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CHANGES IN LAKE ECOSYSTEMS CONNECTED WITH THE POWER-GENERATING INDUSTRY (THE OUTLINE OF PROBLEM); THE KONIN LAKES (POLAND) AS THE STUDY SITES

ABSTRACT: The changes in a water body caused by power- and heat-generating plant vary considerably in their nature, being highly related to a site-specific conditions and the mode of the plant functioning. A new thermo-mictic regime arises with a different cycle and seasonality which in turn induces the new pattern of niches and the species composition of biota. The changes also occur connected with the pollution (increase of salinity and hardness, accumulation of contaminants) and eutrophication as well as secondary changes brought about by the fishery practices in heated waters, and by the selective effect of power plants on the mortality and survival of organisms pulled into the cooling system.

KEY WORDS: Lakes, heated waters, pollution, fish impact.

1. THERMAL POLLUTION – SCALE OF IMPACT AND SCALE OF IDENTIFICATION

There is a particularly rich literature on the effects of the discharge of heated waters from the power plants upon the aquatic ecosystems (streams, rivers, dam reservoirs, natural lakes) functioning in a "once-through cooling systems". It deals with the impact on the physical conditions on an ecosystem, its functioning, productivity (primary and secondary production and decomposition), cycling of matter (accumulation, re-mineralization), and on the distribution and dynamics of various communities, on their growth and maturing, on mortality in particular, and on population structure and dynamics. There are a lot of data particularly on the ichthyofauna, both native and that introduced into this type of "heated habitats". Many attempts have been made to model these effects in order to predict them (Majewski and Miller 1979). Numerous monitoring systems have been applied (Majewski and Miller 1979) in which fish have frequently been used as bio-indicators. Many investigations are aimed at determining the allowable temperatures of heated effluents and the required discharging conditions to be used in the respective regulations (Zaric 1978). Finally, a permanent subject of researches carried out in open-water cooling systems is the forced mortality of organisms (fish in particular), increased by their being pulled into the stream of water taken for cooling, and passed through the cooling system (the so-called entrainment mortality) (Schubel and Many 1978).

There have been a number of successful studies summing up the knowledge of the effects of power stations on aquatic ecosystems (Flejs 1970, Jarošenko 1973, Majewski and Miller 1979, Capuzzo 1980, Stolbunov 1985), including those in the Polish literature (e.g., Turoboyski 1968, Horoszewicz 1969, Praszkiewicz 1974, Stangenberg 1975, Kajak 1976, Soszka and Soszka 1976, Horoszewicz and Backiel 1979, Sosnowska 1984a, 1984b). On the basis of the extensive literature these authors are trying to indicate the overall regularities connected with the effects of the discharge of heated waters. They conclude, however, that the recorded effects, particularly with regard to the functioning of a whole ecosystem, vary considerably (being often contradictory) even with the same thermal load and in the same ecosystem type. Hence, it is generally difficult to speak about an overall regularity, e.g., as in the case of the effect of water acidification (acid rains), or eutrophication. In each recipient ecosystem the heated-water discharge is superimposed on a different pattern of natural conditions, where it intensifies the action of some of them and impedes that of others. It often acts together with other factors (which cannot be separated in situ) associated with the functioning of a particular power and heat-generating plant. It is generally believed that the effects of the functioning of a power- and heat-generating plant connected with an open-water system are highly site-specific and cannot be transferred from one system to another.

As it will be discussed below, the high variation and complexity of the discharge effects are not always solely and directly connected with a constant input of higher quantities of heat to an aquatic environment. Therefore the discharge of the hot water into the aquatic systems which is often called "thermal pollution" does not seem to be a proper term.

In the sections that follow some of the causes of the variation in an aquatic ecosystem, evoked by the discharge of heated waters are discussed, as well as the other side-effects of the functioning of a power plant. The description is restricted to the ecosystems of natural lakes and dam reservoirs of the temperate zone, since the conclusions drawn from these habitats will be used for the interpretation of the results from the researches carried on the Konin lakes.

