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Effects of flood on the functioning of the Dobczyce reservoir ecosystem

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Abstract

The effects of two summer floods, in 1997 and 2001 on phytoplankton, zooplankton and fish in the Dobczyce reservoir are presented. Shifts in phytoplankton distribution (from hypolimnion into the whole water column) and species composition (domination of diatoms after the flood) were observed. High water flow eliminated large species of cladocerans and copepods (the most effective filtrators) and favoured development of rotifers. Both, the total zooplankton biomass and chlorophyll *a* concentration after the flood dropped considerably. In the case of fish, the observed changes in their distribution and decrease in concentration were attributed to their behaviour. During the flood, fish were avoiding open water also during the night, but two weeks following the flood they returned to their usual migratory behaviour. The Dobczyce reservoir ecosystem showed great regeneration abilities to recover after the flood.

Introduction

In temperate climate floods during spring and summer are quite a common phenomenon. However, due to poor predictability of their occurrence there is as yet little known about their effects on the functioning of dam reservoir ecosystems. Floods cause a sudden dramatical change in all environmental parameters such as water flow, thermic and oxygen conditions, light penetration, nutrient gradients, etc. The matter transported from the whole catchment area together with large amounts of dissolved and mineral nutrient compounds (mainly nitrates and phosphates) are stored in a lower part of the river or in a dam reservoir, which are zones of intensive sedimentation and deposition. All these changes influence the organisms inhabiting the reservoir ecosystem, from microorganisms to fish. The direct mechanistic effects of the flood wave are destruction of habitats as well as damages to the organisms themselves. The indirect effects are more difficult to observe and last much longer than the flood itself. The aim of this work was to study the changes caused by flood to fish and phyto- and zooplankton communities in a dam reservoir, and to determine the ability of the ecosystem to recover.

Materials and methods

Study area

The submontane Dobczyce reservoir (49° 52′ N, 20° 02′ E) is located at the 60-th km of the Raba river (total length 137.4 km, a right bank tributary of the Vistula), about 30 km south of Cracow. As a result of the landscape configuration the reservoir consists of three distinct parts (Fig. 1). Almost the whole water mass is divided between the down reservoir sub-basin, the Dobczyce Basin (DB) – 39% and the upper reservoir sub-basin, the Myślenice Basin (MB) – 56%, with the Wolnica Bay (WB) occupying the remaining 5%. The WB is the most littoral part of the reservoir as this habitat covers over 50% of its area. The littoral of the MB occupies considerably smaller relative portion of the bottom area, but it is always the largest part of the total reservoir littoral zone. In the DB the size of this habitat is small both, in relative and in absolute units.

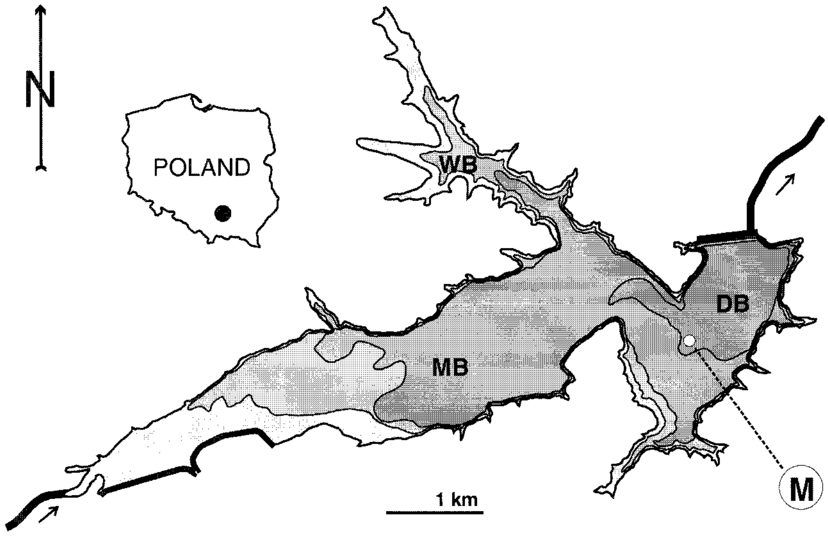

Figure 1. Basin morphology of the Dobczyce reservoir: MB – Myślenice Basin, DB – Dobczyce Basin, WB – Wolnica Bay, M – monitoring station.

