station 3 the highest proportions of green algae and euglenins.

3.3. Zooseston

3.3.1. Distribution of zooseston density and its seasonal dynamics

Eighty-three taxa of planktonic and non-planktonic animals were found, this including 62 species of Rotatoria, 5 of Cladocera, 10 of Copepoda, and unidentified forms of Protozoa, Nematoda, Oligochaeta, Chironomidae, Tardigrada, and Hydracarina. In the above-mentioned taxa rotatorians comprised 75% and copepods 12%. In terms of absolute numbers, rotifers and protozoans dominated. During winter and spring in the structure of the zooseston a marked dominance of protozoans (60—80%) was noted, one species of rotifer *Philodina sp.* constituting about 20%. In summer this tendency was reversed: the proportion of rotifers, chiefly *Philodina sp.* increased (by 30 to 70%) while that of protozoans decreased (10—30%), (fig. 6).

In winter, small numbers of protozoans occurred in the upper part of the section studied, while at Station 5 an increase took place. In summer the opposite was observed — greater numbers occurred at Stations 1 and 2, but were much smaller at the remaining stations (fig. 7).

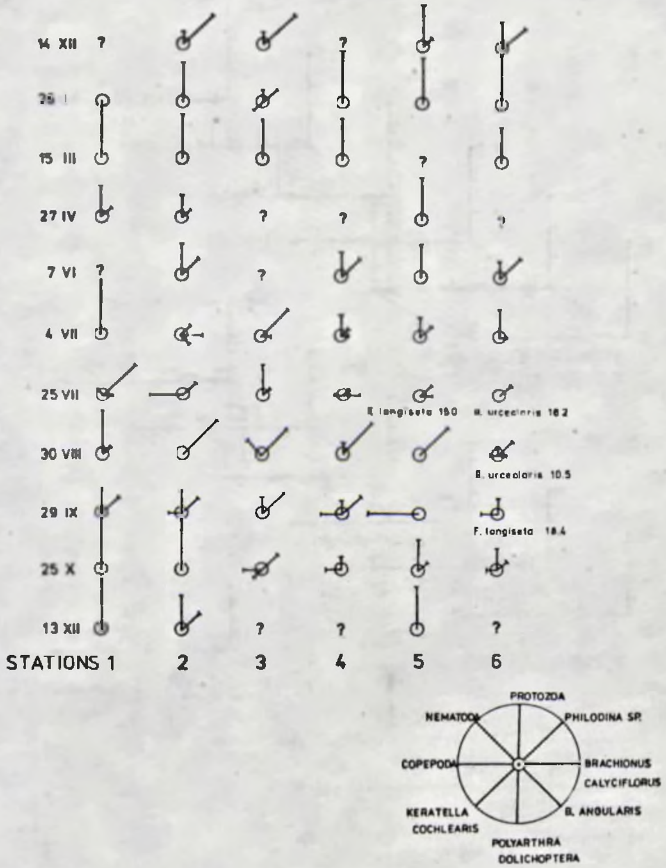

Fig. 6. Dominance structure of the zooseston of the Vistula. The radius of the large circle stands for 100%. The radius of the small inner circle stands for 10%. The species *Filinia longiseta* and *Brachionus urceolaris*, not included in the legend, which achieved a dominance of over 10% have been additionally marked together with the corresponding percentage of dominance. ? — data lacking

With respect to function, the dominating species were microfiltrators feeding on food particles under 20 μm in diameter, chiefly from 3 to 5 μm. Mature Copepoda and their final copepodite stages alone were the exception here. *Eucyclops serrulatus* present here is a euryphage, while other species of the genera *Cyclops, Acanthocyclops,* and *Thermocyclops* are zoophages.. However, mature stages were seldom found, mainly nauplii and copepodite stages, feeding on detritus, bacteria, and algae, occurring in the zooseston. In the group of numerous subdominants also found were species of brackish waters, *Synchaeta salina* and *Brachionus plicatilis.*

