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DEVELOPMENT AND STRUCTURE OF THE GOCZAŁKOWICE RESERVOIR ECOSYSTEM XVII. GENERAL REGULARITIES

ABSTRACT: The formation and succession of the Goczałkowice reservoir biocoenoses are described on the basis of 28 years' continuous studies. Factors affecting the development of biocoenoses are discussed, and biocoenotic relationships in the reservoir itself and between the river and the reservoir are presented. As the reservoir is used by water-supply systems, measures are recommended aimed at controlling its further eutrophication.

KEY WORDS: Reservoir, ecosystem, succession, zonation, biocoenotic relationship.

1. INTRODUCTION

At the suggestion of Professor Dr. Karol Starmach systematic hydrobiological studies have been carried out in the Goczałkowice reservoir since its beginning in 1955 to date. The results of regular investigations, obtained in the years 1955–1982, have been summarized and presented in the present series of papers covering the following topics: meteorological conditions (A u g u s t y n 1986), hydrochemistry (K a s z a and W i n o h r a d n i k 1986), phytoplankton (P a j ą k 1986), zooplankton (K r z a n o w s k i 1986), macrophytes (K u f l i k o w s k i 1986a), zoobenthos (K r z y ż a n e k 1986) and fishes (S t a r m a c h 1986). The series also contains papers describing the characteristics of the catchment area (K a s z a 1986), soils in the area of the future reservoir (M a z u r and K o m o r n i c k i 1986), characteristics of the reservoir itself and the method of its use (W i n o h r a d n i k

1986), as well as the results of short-term supplementary researches into the photic conditions (S z u m i e c 1986) and their importance to macrophyte production (C z a r n o w s k i et al. 1986), the periphyton on higher plants (M r o z i ń s k a 1986), plant-dwelling fauna (K u f l i k o w s k i 1986) and birds (B o c h e ń s k i 1986). In the present paper use has also been made of the rich literature on the Goczałkowice reservoir, and unpublished data at the disposal of the Laboratory of Water Biology, Polish Academy of Sciences, Cracow, and of the Hydrobiological Station at Goczałkowice.

The studies have been of a descriptive nature, so they have provided some documentation which has made it possible to trace the formation process and the succession of biocoenoses in the reservoir in relationship to changes in environmental conditions over the period of 28 years. They have also made possible the determination of the spatial distribution of biocoenoses, and a trial for establishing biocoenotic relationships in the reservoir. On the basis of the results obtained from the investigations certain measures have been recommended for the water-supply practice, which may slow down the progressing process of eutrophication of the reservoir water.

2. DESCRIPTION OF THE RESERVOIR

The Goczałkowice reservoir has been built at the 67th km of the Vistula river (49°51′ N, 18°52′ E) in 1955 as an intake of drinking water for the Upper Silesian Industrial Region, and a water storage reservoir. It is not deep, and there are large shallow water zones in it. Its water is exchanged 2 – 4 times a year. At the highest water level the surface area of the reservoir is 32 km^2, average depth 5 m, maximum depth 14 m, and the area of the littoral zone represents 26% of the reservoir surface area. At the lowest water level the reservoir area is about 20 km^2, average depth 2.5 m, maximum depth 10 m, and the littoral area comes up to 40%. The reservoir is 12 km in maximum length and 5 km in width. Circadian and seasonal water level variation is not wide. However, in periods of repair work done on the sluice gate, or protracted droughts the water level is lowered considerably, due to which even 1/4 of the reservoir floor is uncovered. Such lowerings of the water level took place in 1965, 1972, 1978, 1979. The reservoir is covered with ice for 3 – 4 months a year, from December until February or March. In the reservoir area westerly winds from the Moravian Gate prevail. Due to the east-to-west orientation of the reservoir, there often occur strong waves, the north-eastern banks of the reservoir being particularly exposed to their action. As a result of the strong waves and small depth, there is no thermical water stratification in the reservoir.

3. SUCCESSION OF BIOCOENOSES IN THE RESERVOIR

Four periods have been distinguished in the 28-year history of the reservoir. In the first period, in 1955 when the reservoir was filled, all existing terrestrial communities were destroyed, and so were river communities not adapted to the new environmental conditions. In areas that were being flooded mass escape of terrestrial animals could be seen. Among the animals that were trying the escape towards the shore and were carried away by waves various coleopteran species prevailed. Only some of the organisms that had inhabited small bodies of placid water before their being engulfed by the reservoir water could spread in the border zone of the whole reservoir owing to a lack of competition from other organisms. This can be exemplified by the outbreaks of some aquatic plants (*Utricularia vulgaris* L., *Lemna minor* L., *Elodea canadensis* Rich.). There also appeared the first aquatic animals, mainly bugs (*Corixa* sp.). This period was in principle very short. At the end of the first four weeks of the filling of the reservoir in some parts of it only few oligochaetes and amphibiotic chironomids (*Pseudosmittia* sp., *Smittia* sp.), representing terrestrial forms, could be seen. Only in the fish communities did typical river species continue to live there for a longer time and disappeared from the reservoir completely only in 1958. But their numbers decreased rapidly as the filling of the reservoir progressed.

In the second period that lasted from the filling of the reservoir in 1955 until the early 60s two stages could be distinguished in the formation of biocoenoses.

The first stage, which can be referred to as the stage of initial formation of reservoir biocoenoses, began as early as three months after the filling, and lasted about 2 months. There appeared the first organisms specific to reservoirs. The first blooms of phytoplanktonic *Aphanizomenon flos aquae* (L.) Ralfs were recorded, and there appeared large numbers of some cladoceran species in the zooplankton, and chironomid larvae in the benthos. River fish species continued to escape from the reservoir.

The second stage of the formation of reservoir biocoenoses began in 1956 and ended in 1961. It was characterized by a lack of chemical and biological stability. Bottom sediments had not formed yet, the decomposition of the flooded terrestrial vegetation continued, and so did the leaching of the primary soils. The shores of the reservoir were being transformed. In some places the washing away of the banks of the reservoir was as extensive as 20 – 35 m. But at the same time there formed near-shore beaches and shoals which prevented erosion of the banks (P a s t e r n a k 1964). At this stage high levels were recorded of organic matter (oxidizability 5.5 – 6.9 mg $O_2 \cdot dm^{-3}$)[1] mineral suspension (4.6 – 11.9 mg $\cdot$ dm^{-3}), water colour (26.6 – 34.5 mg Pt $\cdot$ dm^{-3}), and a relatively low water transparency (1.1 – 1.3 m). The amount of calcium (22.9 = 33.6 mg Ca $\cdot$ dm^{-3}), magnesium (2.3 – 4.2 mg Mg $\cdot$ dm^{-3}) cations, and of chloride (7.2 – 10.8 mg Cl $\cdot$ dm^{-3}) and sulphate (18.0 – 40.5 mg $SO_4 \cdot dm^{-3}$) anions was at that time low. The amounts were also small of nutrients: nitrogen (0.13 – 0.38 mg $N-NO_3 \cdot dm^{-3}$) and phosphorus (0.002 – 0.007 mg $P-PO_4 \cdot dm^{-3}$).

Mean nutrient content for that period was 0.28 mg $N-NO_3 \cdot dm^{-3}$ for nitrates, and 0.005 mg $P-PO_4 \cdot dm^{-3}$ for phosphates. There was a dynamic growth of

[1] The chemical values specified represent the range of mean annual quantities.

plankton. In the phytoplankton large numbers of algae were recorded, and water blooms could often be seen (1956 – blooms of *Synura uvella* Ehr., 1957 – of *Asterionella formosa* Hass., 1958 – of *Ceratium hirundinella* (O. F. Müll.) Bergh., and *Asterionella formosa*). A similarly dynamic growth was recorded for the zooplankton, where the indicator forms were rotifers. In the ichthyofauna of the reservoir the pike (*Esox lucius* L.) developed dynamically.