2. THE THERMAL HABITAT AND THE THERMAL RESISTANCE OF ORGANISMS. TEMPERATURE AS A SELECTION FACTOR

A continuous (i.e., throughout the year), and as a rule point-type discharge of additional quantities of heat into a water body, the thermal regime of which is determined by the climatic conditions of the temperate zone, constitutes an important factor that changes the physical environment. In general, the changes are of the type of: disturbances in the seasonal thermal cycle and frequent absence of the ice cover, longer spells of high temperatures that normally occur only in summer (their earlier occurrence in spring and later disappearance in autumn), faster temperature rise in late winter and early spring, and a gentler temperature fall in late autumn, and finally, spatial differentiating, sometimes very acute, of the environment into zones that are permanently more heated or less heated, their range varying considerably. The latter phenomenon, i.e., thermal zonality of the habitat, is an entirely new phenomenon, that is unknown to the biocoenose of a natural lake.

There is an immense literature on the effect of temperature, especially that of the range of 25 – 35°C, on the different life functions of organisms (growth, respiration, production, development). Many studies in this field have been concerned with thermal pollution. For most hydrobionts (algae, macrophytes, invertebrates) constituting the main biota of the temperate lakes the above temperature range is not lethal in the literal sense, i.e., it does not cause mass mortality, particularly if a sufficiently long acclimation period is allowed. For instance, D o n z e (1979) has found the following zooplankton mortality levels in water at various cooling stages: at 30°C – 0%, at 34°C – 50 – 80%, but at 40°C – 50 – 100%, depending on the taxonomic group. This is connected with the fact that, firstly, most of these organisms belong to eurythermic species of a rather high thermal tolerance (they usually withstand the diurnal migration from warm to cold layers). Secondly, in natural conditions temperatures of the range of 28 – 32°C, often higher, occur, e.g., in the shallow waters of the lake littoral, or even on the lake surface, although their duration is shorter there than in a lake that receives heated waters, and so is their spatial range. Therefore, the hydrobionts of natural aquatic ecosystems experience these temperature but only occasionally. However, as indicated, e.g., by I v l e v a's (1981) studies, at the temperature range of 25 – 30°C the metabolic rate of invertebrates is lower than at lower temperatures. For example, at the above range of temperatures the Q_{10} for Crustacea is 2.08, while at 20 – 25°C – 2.12, and at 0 – 5°C – 2.40.

T r u b e c k a j a (1981) has demonstrated that in cladocerans acclimated for two generations the consumption rate at various food concentrations is lower at 28°C than at 20°C. Thus, above 25°C the rate of increase of the consumption is reduced.

In other studies (S e m e n č e n k o et al. 1983) the term has been introduced of the so-called temperature of maximum metabolic activity, i.e., one at which the highest rate of physiological processes is recorded. It varies between species. For typically cold stenothermic species, e.g., *Limnocalanus macrurus* Sars. it is lower (~20°C), while for other crustaceans it is higher. For instance, for *Simocephalus vetulus* O. F. Müller it is

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36°C, and for *Sida cristallina* O. F. Müller and *Bosmina longirostris* O. F. Müller ~ 28°C. The same authors also studied the temperature at which 50% mortality occurs: for *L. macrurus* it was 26°C, for the remaining species – 28–36°C. However, the above studies apply to situations where organisms had a sufficiently long period of acclimation to high temperatures; they do not concern the so-called acute responses associated with a thermal shock. As it is known, these responses are usually manifested by a rapid rise in the metabolic rate followed by the cessation of physiological functions.

The above knowledge on the thermal requirements of organisms (especially fish) has provided the basis for introducing appropriate restrictions in the use of surface waters for cooling (H o r o s z e w i c z 1969, M ü l l e r 1970, B a c k i e l et al. 1971). In all countries, Poland included (G a d k o w s k i 1971), the temperature of the discharged waters should be checked from the point of view of the fishery management and water quality in relation to natural temperature variations. Water temperature in the discharge canal at the power station should not be higher than 35°C, the maximal summer (June-August) water temperature in the receiving lake – not higher than 28.5°C, and during other seasons – not higher than 10°C more than the "natural" temperature of water. The temperature range is regulated by water flow and by a system of canals with an average water cooling rate of 1°C per km. In unfavourable atmospheric conditions in summer a higher degree of lake heating is allowed, no higher, however, than 30°C and only for several days. The same applies to other countries, e.g., Holland (P o l i c y ... 1982) and the Soviet Union (P i d g a i k o 1971). However, for the interpretation of the changes taking place in the cooling reservoir some important factors must be taken into account, i.e., those indicated by the above investigations of the thermal tolerance of organisms and by provoked changes in the seasonal cycle of the environment.

