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POTENTIAL USES OF WASTE WATERS AND HEATED EFFLUENTS

by

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Cover photograph: Licheń Lake (courtesy: J. Waluga).

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BACKGROUND

The Food and Agriculture Organization of the United Nations (FAO) has a considerable interest in promoting fishery development and in combatting water pollution. In informal contacts with Polish scientists it had been noted that considerable research was being carried out in Poland on utilization of wastes for fish culture with the objective also to control water pollution. The Organization therefore proposed a fact-finding tour to Poland and the Swedish International Development Authority (SIDA) agreed to pay the travel costs, thereby making the visit possible. The author spent ten days in Poland at the beginning of February 1971 visiting several research institutions in order to collect information on how pollutants (domestic wastes, industrial wastes, and heated effluents) are being utilized for fish production. This is an aspect which in Poland gets much attention, while in many other countries it is regarded with indifference or suspicion.

Information obtained during discussions and supplemented with scientific articles (published mostly in Polish only) are compiled in the following chapters.

ACKNOWLEDGEMENTS

The well-planned programme for the visit was kindly arranged by Dr. Jósef Kossakowski, Director, Inland Fisheries Institute, Olsztyn-Kortowo. The language problems encountered in going through Polish documents and occasionally during discussions were overcome thanks to the help of Mrs. Maria Bnińska, Inland Fisheries Institute. Thanks are also due to the many scientists and administrators who discussed their current and future work with the author in an open and friendly atmosphere.

I. THE USE OF DOMESTIC WASTE WATER FOR FISH CULTURE IN POLAND

Abstract

In Poland detailed investigation of fish culture in biologically treated waste water proved that common carp can be cultivated all the year in undiluted effluents from an activated sludge plant. It is recommended to use two-year-old carp since carp fry are adversely affected by retention times shorter than ten days and low oxygen concentration. These larger fish also have better treatment effect on the effluents. Fish yields over 1 000 kg/ ha were obtained without artificial feeding. Short notes are given on places where wastes of different types are utilized for fish culture.

Résumé

En Pologne, des investigations détaillées sur la culture du poisson dans des eaux résiduaires biologiquement traitées ont prouvé qu'il est possible de cultiver la carpe toute l'année dans des rejets sans dilution provenant d'un processus de boue activée. Il est recommendable d'utiliser des carpes de deux ans parce que les alevins sont inversement affectés par une période de rétention inférieure à dix jours. Le poisson adulte a, en outre, un meilleur effet de traitement sur les rejets. On a obtenu des rendements de poisson de plus de 1 000 kg/ha sans alimentation artificielle. De brèves notes sont aussi données sur quelques endroits où l'on utilise des rejets différents pour la pisciculture.

1. INTRODUCTION

Water pollution by domestic waste water is creating problems at an increasing rate. The increasing population and the even more rapid urbanization makes the problem more pronounced, not only in the developed nations but all over the world. Especially in the developing countries the problem is difficult to handle due to several circumstances: shortage of capital, shortage of technical know-how, and inadequate administration. The shortage of proteins in these countries is well-known. It is therefore natural that FAO should take a vivid interest in possibilities to grow fish in domestic waste water in order both to control water pollution and obtain cheap proteins.

Most of the literature on this subject comes from German sources (Allen, 1969), but not very much is known on the activities in the socialist countries, partly because of difficulties in obtaining translated literature.

2. FISH CULTURE IN BIOLOGICALLY TREATED DOMESTIC WASTE WATER

Extensive investigations were carried out by Wolny (1962, 1967) at the sewage treatment plant at Kielce (Fig. 1) in southern Poland during the period 1958 to 1961. The sewage from the town is treated by the activated sludge method (without clorination) and the aim of the investigation was to determine if fish could be reared in the undiluted effluents over the whole year. In the literature it has been stated that fish culture in sewage is only possible with extensive dilution which would constitute a severe limitation of the method.

Investigations were carried out in five ponds of which two were stocked with common carp (Cyprinus carpio) and two were left unstocked as control ponds. Parallel investigations were carried out in ponds with and without overflow. The deepest pond was used as a wintering pond (Table 1). The effluent from the treatment plant had a composition normal for biologically treated domestic effluents (the phosphate content was lower than that usually found after the introduction of washing agents rich in phosphate).

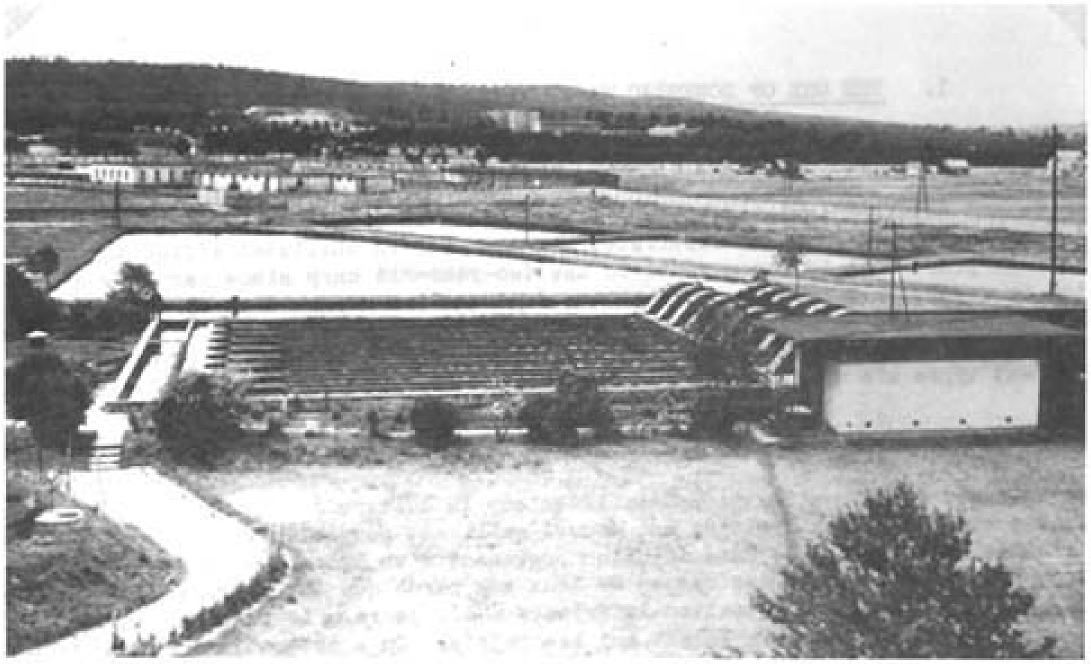

Fig. 1 Kielce sewage treatment plant and fish ponds. Photo: P. Wolny

Table 1

The characteristics of experimental ponds (from Wolny)