The succession of communities associated with the bottom sediments was slightly different. Two stages have been distinguished: the first one lasted from 1956 till 1969. At that stage there occurred a mass growth of submerged macrophytes over a considerable area of the reservoir, but a reed-rush zone had not developed yet. On the reservoir bottom chironomids occurred in large numbers, with *Chironomus* sp. I (? *Ch. plumosus* L.) and *Ch.* sp. II (? *Ch. thummi* K.) as the dominant forms. At the second stage that lasted from 1960 to 1963 emergent macrophytes began to appear and form the reed-rush zone. In the benthos, other groups – mainly oligochaetes, began to play an important role besides chironomids, among which *Chironomus* sp. I (? *Ch. plumosus*) dominated.

The third period lasted from the early 60s to the early 70s. It was in that period that the actual formation of the reservoir biocoenoses took place and at the same time a decrease in numbers. There arose layers of formed and diversified bottom sediments. The content of organic matter in the water dropped (oxidizability 4.0 – 4.7 mg $O_2 \cdot dm^{-3}$), and the water colour decreased (20.3 – 26.3 mg $Pt \cdot dm^{-3}$). But there was an increase in transparancy (1.5 – 2.0 m) and in the content of components contributing to the mineralization of the water. For example, the content of chlorides grew successively from 7.5 mg $Cl \cdot dm^{-3}$ in 1961 to 12.9 mg $Cl \cdot dm^{-3}$ in 1971. The content also increased of nutrients (0.32 – 1.04 mg $N - NO_3 \cdot dm^{-3}$) in the reservoir water. A decrease in phytoplankton numbers could be seen, and water blooms were less frequently recorded. A decrease in numbers was also observed in the bottom fauna. Dominant among the chironomids were larvae of the genus *Procladius*. An important component of the benthos biomass was mussels, primarily *Anodonta cygnea* L. No major differences could be seen, in comparison with the preceding period, in the macrophytes and zooplankton. The period considered can be defined as the period of oligotrophication in the history of the reservoir. The composition of the ichthyofauna changed twice at that stage. In the years 1961 – 1965, the roach (*Rutilus rutilus* (L.)) was the dominant species in the fish communities. Only in 1966 was it replaced by the bream (*Abramis brama* (L.)), considered characteristic of dam reservoirs. If the ichthyofauna alone is taken into account, it ought to be assumed that it was only in 1965 that the formation of biocoenoses was completed, that is to say, 10 years after the filling of the reservoir, whereas the period of stabilization began in 1966.

The fourth period that has lasted from the early 70s to date has been the period of a gradual increase in fertility of the reservoir. The content of organic matter and the colour of the water remained at about the same level as in the preceding years, but water transperency was reduced, particularly in the years 1979 – 1982, down to 1.0 – 1.4 m. The content increased considerably of calcium (25.1 – 30.0 mg $Ca \cdot dm^{-3}$), magnesium

(3.5 – 4.5 mg $Mg \cdot dm^{-3}$) and chlorides (13.4 – 19.4 mg $Cl \cdot dm^{-3}$). Fluorine traces were for the first time found in the reservoir in 1973. The content of this element began to increase rapidly from 0.02 mg $F \cdot dm^{-3}$ in 1974 to 0.22 mg $F \cdot dm^{-3}$ in 1982. There also occurred an increase in nutrient concentration. At that time the level of nitrates was 0.58 – 1.34 mg $N-NO_3 \cdot dm^{-3}$ (the average for the period being 0.94 mg $N-NO_3 \cdot dm^{-3}$), and the level of phosphates 0.005 – 0.016 mg $P-PO_4 \cdot dm^{-3}$ (the average – 0.009 mg $P-PO_4 \cdot dm^{-3}$). In the years 1975, 1976, 1978 average phosphorus levels during the year were higher than 0.010 mg $P-PO_4 \cdot dm^{-3}$. This level is commonly considered to be the threshold level, above which phytoplankton can develop in large numbers. This was reflected in the development of plants and animals in the reservoir. From 1974 on, there was a steady growth in numbers of the phytoplankton, and there occurred blue-green algal blooms (*Microcystis aeruginosa* Kütz.). After 1970, the level of zooplankton numbers was low, but stable. One of the probable causes impeding the development of zooplankton was blue-green algal blooms, and the copper-treatment ($CuSO_4$) applied by the staff of the Water Supply Department to combat them. The reed-rush zone area remained unchanged, but the area overgrown with submerged vegetation (*Potamogeton crispus* L., *P. lucens* L., *P. perfoliatus* L.) increased. In the benthos, at first a growth, and then, towards the end of that stage, a gradual decrease in numbers of the fauna was observed. The genus *Procladius* accounted for 60% of the numbers of chironomids, whereas among the bivalves *Unio pictorum* L. became dominant, thus succeeding *Anodonta cygnea*. Dominant among the fish in fishery catches was the bream (*Abramis brama*).

4. SPATIAL DISTRIBUTION OF BIOCOENOSES IN THE RESERVOIR

In the period of ecosystem stabilization 6 characteristic zones have been distinguished in the Goczałkowice reservoir (Fig. 1). They differed in the taxonomic composition and numbers of the macrophyte, zoobenthos and zooplankton communities. The periphyton has been presented for selected plants, specific to a given zone, as a percentage of the occurrence of the particular groups. The phytoplankton has only been described for the central zone. Hydrochemical investigations have not revealed any major inter-zonal differences.

The central zone A, with depths from 6 to 10 m and a muddy bottom, is little-varied faunistically. The dominant group in the phytoplankton was Bacillariophyceae (46%), among which *Cyclotella* sp., *Melosira granulata* (Ehr.) Ralfs, *Synedra acus* Kits. and *Asterionella formosa* dominated. The remaining groups occurred in the following per cent proportions: Chlorophyceae 29%, Cyanophyceae 12.4%, Cryptophyceae 10%, Chrysophyceae 2.6%. In zooplankton communities of an average density of 1530 indiv.$\cdot dm^{-3}$ rotifers predominated (1105 indiv.$\cdot dm^{-3}$), the following being particularly numerous: *Polyarthra vulgaris* Carlin, *Keratella cochlearis* Gosse, *Synchaeta pectinata* Ehr. and *Conochilus unicornis* Rouss. In the zoobenthos, bivalves (*Pisidium*) and Ceratopogonidae occurred sporadically, besides chironomids and oligochaetes. A