When considering the distribution of the zooseston along the river

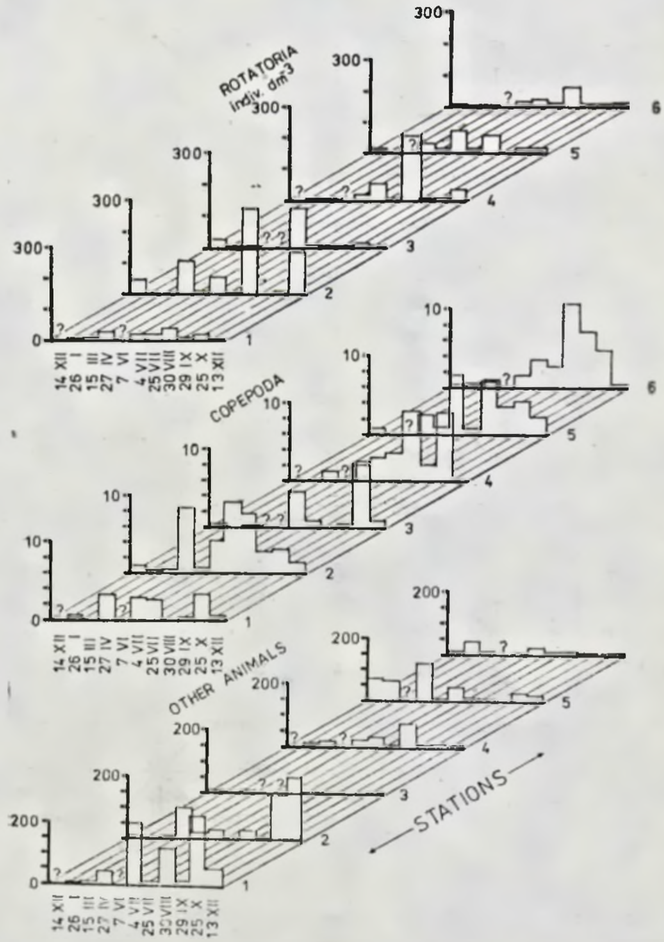

Fig. 7. Changes in the numbers of the main systematic groups of seston animals at particular stations

it can be seen that the highest density of zooseston (chiefly rotifers) occurred at Station 2. Below the dam (Station 3) the numbers were several times smaller, being comparable with those in the river above the reservoir (Station 1).

At Station 4 the zooseston numbers were greater than at Station 3, but decreased gradually at more distant station (5 and 6). The smallest numbers of rotifers were observed in autumn and winter, and the greatest in summer. Station 1, where the differences were small, did not conform to this rule. At Station 2, the numbers in these two seasons differed about fivefold (by up to 300 indiv. dm^{-3}) and showed strong fluctuations. At Station 3 the numbers and also their changes were very small. At further stations, fluctuations in the numbers were once again observed in the summer but their amplitude was smaller (from 20 to 80 indiv. dm^{-3}).

The distribution of the numbers of copepods and rotifers along the studied section of the river was similar: small in the river above the reservoir (Station 1, 0.0—3.5 indiv. dm^{-3}), an increase within the reservoir (Station 2, 0.0—9.6 indiv. dm^{-3}), a decrease below it (Station 3, 0.21—4.5 indiv. dm^{-3}) and a further increase at the lower-lying stations (4—6) up to quantities similar to those occurring in the reservoir.

In the seasonal aspect it may be noted that the smallest numbers of copepods occurred in winter. In spring and summer their numbers increased fairly regularly at all stations except 1 and 3. The numbers of Cladocera were not great, at most 1.26 indiv. dm^{-3}. *Lathonura rectirostris, Bosmina longirostris, Daphnia cucullata, D. longispina,* and *D. pulex* were found.

The biomass of the zooseston varied considerably during the year. In winter it was very small, around 10 mg m^{-3}, and much larger in summer, around 100 mg m^{-3}. In the reservoir (Station 2) the biomass of the zooseston doubled, to fall markedly below it (Station 3), while in further stretches of the river it again increased (fig. 8).

