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

10. General considerations

Andrzej Kownacki

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

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A b s t r a c t — In the Upper Vistula in unregulated sections where the water is well oxygenated, a complex biocenosis develops, conducing intensive processes of self-purification. In the Łączany Reservoir the biocenosis is much poorer (bacteria, protozoans, Oligochaeta, and plankton), hence the self-purification processes progressed far more slowly here. The planned cascade construction on the whole Upper Vistula will slow down these processes and extend the zone of heavy pollution.

K e y w o r d s: regulated river, pollution, biocenosis, ecosystem, model, self-purification.

1. Introduction

In the period 1982—1983 a research team from the Institute of Freshwater Biology of the Polish Academy of Sciences in Kraków carried out comprehensive hydrobiological investigations of the Upper Vistula in the region of the water stage at Łączany. These embraced the chemical composition of the water (K a s z a 1988), assessment of its fertility using algal growth test (B e d n a r z 1988), bacteria (S t a r z e c k a 1988), seston (B e d n a r z, Ż u r e k 1988), sessile algae (K w a n d r a n s 1988), ciliates (G r a b a c k a 1988), macrobenthos (D u m n i c k a, K o w n a c k i 1988b), and ichthyofauna (W ł o d e k, S k ó r a 1988). The aim of these investigations was to predict how cascade construction on a polluted river such as the Vistula in the section between Oświęcim and Kraków will affect the quality of its water and the composition of the biocenoses developing there. Efforts were also made to determine the rate of self-purification processes in a regulated and unregulated section of the river, and to assess the role of the biocenoses in these processes.

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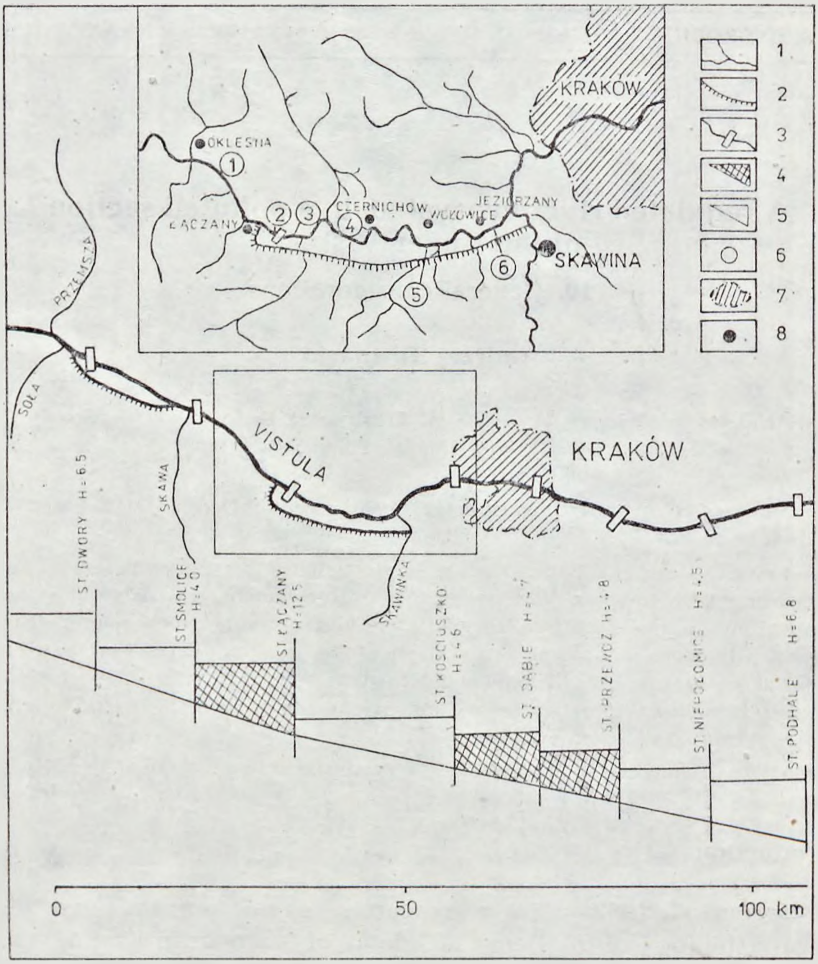