At the normal damming level (altitude 269.9 m) the total reservoir area is 928 ha, volume 99.2 × 10^6 m^3, mean depth 11 m and maximal depth 27 m. The water level may range from 256.7 to 272.6 m altitude, which corresponds to change in area from 335 to 1055 ha and in capacity from 14.5 to 125 × 10^6 m^3. The catchment basin area amounts to 763 km^2 and is inhabited by a population of 90–100 thousand people. In the land use predominate arable fields and permanent crops (pastures, meadows and orchards), which constitute 40.5% and 10.5% accordingly, and the remaining 39% of the total area is covered by natural vegetation (deciduous and mixed forest) (Amirowicz, 1998). The main inflow of the reservoir is the Raba river, which supplies 88.6% of water. Based on an average level of inflow (10 m^3s^{-1}) the water in the basin is exchanged about 3 times a year.

Environmental parameters

Dobczyce reservoir is a water body having characteristic eutrophic type changes in the flora and fauna and in the trophic relations. The watershed of the Raba river with its biological and anthropogenic processes contributes the most to the eutrophication process of Dobczyce reservoir. From the beginning of reservoir exploitation in 1986 until the year of 2001 the following concentrations of nutrients were recorded as the average values from the water column in the pelagial of DB: 0.1–0.436 mg PO_4 dm^{-3}, 0.04–1.85 mg N-NH_4 dm^{-3} and 0.32–2.83 mg N-NO_3 dm^{-3} (Bednarz, 2000; Mazurkiewicz-Boroń, 2000). The reservoir is of dimictic type, stratifying between May and September (Amirowicz, 2000). Secchi disc ranges from 0.3 m in spring to 5.7 m in autumn.

Phytoplankton

The samples for algal and chemical analyses were collected from the monitoring station (M in Fig. 1) situated in the central region of the Dobczyce Basin. This is the deepest part of the Dobczyce reservoir, the area where the system is most stable and closest to lake ecosystem. The samples were taken every other week in 1997 and every month in 2001. The samples for taxonomic and quantitative analyses of algae were preserved with Lugol's solution and concentrated by sedimentation (Starmach, 1955). Phytoplankton biomass was calculated for biovolume by comparing algae to their geometrical shapes (Rott, 1981). The physicochemical parameters were analysed according to APHA (1992). Chlorophyll *a* was measured by hot ethanol method (Nusch, 1980).

Zooplankton

Zooplankton was taken from the same monitoring station and at the same time intervals as phytoplankton. Samples for taxonomic and quantitative analyses of zooplankton were collected using a 5-l sampler from the following depths: 1, 3, 6, 10, 15 and 20 m. The total volume sampled at each depth was 30 l.

The samples were concentrated with plankton net (# 50 μm) and treated with a 4% formalin solution, after which sub-samples were analyzed under microscope (magnification 10–20×) in 0.5 ml chambers. Dry weight was assessed according to the published regression formulae and equations (Cummins et al., 1969; Dumont et al., 1975; Botrell et al., 1976; Ruttner–Kolisko, 1977; Persson & Ekbohm, 1980).

Fish

Currently in the Dobczyce reservoir occurs a fish community, which consists of 21 species. Among them dominate bream (*Abramis brama* L.), perch (*Perca fluviatilis* L.), roach (*Rutilus rutilus* L.), bleak (*Alburnus alburnus* L.) and pike-perch (*Stizostedion lucioperca* L.) (Amirowicz, 1997).

Hydroacoustical monitoring of fish abundance and distribution was performed only in the season of 2001. Surveys were done on 24 May, 2 August (immediately after the passing of the flood wave) and on 14 August. The Biosonics 101 dual beam echosounder with frequency 420 kHz, narrow beam 6° and wide beam 15° was used. The main echosounder parameters were as follow: pulse length $\tau = 0.4$ ms, TS threshold $= -70$ dB, repetition rate $= 5$ pulses per sec, single target criteria 0.8 τ to 1.5 τ. To estimate fish density the echocounting method was applied with TVG function set to 40 log R. Our version of the echosounder did not allow for the simultaneous 40 log R and 20 log R measurements, therefore the echointegration was not performed because of time limitation. Survey was done during a day and at night along the same zigzag transects covering all three basins of the reservoir. Due to narrow beam and small sampling volume at shallow depths, only parts of the reservoir with depths larger than 3 m were investigated. Acoustical data were analyzed using Biosonics Echo Signal Processing (ESP) Software.

Results

Summer floods caused by heavy rainfalls are not unusual phenomenon in the temperate reservoirs. However it seems that recently they became more frequent. In the Dobczyce reservoir, which was filled up in 1986, the first high water with the flow exceeding 300 m^3s^{-1} (the critical value, above which we say about 'flood conditions') had place in 1987 (max flow reached 451 m^3s^{-1}), then the next floods were observed in 1996 (529 m^3s^{-1}), in 1997 (884 m^3s^{-1}) and in 2001 (484 m^3s^{-1}). On the last two occasions, in July 1997 and July 2001 (Fig. 2) the main environmental parameters and living organisms were measured before and after the passing of flood wave. Since samples were taken in two weeks and one month intervals respectively, it was not possible to register situation immediately after the flood, rather the indirect consequences of the flood wave on planktonic communities, or phases of their gradual recovery were described.