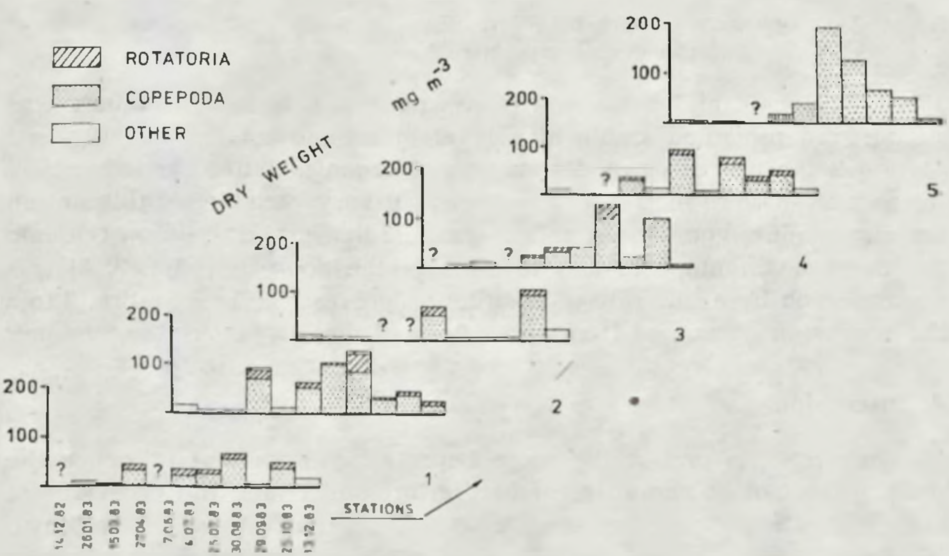

Fig. 8. Biomass of the zooseston expressed in mg dry weight in m^3 at particular stations. ? — data lacking

3.3.2. Destruction of organic matter by the zooseston

The low water temperature (4—6°C) in the winter from December to April limited the development of the zooseston and strongly suppressed its metabolic rate, even down to values of 0.004 dm^3 O_2 m^{-3} d^{-1}, (fig. 9).

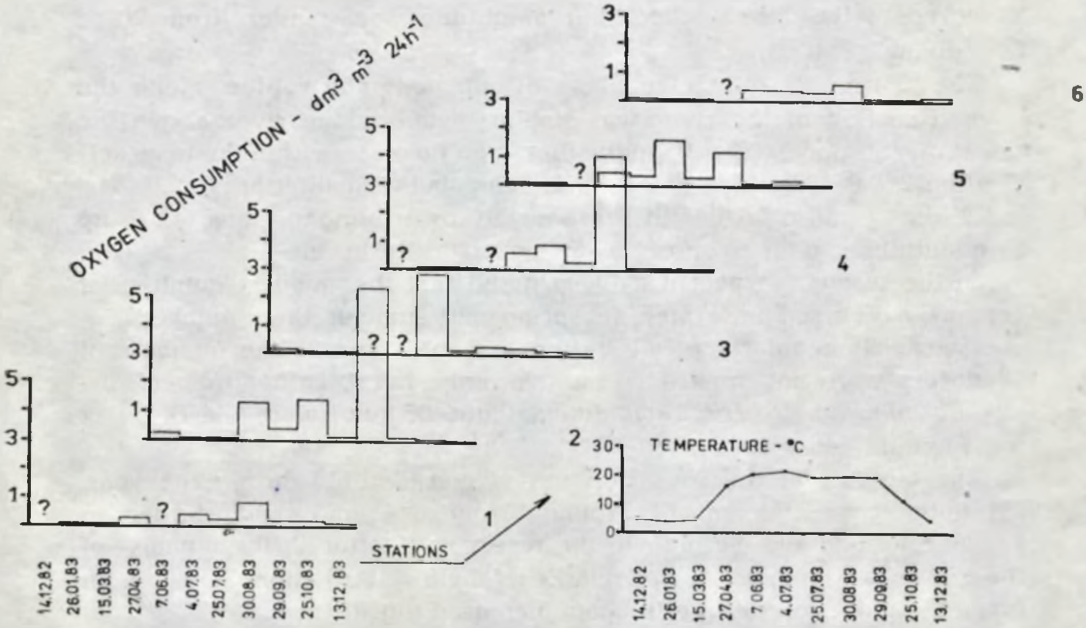

Fig. 9. Diel oxygen consumption by the zooseston at Stations 1—6 and the course of changes in temperature. ? — data lacking

At Stations 1 and 6 the rate of oxygen consumption in summer was similar and remained stable at a level of around 0.4 $dm^3\ m^{-3}\ d^{-1}$. At Station 2 the processes of destruction of organic matter carried out by the zooseston were intensive in summer but very variable. At this station the maximum oxygen consumption was 5.33 $dm^3\ m^{-3}\ d^{-1}$. Below the dam the decrease in numbers and biomass of the zooseston (fig. 7, 8) was accompanied by a low rate of destruction processes. From Station 3 to 5 the zooseston consumed from about 0.5 to 4 $dm^3\ O_2\ m^{-3}\ d^{-1}$ in summer.