Fig. 1. The Upper Vistula, showing cascade building and stations on the investigated river section. 1 — rivers; 2 — canal; 3 — water stages, dams; 4 — water stages built, 5 — water stages under construction and planned; 6 — stations; 7 — cities; 8 — towns and villages

The investigations were carried out on a 25 km section of the River Vistula between kilometres 33 and 58, at six stations (fig. 1) (Dumnicka, Kownacki 1988a). In this section, the Vistula is heavily polluted by communal and industrial wastes and salted (a salinity of about 1‰) by minewater from the Upper Silesian Industrial Region, Oświęcim, Jaworzno, and Alwernia. The water in the river showed a high content of suspended matter, BOD_5, oxidability, content of ammonia nitrogen, and chlorides. The content of dissolved oxygen above the water stage at Łączany was small, increasing twofold below it. The fertility of the water assessed using algal growth tests was very high at all the stations.

Nevertheless, in the river section between Oświęcim and Kraków very intensive processes of self-purification are taking place, evidenced

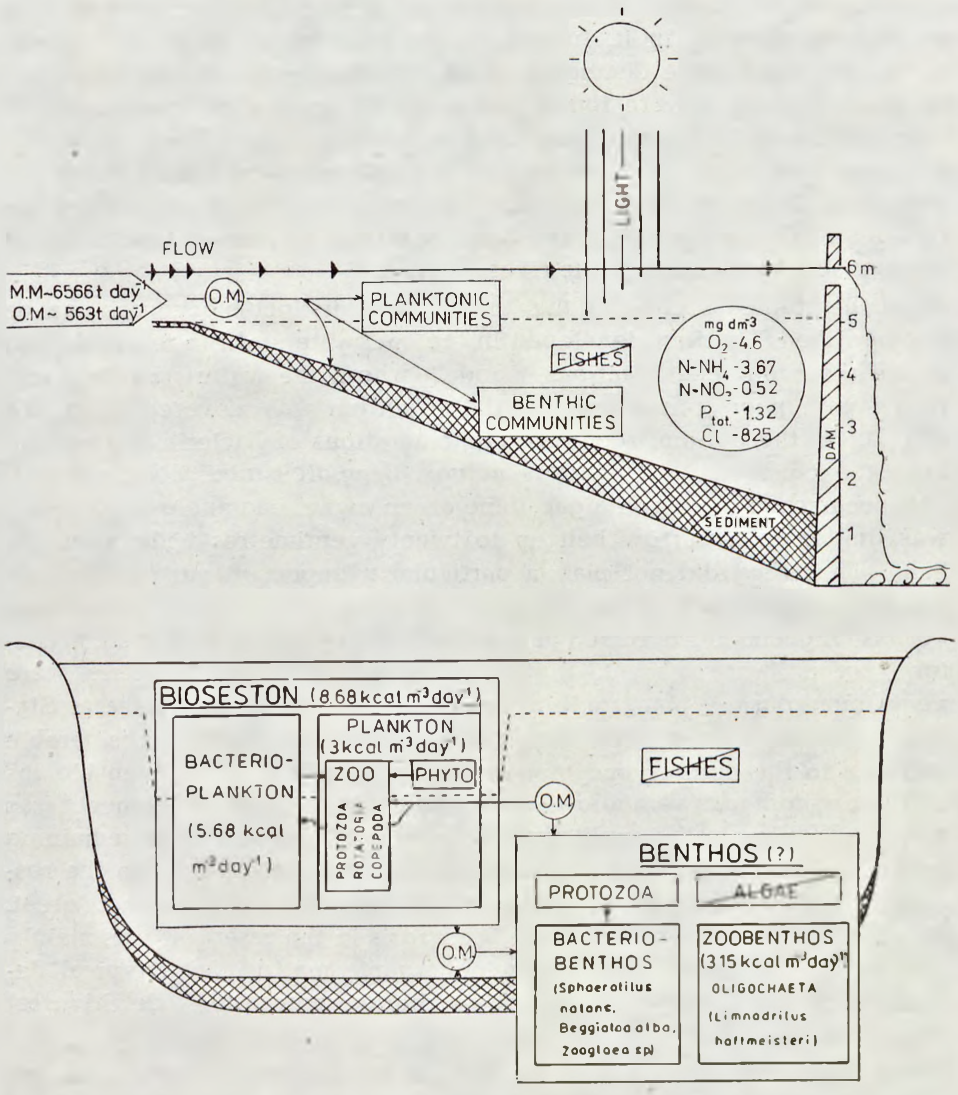

Fig. 2. The ecological relationships and simplified food web in the Łączany water stage (Station 2). The numerical values in parentheses give the magnitude of respiration of some elements of the biocenosis. Arrows indicate the flow of matter. O.M. — organic matter; M.M. — mineral matter

by the falling values of all the indices of pollution (Dojlido, Woyciechowska 1983).

2. Discussion

Despite such heavy pollution, the Upper Vistula has not become a dead sewer — quite varied communities of plants and animals as well as bacteria develop in it. In the studied section of the River Vistula, 97 taxa of algae were distinguished in the periphyton. In the zooseston 83 taxa of animals were found, including 62 species of Rotatoria, 5 of Cladocera, and 10 of Copepoda. On the bottom in the silt and on stones 49 species of ciliate and 40 taxa of macrofauna were found, including 20 species of Oligochaeta and 12 of Chironomidae. Moreover, 17 species of fish still live in the river. The activity of this biocenosis results in the gradual self-purification of the river.