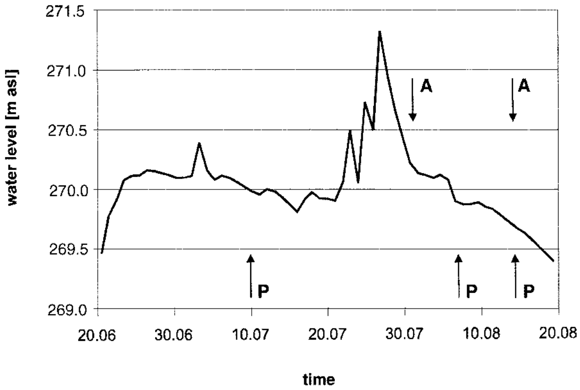

Figure 2. Changes of reservoir damming level in 2001, P – phyto- and zooplankton samples:10 July, 7 and 14 August, A – acoustical survey: 2 and 13 August.

On 9 July 1997 a peak flow rate exceeded annual mean discharge of 10 m^3s^{-1} about 90 times and on 27 July 2001 about 50 times (Fig. 3). These extreme conditions must have had an effect upon the organisms inhabiting the reservoir.

Environmental parameters

Water inflow from the watershed caused biotic and abiotic destabilization of the reservoir, which before the flood showed features of summer stagnation. There was an increase in temperature and dissolved oxygen in the hypolymnion (Fig. 4) An inflow of water rich in suspended particulate matter caused the lowering of water transparency from 2.5 m to below 1 m, and an increase of mineral content in a deep hypolymnion. Phytoplankton bloom rich before the flood was inhibited. Several days following the inflow of the flood wave there was an increase of nutrients in the reservoir.

Phytoplankton

In both years, flood had clear effects on phytoplankton concentrations, distribution and composition (Fig. 5).

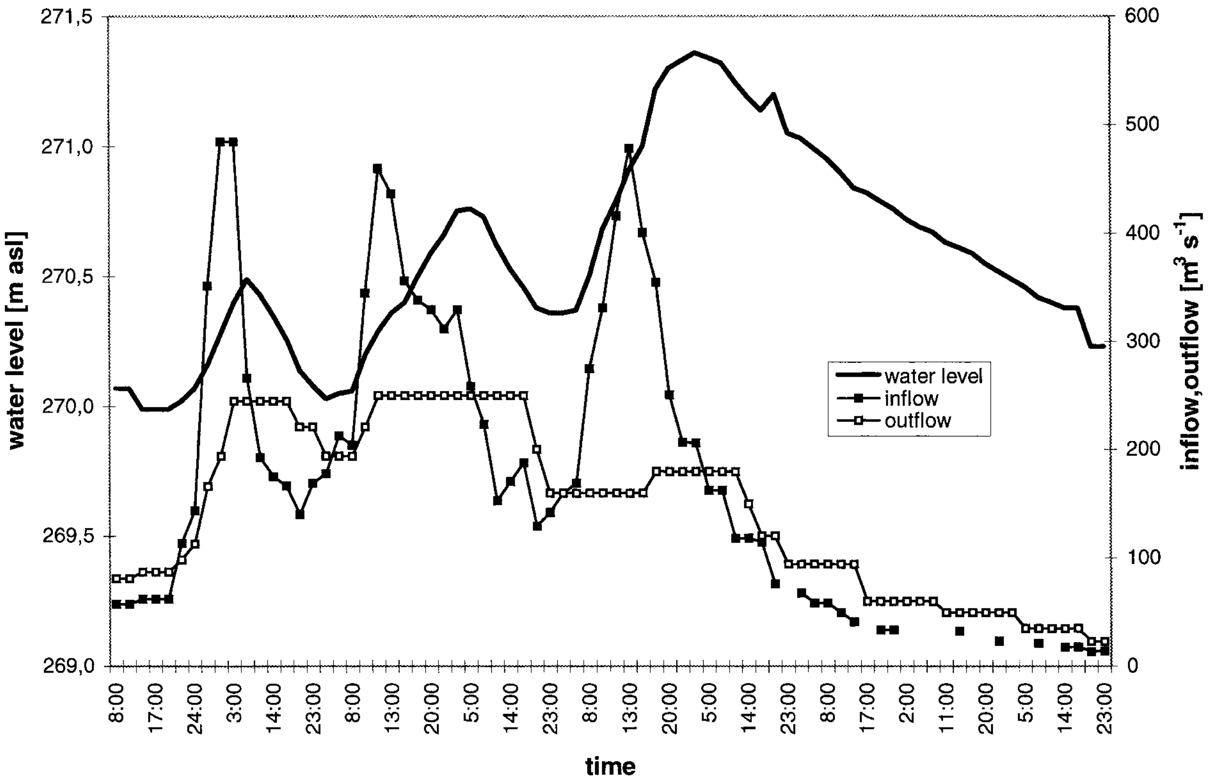

Figure 3. Management of water in the Dobczyce reservoir during the flood in 2001.