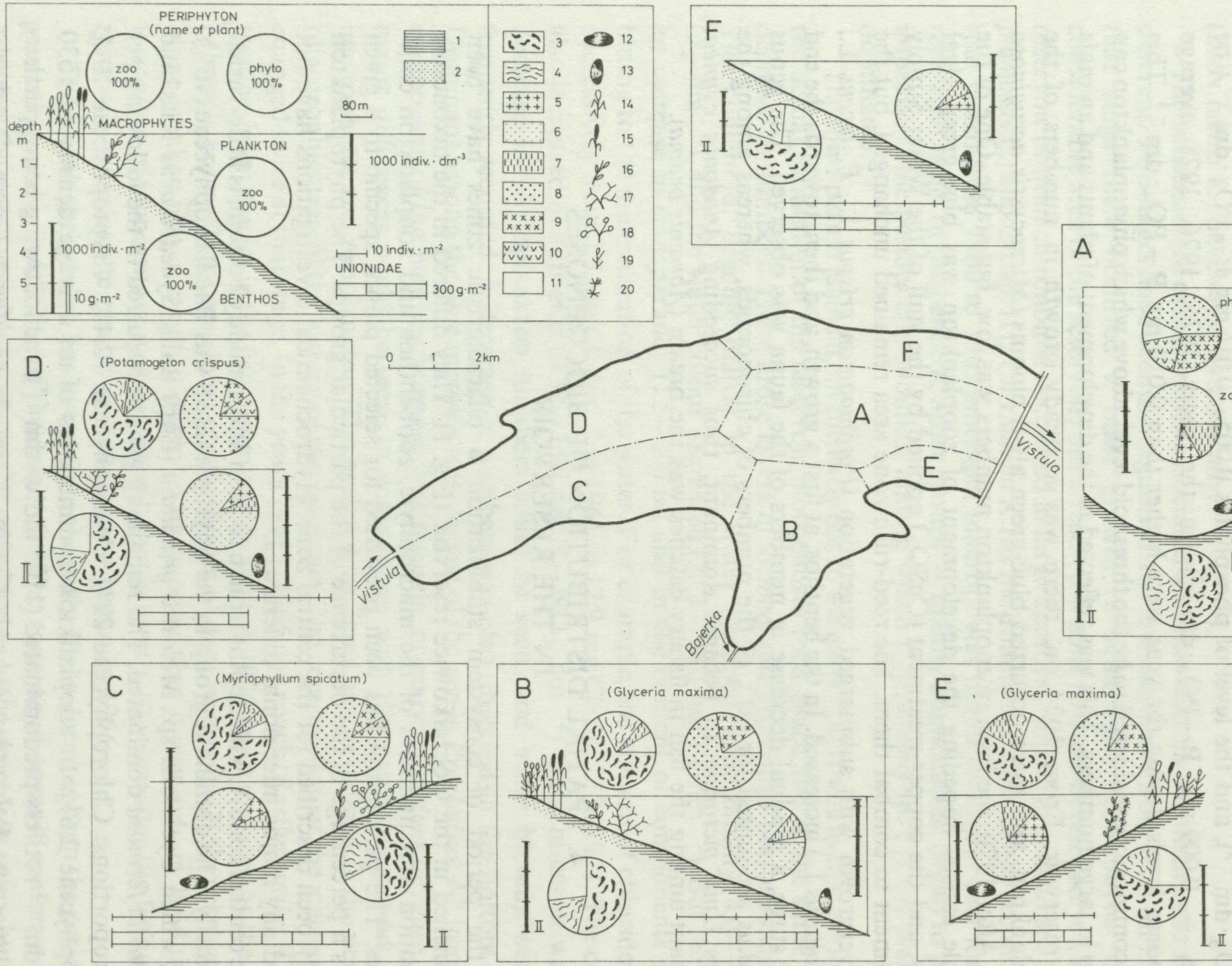

Fig. 1. Spatial distribution and characteristics of the Goczałkowice reservoir biocoenoses

1 – mud, 2 – sand, 3 – Chironomidae, 4 – Oligochaeta, 5 – Protozoa, 6 – Rotatoria, 7 – Crustacea, 8 – Bacillariophyceae, 9 – Chlorophyceae, 10 – Cyanophyceae, 11 – remaining groups, 12 – *Anodonta cygnea*, 13 – *Unio pictorum*, 14 – *Phragmites australis*, 15 – *Typha latifolia*, 16 – *Potamogeton lucens*, 17 – *P. crispus*, 18 – *Myriophyllum spicatum*, 19 – *Glyceria maxima*, 20 – *Batrachium aquatile* (a more detailed discussion of the Figure can be found in the text)

total of 17 chironomid taxa have been identified, the following forms having been most frequently-encountered: *Chironomus* sp. I (? *Ch. plumosus*) and *Procladius* spp., and in the last years also *Microchironomus* sp. (? *M. tener* K.). During the last 10 years the average density was 1432 indiv. · m^{-2} (891 chironomids, 460 oligochaetes).

The river Bajerka bay zone B, with depths of 2 – 4 m and a muddy or mud-sandy bottom, was overgrown with macrophytes, mainly *Glyceria maxima* Hoelm., *Typha latifolia* L., *Potamogeton lucens* and *P. crispus*. Plant periphyton, dwelling on *Glyceria maxima*, consisted primarily of Bacillariophyceae (73.9%) and Chlorophyceae (22.2%), and the plant-attached fauna mainly of Chironomidae and Oligochaeta. The zooplankton, of a medium density of 1610 indiv. · dm^{-3}, consisted almost exclusively of rotifers (1340 indiv. · dm^{-3}). There was a fairly abundant zoobenthos, with an average density of 1494 indiv. · m^{-2} and a clear dominance of the chironomids, primarily *Procladius* sp. and *Cryptochironomus defectus* K. Of the family Unionidae *Unio pictorum* was dominant near the eastern shore, and *Anodonta cygnea* near the western shore.

The south-western, near-shore zone C, with depths of 1 – 3 m and a muddy bottom had the largest surface area overgrown with submerged macrophytes, particularly *Myriophyllum spicatum* L. In the plant periphyton growing on *M. spicatum* Bacillariophyceae constituted 76.7%, Chlorophyceae 16.7% and Cyanophyceae 6.6%. Chironomids represented over 70% of the fauna dwelling on this plant species. There also was a certain proportion of: oligochaetes, cladocerans and trichopterans. The zooplankton, too, appeared to be more abundant than in the remaining zones of the reservoir; its average density was 2092 indiv. · dm^{-3}, rotifers dominating in it – mainly *Euchlanis dilatata* Ehr. In this zone also the most abundant zoobenthos, of an average density of 1783 indiv. · m^{-2}, mainly chironomids (949 indiv. · m^{-2}), was found. Dominant in the family Chironomidae were the following: *Procladius* spp., *Cricotopus sylvestris* (Fabr.), *Psectrocladius* spp. and *Polypedilum* sp. (? *P. nubeculosum* Mg.). The dominant species of the family Unionidae was *Anodonta cygnea*.

The north-western, near-shore zone D, with depths of 1 – 4 m and a muddy bottom, was also profusely overgrown with submerged macrophytes, particularly various species of the genus *Potamogeton*. On *Potamogeton crispus*, a dominant plant, particularly abundant were periphytic Bacillariophyceae (81.2%). The plant-dwelling fauna consisted of 98 invertebrate animals, chironomids being particularly abundant among them. The zooplankton average density was 1912 indiv. · dm^{-3}, including 1560 rotifers. The zoobenthos was less abundant than in zone C, its density being 1460 indiv. · m^{-2} (881 chironomids, 336 oligochaetes). Dominant among representatives of the family Chironomidae were: *Procladius* spp., *Cricotopus* spp., *Dicrotendipes* sp. (*D. nervosus* Staeg.) and *Glyptotendipes* spp., and among those of the family Unionidae – *Unio pictorum*.

The south-eastern, near-shore zone E, with depths of 1 – 4 m and a muddy floor, was grown up with macrophytes – mainly the submerged ones, the overgrown area being much smaller than that in the upper part of the reservoir. Dominant were various species of the *Potamogeton* genus, mainly *P. lucens*. In the plant periphyton clinging to this plant positively dominant were Bacillariophyceae (78.5%), Chlorophyceae and Cyanophyceae representing only small proportions of it (14.4 and 7.1%, respectively). On *Potamogeton lucens* a very diverse animal community dwelt, primarily chironomids (60%), oligochaetes, cladocerans, trichopterans and ephemeropterans. Plankton animals were less abundant; their average numbers were 1358 indiv.$\cdot$dm^{-3}, rotifers predominating. The zoobenthos was poor, too; its average density was 1266 indiv.$\cdot$m^{-2}, mainly Chironomidae (*Procladius* spp., *Cryptochironomus defectus*, *Polypedilum* sp. III (? *P. nubeculosum*) and Tanytarsini). Among representatives of the family Unionidae *Anodonta cygnea* was dominant.