Pond No.	Area m^2	Average depth m	Utilization of ponds and overflow		
			1958	1959	1960
1	321	0.7	z p 2	z p 2	k bp
2	1 800	1.0	z bp	z bp	z bp
3	931	8.7	z bp	z bp	k bp
4	931	0.8	k bp	k bp	z p 10
5	840	1.1	k bp	k bp	z p 3

Explanations: z: stocked pond; k: control pond; p: pond with overflow;
bp: stagnant pond; figures: retention time (days)

Development of aquatic plants was very effectively prevented by the fish in the stagnant ponds only. The reason was that when feeding on the bottom fishes stir the sediments thereby decreasing transparency and consequently also growth of aquatic plants. In flowing water the effect is, however, less pronounced as the suspended sediments are continuously removed.

Development of phytoplankton was influenced by the fish and green algae with short development cycle (Chlorella and Scenedesmus) were dominant in the stocked ponds throughout the vegetation season, whereas in the unstocked ponds other algae forms dominated (Oscillatoria, Scenedesmus, Pediastrum).

The dissolved oxygen was higher in stocked than in unstocked ponds due to the species composition of phytoplankton and the effect was more marked in stagnant ponds. The oxygen content never fell under 3 mg/1 at which level the crucian carp stops feeding. The development of bottom fauna was favoured by stocking. Both numbers of individuals and weight of bottom fauna per m^2 were greater in the stocked ponds. The fish also increase the bottom surface by ca 35 percent by continuously "digging" in the bottom. In ponds with overflow it was found that the bottom fauna was eaten to a less extent by fish. The oxygen content was lower at the bottom in these ponds and in order to utilize the bottom fauna such ponds should be stocked not with fish fry but with two-year-old fish which have lower oxygen requirements. The sewage was rich in fat and in autumn the carp was feeding also on floating fat particles. The good food conditions resulted in lower weight losses during winter and also in fish flesh with higher content of fat and protein as compared to values obtained at the fish ponds at Żabienieo with fish of the same age reared in unpolluted water (Table 2).

Table 2

The content of fat, protein and dry weight in the body of carp fry on 9 April 1961 after wintering (percent) *[from Wolny]*

Winter pond No.	Food of fry during growth	Water supply	Average weight per specimen g.	Fat	Protein	Dry weight
3	natural	purified sewage	11.1	4.1	12.7	21.4
13	natural	river (Żabieniec)	12.3	1.4	9.1	12.4
3	ground barley	river (Żabieniec)	48.1	5.9	11.9	21.0

The increase in weight was much higher than what is usually obtained without additional feeding in Polish carp ponds. For fry the increase in weight in stagnant ponds was two to three times higher than in the ponds at Żabieniec. In ponds with overflow, however, the increase was lower than in common ponds. For two-year-old fish the increase was six to eight times that in common ponds without additional feeding and there was no significant difference between ponds with or without overflow. The highest production obtained amounted to 1 317 kg/ha, the highest yield ever obtained in Poland.

The mortality of the larger fish and fish fry was not different from normal ponds provided the retention time for the ponds with fry was not less than ten days. There was also no difference in occurrence of parasites or diseases as compared with normal ponds. Carps were kept over the winter for five months in one deep stagnant pond filled with treated sewage. No abnormal mortality occurred although the oxygen content in December and January was somewhat lower than in common ponds (Table 3). No tainting of fish flesh was noticed, nor did any public health effects appear.

Table 3

The average oxygen content in mg per 1 and percent oxygen saturation in water in winter ponds - 1958/59 and 1960/61 [from Wolny]

Month	Winter pond with purified sewage from Kielce				Winter ponds with unpolluted river water at Żabieniec			
	mg/1 O_2		%		mg/1 O_2		%	
	1958/59	1960/61	1958/59	1960/61	1958/59	1960/61	1958/59	1960/61
December	8.21	7.36	57.4	60.4	-	12.60	-	95.0
January	9.27	6.67	65.3	50.3	12.40	-	87.0	-
February	11.23	-	80.8	-	12.69	13.58	89.3	95.5
March	16.23	-	129.1	-	13.63	13.92	107.3	105.0

The following conclusions were drawn from the investigation:

Successful carp culture can be obtained the whole year in undiluted biologically treated domestic waste water.

Conditions for fish culture are better in stagnant ponds than in ponds with overflow; ponds with overflow should be stocked with two-year-old fish or not have less than ten days retention time.

Stocking with fish provided additional treatment of the waste water and larger sized fish have better effect on reduction of organic matter than fish fry. A 50 percent reduction in bacteria was observed.

Optimal rate of stocking with fish is, because of the good food supply, higher than in normal ponds and was, in Kielce, found to be 25 000–35 000 fry or 2 500–3 000 two-year-old fish per ha.

3. OTHER EXPERIENCES WITH FISH CULTURE IN DOMESTIC WASTE WATER

The investigation undertaken at Kielce by Wolny seems to be the only scientific investigation in this field in Poland. There are, however, other places where sewage and organic wastes are being utilized for fish culture and the following were mentioned.

At Legnica untreated domestic waste water is spread over grass fields and from there it is drained into fish ponds covering 50 ha. This practice has been going on for 20 years and the fish production is 500–700 kg/ha without additional feeding.

At Zaglówek untreated domestic waste water is led into a series of ponds covering 55 ha. The first pond does not hold fish. With supplemental feeding a production of 3 000 kg/ha has been obtained in some ponds.

An attempt to grow fish in domestic waste water mixed with 65 percent waste from a metal factory at Czestochowa was not succesful because of high phenol content.

A limited investigation was undertaken of fish culture in biologically treated dairy wastes at Leszno. The ponds were too shallow for continuous fish culture but still a production of 800 kg/ha was obtained in one vegetation season. This experiment may be repeated and a similar investigation at Wilga has been discussed.