In 1997 before the flood, centric diatoms and green algae dominated the phytoplankton. Maximum chlorophyll *a* concentration was 16.58 $\mu g\ l^{-1}$. Algae developed mainly in the epilimnion. A week after the inflow of the flood wave only the centric diatoms were present in the phytoplankton. Two weeks following the dominance of diatoms, they were replaced by green algae. The peak domination of *Chlorophyta* occurred a month after the flood wave.

In 2001 before the flood, the phytoplankton was dominated by chrysophytes (*Dinobryon* sp., and *Uroglena americana*). Development of algae was very intensive only in the epilimnion – max. chl *a* 44.99 $\mu g\ l^{-1}$. After the flood chl *a* was reduced (max. 11.84 $\mu g\ l^{-1}$) and algae were present in the whole water column. Many cryptophytes and colonial diatoms were observed in the phytoplankton communities (*Asterionella formosa*, *Aulacoseira granulata*).

Zooplankton

The floods observed in 1997 and 2001 had clear effect on the concentration and species composition of zooplankton. The mineral suspension carried into reservoir by flood first of all eliminated the large species of cladocerans known to be the most effective filtrators and also some species of copepods. In case of rotifers it was the opposite, the flood wave caused an intensive growth of these species, which became the dominant group of zooplankton. Their share in the total zooplankton abundance accounted to 85.2% in 1997 and 91.8% in 2001

After the flood, such species as *Keratella cochlearis* f. *tecta* (Gosse), *Brachionus angularis* (Gosse) and *Pompholyx sulcata* (Hudson) appeared in the reservoir. They were absent before the flood. Usually these species are related to the conditions of increased trophic level or high concentrations of suspended matter. Observed reduction of density and dry weight in zooplankton (except of rotifers which showed intensive growth) could be the result of several processes, such as washing out, decrease in reproduction, death due to mechanical damage, and sinking as consequence of mineral suspension deposited upon the plankton organisms. However, the zooplankton community was capable of rapid regeneration during less than a few weeks.