The north-eastern, near-shore zone F, with depths of 1 – 4 m and a sandy bottom was devoid of macrophytes. The average level of zooplankton numbers was 1353 indiv.$\cdot$dm^{-3}, including 1131 rotifers. The zooplankton was poor, on the average 952 indiv.$\cdot$m^{-2}. The dominant representatives of the family Chironomidae were: *Procladius* spp., *Cryptochironomus defectus, Microchironomus* sp. (? *M. tener*) and Tanytarsini. Dominant among representatives of the family Unionidae was *Unio pictorum.*

On the basis of the above-presented results it has been established that in zones C and D, located in the upper part of the reservoir, the highest numbers of plant and animal organisms are found. Zone B, located in the river Bajerka bay, appears to be somewhat poorer in this respect, though fertile, too. The poorest are zones E and F situated in the lower part of the reservoir along its edge. The cause of the higher fertility of the upper part of the reservoir is a continuous input of nutrients and organic matter brought in with the water of the rivers Vistula and Bajerka. It is in this part that the sedimentation and accumulation of these substances are particularly intensive. They are subsequently used by the developing biocoenoses. The low numbers of plants and animals in zone F is mainly the result of waves caused by winds mainly from west, due to which there have arisen large sandy shoals, but there has not formed a belt of higher plants. It is more difficult to indicate the cause of the biocoenotic impoverishment of zone E.

5. BIOCOENOTIC RELATIONSHIPS IN THE RESERVOIR

The factors determining the development of biocoenoses typical of the Goczałkowice reservoir are first of all the morphology (location), the use of the reservoir, climate and the nature of the catchment area (Fig. 2).

The building of the reservoir across the Vistula has brought about rapid changes in the hitherto stable river ecosystem. Large plain areas situated in the Oświęcim-Racibórz Basin have been flooded. At the same time the water current velocity has been reduced. During a year the water in the reservoir is exchanged 2 – 3 times. The reservoir is very large, not very deep and with large shallow areas along the edge. Because the reservoir is used by water-supply systems which always take the same amount of water from it, the circadian or seasonal water-level variations in it are not

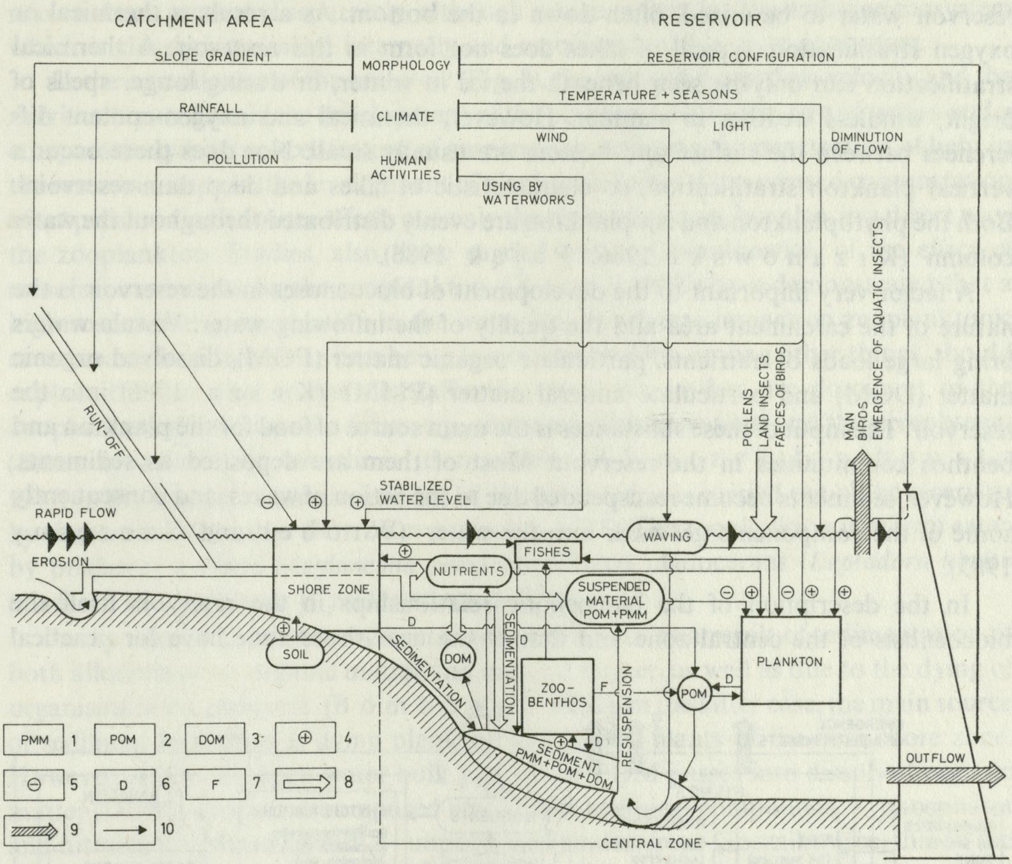

Fig. 2. Pattern of ecological relationships between environmental conditions in the catchment area and in the reservoir, and the particular elements of the biocoenosis in the Goczałkowice reservoir
1 – particulate mineral matter, 2 – particulate organic matter, 3 – dissolved organic matter, 4 – favourable factor, 5 – unfavourable factor, 6 – dead organisms, 7 – faeces, 8 – input, 9 – output, 10 – circulation in reservoir

high. Owing to this, in its edge areas not exposed to frequent drying subject to which are those in power-generation and compensation dam-reservoirs, a broad belt of rushes has developed. This has contributed to the reinforcement of the shores which are now less intensively washed away, and on the other hand it provides a barrier which protects the reservoir against the input of nutrients from surrounding fields.

Another factor influencing the formation of biocoenoses is the climatic conditions, and particularly the force and direction of the wind. In summer, in the Goczałkowice reservoir area westerly winds prevail (A u g u s t y n 1986). The wind direction is parallel to the longer, east-west, axis of the reservoir. In the years 1958 – 1962, the mean annual wind velocity was 2.2 $m \cdot sec.^{-1}$ (P a s t e r n a k 1964), being thus higher than 1 – 2 $m \cdot sec.^{-1}$, as reported by W i ś n i e w s k i and P a c h n i k (1959) to be the minimum wind velocity to start waves. Winds and wind-caused waves cause the reservoir water to be mixed, often down to the bottom. As a result, a thermical or oxygen stratification, typical of lakes does not form in this reservoir. A thermical stratification can only be seen beneath the ice in winter, or during longer spells of bright, windless weather in summer. However, thermical and oxygen-content differences between the surface and bottom are usually small. Nor does there occur a vertical plankton stratification, so characteristic of lakes and deep dam-reservoirs. Both the phytoplankton and zooplankton are evenly distributed throughout the water column (K r z a n o w s k i 1986, P a j ą k 1986).

A factor very important to the development of biocoenoses in the reservoir is the nature of the catchment area and the quality of the inflowing water. Vistula waters bring large loads of nutrients, particulate organic matter (POM), dissolved organic matter (DOM) and particulate mineral matter (PMM) (K a s z a 1986) into the reservoir. The input of these substances is the main source of food for the plankton and benthos communities in the reservoir. Most of them are deposited as sediments. However, sediments become resuspended due to the action of waves, and consequently some of the components get back into the water (W r ó b e l and S z c z ę s n y 1983).