Critical temperatures and the rise in the rate of physiological processes with rising temperatures may greatly differ between the communities of the food chain. This causes differences in the response to seasonal variations in the thermal regime of a heated lake. There may occur a displacement and desynchronization of the growth rate and thereby of the food requirements of the consumers (e.g., fish), and the growth rate of other organisms constituting their food (P r a s z k i e w i c z 1974). Production rate usually rises more slowly than the rate of organic matter decomposition, whereas the overall production growth in each food-chain link is not reflected in a biomass increase (G o l t e r m a n 1976).

In temperate lakes, a significant change in the seasonality of the thermal cycle, and the thermal zonation represent a strong selection factor that also determines the succession of the species. It could be manifested by complete elimination of some species, by an earlier retreat or migration to the cold zones of the "cold-liking" species (which are usually stenothermic) or by immigration or introduction the eurythermic species. Among the latter ones, the selection favours the forms most adaptive, i.e., with the highest rate of reproduction and population growth at higher temperature. Within the phytoplankton the "heat" factor reduces the abundance of sensitive species but it does not eliminate them totally, which results in a higher diversity of this community

(C a i r n s 1971). One other sign is the shift from dicyclic (twice a year) reproduction to monocyclic (once a year), but spread over a long time, which is observed in some copepods (L a r i m o r e and T r a n q u i l i 1981). G a l k o v s k a j a and M o r o z o v (1981) who investigated the thermic adaptability of cladocerans have found that the time needed by these organisms to acquire a new thermal resistance lasts only two generations. These authors assume that the temperature as a selection factor, controls only the survival of the phenotype, but it does not cause a genetical reconstruction of the population.

In other words, the thermal regime, constantly disturbed, constitutes a new factor of natural selection of species and their forms. It would, however, be wrong to conclude that all the changes in a cooling water body can be explained on the basis of thermal regime variation and thermic requirements of organisms.

Efforts to predict the changes in heated-water bodies solely on the basis of the thermic requirements of organisms and the effect of temperature have failed to give consistent results (G o l t e r m a n 1976). In high-temperature zones or periods, commonly observed are: intensification, decline and lack of directional changes in species diversity, numbers or biomass of communities and populations, as well as in the chemical composition of the water and productivity of a lake (F l e j s 1970, B u t o r i n et al. 1971, P i d g a i k o 1971, W h i t e h o u s e 1971, J a r o š e n k o 1973, A s t r a u s k a s and R a c z i u n a s 1975, G o r o b y i 1977, S a p p o and F l e j s 1977, T a r a s e n k o 1977, L a r i m o r e and T r a n q u i l i 1981). The impact of heating is often detectable only in the winter-spring and the autumn periods (M o r g a n and S t r o s s 1969, V i n o g r a d s k a j a 1971a, 1971b, N o t o n 1975, T a r a s e n k o 1977, E l o r a n t a and S a l m i n e n 1984). An activation of bacterial processes and organic matter decomposition is fairly common in the highest-temperature zones (temperature $\geqslant 27°C$) (P i d g a i k o 1971, S t o l b u n o v 1985). Hence these waters are often said to have a higher capability for self-purification (S t a n g e n b e r g 1975), although there are many opposite opinions which indicate a tendency to form blooms in high-temperature zones. For example, P i d g a i k o et al. (1972) have found that an average heating of the waters of the Kurakovskoe reservoir by 3.2°C causes an increase in primary production but a fall in secondary production, hence part of the former remains unused. A similar phenomenon, i.e., destabilization of the production and decomposition processes and plant biomass accumulation, has been found by V a j n s t a j n et al. (1973) in the Ivanskoe reservoir.