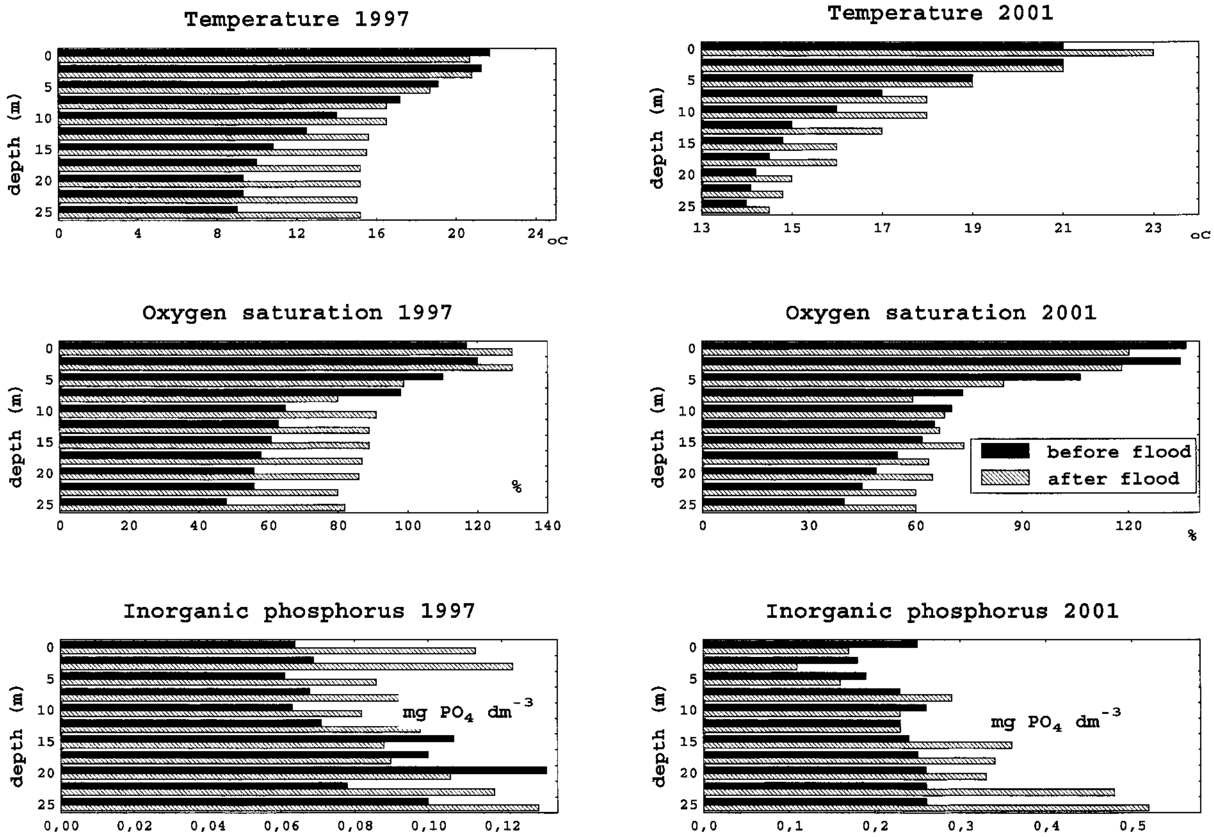

Figure 4. Depth profiles of temperature, dissolved oxygen, inorganic phosphorus of the pelagic zone before flood, and after flood, measured in 1997 on 1 and 15 July, and in 2001 on 10 July and 7 August.

In 1997 in the pre-flood period all the zooplankton groups reached similar density values. A week after the flood wave an intensive growth of rotifers such as *Keratella cochlearis* (Gosse) and *Keratella cochlearis* f. *tecta* (Gosse) was observed. In all the groups of zooplankton a decrease in density was noted two weeks after the high water wave. The most significant changes in the zooplankton dry weight took place two weeks after the passage of the main flood wave, which damaged zooplankton assemblages (Fig. 6). The similar dry weight of cladocerans in spite of decrease in their densities was caused by high concentrations of *Leptodora Kindti* after the flood. In 2001, a week after the flood wave, the same dominant species composition like in 1997 was observed. Also intensive development of *Polyarthra vulgaris* (Carlin) took place. The density of rotifers increased intensively, while the dry weight of large zooplankton species decreased (Fig. 6).

Fish

The effect of flood on fish was clearly demonstrated by their redistribution in space, and noticeably smaller fish concentrations in the offshore part of the reservoir, where hydroacoustics was applied (Fig. 7). Decrease was the most dramatic in the MB, which extends along the river valley, and was much smaller in the other two basins, shallow WB and deep, situated down reservoir DB.

The difference between the day and night estimates of fish abundance can be considered as a measure of fish horizontal migrations from the littoral during the day to open water at night. From Fig. 8 it can be seen that these migrations were much less extensive during the flood (2 August 2001) than before and after it. It is also clear that the change in fish behaviour was most pronounced in the MB, most affected by flood and having the largest part of the total reservoir littoral zone. Normally fishes in the reservoir are concentrated near the tributary mounts on shallows and