In the description of the biocoenotic relationships in the reservoir itself the biocoenosis of the central zone and that of the near-shore zone have for practical

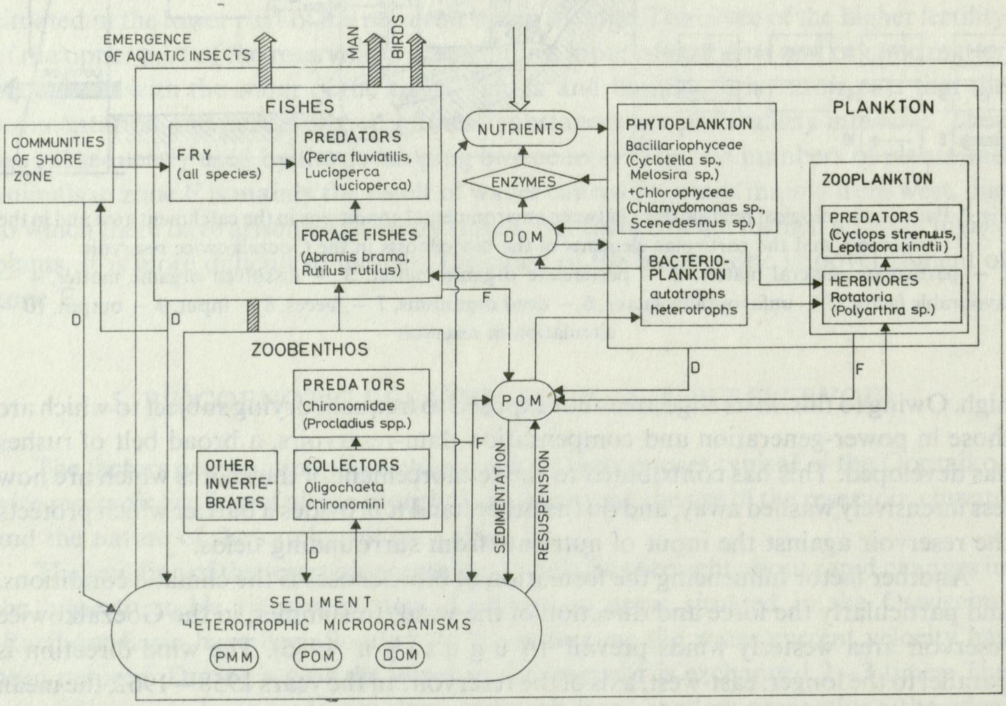

Fig. 3. Pattern of biocoenotic relationships in the central zone of the Goczałkowice reservoir, based on dominant taxa

In brackets species and genera are given; other denotations as for Figure 2 reasons been presented separately, although we are in fact dealing with one ecosystem which is closely interlinked internally and associated with a river ecosystem.

In the central zone of the reservoir (Fig. 3), the reduced water flow velocity and the nutrient inputs favour the development of the plankton. However, strong waves and a comparatively high concentration of suspensions, reducing the penetration of light in the reservoir, impede the development of planktonic forms. An increased concentration of suspensions in the water affects not only the phytoplankton, but also, in a direct way, the zooplankton. Studies, also those carried out at Goczałkowice, of the effect of mineral suspensions on the zooplankton (Żurek 1980) have demonstrated that a high suspension concentration in the water has an adverse impact on zooplanktonic crustaceans, its effect on rotifers being less intensive. This, among other things, should explain the fact that in the Goczałkowice reservoir rotifers are dominant in the zooplankton. Planktivorous fishes, e.g., the roach (*Rutilus rutilus*) and the silver bream (*Blicca bjoerkna* (L.)), also limit its numbers (Klimczyk-Janikowska 1974, 1978). Besides, a certain number of plankton forms is carried out of the reservoir by the outflowing water (Krzanowski 1977). The zooplankton is in turn eaten by predatory rotifers (*Asplanchna priodonta* Gosse), cladocerans (*Leptodora kindtii* (Focke)) and copepods (*Cyclops strenuus* Fisch.).

In the central zone of the reservoir sediments arise as a result of sedimentation of both allochthonous organic matter and mineral matter, as well as due to the dying of organisms in the reservoir (Bombówna 1962). In the latter case, the main source of sediment formation is dying plankton and higher plants of the near-shore zone. However, still in the open water bulk part of the POM passes into dissolved organic matter (DOM) which is decomposed into simple chemical compounds – phosphates and nitrates (G. Mazurkiewicz – unpublished studies from Goczałkowice) due to the action of enzymes (e.g., phosphatase) secreted primarily by the bacterioplankton, and to a lesser extent by the phytoplankton, and even zooplankton. Sediments are decomposed by groups consisting of microorganisms and animals feeding on the detritus. The community of benthonic organisms is used by predatory invertebrates (chironomids – *Procladius* spp. (Krzyżanek 1986)) and fishes, mainly the bream (*Abramis brama*) population, dominant in the reservoir (Starmach 1986).

In the near-shore zone, the pattern of biocoenotic relationships is more complex (Fig. 4). This is due, above all, to a considerable diversification of this zone. In the Goczałkowice reservoir a belt of emergent vegetation, a belt of submerged vegetation and an intermediate zone, the littoriprofundal zone have been distinguished.

In the emergent vegetation belt the dominant element is a closed reed (*Phragmites australis* (Cav.) Trin.), cattail (*Typha latifolia*) and manna-grass (*Glyceria maxima*) belt (Kuflikowski 1986a). These plants take up nutrients from both the soil and sediments. Submerged parts of these plants are grown up with periphytic algae (*Oedogonium, Coleochaete*) (Mrozińska 1986). These supplies are used by the plant-dwelling fauna (Kuflikowski 1986b). Miners, mainly chironomids, feed directly on higher plants, whereas scrapers – gastropods, trichopterans and chironomids (*Cricotopus* sp.) feed on the periphyton. The particulate organic matter (POM)

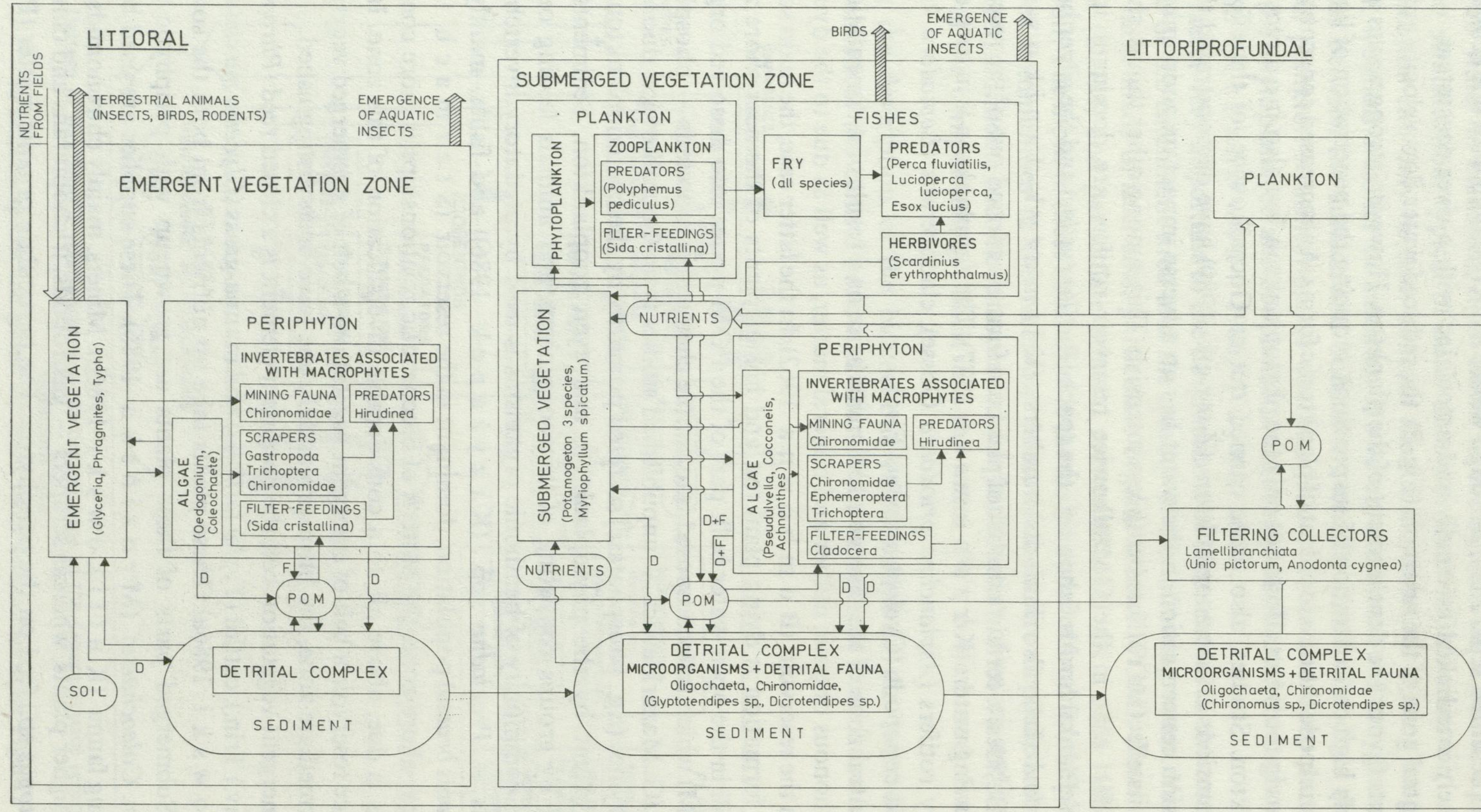

Fig. 4. Pattern of biocoenotic relationships in the near-shore zone of the Goczałkowice reservoir, based on dominant taxa
The plankton of the littoriprofundal zone is similar to that of the central zone. In brackets species and genera are given; other denotations as for Figure 2