In the studied section of the Vistula, two distinct biocenoses can be distinguished. The first developed in the backwaters of the reservoir and in the reservoir itself (Stations 1 and 2) where the water was deep and turbid with poor transparency and the bottom was covered with silt (fig. 2). On the bottom, zoogloeal agglomerations of bacteria were found almost exclusively (*Sphaerotilus natans, Beggiatoa alba, Zoogloea* sp.). The occurrence of sessile algae (blue-green algae, euglenoids), however, was limited to a narrow belt up to twenty centimetres wide, near the bank. Thus they did not play a particularly important part in the biocenosis. On the bottom, bacteriophagous ciliates developed and detritivorous Oligochaetes occurred in masses (*Limnodrilus hoffmeisteri*). Predatory forms were absent. In the water, heterotrophic bacteria were very numerous. A planktonic association developed, especially at Station 2 in the reservoir itself. In the summer there was a considerable increase in the number and biomass of the phytoplankton. Even blooms of *Chlamydomonas reinhardtii* were observed. This development was however limited to the sunlit surface layer of the water. In the remaining seasons the abundance of the plankton was quite small even in the reservoir, hence its role in the self-purification processes was not great. Hence it may be assumed that the biocenosis in the reservoir was mainly geared to the utilization of incoming organic matter and a typical detritus food chain (organic matter — microorganisms — detritivores) preponderated here.

A different type of biocenosis was found in the unregulated section of the river (Stations 5 and 6) where the water runs over stones and light penetrates to the bottom (fig. 3). On the stony bed in the whole cross-section of the river a thick coating of algae developed (*Cladophora glomerata, Oedogonium* sp., and diatoms — *Nitzschia palea*) in which many algivorous animals such as ciliates and invertebrates (*Nais elinguis, Cricotopus (C.) bicinctus,* snails) found favourable living conditions. Besides, predatory leeches were found, their share being particularly large in the biomass of invertebrates. Thus a complex grazing food chain