4. ADMINISTRATIVE VIEWS

The Polish authorities dealing with water pollution problems do recognize the beneficial effects from utilizing domestic waste water as well as other wastes for fish culture or in agriculture. Their first priority for the years 1971–1975 is, however, to build 1 000 new treatment plants and new water reservoirs with a total capacity of 5 000 million m^3 and over 9 000 million złoty (ca $300 million) will be invested. Only after 1975 will the authorities actively propagate the use of fish culture in wastes in order to obtain additional treatment and increased protein production.

5. CONCLUSIONS

From the Polish investigation it is clear that fish culture in domestic waste water can give very high fish yields at low cost. It is also clear that with biologically treated sewage fish culture can be undertaken on a continuous basis. In order to convince engineers and authorities of the suitability of the method, closer investigations should be undertaken of the treatment effect of the fish ponds on the final effluents.

With regard to some developing countries the method would be of great value where due to favourable climatic conditions, it might be possible to cultivate fish in domestic sewage without pretreatment or dilution. Dr. Wolny especially pointed out that care should be taken to stock larger sized fish with low oxygen requirements in the first pond in a lagoon system because thereby both the efficiency of the treatment process and the fish yield would be increased.

Where domestic wastes are mixed with industrial effluents fish culture in the treated effluents can be successful only if there is satisfactory control of the industrial discharges. Fish culture can then give the necessary motivation to bring forward the needed pretreatment.

On the other hand, on many occasions there has been mentioned the public health implications of eating fish grown in domestic waste water. This objection is usually raised by some scientists from highly industrialized countries and are based more on emotion than practical experience. It is, of course, not proposed that the public health aspect should be ignored; on the contrary, this aspect should be further investigated and the risk be weighed against the advantage.

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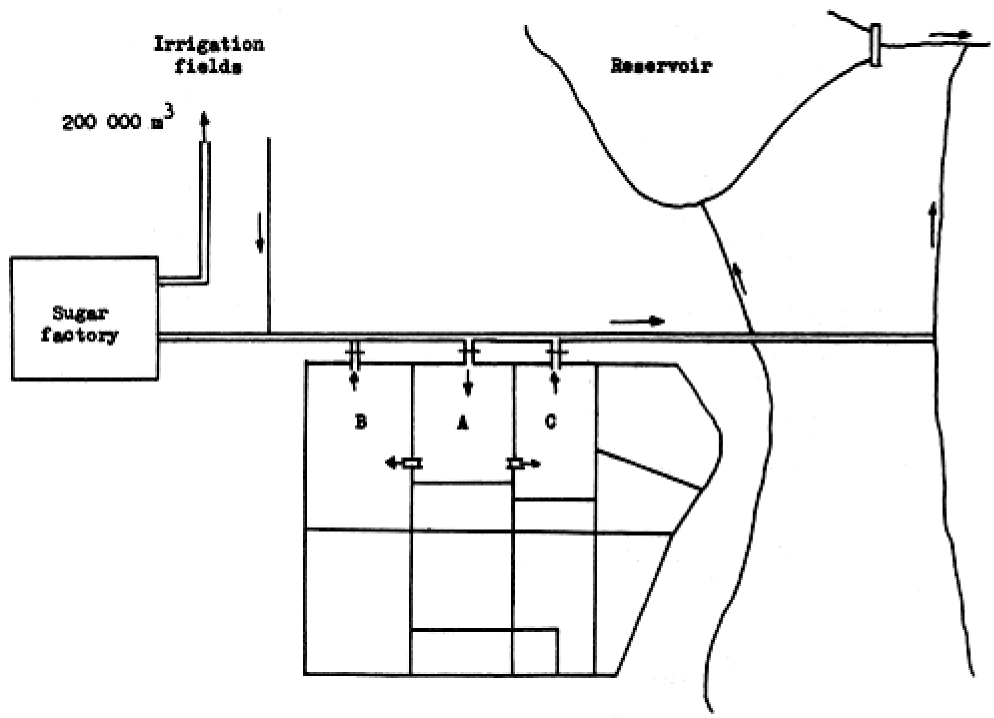

A - holding reservoir; 8.4 ha, 80 000 m^3

B - fish pond 1; 10.8 ha

C - fish pond 2; 7.9 ha

Fig.2 Treatment of sugar factory wastes, Gołysz

II. TREATMENT IN FISH PONDS OF WASTES FROM A SUGAR FACTORY

Abstract

Experiments undertaken in Poland on fish culture in sugar beet factory wastes show that fish culture in a yearly cycle is possible and that very good treatment effects as well as good fish yields can be obtained. Effluents are collected and stored during autumn and winter. In spring the effluents are diluted according to the self-purification obtained and led to ponds which are then stocked with carp. Before winter the fish ponds are emptied into the recipient and the fish are caught for consumption.

Fish culture in waste effluents should be further encouraged especially in developing countries in order both to control water pollution and to obtain cheap and much needed proteins.

Résumé

En Pologne des expérimentations entreprises en pisciculture avec les rejets d'une usine de betteraves à sucre prouvent qu'il est possible de développer la pisciculture en un cycle annuel et d'obtenir de très bone effets du traitement et aussi de bons rendements en poisson. Les rejets sont assemblés et entreposés pendant l'automne et l'hiver. Au printemps ils sont dilués selon l'auto-épuration obtenu et mis danss des étangs qui sont ensuite peuplés de carpes. Avant l'hiver les étangs sont vidés dans le milieu de décharge et le poisson est capturé pour le consommation.

La pisciculture en eaux résiduaires doit être encouragée surtout dans les pays en voie de développement pour lutter contre la pollution des eaux et aussi pour obtenir économiquement des protéines indispensables.

1. INTRODUCTION

The wastes from sugar beet factories constitute a problem in many countries. Not only are the wastes very rich in organic matter, they are also produced only during three to four months each year. If a conventional treatment plant is built and designed for the big flow of effluents during this limited time, it will stand idle two-thirds of the year which is not an economical solution. Lagoons with or without artificial aeration are widely used but have led to objectionable smell and the purification process in these lagoons often is so slow that when the wastes have to be discharged to make room for the new season's effluents, they give rise to severe pollution. The problem is worsened by the fact that the factories are located in the beet-producing areas so as to give minimum transport costs for the beets but without due regard to the availability of a suitable recipient watercourse.