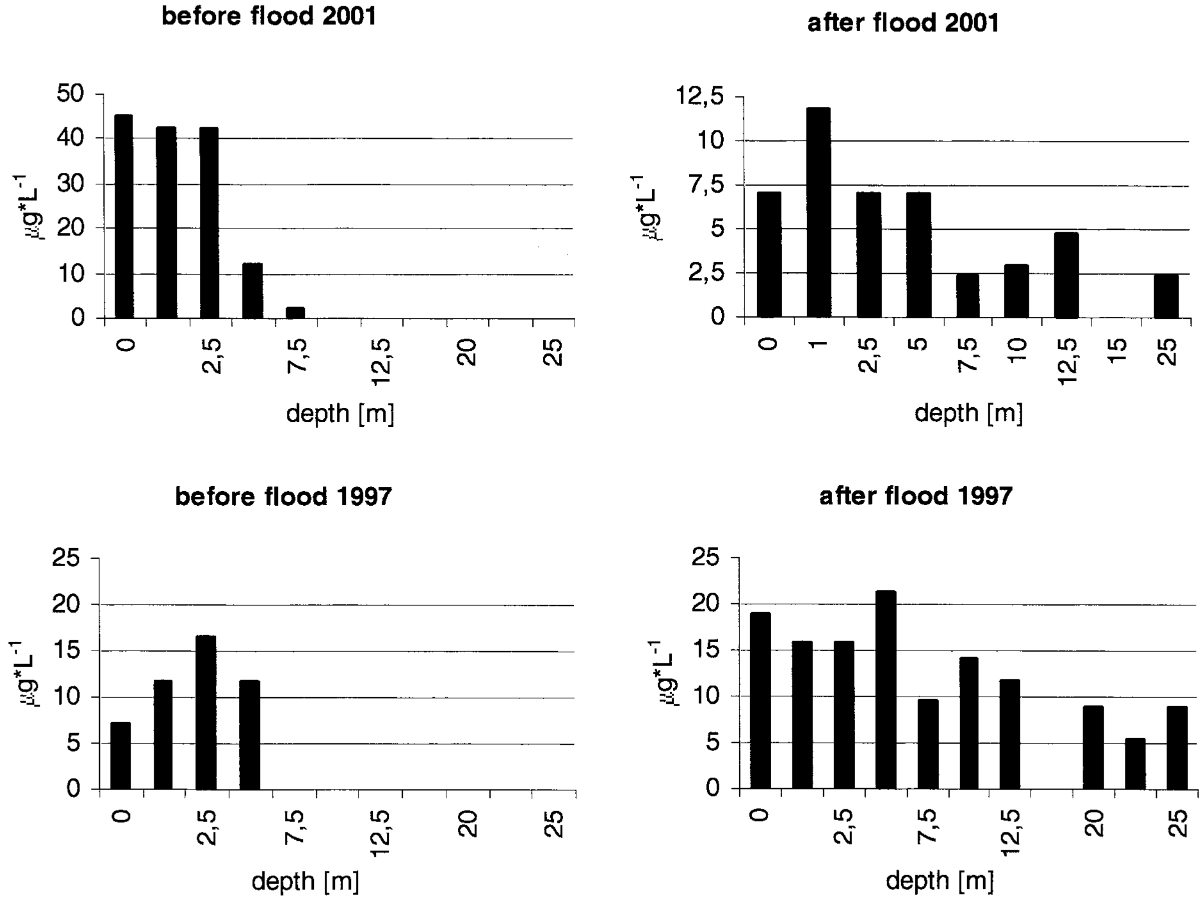

Figure 5. Chlorophyll *a* concentrations before and after the flood, measured in 1997 on 1 and 15 July, and in 2001 on 10 July and 7 August.

in the littoral, and only at night they come out to open water to feed on the abundant resources offshore (Fernando & Holčik, 1991). It seems that during the flood fish were much less migrating to open water at night, probably because there was no their usual food there. The zooplankton communities have been destroyed or washed out. Only nearly two weeks after the flood the situation in the quietest WB has started to recover back to normal, while in the MB the migrations were still very weak (Fig. 8).

The applied −70 dB treshold accounts for adult fish as well as young of the year (Y0Y) fish and may be also for some invertebrates (Świerzowski et al., 2000). One can discuss if it is appropriate to take into consideration very small fish, abundance of which may fluctuate within a considerable range. Therefore data for two different thresholds, −70 and −50 dB are compared (Table 1). Although in the case of higher threshold (larger fish) we do not observe decrease in fish densities immediately after the flood (probably it is obscured by seasonal changes in fish abundance), the comparison of fish density in August in a year with no flood and on two dates in August 2001, clearly shows the decrease of fish densities in open water due to high water wave. Two weeks after the flood on August 14, 2001, fish concentrations were nearly the

Table 1. Fish densities in the Dobczyce reservoir in a year with and without flood, estimated acoustically with different thresholds for the minimal fish length (TS value in dB)

Date of survey	Fish density at night [ind 1000/m^3] Threshold = −70 dB	Threshold = −50 dB
24 May 2001	38.3	0.36
2 August 2001	27.3	1.98
14 August 2001	32.2	4.91
18 april 2002	4.46	0.26
1 August 2002	37.5	5.03