A frequently-recorded phenomenon is an exuberant growth of higher plants, e.g., *Nuphar luteum* L. (L a r i m o r e and T r a n q u i l i 1981) in shallow and heated parts of a water body and in the effluent canals, or development of new species (*Najas marina* L., *Vallisneria*). This also applies to epiphytic vegetation (K l a r e r and Hi c k m a n 1975). For this reason, herbicides are often used (J a r o š e n k o 1973, G a l l u p and H i c k m a n 1975, G a l l u p et al. 1975).

In his survey of data from the Soviet studies in dam reservoirs S t o l b u n o v (1985) states that a coherent effect can only be seen in zones of particularly intensive heating, that is, when the temperature is $\sim 30°C$ then primary production clearly decreases; in other cases the effect is unpredictable and dependent jointly on the thermal load, climatic region and limnological character of the heated-water body.

3. THE NEW MICTIC REGIME – THE MAIN EFFECT OF HEATED WATERS

The discharge of heated waters into a lake is not only a continual input of increased quantities of heat (above the natural level dependent on the climatic conditions), but also a forced water movement, which in turn changes the pattern of currents, mixing and turbulency in a water body. The range and nature of these changes depend on the previous mictic conditions and lake depth as well as on the way of the discharge and amount of heated water discharged. They will be different in the case when the heated waters are released freely into the surface waters of the lake than when the discharge is combined with waterfall, i.e., with a simultaneous vigorous water mixing at the discharge site.

A change in the mictic regime of a lake, forced by the discharge of heated waters is no doubt a factor of a wider scale of influence than the temperature itself. It brings about significant spatial changes, horizontal and vertical, that is, affects the water movement rate within the whole lake, as well as the rate of vertical mixing.

There is a considerable diversity of the thermo-mictic systems in lakes receiving heated waters, dependent on their depth and way of water discharge. A point or band (release over a longer shoreline segment) discharge of water can be accompanied by both a deeper mixing (often down to the bottom) and a complete lack of thermal stratification or otherwise by an intensified stratification if only the surface waters are heated. The range of the forced vertical and horizontal mixing may vary considerably.

The consequences of changes in the spatial system combined with the thermal stratification are significant for the functioning of a water body. When they coincide with intensified stratification, they may cause a permanent isolation of the deeper and above-bottom layers, thereby stimulating possible oxygen deficits. The deepening of the mixing layer (epilimnion) is followed by an acceleration of the cycling of matter in the trophogenic layer by the transport of nutrients from deeper waters. Finally, a total disappearance of thermal stratification is followed by constant oxygenation of the near-bottom layers and thereby a change of the rate and direction of the exchange of nutrients between the water and the sediments could be affected. Due to this the release of elements (e.g., phosphorus) could be inhibited, but bacterial decomposition processes are probably stimulated. The new thermo-mictic system in a water body may be an agent that affects the spatial pattern of niches in an ecosystem, and therefore the distribution of plankton and nekton (fish) species. In conjunction with the above-mentioned thermal selection it provides new factors for species and form selection.

Changes in the thermo-mictic conditions of a heated lake are no doubt important, yet not the only, factors in the impact of a power plant working in the once-through cooling mode.

4. ASSOCIATE CAUSES OF CHANGES IN HEATED WATER BODIES

Many investigators raise the problem of other direct or indirect influences, the effects of which can be difficult to separate from the main effect like that described above (K o n e n k o et al. 1971). First of all, cooling water bodies were not isolated from other sources of pollution. Heated lakes and reservoirs are, like all water systems, subject to eutrophication from non-point sources (watershed), precipitation, or directly from nutrient-rich supplying river waters. Also municipal sewage and industrial effluents are often discharged. Permanent or frequent algal blooms are found in such water bodies. Hence in some papers the problem of a synergic effect of the input of nutrients (N and P) (that is eutrophication), and of the discharge of heated waters is discussed (G o l t e r m a n 1976). The question arises as to whether lakes with their thermo-mictic regime so significantly changed are more, or less vulnerable to eutrophication and its consequences. H i l l b r i c h t - I l k o w s k a et al. (1986) have found that many of the typical eutrophication indicators do not apply to heated lakes in the environs of Konin (Poland), although some changes in the structure of the biota indicate eutrophication.