These problems were all present for a sugar beet factory near Gołysz, south-west of Kraków, and the pollution in the small recipient stream became very severe although the factory did not discharge its waste directly but spread it on farmland and returned the drainage to the recipient. In 1966 the Research Station of the Polish Academy of Science which is situated in the area (Fig.2) started investigations on the possibilities of treating the wastes from the factory in fish ponds. It has, however, during the experiments, not been possible to take more than about one-third of the effluents into the pond treatment system because other research is carried out in the other ponds.

The sugar factory operates from mid-October until January and has a rather advanced recirculation system resulting in wastes with high content of organic material. For the effluents from the factory the following figures are representative:

Chemical Oxygen Demand (COD)	1 400 mg/l
Biological Oxygen Demand (BOD)	960 mg/l
Permanganate value	60 mg/l

2. FIRST SERIES OF EXPERIMENTS

The objectives of the initial experiments were to investigate whether the wastes could be treated in ponds stocked with fish in a one-year cycle, and if dilution of the wastes would be necessary. The experiments were carried out from 1966–1968.

Two similar ponds were filled with wastes during the production season of 1966–67. Pond 1 was filled only with wastes and in pond 2 the wastes were diluted with clean water in the ratio 4:1 wastes:water. In May 1967 the undiluted wastes in pond 1 were still completely void of oxygen and no fish was stocked then. In autumn 1 000 two-year-old carp were stocked and the pond was not utilized by the 1967–68 campaign. In the spring of 1968 another 1 000 carp, this time one-year-old, were stocked. It was thus found that undiluted wastes could not be treated in a one-year cycle and a two-year cycle would have severe economical implications.

In pond 2 the diluted wastes had undergone self-purification so that in May oxygen was present in sufficient concentration to make fish stocking possible. The pond was stocked on 1 June with 650 kg/ha one-year-old carp. The pond was emptied and the fish collected on 1 October. The pond was then left empty during the winter and in spring it was filled with clean water. During the summer the pond was quite normal. It was not affected by its use for waste treatment the preceding year, and it was thus established that for the waste from this factory, treatment in fish pond of waste diluted 4:1 could be undertaken on a one-year cycle.

Primary production was found to start in both ponds as soon as dissolved oxygen became available. The chlorophyll content was up to four times that found in normal ponds and oxygen saturation was also very high (reached 800 percent in pond 1 during the second summer).

There was a very high production of zooplankton. Daphnia magna had mass development giving a reddish colour to the water. This development also occurred momentarily in early spring but stopped suddenly when available oxygen was used up. Bottom fauna developed in pond 1 in July the first summer; only then was oxygen available at the bottom. Only two species developed (Chironomus plumosus and Glyptotendipes) and biomass reached as high as 135 g/m^2. The second summer bottom fauna developed in March, the fauna became gradually more diversified, and by the end of July, it had a composition like in a normal pond. In pond 2 bottom fauna developed earlier than in pond 1 and maximum biomass reached 70 g/m^2. Chironomus plumosus was dominant but other species were also present. During the second summer an entirely normal bottom fauna developed in the pond. Oligochaete did not develop in either of the ponds.

The first series of experiments proved that diluted wastes could be treated in a yearly cycle, and that this was not possible with undiluted wastes. The fish production during this experiment was 400 – 500 kg/ha without artificial feeding. This should be compared with ordinary fish farms in this region of Poland where a production of 500 kg/ha is obtained with chemical fertilization.

3. SECOND SERIES OF EXPERIMENTS

The second series of experiments were started in 1969 with the objective to find the optimum rate of dilution. During this experiment the wastes are collected in one storage reservoir where it undergoes anaerobic self-purification during winter and spring. The fish ponds are empty during winter and are filled in late spring with wastes diluted according to the BOD remaining after self-purification obtained during winter and early spring. It is thought that this should be the best sequence of operation and the technique has already been applied to other sugar factories in Poland. The rate of dilution needed will depend on the composition of the waste, which varies between different factories, and also on the climatic conditions which affect the rate of self-purification.

4. CONCLUSIONS

The reduction in BOD is sufficient so that the fish ponds can be emptied into small rivers in autumn without any pollution problems occurring. The drainage from the fields irrigated with fresh wastes, on the other hand, when discharged still have BOD ca 600 mg/1.

In warmer climates this process should be even more advantageous. The higher temperatures would speed up the initial self-purification process and the growth rate of fish would be higher. Dr. S. Wróbel, who is in charge of the investigations, thought that investigations should be carried out on this process in tropical and semi-tropical areas. The problems with strong organic wastes in these areas are well documented and are likely to increase with time, as are the protein deficiencies in the developing countries.

There are indications that the interest in use of wastes for protein production will increase (Allen, 1970) but better communication and unified efforts between engineers and biologists are needed if the conventional hesitant attitude is to be changed.