produced in this zone is eaten by filter-feeders, mainly by minute crustaceans (cladocerans – *Sida crystallina* O.F.M.). The numbers of this community are controlled by predatory invertebrates, primarily the Hirudinea. Dying higher plants accumulate in the sediments and are decomposed by detritus-feeding fauna and microorganisms. Waves move part of the sediments into deeper areas of the reservoir. Besides aquatic organisms, this zone is also used by terrestrial organisms – insects, birds, rodents. The closed reed-rush zone contains the inflow of nutrients from the banks.

In the submerged vegetation zone dominant are species of the genus *Potamogeton* and *Myriophyllum* (K u f l i k o w s k i 1986a). They take up nutrients from the sediments and directly from the water. Their leaves and stems are overgrown with diatoms (*Pseudouvella, Cocconeis, Achnanthes*) (M r o z i ń s k a 1986). Higher plants and the periphyton are the source of food for the plant-dwelling fauna and herbivorous fishes (the rudd – *Scardinius erythrophthalmus* L. – K l i m c z y k - -J a n i k o w s k a 1975). In this zone a rich plankton develops. In the zooplankton cladoceran filter-feeders (*Sida crystallina*) predominate, while rotifers are less numerous (K r z a n o w s k i 1986). The rich plankton is the food first of all of the fry of all the fish species found in the reservoir. The fry develops and feeds in this zone, and it is in turn eaten by predatory fishes (the perch (*Perca fluviatilis* L.), the pike-perch (*Lucioperca lucioperca* (L.)), the pike (*Esox lucius*)).

In the littoriprofundal zone high plants are already absent. The plankton that develops in the bulk of open water is like that found in the central zone (K r z a- n o w s k i 1986), but the factor that makes this zone different is the abundance of mussels (*Unio pictorum, Anodonta cygnea*) (K r z y ż a n e k 1976, 1986). Though they live in the reservoir bottom, they utilize the suspended particulate organic matter (POM) that forms from the dead plankton of this zone, or is moved into it from neighbouring zones.

The above pattern applies to average conditions prevailing in the reservoir in a stabilized state. There are, however, a number of factors which disturb these regularities.

A factor that temporarily yet significantly affects the development of the reservoir biocoenoses is the hydrological conditions, notably the lowering of the water level and floods. Every several years the water level in the reservoir must be lowered considerably to make it possible to do repair-maintenance work on the dam, or it drops due to droughts. At low water levels large areas of the reservoir bottom are uncovered. Water level lowering occurred several times in the history of the reservoir, viz. in 1965, 1972, 1978, 1979. It is a factor that causes considerable changes in the whole reservoir ecosystem. Water level lowering caused the following: uncovering of the most productive shallow areas, reduction in zooplankton numbers, dying of large numbers of macrophytes and benthonic animals of the near-shore zone, particularly mussels. In the following years considerable changes could be seen in the taxonomic composition and numbers of the plant and animal communities. The water level lowering in 1965, for example, was followed by the extinction of *Elodea canadensis* and *Myriophyllum* *verticulatum* L., but there appeared *Rorippa amphibia* (L.) Bess. a species new to the reservoir. In other years the vegetation occupied the same places as in the year preceding the lowering of the water level. In 1972, the lowering of the water level caused a change of dominance among mussels, from *Anodonta* to *Unio*. In the successive years following a water level lowering the density of the phytoplankton was much lower. The same was true of the zooplankton, but in the latter reduced numbers were accompanied by changes in the taxonomic composition. The proportion of protozoans dropped, but that of rotifers increased, this group representing almost 90% of the whole zooplankton. A growth in numbers of the bream in the reservoir took place only in 1965, i.e., after the first water level lowering. This may have been one of the causes of the decline of the roach population, competing with the bream.

A much frequent phenomenon is a rising of the water level due to a freshet. The flood waters that flow into the reservoir rapidly and are colder and of a higher turbidity, due to a high content of silty materials, affect mainly the zooplankton, reducing their numbers by 40 – 70%. However, the effects of a flood do not last long. Each flood period was followed by a gradual growth in numbers of the zooplankton caused by the increased fertility of the reservoir as a result of the new input of organic substances and nutrients. The effect of a flood is also noticeable in the communities of benthonic animals, especially when a freshet comes after a long low-water period in the reservoir.

6. CONCLUSIONS FOR PRACTICE

Thirty years ago when hydrological investigations were started in the catchment area of the future reservoir, and then in the reservoir itself it was assumed that a scientific basis would be obtained for a rational use of the reservoir by water supply systems, and guidelines to be followed in the building of similar reservoirs. The cause of the deterioration of the quality of the water to be used in water supply system is the excessive growth of the plankton, and the phytoplankton in particular. The water that passes through the treatment Station contains abundant plankton which is deposited on the filters, causing their clogging. It then dies causing a deterioration of the taste and smell of the water. The cost of the treatment of such a water, to bring it to the standard required, is very high. The mass development of the plankton is caused by excessive concentrations of nutrients, particularly phosphates and nitrates in the reservoir water.

As in the newly-filled reservoir the terrestrial vegetation and the primary soils that had been flooded were being decomposed, the reservoir water at that time contained large amounts of organic matter which brought about a mass growth of the phytoplankton and numerous water blooms, caused by diatoms and dinoflagellates. This situation lasted in the reservoir about 6 years (1955 – 1961).

The period of a dynamic growth of biocoenoses, also of the phytoplankton, during the first years following the filling is typical of dam reservoirs, and cannot in principle be avoided. It seems, however, that it could be shortened by appropriately preparing the floor of a future reservoir (stripping off the fertile soil, carefully removing the vegetation, etc.).

After that period the reservoir biocoenoses got stabilized, at the same. time becoming poorer numerically. The phytoplankton was reduced in numbers and for many years (1962–1974) remained at the same level. One of the probable causes of the poor phytoplankton growth in that period was a mass development in the near-shore zone of higher plants, with the periphyton clinging to them, which take up and store considerable amounts of nutrients. However, a continuous input of nutrients to the reservoir from the catchment area mainly with the Vistula waters (296–495 tons N-mineral · year^{-1}, 3.8–7.8 tons P-tot · year^{-1}), to a lesser extent with the Bajerka waters (14.5–23.0 tons N–mineral · year^{-1}, 0.8–1.6 tons P-tot. · year^{-1}), the Knajka waters (14.7 tons N-mineral · year^{-1}, 1.82 tons P-tot. · year^{-1}), with precipitation (36–46 tons N-mineral · year^{-1}, 0.5–0.8 tons P-tot. · year^{-1}), and with the run-off from the banks (9.2 tons N-mineral · year^{-1}, 1.1 tons P-tot. · year^{-1}) raises their concentration in the water (data of the years 1973–1975, Kasza 1977, Kasza and Winohradnik 1986). Initially, this rise in their concentration was not conspicuous, because the self-regulating inner mechanisms of the reservoir were strong enough to reduce it. After some time the rising nutrient concentration caused a breakdown of the self-regulation system of the reservoir. Since 1975, a growth in numbers of the phytoplankton, and temporary blooms of blue-green algae *Microcystis aeruginosa* have again been observed. Copper treatment ($CuSO_4$) of the water prevents the development of phytoplankton only for a short time, and is at the same time dangerous, because it may cause contamination of the drinking water with copper. There would have been even a greater mass growth of algae if there had not been a simultaneous dynamic growth of higher submerged plants. By taking up large amounts of nutrients they have contributed to the maintaining of the quality of the reservoir water at the level of class I according to the Polish Standards for water quality. The continuous input of nutrients with the waters of the Vistula is unavoidable, and an increasing anthropopressure (agriculture, industry, tourism) in the catchment area aggravates the situation yet further. At the present stage attention should be focussed primarily on ways of eliminating phosphorus compounds which are responsible for the mass growth of the phytoplankton.