In many cases heated lakes are also noticeably contaminated with substances derived from the dust and smoke of their "own" power plants, getting there either directly or indirectly (with the surface runoff). In Lake Sangchris (L a r i m o r e and T r a n q u i l i 1981) a considerable accumulation of chromium, copper and mercury has been found in the sediments and macrophytes near a power plant, and in Lake Wabamum (G a l l u p and H i c k m a n 1975) an increase in the content of silicon brought in with the ashes. In cooling dam-reservoirs in the USSR higher levels of sulphates are often detected as the result of air pollution (P i d g a i k o 1971). In some lakes, including brackish backwaters (P i d g a i k o 1971, J a r o š e n k o 1973), a steady increase has been recorded of the concentration of inorganic compounds, which is attributed to their higher solubility at higher temperatures, and to intensified evaporation. This leads to conspicuous biotic changes (e.g., introduction of marine species, e.g., *Najas marina*), generally related to the increased salinity of these water bodies. The above phenomena result also from the discharge of post-mining waters into the same heat-receiving water bodies, as can be exemplified (see later) by the Konin lakes. In some lakes a considerable rise is observed of the concentration of chlorides and chloramines due to the chlorinating of the water used for cooling (C a p u z z o 1980).

Generally, it should be said that this type of impact of a power plant, associated with the effects of a permanent increase in evaporation and concentration of dissolved compounds (salinity, hardness), including those from external sources — natural and anthropogenic, is comparatively little known, although it is noticeable, particularly if the researches are continued for many years. S t u a r t and S t a n f o r d (1978) mention one other aspect of this situation: an increase in the concentration of inorganic salts can accelerate their precipitation and sedimentation, i.e., their loss from the nutrient-rich layer.

5. HEATED-WATER FISHERY – A SECONDARY YET IMPORTANT FACTOR

In the aquatic system affected by the heat discharge a rapid and permanent change in the composition and dynamics of the ichthyofauna usually occurs. The literature concerned with the fate of fish in heated water bodies is particularly rich, and the general conclusion is that this component of a lake biocoenose is the quickest to respond, and its reaction is the strongest (Horoszewicz and Backiel 1979). Breeding periods are changed, growth is accelerated, so more food is needed and thereby pressure upon invertebrate communities is intensified and prolonged. There is also a change in mobility and of the range of aggregating and feeding grounds. The increase in competitive pressure for food is recorded, often leading to the shift to alternative food, or even to the food avoided before (Pidgaiko 1971, Winberg 1977, Larimore and Tranquili 1981). Finally, some species are eliminated and replaced by others, e.g., some predatory species (pike, perch) (Wilkońska and Żuromska 1983b). New fish species (e.g., grass carp) are often introduced into heated lakes since there is a favourable higher temperature (especially in spring) and the rich vegetation. Intensive fishery operations are often applied (Jarošenko 1973). Generally, it must be stated that in heated lakes the pressure of ichthyofauna on food organisms and on the habitat increases considerably, becomes stronger and multidirectional, temporarily, and in some parts of a heated lake, highly concentrated. In the light of what is already known about the structuring effect of fish on invertebrate communities and on the environment it may be stated that natural and man-made water bodies with a thermo-mictic regime changed due to the discharge of heated waters become water bodies whose functioning can largely be determined by the ichthyofauna. This fact is rarely used in the interpretation of the effects of hot water discharge into lakes.

6. THE POWER PLANT AS A SELECTIVE PREDATOR

A particular aspect of the impact of a power plant on aquatic environments is the problem of increased mortality and damage to the organisms pulled into the cooling system, and the effect of this on their dynamics and possible elimination (so-called entrainment mortality). It is a complex phenomenon as includes both a thermal shock, physical damage and chemical effects of the contaminants introduced into the cooling water. Fox and Moyer (1975) have found that due to chlorination, the primary production of water bodies has been reduced by about 57% after the passage of water through the cooling system of a power plant. Without chlorination this reduction has been only 13%. Schubel and Many (1978) estimate the loss in general at 30% for various organisms (from algae to small fish). They have also found that a power plant acts as a "selective predator" causing variation in the chances of organisms to survive from 0 to 100%, depending on the body size and shape and resistance to thermal stress. For example, the disappearance of *Leptodora kindtii* Focke is often interpreted in this way (Larimore and Tranquili 1981). Krzanowski (1979) estimated zooplankton mortality due to damage caused in the discharge canal at about 24%. This is mainly the result of thermal shock (mixing of hot and cold waters). In other studies this mortality is estimated at 42% (Gorobyi 1977). Lower values (2–3%) were obtained by de Nie (1982) for most cladocerans, but 20–25% for *Leptodora, Diaphanosoma* and *Ceriodaphnia*. Stuart and Stanford (1978) have even found a slight (~13%) stimulation of phytoplankton production by the cooling system, and no damage to algal cells. However, studies of invertebrates and algae do not indicate that an increased mortality during the passage through a power plant unequivocally affects their abundance and dynamics in the recipient lake. Hence the fairly common opinion is that there is no permanent destructive effect of power-plant equipment on the plankton (Koops 1975, de Nie 1982).