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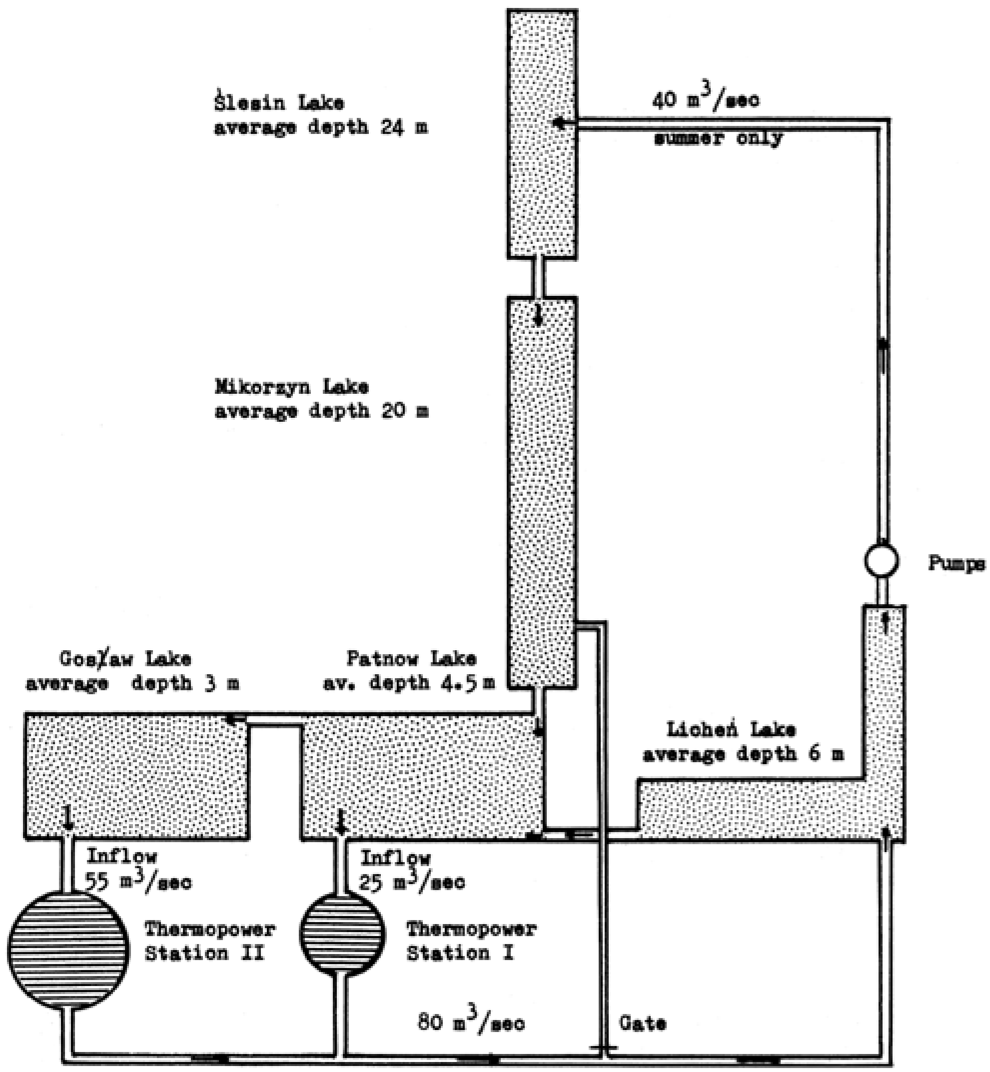

Fig.3 Konin Project Diagram

III. BIOLOGICAL CONTROL AND UTILIZATION OF HEATED EFFLUENTS, KONIN PROJECT

Abstract

Detailed investigations are carried out on the biological effects of heated effluents on a system of five interconnected lakes in central Poland which are used as circulating cooling system for two base-load thermopower stations. The eutrophication has been turned into valuable fish production through a combination of increased growth rates and introduction of eel, common carp, and Chinese carps. Thanks to the strict biological management, no adverse growth of aquatic plants or plankton has occurred, the latter being of vital importance for the operation of the power stations.

Résumé

Des investigations détaillées ont été faites sur les effets biologiques des effluents réchauffés dans un système de cinq lacs interconnectés en Pologne centrale, utilisés comme refroidisseurs pour deux stations thermiques à système continue. L'eutrophisation a été utilisé pour la production substantielle de poisson par la combination de l'augmentation des taux de croissance et l'introduction d'anguille, carpes commune et chinoises. Grâce à la stricte exploitation biologique on n'a observé aucune augmentation de plantes aquatiques ou de plancton, ce dernier facteur ayant une importance vitale pour le bon fonctionnement des stations therniques.

1. INTRODUCTION

The Konin Project in Central Poland is an outstanding example of an integrated approach for utilization of cooling waters. The Project consists of two base-load thermopower stations discharging cooling water at 80 m^3 per second with a temperature varying from 10.1 to 35.0°C into a system of five interconnected lakes in series with a total area of 1 100 ha. The cooling water for the stations is withdrawn from the end of the same lake system. The aim of the research project sponsored by the Council for Mutual Economic Assistance (CMEA) is to prevent harmful effects to the thermopower stations and to the environment by use of biological control methods. The research work has been carried out since 1958 by the Inland Fisheries Institute, Olsztyn-Kortowo. Since 1965 monthly samples have been taken of water, benthos, plankton and fish.

In 1958 the first thermopower station was put into operation and the cooling water was taken from Patnow Lake and discharged into Lichen Lake through open channels (Fig.3). Comparative investigations were initiated of several parameters in heated and unheated lakes in the same system. In the spring of 1968 heated water was discharged for the first time also into Mikorzyn Lake through a channel which can be closed with a gate. The direct discharge into this lake is done as an extraordinary measure. In 1969 the second power station was started. This station takes its cooling water from Gosław Lake and discharges it into the existing channel leading into Lichen Lake.

The cooling system is operated differently in winter and summer. In summer all five lakes are involved and the output of the power stations is slightly decreased. Water is then pumped in a channel from Lichen Lake into Ślesin Lake with a maximum flow of 40 m^3 per second. In winter the pumping station is not operated and the water flows from Licheń Lake into Patnow Lake only and subsequently into Gosław Lake. The lake system is situated at the upper end of a drainage basin and the natural flow of water is negligible compared to the induced flows.

2. EFFECTS ON ENVIRONMENT

2.1 Physical Effects

2.1.1 Thermal conditions

The differences in temperature and the yearly changes during the period 1965–1970 for surface and bottom layers in the most heated and in one unheated lake are shown in Fig.4. The greatest difference in surface temperature occurs during December to April, reaching about 13°C. In summer the maximum difference is 9°C. The temperatures of the bottom waters differ much more - the differences in summer being about 20°C and in winter about 9°C.

The two deepest lakes, Ślesin and Mikorzyn, have a marked stratification whereas Lichen Lake is only stratified in its deepest parts and the two shallow lakes, Gosław and Patnow, are completely mixed.

The summer stratification in Licheń Lake begins at the end of April and ends at the end of September, while in unheated lakes the stratification lasts from the middle of April to the middle of November.

The Polish Meteorological Institute carries out daily measurements of air and surface water temperatures in the Konin area. High temperatures are observed throughout the year in Lichen Lake; in winter there is a complete lack of ice cover and a partial lack of ice cover on Gosław and Patnow Lakes.