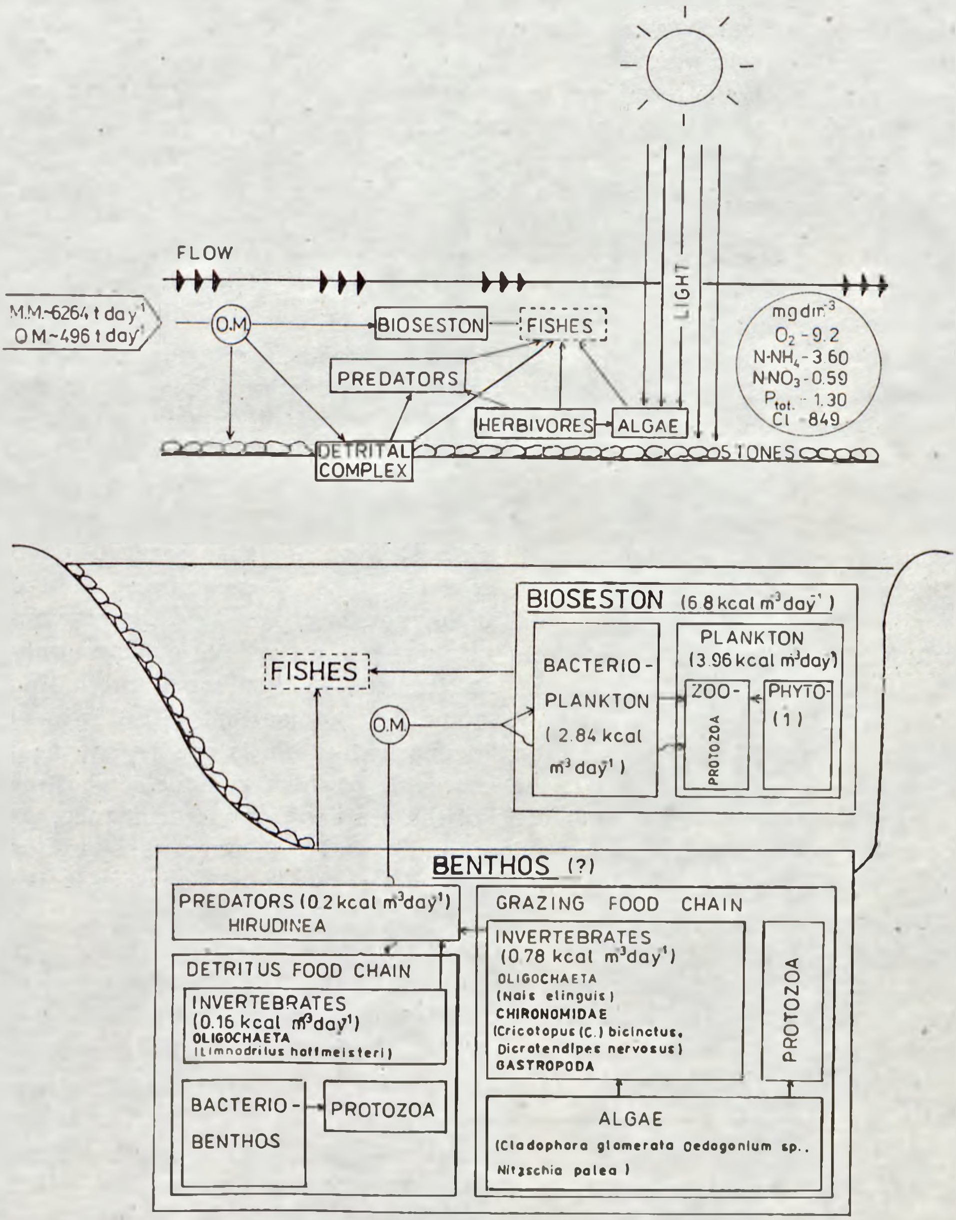

Fig. 3. The ecological relationships and simplified food web of the unregulated section of the River Vistula below the water stage at Łączany (Station 5). The broken line designates fragmentary associations. 1 — in the phytoplankton, sessile algae torn away from the bottom prevail. Other explanations as in fig. 2

(algae — 1st order consumers — predators) was formed. Moreover, there was a less well developed detritus food chain, whose abundance was also regulated by predatory invertebrates and, to a very small degree, by fish. On the other hand, seston communities did not play any great significant role. In the phytoseston, sessile algae torn away from the substratum preponderated and in the zooseston infrequent Rotatoria and Copepoda washed out from stagnant pools at the banks. Such a varied biocenosis has a much greater potential to conduct self-purification processes in the river. At Stations 3 and 4 the river had a transitional character.