7. THE LAKES OF THE KONIN REGION AS THE SITE OF STUDIES OF THE MULTIDIRECTIONAL IMPACT OF THE POWER-GENERATING INDUSTRY ON AQUATIC ECOSYSTEMS

The Konin lake system [1] that has functioned as an open cooling system of two power- and heat-generating plants since 1958 offers possibilities of carrying out studies in all the above-mentioned directions of research. Various studies, including fishery and environment investigations, date from the period before the starting of the operation of the power plants (i.e., before 1956). Comprehensive environmental and biological studies have been continued since 1965, involving many institutions such as: Institute of Inland Fisheries, Institute of Ecology of the Polish Academy of Sciences, Institute of Meteorology and Water Management, Adam Mickiewicz University in Poznań, Centre for Environment Protection at Konin, Department of Environment Protection of the Power Plant at Konin.

The ecological studies of the Konin lakes, carried out so far, have followed four main directions [2]:

(1) Looking for long-term trends in the functioning of the whole lake system and in particular lakes, and their relationship to the successive development of the cooling operations and to some other anthropogenic factors (Korycka and Zdanowski 1976, Zdanowski and Korycka 1976);

(2) An analysis of changes in the lakes in relationship to different ranges of the impact of the heated-water discharge, varying between years and seasons;

[1] A detailed description of the location and limnological data can be found in Hillbricht-Ilkowska and Zdanowski (1988).

[2] The selection of publications at this point of the paper has been restricted to those that seemed most important for the illustration of the main research lines. A full list of investigations concerned with the Konin lakes can be found in the respective specialist papers included in this volume.

(3) Recognition of the general nature of disturbances in the functioning of the lakes, their biological structure and the ecology of particular biota (especially fish) that can be attributed to the new thermo-mictic regime, by comparison with natural lakes, not thermally disturbed but exposed to similar climatic conditions and to similar non-point sources of pollution and eutrophication (Patalas 1970, Hillbricht-Ilkowska et al. 1976, Zdanowski 1976, Hillbricht-Ilkowska and Zdanowski 1978);

(4) A detailed identification of changes in the native ichthyofauna, particularly in its dynamics, catches, mobility, growth and development of fish and of fish fry (especially commercial species), variation in their food supply and the possibilities (partly realized) for increasing the composition of the ichthyofauna and fishery productivity by introducing new species (like herbivorous) (Rola... 1972, Zawisza and Backiel 1972, Marciak 1977, Niewiadomska 1977, Wilkońska 1977, Wilkońska and Żuromska 1977a, 1977b, 1977c, 1978, 1983a, 1983b, Żuromska 1977).

The following processes determining the functioning of the lake systems were studied:

(a) dynamics of the cycling of matter (especially of phosphorus and nitrogen compounds) in the new thermo-mictic system, and in the oxygen conditions associated with it (Korycka and Zdanowski 1976, Zdanowski and Korycka 1976);

(b) lake productivity, that is, the rate of primary production, decomposition and secondary production in the lake pelagial zone, and efficiency in the pelagial food chain (Patalas 1970, Hillbricht-Ilkowska et al. 1976, Hillbricht-Ilkowska and Zdanowski 1978).