4. Discussion

The seston is one of the more important factors that influence the development of communities of bottom organisms and the processes of the cycling of matter in rivers. Depending on the ratio of abioseston to bioseston, the course of the biological processes taking place in rivers may vary. Large quantities of abioseston increase turbidity, this in turn bringing about a decrease in the primary production in the river. In river phytoseston diatoms usually preponderate in number (70—85%) (Margalef 1960, Cyeyeb 1978, Witton 1985), rotifers being the dominant group in the zooseston (Klimowicz 1981, Pawłowski 1970). In wide, slowly flowing rivers the participations of green and blue-green algae, protozoans, and copepods increases (Heuss 1975, N u s h 1978, W i t t o n 1985). An increase in share of green algae and their attainment of preponderance in number is a feature of the lower course of very fertile and polluted rivers, such as the Rine (F r i e d - r i c h, V i e h w e g 1984). The biomass of phytoseston in rivers is usually small, no more than 6 mg dm^{-3} of water at most (C y e y e b 1978). In polluted rivers, chiefly in β- and α-mezosaprobic zones, communities of algae develop with a preponderance of *Nitschia palea, Gomphonema parvulum, Navicula cryptocephala, Synedra ulna, Chlamydomonas sp.*, and *Chlorella vulgaris* (E s h o, B e n s e n - E v a n s 1983).

The observations of the development of the seston of the Upper Vistula show that diatoms, green algae, protozoans, and rotifers dominated there. Hence the composition is typical of polluted rivers. The biomass of the phytoseston and the number of algae were small (maximum biomass 0.23 mg dm^{-3} and maximum number 227 000 indiv. dm^{-3}). This was connected with the large quantity of abioseston, since the water in this section of the river was fertile (B e d n a r z 1988, K a s z a 1988). The heavy loading of the Vistula with suspended matter and dissolved compounds (dry residue 1099—2805 mg dm^{-3}, according to K a s z a 1988) did not lead to impoverishment of the species composition of the bioseston. Most of the species of alga distinguished as characteristic of the upper section of the Vistula in 1933 (S t a r m a c h 1938) can in the present study also be classified among those that are a permanent component of the phytoseston. The recorded number of taxa of seston animals was only slightly smaller than the figures given for the middle course of this river, but distinctly greater than those found in earlier investigations (S t a r m a c h 1938, K y s e l o w a, K y s e l a 1966, S t a r z y k o w a 1972). The continuing increase in pollution of the river from 1933 to 1983 chiefly concerned salinity and the quantity of organic matter. An increase in salinity from 60 mg dm^{-3} (S t a r m a c h 1938) to 1438 mg Cl^{-} dm^{-3} in the 1982—1983 period (K a s z a 1988) brought about the appearance of species of brackish waters in the seston. The following were recorded: *Fragillaria construens* var. *subsalina, Surirella ovata* var. *salina, Synedra tabulata* together with its *fasciculata* variety, and *Nitzschia filiformis,* which were the dominants, *Thalasiosira fluviatilis* in the phytoseston, and also *Synchaeta salina* and *Brachionus plicatilis* in the zooseston. It is very likely that the constant increase in salinity led to gradual elimination of freshwater species of the Cladocera group within the Łączany Reservoir. S t a r z y k o w a (1972) stated that in 1966 there were 14 species of Cladocera in this reservoir. At present, single specimens of Cladocera were found in only 2 of the 11 samples. To confirm, the above conclusion the data of A n d e r s o n (1948) may be quoted, according to which 1449 mg Na dm^{-3} of water causes immobilization of 50% of the *Daphnia magna* population. Other observations (S a b a - n e e f f 1956) indicate that the high concentrations of salt in the presence of suspensions have an adverse effect on the feeding of zooplankton, hence causing a decrease in its numbers. Moreover, Cladocera are not adapted morphologically to life in a turbulent environment with a high content of suspended matter. All these adverse factors form an environment hostile to the occurrence of cladocerans in rivers (P a w ł o w s k i 1970, P a g g i 1981, K l i m o w i c z 1981), thus a large participation of these animals in the Vistula was not to be expected. However, in the reservoir at Łączany cladocerans would have found conditions favouring their development were it not for the increase in salinity and the large quantity of suspended matter. A negative relationship between the number of Cladocera and the quantity of suspended matter was also found in the shallow Goczałkowice Reservoir (Ż u r e k 1980).

The number and biomass of seston algae in the studied upper section of the Vistula were fairly small in comparison with data from its middle course (T y s z k a - M a c k i e w i c z 1983). The causes of this phenomenon lie in the large quantity of suspended matter, resulting in the poor supply of light in the water.