It should be noted that changes in the biocenoses do not correspond to those in the chemical parameters responsible for changes in the water quality. Over the whole length of the river section studied the range of changes in the mean values of chlorides, ammonia nitrogen, phosphates, oxidability, and BOD_5 had a small range of variation. Only below the water stage at Łączany (Station 3) did the degree of oxygen saturation of the water increase, remaining constant further downriver. At this station the concentration of total phosphorus also suddenly increased (Kasza 1988). Nevertheless the differences between the biocenoses of Stations 2 (the reservoir) and 3 (the river) were not very great. Though the quantity of bioseston in the water did decrease, this can be accounted for by changes in the velocity of the current. In contrast, in the communities associated with the bottom, algae continued to occupy only a narrow strip near the banks, detritivorous Oligochaeta prevailing among the invertebrates. Hence it should be assumed that with this level of pollution the factor causing the biocenoses to differ is not the chemical composition of the water but the character of the river and its bottom and the possibility of oxygenation of the water through turbulence. At Stations 2 and 3 the water was deep and turbid with poor transparency and the bottom silty or sandy. This did not create conditions conducive to the development of algae. Nevertheless, the large quantities of suspended organic matter gave detritivorous forms the chance to develop. At Stations 5 and 6 the swift current and small depth facilitating good access of light and oxygenation of the water controbuted to the development of algae which initiate the grazing food chain.

Pollution of the Vistula dates back to the end of the previous century. However, a significant increase in the amount of pollution has taken place during the last 30 years. For example, at Okleśna (Station 1) in 1964—1965 the average BOD_5 was 10 mg O_2 dm^{-3}, while in 1982—1983 the BOD_5 was 20 mg O_2 dm^{-3} (Bombówna, Wróbel 1966, Kasza 1988). However, the composition and number of communities of sessile algae and invertebrate fauna at this station 18 years ago were similar to what they are now (Kyselowa, Kysela 1966, Zięba, Zaćwilichowska 1966, Kwandrans 1988, Dumnicka, Kow n a c k i 1988b). This means that the biocenoses living in the Vistula came into existence many years ago and have become adapted to life in strongly polluted water — the further increase in pollution has not changed their composition and number. Only the increase in the salinity of the Vistula has led to the appearance of several not previously recorded halophilous species. This was especially evident in the communities of sessile algae, in the phytoseston, and zooseston (K w a n d r a n s 1988, B e d n a r z, Ż u r e k 1988).

The Upper Vistula carries enormous quantities of suspended matter, chiefly coal dust, which considerably limits the transparency of the water. The assumption that the construction of water stages on the Vistula will, owing to intensive sedimentation of suspended matter, result in an improvement in the quality of the water (W r ó b e l, S z c z ę s n y 1983) seems to be unfounded. As evidenced by the investigations carried out for many years on the Carpathian reservoirs, sedimentation of suspended matter in this type of cascade would not be particularly high (Ł a j c z a k unpubl.). At present, the water stage at Łączany does not bring about any significant decrease in the content of suspended matter. Occasionally, owing to scouring of sediment from the Łączany Reservoir, even an increase was observed in the content of suspended matter in the water below it (S c h m a g e r 1982, 1988).

To reassume it should be said that the water stage at Łączany does not improve the quality of the water in the Vistula. The biocenosis developing there, forming a simple detritus food chain, gives a high production but disperses energy to a smaller degree (O d u m 1982). Meanwhile, in sections of the Vistula where the natural hydrological character has been preserved or which have been regulated only slightly, a relatively complex biocenosis is developing, forming an intricate food web, owing to which selfpurification processes proceed much more efficiently.