The lack of ice cover in the heated lakes has changed some fishing operations; for example, bream was previously caught in winter by nets under the ice, a rather difficult operation which restricted the catches.

The evaporation from the surface of the heated lake is double that of the unheated lakes (Chojnowski, 1970).

2.1.2 Oxygen content

Oxygen content and temperature were investigated simultaneously and it was found that the heating has no influence on the oxygen content or on the saturation of oxygen. In the surface layers of the most heated lake (Licheń), the oxygen content never falls below 6 mg/l throughout the year. Since the lake is rather shallow (average depth 5 m) the oxygen content at the bottom does not fall below 1 mg/l. The thermoclines as well as the oxygen gradients of the unheated lakes are more pronounced than in the heated lakes and the oxygen content decreases rapidly at the depth of 5–7 m. This is also due to the fact that the unheated lakes are deeper. The decrease in oxygen content of the water before and after passing through the thermopower stations does not exceed 2.4 mg/l in summer and winter, and 0.6 mg/l in spring and autumn.

2.2 Chemical Effects

Very little change due to the heating has been observed in the chemistry of the water in the lakes. The general tendency was a slight enrichment of the water but this was probably due to effluents from a coal mine situated near Lichen Lake (Korychka, 1970)

2.3 Biological Effects

2.3.1 Primary production, phytoplankton

Primary production has been investigated over a seven-year period and detailed investigations were carried out during the four-year period, 1966–1969. During the warmest period of 1966 very detailed measurements were carried out at two-day intervals on the most heated (Lichen) and one unheated lake (Mikorzyn). These results gave a basis for comparison of further data. The average primary production of Lichen Lake (temperature 26°–28.5°C) was 7.0 g of oxygen per m^2 per day, and for Mikorzyn Lake it was 3.8 g of oxygen per m^2/day, viz. primary production was increased 100 percent in the heated lake. It was clearly seen from the data obtained that primary production of Lichen Lake is very high, being in the range of production of very highly eutrophic lakes. The transparency of water in Lichen Lake was, however, equal or only slightly smaller than in unheated lakes. The high production in Lichen Lake is caused mostly by the more rapid turnover, depending directly on the temperature, while biomass of phytoplankton is only slightly higher than in unheated lakes. The species diversity of phytoplankton increases with temperature (Fig.5) and no dominant species develop.

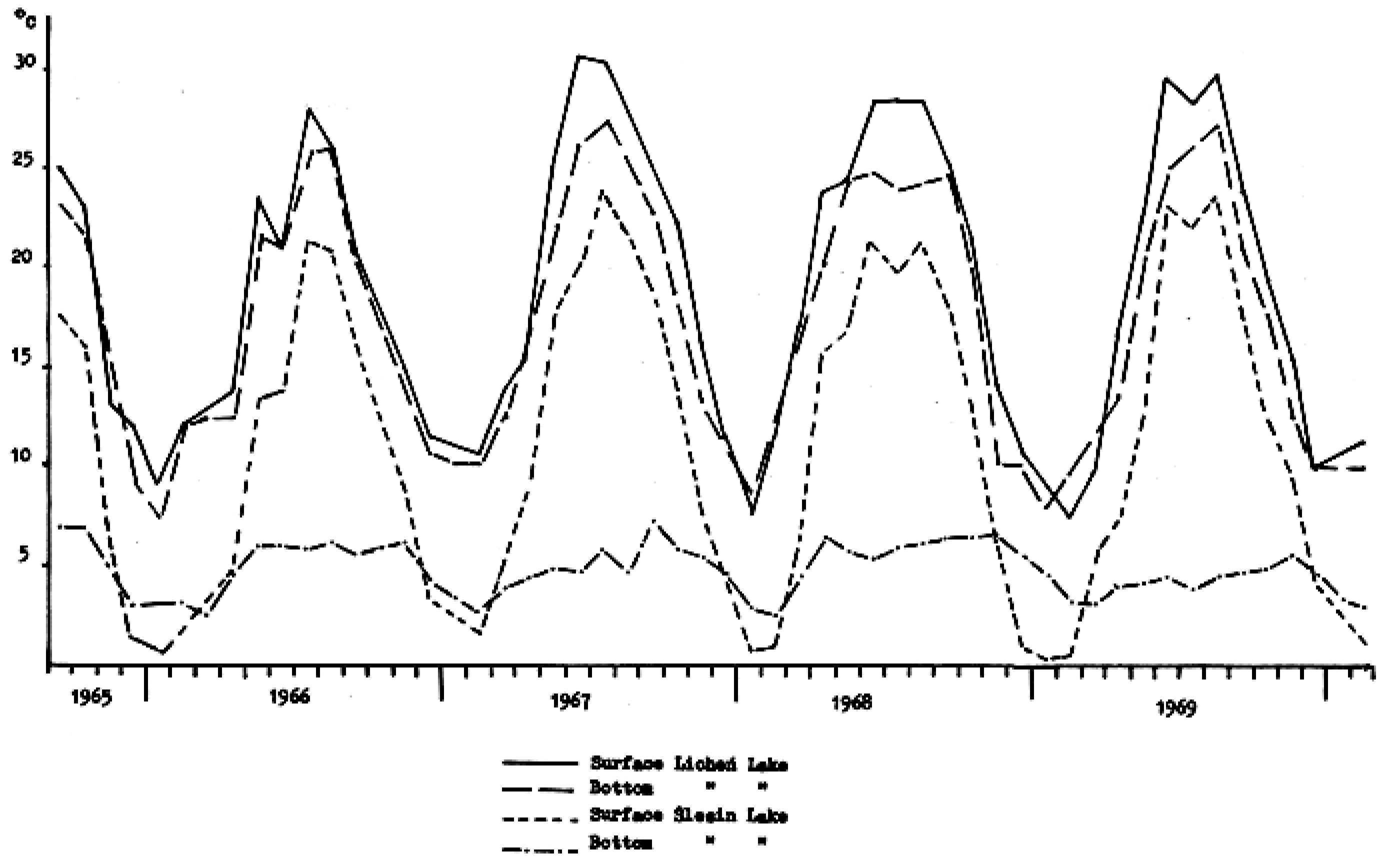

Fig.4 Water temperatures 1965–1969

The values obtained in the following years confirm the result of the intensive investigation from 1966. Detailed calculation of the production factors show that in Lichen Lake there are still some reserves of production which are not at present utilized by higher trophic levels (Patalas, 1967, 1970; Półtoracka-Sosnowska, 1967).