Another aim of these and of some other studies was also to analyse the structural changes, i.e., in the composition, dynamics, biomass and quantitative relations among macrophytes, zoobenthos, phytoplankton and zooplankton (Półtoracka 1968, Sosnowska 1974, 1984a, 1984b, Dąmbska 1976, Dąmbska et al. 1976, Hillbricht-Ilkowska et al. 1976, Leszczyński 1976a, 1976b, 1976c, Stańczykowska 1976, Burchardt 1977, Wróblewski 1977, Stańczykowska et al. 1983).

However, studies of the Konin lakes were carried out with varying intensity in particular lakes. Most of the studies were concentrated on the following lakes: Licheńskie, Gosławskie, Ślesińskie and Mikorzyńskie (northern part of L. Wąsosko-Mikorzyńskie). For analysing the spatial and long-term effects the authors took into account differences in the degree of heating of these lakes in different time periods. For instance, in the 1st period of the functioning of the cooling system (1960 – 1969) the situation in L. Licheńskie – heated for the longest time and most intensively, was compared with that found in lakes Ślesińskie and Mikorzyńskie – not heated at that time. From 1970, the similar comparisons were made between two different parts of L. Ślesińskie – one of which was intensively heated and mixed, and the other in which only the surface layer was heated. In the same period the situation found in L. Ślesińskie was compared with that in L. Mikorzyńskie prior to the inclusion of both of these lakes into the cooling system (1960–1969) and thereafter (1970–1984).

On the basis of all the studies that have been carried out, two important suggestions have been formulated:

(1) changes in the thermo-mictic system of the lakes are generally followed by an intensification of the cycling of matter and energy flow, which is not accompanied by biomass increase and accumulation in successive food-chain links. This phenomenon has been described as advantageous from the point of view of eutrophication, because it does not lead to permanent algal blooms;

(2) the response of lake ecosystems to raised temperatures and water movement is stronger when this agent has just been introduced than when its effects have continued for a long time (adaptation).

The series of papers included in this volume contain the results from studies carried out during the last 8–10 years, i.e., since 1978, following similar research lines and methods as before. One of the objectives of these studies was to answer the following questions: Have the tendencies of long-term and spatial changes in lake productivity and biotic structure, observed in the previous period, i.e., 1960–1975 persisted? What are the effects of the simultaneous impact of the permanently disturbed thermo-mictic regime and other changes, like fishery practices, pollution, continual sewage discharge and the like? What is the reaction of a lake ecosystem to a persisting thermal zonation – horizontal thermal diversification of water masses? These problems will be considered in 13 successive papers on the basis of the results obtained during recent years and those recorded in earlier years, partly published (see above).

8. SUMMARY OF CONCLUSIONS

In a very general summing-up of the above studies of the impact of a heated-water discharge on the ecosystems of reservoirs and natural lakes it may be stated that:

(1) Functional and biocoenotic effects are fairly well known for various local conditions (in situ), but the results vary. It is often impossible to distinguish between a possible effect and variation related to the diversity of natural situations, particularly in the case of low and moderate levels of heating.

(2) The prevailing view is that this effect is unequivocally manifested in situations created by very intensive heating, that is, when temperatures rise rapidly or for a longer period over 28°C. Under such thermal conditions the synchronization is disturbed of the life cycles of organisms, their physiological functions and ecosystem processes, particularly decomposition, in relation to production processes.

(3) The opinion prevails that there is no unequivocal destructive effect on the population dynamics and survival rate of various organisms (except fish) of the mortality caused by their being pulled into the cooling system.

(4) The fact is emphasized that there is a synergic effect of heating and other changes, particularly those connected with the forced water mixing, contamination created by the power plant and associated industry (mining), pollution which leads to a

permanent lake eutrophication, and secondary changes connected with the fishery practices in the heated waters.

(5) There is no coherent information on long-term changes in a lake ecosystem permanently functioning in the cooling cycle, that is, with permanently disturbed thermo-mictic conditions.

(6) Morphologically diverse, the Konin lakes, included successively since 1958, into the open cooling system of two power plants, provide a particularly convenient site for studying the effects of the multidirectional impact (heating, increased mixing, pollution) of the power plants and the associated management (industry, fishery) on the aquatic ecosystems. As the researches on the biotic changes, productivity and lake environment have been carried out for over 20 years, there is a considerable amount of information on the long-term succession trends in these lakes, and on spatial changes connected with the thermal zonation. This makes the studies of these lakes particularly important to the world limnology.