A similar situation was observed on a section of the River Isère polluted by communal and industrial wastes from Grenoble, on which three cascades were built (W a s s o n 1976, 1977, G a y, S e r r a - T o s i o 1982). On lotic stretches the river had a stony-gravel bottom and was well oxygenated. Silt collected in the reservoirs, and the current became less swift and the oxygenation poorer. These two zones in the river each had a distinct biocenosis. In the river on a stony bottom a plant coating composed of green algae (*Cladophora*), diatoms, and bacteria (*Sphaerotilus natans*) developed. It was inhabited by a fairly varied fauna in which, besides unidentified Oligochaeta, Chironomidae (*Cricotopus* (*C.*) *bicinctus*), snails, and leeches also appeared. Other groups of fauna were lacking. Nevertheless, in all the cascades, despite their considerable distance from the source of the effluent (about 40 km, 50 km, and 60 km for cascades I, II, and III, respectively) Oligochaeta

(*Tubifex tubifex, Limnodrilus hoffmeisteri, L. udekemianus*) were found almost exclusively. Chironomidae were few, and their numbers did not increase until cascade III.

In the River Saale, polluted with paper mill waste, after the construction on it of several large dam reservoirs the quality of the water also deteriorated (S c h r ä d e r 1958). Previously the selfpurification process had taken place on a 20 km section of the river. After construction of the reservoirs, following an initial improvement, successive pollution of the reservoirs took place and the last one, Hohenwarte, lying 75 km from the source of pollution, became polluted 12 years after its coming into existence. In the relatively large and deep reservoirs, oxygen shortages occurred in summer in the epilimnion, H_2S collected at the bottom, and the content of organic mater increased considerably. This led to a distinct fall in phytoplankton numbers, and even periodic extinction. During the period of autumn circulation, when the water of the epi- and metalimnion was oxygenated, phytoplankton developed in masses. In the sediment on the bottom of the reservoir, of the highly complex zoocenosis, in which even specimens of *Gammarus* occurred at 50 m, only Oligochaeta remained. The number of fish in the reservoir fell markedly. Once polluted, the reservoir did not purify itself (data from the period in which studies were carried out), because the load of pollution it contained caused occasional deficits of oxygen and extinction of the biocenosis.

3. Conclussions

The cascade construction on the Upper Vistula will have a profound effect on the entire ecosystem. The river will change in character. It will be much deeper and, with the present turbidity of the water, this will reduce the possibility of development of an algal coating on the bottom. The current will be laminar, the river bottom will rapidly become silted, and oxygenation of the water will decrease. In such an environment, similarly as in the Łączany Reservoir at present, mainly a biocenosis of detritivores will be able to develop. The plankton developing in the sunlit upper layer will not replace the "dismembered" grazing food chain which developed on the bottom in places with a swift current, in shallow and well oxygenated water.

The construction of new cascades, without prior elimination of pollution will exacerbate the situation on this section of the Vistula, and self-purification processes will move a long way downriver and will not be reasonably intensive till beyond the cascades.

The planned introduction of navigation on this section of the Upper Vistula will further contribute to an increase in the pollution and deoxygenation of the water. Barges moving on the Vistula, will be a relatively shallow waterway, will churn up the bottom sediment, stirring it into the water and thereby increasing turbidity. Disturbance of the bottom will release noxious gases (ammonia, hydrogen sulphide, methane) formed during the anoxic decomposition of organic matter accumulated in the sediment (S c h m a g e r 1982) into the water. This will prevent plankton from developing in the surface layer of water.

Moreover, the water stages coming into existence will bring about unfavourable changes in the vicinity of the river, causing submergence of adjacent land, which will demand the drainage of large areas. For instance, after construction of the water stage at Łączany, 6300 ha had to be drained (K l o z e 1983). The possibility of considerable contamination of the ground water should also be borne in mind.