There are many methods for phosphorus elimination from the cycle in an aquatic environment. The most recommendable of them for the conditions of the Goczałkowice reservoir seems to be the method based on the use of an initial (preliminary) reservoir. In the initial reservoir phosphorus is eliminated by being assimilated by bacteria and phytoplankton which are then sedimented in the same initial reservoir. Phosphorus is also eliminated by sedimentation along with mineral suspension. This method has been developed for the Goczałkowice reservoir by Dr. H. Kasza (unpublished data). Under the conditions of the Goczałkowice reservoir the building of an initial reservoir would be comparatively cheap. The Vistula flows into the reservoir between two dykes that extend far into it and stick out about 2 m above the water surface. By constructing a barrier across the channel between the dykes a small reservoir could be created to be used for a preliminary purification of the inflowing river water. By extending the barier to the left and right river banks three separate preliminary-purification reservoirs could be obtained with a surface area of 168 ha. In this way about 50% of the phosphorus contained in the Vistula water could be eliminated. A detailed technical description can be found in H. Kasza's paper (unpublished).

The idea of initial reservoirs has already been put forward by ichthyologists (W a j d o w i c z 1970), but the aim was to create favourable conditions for fish spawn. When building these initial reservoirs one must take into account the protection of higher plants, both the rushes and the submerged vegetation which play an important role in the removing of nutrients from the reservoir water. Though the reeds and rushes keep back a large proportion of the nutrients input from the surrounding fields, some edge areas of the reservoir are devoid of this vegetation (zone F), and arable fields reach the reservoir shores. To stop the inflow of nutrients from the surrounding fields, a protective forest belt should be created on the reservoir shores hitherto unforested.

In the Goczałkowice reservoir planned fishery management has been used since the beginning. Planned fishery catches have been carried out since 1957. Fish, as the last trophic link, store in their bodies considerable amounts of phosphorus and nitrogen. Fish catching, apart from supplying large amounts of proteins, will contribute to an irreversible removal of large quantities of nutrients from the reservoir. On the basis of the experience gained concerning the Goczałkowice reservoir, planned fishery management should be recommended also for other water-supply reservoirs.

7. CONCLUSIONS AND DISCUSSION

As there is no generally-applicable classification of dam reservoirs, the description of such a reservoir must contain many characteristics to provide its "visiting card". In the Goczałkowice reservoir, which arose on a river in the temperate zone, the thermical conditions clearly vary with the seasons, but differences in the vertical thermic stratification are small. In respect of its surface area the reservoir belongs to medium-size water bodies, but as regards its depth it is included among shallow water bodies (V o r o p a e v and V e n d r o v 1979). On account of its shape it should be included among lake-like (expanded) water bodies (Ž a d i n 1961), but as regards the water-exchange rate – among limnetic water bodies exchanging water less than 5 times a year (S t a r m a c h 1958). On account of the purpose it serves, this reservoir belongs to municipal-industrial (water-supply) water bodies (C y b e r s k i 1968).

It is, however, more difficult to include biological features in classification categories of this type. During its existence a dam reservoir undergoes a fast evolution. The leaching of the primary soils and decomposition of the flooded terrestrial vegetation, and then an incessant input of suspensions and chemical substances with the water cause changes in the physico-chemical properties of the water and sediments in a reservoir, and, consequently, in the biological parameters. Biological features must therefore be considered in a temporal aspect.

In the history of the Goczałkowice reservoir four periods have been distinguished. The first period was the period of destruction of terrestrial and river communities, in the second period there developed biocoenoses specific to the reservoir, during the third period the reservoir attained a stabilized state, but its fertility was low, and in the fourth period the fertility of the reservoir increased gradually. The first period was very short, because the filling of the reservoir was completed within several months. The filling of large reservoirs takes much longer, the filling of the Rybinskoe reservoir took 7 years (K u z i n 1972). It must be stressed, however, that the period of destruction of terrestrial and river communities is only distinguished by some investigators (Š a l a r' 1971). In a general classification based on the synthesis of many studies V o r o p a e v and V e n d r o v (1979) have distinguished only three phases in the development of reservoirs on lowland rivers. The first phase is characteristic of a high trophic state, the second of a lowered trophic state ("oligotrophication"), and the third phase of a new rise in the trophic state. These three phases could be clearly seen in the Goczałkowice reservoir. At present, the reservoir is in the third phase of development. The length of the periods (phases) varies from reservoir to reservoir, and in certain cases their sequence may be disturbed. Likewise, the development of the particular elements of biocoenoses may vary between reservoirs.

As in the case of the Goczałkowice reservoir, a dynamic development of plankton communities in the first years following the filling has been reported for many reservoirs (N e j v e s t n o v a - Ž a d i n a 1941, R y l o v 1941, R o l l et al. 1959, S t e p a n e k 1960). There were some differences in the course of succession of the zooplankton communities. In most reservoirs crustaceans usually predominated for a longer time. In the Goczałkowice reservoir crustaceans were very abundant only in the first year after the filling, and were then replaced by rotifers which continued to be the dominant group during the remaining years. The growth, in numbers and biomass, of the bottom fauna was in the Goczałkowice reservoir similar to that reported for the large reservoirs of the Volga and Dnieper cascades, and for small, pond-like water bodies (I o f f e 1961, M o r d u c h a j - B o l t o v s k o j 1961a, 1961b, Z e l i n k a 1962, L j a c h o v 1971, J a n k o v i č 1972, M o r d u c h a j - B o l t o v s k o j et al. 1972, H r u š k a 1973). The filling was characteristically followed by a mass development of fauna, lasting several years, with *Chironomus plumosus* as the dominant species; then the proportions of other groups increased, mainly of oligochaetes and molluscs, in the case of the latter, in some reservoirs *Dreissena polymorpha* Pall. grew in numbers, and in others the family Unionidae, and the period of dynamic growth was finally followed by a decrease in numbers and biomass. Differences usually concerned the duration of the particular periods and dominance in the groups.

A comparison of the formation of the fish communities in the Goczałkowice reservoir with the same process in the Rybinskoe reservoir, best known so far (K u z i n 1972), shows a far reaching analogy. In both of these reservoirs three ichthyofauna development stages have been distinguished. The first stage was very similar in both of them. The roach and the pike appeared in large numbers. In the Goczałkowice reservoir this period lasted 5 years, in the Rybinskoe 7 years. This must no doubt have been related to differences in the duration of the filling of the reservoirs. In two remaining stages, however, certain differences were noticed. In the Goczałkowice reservoir the roach was dominant for 4 years, and only in the tenth year did the bream become the dominant fish. In the Rybinskoe reservoir it was already at the second stage that a fish community developed in which the dominant fish was the bream with pike-perch and burbot as associate species. This community persisted for 10 years and was then replaced by the roach and *Abramis ballerus* (L.).