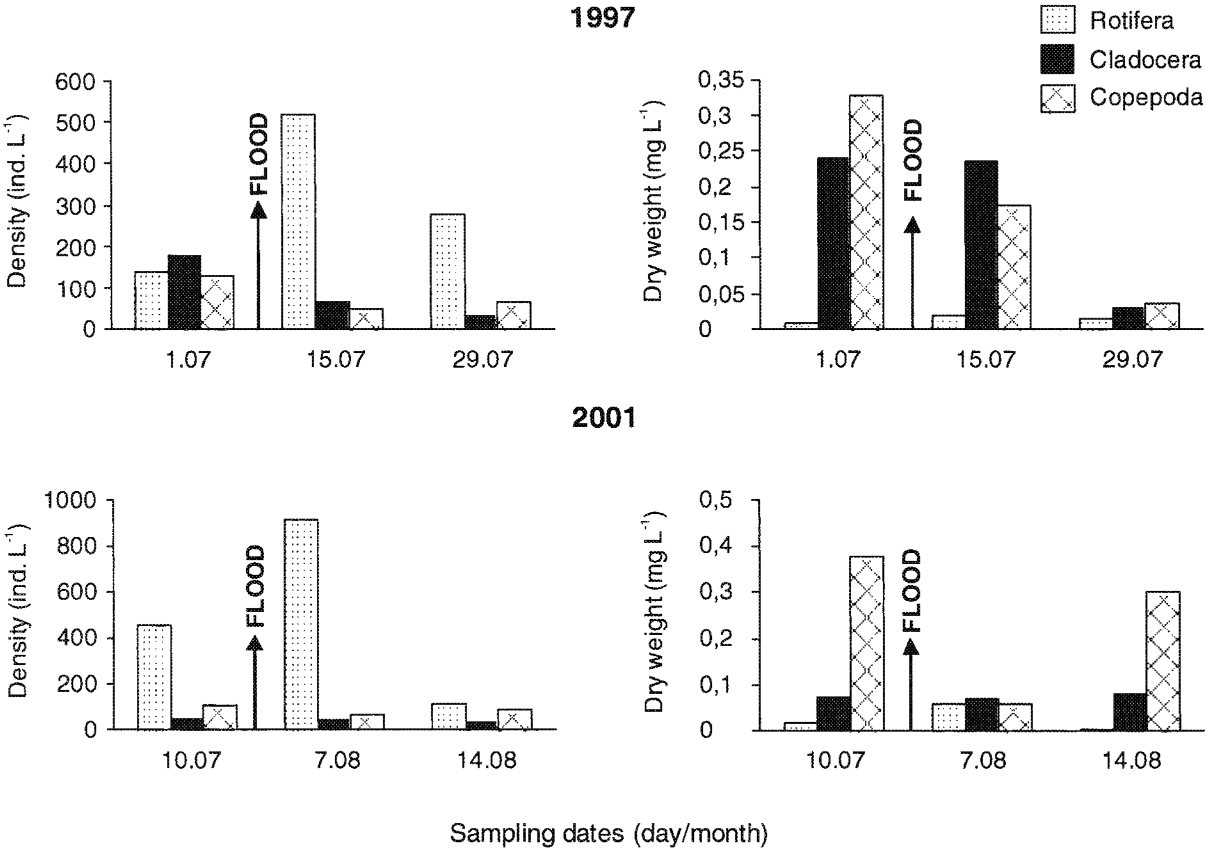

Figure 6. Density and dry weight of zooplankton before and after the flood.

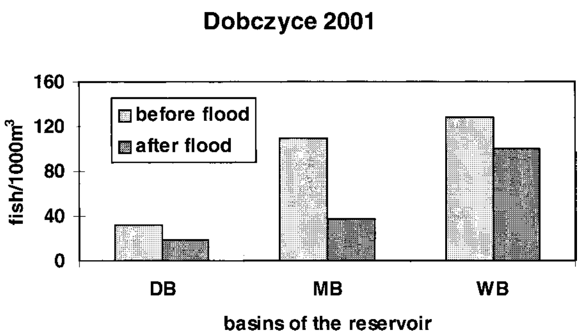

Figure 7. Fish density in three basins of the Dobczyce reservoir before (24 May 2001) and after the bflood (2 August 2001).

same as in August 2002, a year later, when there was no flood. This means that observed decrease in estimated abundance during the flood was not the real one, but it was the result of fish behaviour, namely avoiding pelagic waters during the flood. Obviously the effect of flood was much stronger in case of smaller fish.

Discussion

Effects of flood on phytoplankton concentration, composition and distribution were observed in both years, 1997 and 2001. Generally before the flood algae developed only in the epilimnion, which is normal during the summer stratification, while after the flood they were present in the whole water column. We did not observe exactly the same pattern of changes in the species composition in both years. Different species of algae were present in the reservoir and obviously different environmental features were responsible for their development. However, during both years, after the flood the same group – diatoms – dominated the phytoplankton. Species belonging to this group are tolerant of low temperature and mixing, but need high concentration of nutrients. Therefore domination of diatoms was probably related to intensive mixing of water caused by flood. The inflowing flood waters led to environmental conditions similar to the spring ones. After the flood in 1997 centric diatoms