5. Polish summary

Ekosystem uregulowanego i zanieczyszczonego odcinka Górnej Wisły

10. Ogólne prawidłowości

W latach 1982—1983 przeprowadzono badania hydrobiologiczne Górnej Wisły w rejonie stopnia wodnego w Łączanach na sześciu stanowiskach (ryc. 1) usytuowanych pomiędzy 33—58 km biegu rzeki. Celem tych badań było danie prognozy, jak kaskadowa zabudowa zanieczyszczonej rzeki, jaką jest Wisła na tym odcinku, wpłynie na jakość wody i skład rozwijających się tam biocenoz oraz na szybkość procesów samooczyszczania. Wisła na tym odcinku jest zanieczyszczona przez ścieki komunalne, przemysłowe oraz zasolona (zasolenie około 1‰) przez wody kopalniane pochodzące z Górnośląskiego Okręgu Przemysłowego i Oświęcimia. Woda w rzece charakteryzuje się wysoką zawartością zawiesiny i BZT_5, utlenialnością, zawartością azotu amonowego oraz chlorków. Natomiast ilość rozpuszczonego tlenu w wodzie powyżej progu w Łączanach jest niska, a poniżej progu jego ilość wzrasta dwukrotnie. Żyzność wody oceniana metodą testów glonowych jest bardzo wysoka na wszystkich stanowiskach.

W badanym odcinku Wisły wyróżniono dwa typy biocenoz. Pierwszy występował w zbiorniku (ryc. 2). Na mulistym dnie rozwijały się zooglealne skupienia bakterii, orzęski oraz detrytusożerne Oligochaeta. Glony porośłowe były ograniczone wyłącznie do kilkunastocentymetrowego pasa przybrzeżnego. W toni wodnej masowo rozwijały się bakterie heterotroficzne oraz mniej liczny plankton złożony głównie z zielenic i wrotków. Brak było form drapieżnych. Biocenoza ta stanowi typowy łańcuch troficzny detrytusożerców, w głównej mierze nastawiony na rozkład dopływającej materii organicznej. Drugi typ biocenozy spotykano w nie uregulowanym odcinku rzeki, gdzie woda płynie po kamieniach i światło dochodzi do samego dna (ryc. 3). Na kamieniach na całym przekroju rzeki rozwija się gruba pokrywa glonów (*Cladophora glomerata*, okrzemki), w której znajdują korzystne warunki do życia liczne formy glonożerne orzęsków i bezkręgowców, tworząc złożony łańcuch spasania. Znacznie słabiej rozwijał się łańcuch troficzny detrytusożerców. Liczebność obu tych ogniw regulują drapieżne pijawki i w mniejszym stopniu ryby. Natomiast seston nie odgrywa większej roli.

Nie stwierdzono wyraźnej korelacji pomiędzy zmianą parametrów chemicznych odpowiedzialnych za jakość wody a zmianą typu biocenoz. Przy tak wysokim stopniu zanieczyszczenia czynnikiem różnicującym biocenozy staje się charakter rzeki i jej dna, możliwość turbulencyjnego natlenienia wody oraz dostępność światła.

Kaskadowa zabudowa Górnej Wisły spowoduje, że z niedużej rzeki o szybkim prądzie zmieni się w ciąg szeroko rozlanych, stosunkowo głębokich zbiorników o wolnym prądzie i słabym natlenieniu wody. W tym środowisku, podobnie jak obecnie w zbiorniku w Łączanach, będzie się rozwijać biocenoza detrytusożerców złożona z bakterii, orzęsków i Oligochaeta. Rozwijający się w prześwietlonej, powierzchniowej warstwie wody plankton nie zastąpi zdemontowanego łańcucha troficznego spasania, który rozwijał się w rzece na dnie kamienistym w miejscach o szybkim prądzie, w płytkiej i dobrze natlenionej wodzie. Spowoduje to spowolnienie procesów samooczyszczenia i wydłuży strefę zanieczyszczonej rzeki.

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