2.3.2 Zooplankton

Detailed investigations during the period 1965–1970 gave the following summary results:

In summer the production of zooplankton in Lichen Lake was twice as big (13.18 g/m^2/ day) as in unheated lakes (7.20 g/m^2/day). At the same time the production of phytophagous zooplankton was four times greater in the heated (3.9 g/m^2/day), than in the unheated lake (0.9 g/m^2/day). The daily turnover varied in Licheń Lake for different species from 0.14 to 0.40. The rise of temperature by about 6°C doubles the production of zooplankton due to quicker turnover while the biomass of zooplankton remains constant. The production of predatory forms of zooplankton is slightly lowered by the temperature increase. The ratio between the production of plant-eating forms and primary production considered as the index of ecological productivity is 0.11 in the unheated lake and 0.13 in the heated lake. Thus Lichen Lake may be considered as a very productive reservoir. The heating of a lake not only raises the production but also raises the rate of energy flow from one trophic level into another (Patalas, 1967, 1970).

It was found that in the heated lake Daphnia cucullata had a 20 percent greater body length than in lakes with normal temperature and its rate of growth was 40 percent higher as compared with its rate of growth in the same lake eight years ago.

2.3.3 Bottom fauna

Investigations showed that the biomass of bottom fauna was slightly lower in the heated lake and that the species composition was not changed. Instead of the normal two maxima per year, only one maximum appears in the heated lake but the reason for this is not clearly understood.

2.3.4 Fish

Before the start of the thermopower plants the lake system had a fish fauna typical for the region and unaffected by pollution. The fishery on the lakes has for a long time been carried out by state fisheries and detailed records of catches of different species have been kept since 1955.

This has given much valuable background information for investigation of changes in the fish population. The changes are due both to the heating of the lakes (Licheń and Patnow from 1958, Mikorzyn from spring 1968, and Ślesin and Gosław from 1969), and to introduction of new fish species.

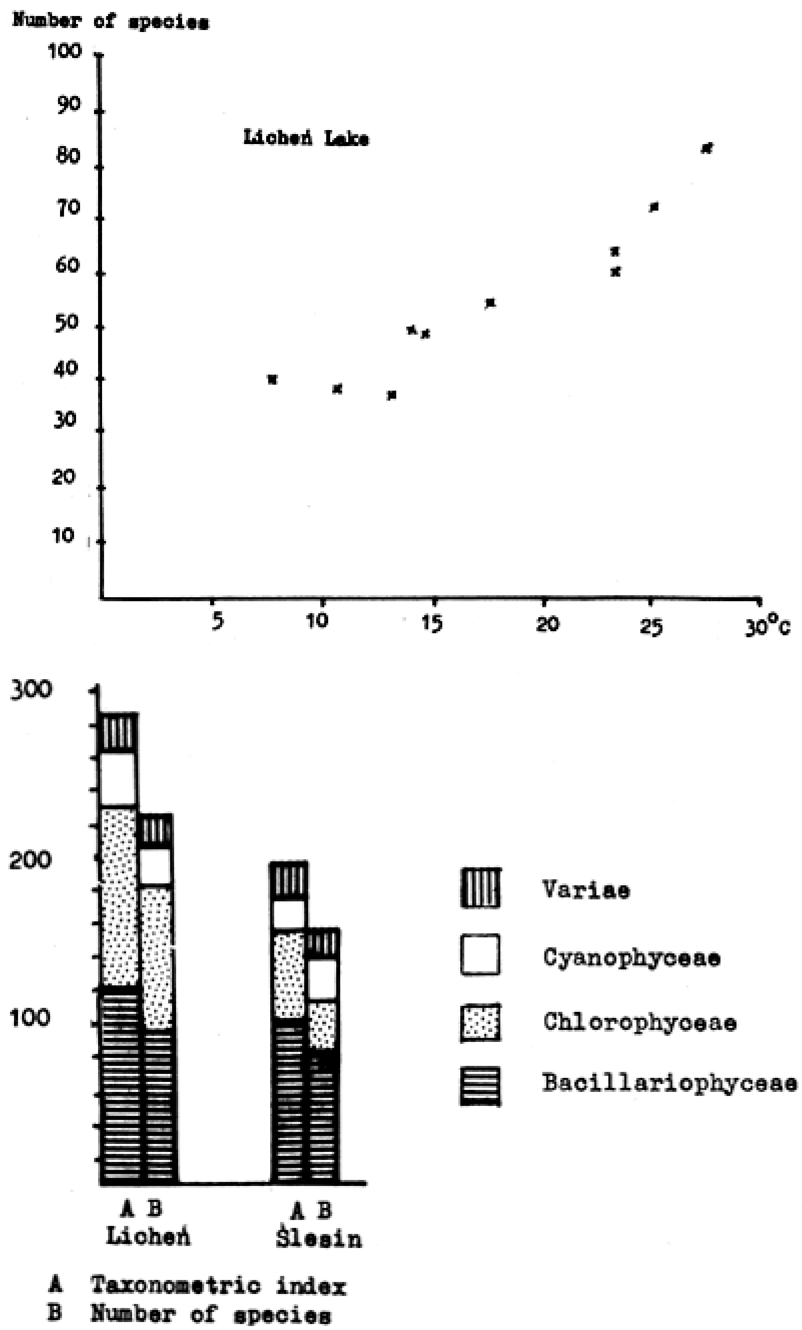

Fig. 5 Phytoplankton (except diatoms)

Lethal temperature: Detailed investigations of lethal temperatures for fourteen species in Lichen Lake undertaken by Dr. L. Horoszewiez (which will be published in 1971) show that after three generations in heated water the fish does not show any inherited adaptation to higher lethal temperatures. The lethal temperature was found to be specific for each species and the results are in agreement with the results of Alabaster and Downing (1966) who found a linear correlation between lethal and acclimatization temperatures.