An important factor shaping the development and composition of the bioseston was the character of the river at particular stations (D u m n i c k a, K o w n a c k i 1988a).

The reservoir in Łączany distinctly slowed down the current of water, and also caused sedimentation of heavier particles of the abioseston. This favoured the development of algae and planktonic animals. In the study period even a bloom of the alga *Chlamydomonas reinhardtii* occurred. The greatest numbers and biomass of phyto- and zooseston, and also the greatest respiration of the zooseston were found in the water of the reservoir. Comparison of the waters of the reservoir (Station 2) and those of the river above it (Station 1) indicates that the reservoir functions like a sewage treatment plant, cleaning the river from loads of organic matter. In the summer the consumption of oxygen by the zooseston in the reservoir was 3—6 times greater than in the river above it. Following a distinct decrease in the biomass and numbers of the seston organisms at Station 3 below the reservoir, it increased slowly in the next stretch of the river.

When the river changed in character to submontane (Station 5) a distinct decline took place in the values of the biological parameters measured (B e d n a r z 1988, D u m n i c k a, K o w n a c k i 1988b, K w a n d r a n s 1988, S t a r z e c k a 1988), evidencing a certain improvement in the quality of the water. The fact that they again increased slightly at Station 6 may have been caused by the inflow of additional pollution, or perhaps be of secondary nature. The distinct decrease in the biomass of the algae at Station 5 in relation to only a slight decrease in their number additionally reflected the increase in the fraction of smaller forms of algae in the seston.

5. Polish summary

Ekosystem uregulowanego i zanieczyszczonego odcinka Górnej Wisły

5. Seston

Badania sestonu Wisły prowadzono od grudnia 1982 do grudnia 1983 r. na sześciu stanowiskach położonych między 33 a 58 km biegu rzeki (ryc. 1). Na tym odcinku nie ma żadnych dopływów ani zrzutów ścieków. Zbiornik w Łączanach powodował sedymentację grubszego abiosestonu, który mimo to na wszystkich stanowiskach stanowił 85—95% pokrycia powierzchni preparatów mikroskopowych. Wysokie zasolenie wód nie wpłynęło na zubożenie składu gatunkowego biosestonu, poza znaczną eliminacją Cladocera i zmianą struktury zespołu glonów w kierunku pojawienia się gatunków słonawolubnych (ryc. 2). W badanym odcinku rzeki stwierdzono występowanie 210 taksonów glonów i 83 taksonów zwierząt sestonowych. W zoosestonie Rotatoria stanowiły 75% wszystkich taksonów, Copepoda 12%, Cladocera 6%, a inne, w tym Oligochaeta, Chironomidae, Nematoda, Tardigrada, Protozoa i Hydracarina razem stanowiły 7%.

W ciągu rocznego okresu badawczego obserwowano zmiany liczebności i biomasy glonów (ryc. 3) i zwierząt sestonowych (ryc. 7 i 8). W sezonie letnim i jesiennym na wszystkich stanowiskach zaznaczył się duży udział sinic w ogólnej liczebności glonów i nieco mniejszy w ich biomasie (ryc. 4). W średnich rocznych liczebnościach i biomasie glonów zwraca uwagę znaczny udział zielenic na stanowisku 2 oraz przewaga okrzemek na pozostałych stanowiskach (ryc. 5). W zoosestonie, w okresie zimowo-wiosennym dominowały pierwotniaki (60—80%), a w lecie wrotki, głównie *Philodina* sp. (30—70%, ryc. 6).

Sucha masa zoosestonu wykazywała silne fluktuacje w ciągu roku, a także wzdłuż biegu rzeki (ryc. 8). Wrotki i pierwotniaki, mimo dużej niekiedy liczebności (ryc. 7), stanowiły tylko 2—22% suchej masy zoosestonu. Rozkład liczebności wzdłuż biegu rzeki przebiegał według następującego schematu: niewielka ilość zwierząt sestonowych powyżej zbiornika (st. 1), kilkakrotny wzrost liczebności w zbiorniku łączańskim (st. 2), gwałtowny spadek poniżej stopnia wodnego (st. 3) oraz ponowny wzrost liczebności zoosestonu w rzece (st. 4) (ryc. 7, 8).

Procesy destrukcji wykazywały niską intensywność od listopada do kwietnia, a wysoką w lecie (ryc. 9). W miarę oddalania się od zapory respiracja zoosestonu malała, choć jego biomasa wzrastała (ryc. 8).

6. References

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