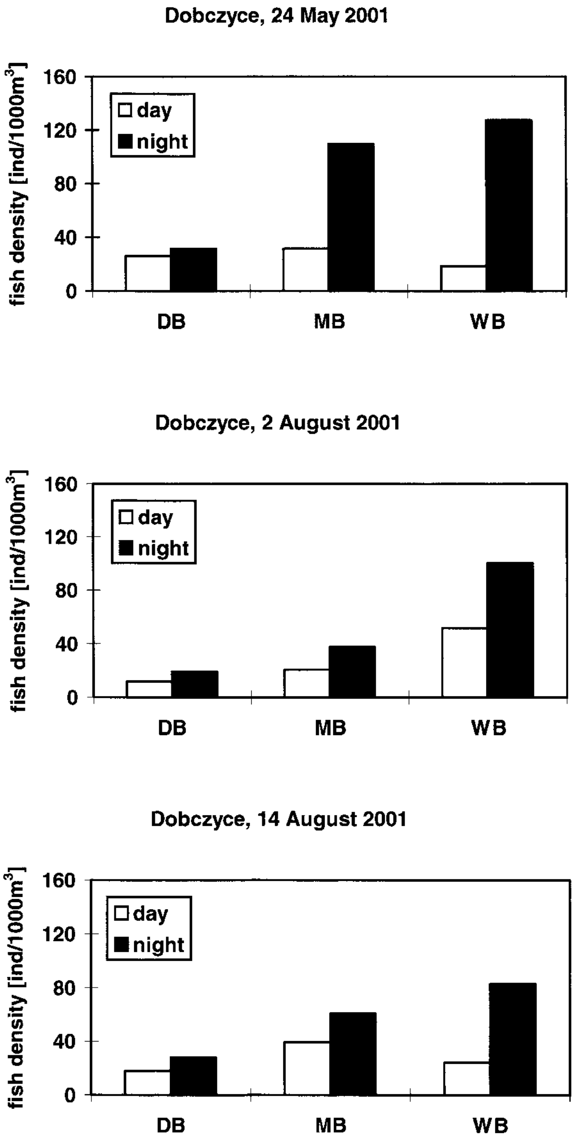

Figure 8. Day/night acoustical estimates of fish density in three basins of the Dobczyce reservoir: MB – Myślenice Basin, DB – Dobczyce Basin, WB – Wolnica Bay.

became a dominant group of phytoplankton. After the flood in 2001 different species of diatoms dominated, mainly colonial diatoms such as *Asterionella formosa* and *Aulacoseira granulata.* A stable water column is not preferred for existence of these diatom species because their colonies are massive and they are unable to stay in stable conditions. *Aulacoseira* is a species characteristic of well-mixed, moderately eutrophic water bodies with relatively high Si concentrations and was frequently observed during the mixing periods (Kilham & Kilham, 1975).

The other observed effect of flood was a change in the behaviour of Cyanoprokaryotes. Usually in the Dobczyce reservoir, during the autumn (September, October) mainly species such as *Microcystis aeruginos*a (Wilk-Woźniak, 1996) or *Woronichinia naegeliana* (Wilk-Woźniak & Mazurkiewicz-Boroń, 2002) are in bloom, however in years with flood no Cyanoprokaryota bloom occurred in the autumn

The flood had also clear effect on zooplankton, both the concentration and composition. Small organisms such as rotifers were dominating in the period after the flood wave, while large boded species were either washed-out or dead. Temperature, water turbidity, concentration of mineral suspension are important factors decisive for the behavior patterns of plankton animals. A decrease in water temperature reduces the rate of zooplankton reproduction. Also amount of mineral suspension contributes to mechanical damage to the filtration apparatus and the extinction of large animals (Pociecha & Wilk-Woźiak, 2000). By contrast the suspension has stimulating effect upon small species such as rotifers. Similar result was received by Żurek (1980, 1982) in research reservoirs: Goczałkowice & Rożnów and Pociecha & Wilk-Woźiak (2000) in Dobczyce reservoir. The changes in zooplankton structure and behavior are caused not only by prey and predator relations, but also by hydrological changes in a dam reservoir ecosystem during the flood. Plankton animals concentrate at different depths in the water column before and after the flood because they are transported to different locations by water currents. This changes their usual distribution, which results from search for the right compromise between two conflicting demands: to maximize feeding and to avoid predators (Gliwicz, 1986).

The observed decrease in fish concentrations could result from different processes, such as dilution in larger water volume, washing out of some fish, or a change of fish behaviour. If the decrease in fish concentration was mainly due to dilution, than we should expect the largest effect in the shallowest WB, because the change in the water volume in the WB was the largest. But this was not the case. On the contrary, in the WB the effect of flood was the least pronounced (Fig. 7). If washing out of fish was the most important effect, than we would not observe an increase in the fish density just a few days later. This mechanism was stronger for small than for the large fish but was not the most significant either. So, it can be concluded that the most important factor leading to the apparent decrease in fish concentrations was the fish behaviour, i.e. avoiding open water, where acoustical methods are applied. In the central MB, which is along the river valley and where the effects of flood were the strongest, the difference in fish densities as observed before and after the flood was the most dramatic.

Although floods affect strongly all the environmental parameters in the reservoir, they do not destroy water ecosystems. The presence of restored plankton communities occurring within a short time following a flood demonstrates the great regenerating abilities of the reservoir ecosystems.

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