9. SUMMARY

On the basis of selected literature (84 references) the main trends have been described of changes in an aquatic ecosystem, brought about by the operation of a power plant. It has been found that the changes are very diverse, highly specific in relation to the actual local environmental conditions in the water body, climatic conditions and mode of operation of the power plant. The main directions of these changes are as follows:

(1) Formation, in the water body, of a new thermal environment with a different short-term cyclicity and seasonality and with a marked horizontal thermal zonality. All these factors constitute a new system of selection of species and phenotypes according to their thermal resistance and tolerance, particularly at critical, 28 – 35°C, temperatures.

(2) The diverse degree of intensification of production, consumption and organic matter decomposition processes provoke in turn disturbances in the cycling of matter in the trophic chains of the pelagial and littoral zones.

(3) Formation of a new temporal and spatial system of water mass mixing in the lake. This factor has been considered as the very significantly, affecting the functioning of the aquatic ecosystem under the impact of the power plant, its scale of influence being wider than that of changes in the thermal regime alone.

(4) Input (direct, or with the watershed waters, and precipitation) of various contaminants, like toxic substances, compounds that increase water salinity, and hardness substances which accelerate or modify lake eutrophication.

(5) Secondary changes in a lake ecosystem, brought about by some fishery practices, e.g., introduction of thermophilous, herbivorous fish species, or by the elimination of some species from native ichthyofauna.

(6) Changes due to variation in the mortality of organisms (particularly fish) pulled into the cooling system of the power plant.

A short description has been presented of the state of studies of several lakes of the region of Konin, included successively since 1958 into the cooling system of two power-plants.

10. POLISH SUMMARY

Na podstawie wybranej (84 pozycje) literatury scharakteryzowano podstawowe kierunki zmian, jakie w ekosystemie wodnym wprowadza funkcjonowanie sprzężonej z nim elektrociepłowni. Stwierdzono, że zmiany te są szczególnie różnorodne, o wysokim stopniu specyficzności, zależnym od konkretnego lokalnego

układu warunków siedliskowych w zbiorniku, warunków klimatycznych i sposobu funkcjonowania elektrociepłowni. Główne kierunki tych zmian to:

1. Wytworzenie w zbiorniku nowego siedliska termicznego o odmiennej cykliczności sezonowej i krótkookresowej z silną strefowością termiczną, przestrzenną, które to czynniki tworzą nowy układ doboru gatunków i fenotypów selekcjonując je zależnie od odporności i tolerancji termicznej, zwłaszcza w temperaturach krytycznych, w zakresie 28–35°C.

2. Różny stopień aktywizacji procesów produkcji, konsumpcji i destrukcji materii organicznej doprowadzający do destabilizacji procesu przemian materii w łańcuchach troficznych pelagialu i litoralu.

3. Wytworzenie nowego układu czasowego i przestrzennego krążenia mas wodnych w zbiorniku. Czynnik ten oceniono jako podstawowy, kształtujący funkcjonowanie ekosystemu wodnego poddanego oddziaływaniu elektrowni, o większej skali oddziaływania niż jedynie zmiana reżimu termicznego.

4. Wprowadzenie (zarówno bezpośrednio, jak i poprzez transport obszarowy ze zlewni i z opadem) różnego rodzaju zanieczyszczeń, jak substancji toksycznych, związków powodujących wzrost zasolenia i twardości wód, jak też związków przyspieszających lub modyfikujących proces eutrofizacji wód.

5. Wtórne zmiany w ekosystemie jeziornym, jakie wprowadzają szczególne zabiegi rybackie praktykowane w zbiornikach podgrzanych, np. introdukcja ryb ciepłolubnych, roślinożernych, ustępowanie niektórych gatunków rodzimej ichtiofauny.

6. Zmiany związane ze zróżnicowaną śmiertelnością organizmów (szczególnie ryb) wciąganych mechanicznie w układ chłodzenia elektrowni.

Scharakteryzowano krótko stan badań na kilku jeziorach okolic Konina włączanych sukcesywnie od 1958 r. w obieg chłodzenia dwóch elektrociepłowni.

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