In the Goczałkowice reservoir, from its very beginning, an extremely important element of the biocoenosis was the macrophytes which occupied 6–8% of its surface area. In trough reservoirs of southern Poland, e.g., the Rożnów reservoir, macrophytes occurred sporadically (Loster 1976). In only a few reservoirs is a larger area overgrown with macrophytes – Kievskoe 32%, Ivankovskoe 16.7%; in most cases the per cent macrophyte-cover is low, even in lowland, lake-like reservoirs – Kujbyševskoe 0.1%, Volgogradskoe 0.9%, Rybinskoe 1.3%, Gorkovskoe 1.4% (Voropaev and Vendrov 1979).

Since there is a broad belt of littoral vegetation, and the depth is relatively small, the zonal classification of the Goczałkowice reservoir differs from the commonly applied scheme (Benson 1982). In most reservoirs the following zones are distinguished: riverine zone where water mixing is good, and transport of sediments and POM dominates over deposition, while production takes place primarily on the reservoir floor, or at the expense of allochthonous matter; transition zone with an intensified deposition of sediments and POM and phytoplankton production, and a diminished role of allochthonous matter; lacustrine zone where there is a thermical and chemical stratification, whereas production, which takes place mainly in the bulk of open water, is autochthonous in nature. In the Goczałkowice reservoir, these zones are less conspicuous, but there is a clear difference between the central zone, which corresponds to the euphotic pelagic zone in the open water, and the near-shore zone which corresponds to the littoral and sublittoral zones (Mikulski 1974).

Absent in the Goczałkowice reservoir is also the true thermical and chemical stratification. Due to this, the pattern of ecological relationships in the Goczałkowice reservoir differs from, e.g., that in the deep trough-like Slapy reservoir (Straškraba 1982) where there are no higher plants. This pattern is most similar to the situation found in the Rybinskoe reservoir (Kuzin 1972, Sorokin 1972), although in this case, too, some difference can be seen. In the Goczałkowice reservoir ecosystem the near-shore zone, overgrown with higher plants, plays a much greater role. In the Rybinskoe reservoir the production of macrophytes is 18 times smaller than that of the phytoplankton, while in the Goczałkowice reservoir – taking into account the area covered with macrophytes – only 4 times. For this reason, in the Goczałkowice reservoir a considerable part of nutrients and POM input is accumulated in this zone.

8. SUMMARY

Four main periods have been distinguished in the history of the reservoir.

In the first period, in 1955, as a result of the filling of the reservoir, the terrestrial and river communities were destroyed, and there appeared the first aquatic organisms of the reservoir.

In the second period, from the end of filling of the reservoir in 1955 to the early 60s, the actual formation of biocoenoses took place. This period comprised two stages. The first stage, which began and ended in 1955, lasted 2 months. It has been referred to as the stage of initial formation of biocoenoses. During the second stage, which began in 1956, the formation took place of biocoenoses specific to the reservoir.

During the third period, from the early 60s to the early 70s, the biocoenoses attained a stabilized state and at the same time became impoverished numerically.

In the fourth period, from the early 70s to date, there has been a gradual increase in the fertility of the reservoir.

During the stabilized-state period 6 zones formed, characteristic of the reservoir (Fig. 1): central zone, river Bajerka bay zone, south-western near-shore zone, south-eastern near-shore zone, and north-eastern near-shore zone. The richest in plant and animal organisms were zones C and D located in the upper part of the reservoir, the poorest were zones E and F located in the lower, near-dam part of the reservoir.

The factors that had a significant influence on the formation of biocoenoses typical of the reservoir were, first of all, the morphology, use of the reservoir, climate and nature of the catchment area (Fig. 2).

In the analysis of the biocoenotic relationships in the reservoir the biocoenosis of the central zone (Fig. 3) and that of the near-shore zone have been presented separately (Fig. 4). The near-shore zone biocoenosis was more diversified.

Factors have also been demonstrated which temporarily affect the development of reservoir biocoenoses. They include hydrological conditions, especially water-level lowering, and floods.

The Goczałkowice reservoir is a water-supply reservoir. The quality of its water depends on the presence of plant and animal organisms, particularly on phytoplankton communities. Temporary outbreaks of algae, the so-called blooms, were recorded, particularly blue-green algal (*Microcystis aeruginosa*) blooms after 1974. The factor that caused them to occur was the constant inflow of Vistula water rich in nutrients, especially phosphorus. It has been found that of many methods for phosphorus elimination most recommendable for the conditions of the Goczałkowice reservoir is the method for biological elimination of phosphorus, used in the so-called initial reservoirs, or preliminary-purification reservoirs. The method has been worked out in detail by Dr. H. Kasza (unpublished data). Another way to impede the eutrophication process would be to create a protective forest belt on the banks so far unforested, and apply rational fishery management.

9. POLISH SUMMARY

Wyróżniono 4 główne okresy w historii zbiornika.

W pierwszym okresie, w 1955 r., pod wpływem napełniania nastąpiło niszczenie zbiorowisk lądowych i rzecznych, następnie pojawienie się pierwszych organizmów wodnych zbiornika.

W drugim okresie, trwającym od momentu napełnienia zbiornika w 1955 r. do początku lat sześćdziesiątych nastąpiło formowanie się biocenoz. Okres ten przebiegał w 2 etapach. Pierwszy w 1955 r. został nazwany etapem wstępnego formowania się biocenoz i trwał ok. 2 miesięcy. Drugi etap rozpoczął się w 1956 r. i charakteryzował się tworzeniem właściwych biocenoz zbiornika.

W trzecim okresie, trwającym od początku lat sześćdziesiątych do początku lat siedemdziesiątych nastąpiło ustabilizowanie się biocenoz przy ich równoczesnym zubożeniu ilościowym.

W czwartym, trwającym od początku lat siedemdziesiątych do chwili obecnej, następuje stopniowy wzrost żyzności zbiornika.

W okresie stabilizacji wytworzyło się 6 charakterystycznych dla zbiornika stref (rys. 1): strefa centralna, strefa zatoki rzeki Bajerki, strefa przybrzeżna południowo-zachodnia, strefa przybrzeżna południowo-

wschodnia oraz strefa przybrzeżna północno-wschodnia. Najbardziej zasobne w organizmy roślinne i zwierzęce były strefy C i D leżące w górnej części zbiornika, najuboższe strefy E i F położone w dolnej, przyzaporowej części zbiornika.

Czynnikami, które w sposób istotny kształtowały typowe dla zbiornika biocenozy, były przede wszystkim morfologia, użytkowanie zbiornika, klimat oraz charakter zlewni (rys. 2).

Rozpatrując zależności biocenotyczne w zbiorniku oddzielnie przedstawiono biocenozę strefy centralnej (rys. 3) oraz biocenozę strefy przybrzeżnej (rys. 4). Biocenoza strefy przybrzeżnej była bardziej zróżnicowana.

Wykazano, że istnieją także czynniki, które tylko okresowo wpływają na rozwój biocenoz zbiornikowych. Są to warunki hydrologiczne, a zwłaszcza obniżenie poziomu zbiornika oraz powodzie.

Zbiornik Goczałkowicki jest zbiornikiem wodociągowym. Jakość wody zależy od rozwijających się organizmów roślinnych i zwierzęcych, szczególnie od zbiorowisk fitoplanktonowych. Okresowo notowano masowe rozwoje glonów, tzw. zakwity, zwłaszcza od 1974 r. zakwity sinicowe (*Microcystis aeruginosa*). Czynnikiem, który je powodował, był stały dopływ bogatych w pierwiastki biofilne — zwłaszcza w fosfor — wód rzeki Wisły. Stwierdzono, że wśród wielu metod eliminacji fosforu w warunkach zbiornika Goczałkowickiego godna polecenia jest metoda biologicznego usuwania fosforu, stosowana w tzw. przedzbiornikach lub zbiornikach wstępnego oczyszczania. Metoda ta została szczegółowo opracowana przez dr H. Kaszę (dane nie publikowane). Innym sposobem mogącym łagodzić proces eutrofizacji byłoby stworzenie leśnego pasa ochronnego na niezalesionych brzegach oraz prowadzenie racjonalnej gospodarki rybackiej.

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