Growth rate: The rate of growth has increased for all fish species (Fig.6). For pike-perch (Lucioperca lucioperca) the rate of growth is similar to that found in warm climates; rudd (Scardinus erythrophthalmus) has a growth rate previously found only in the Aral Sea; roach (Rutilus rutilus) has the highest growth rate found anywhere in Poland (Marciak, 1970; Wilkońska, 1970; Źuromska, 1970). The rapid growth rate seems to be accompanied by a shorter life span of fish compared with unheated lakes. The growth of fish fry is very rapid compared to unheated lakes (Fig. 7).

The age determination of fish by scale reading was found to be more complicated in heated waters since the scale rings do not develop in the normal manner and therefore new techniques for scale reading has been developed for the four most important species: pike-perch, rudd, roach and bream (Abramis brama).

Fertility: The heating has changed the fertility of some fish species, in that for some species an increase has occurred while for others the fertility decreased.

Detailed investigations of 23 species of fish fry in Lichen Lake was undertaken in 1966–1969 by Źuromska and Wilkońska (1970). Newly-hatched fry was found already in the beginning of April and all species of fish had intermittent spawnings from April to the end of June. Concentration of newly-hatched fry appeared in May–June and by the end of September the small fishes moved from the shore into the centre of the lake.

Fish parasites and diseases: The question of parasites and diseases has so far not been thoroughly investigated but the data obtained show a striking correlation between elevated temperature and increase in infestation. This is to a large extent due to physical factors; up to 90 percent of the bream was found infested with tapeworm Ligula, because birds acting as intermediate hosts for the tapeworm assemble in great numbers on the ice-free lakes in winter. The rapid growth of bream in the first three years is thereafter retarded due to the tapeworm infestation and the infested bream is also not accepted by the consumers. Blindness of perch and pike-perch due to metacercaria was also found to be correlated to water temperature. Fish fry were found to be affected by protozoa to an unusually high extent. Generally it seems that the heating of lakes increases the problems of fish parasites, partly offsetting the beneficial effects of increased temperatures.

Behaviour: The increase in temperature induced some changes in behaviour of fish. For example, it was found that eel (Anguilla anguilla) *[introduced]*, does not spread into adjoining lakes but stays in the most heated lake. A detailed investigation was done on the migration of bream between the different lakes in the system. 1 000 bream were tagged and released in each lake. Bream released in the unheated lake (Ślesin) migrated into the heated lake (Licheń) and remained there, whereas bream released in the heated lake migrated into the unheated lake during summer but returned to the heated lake in winter (Frieske, 1970).

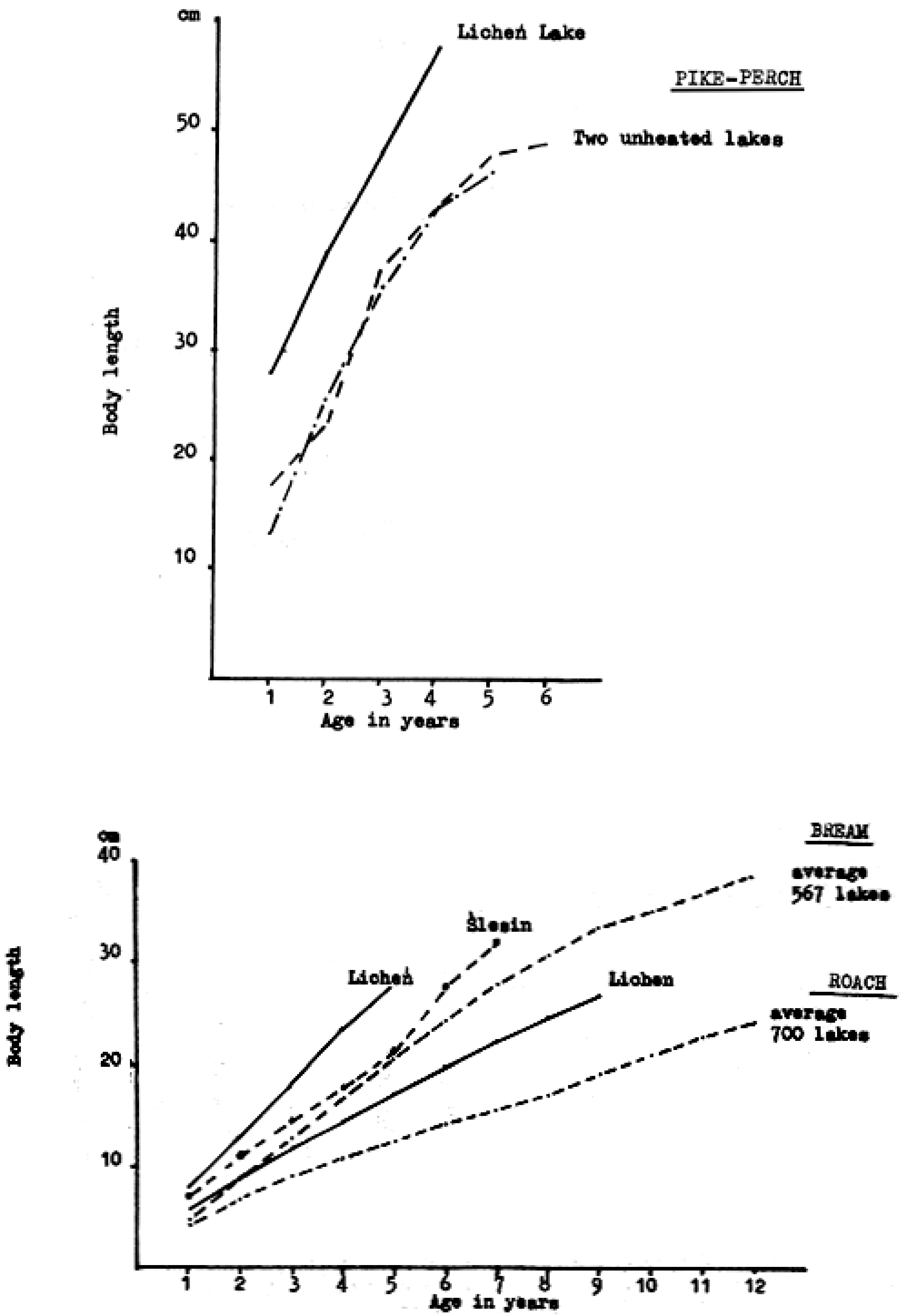

Fig.6 Growth of fish

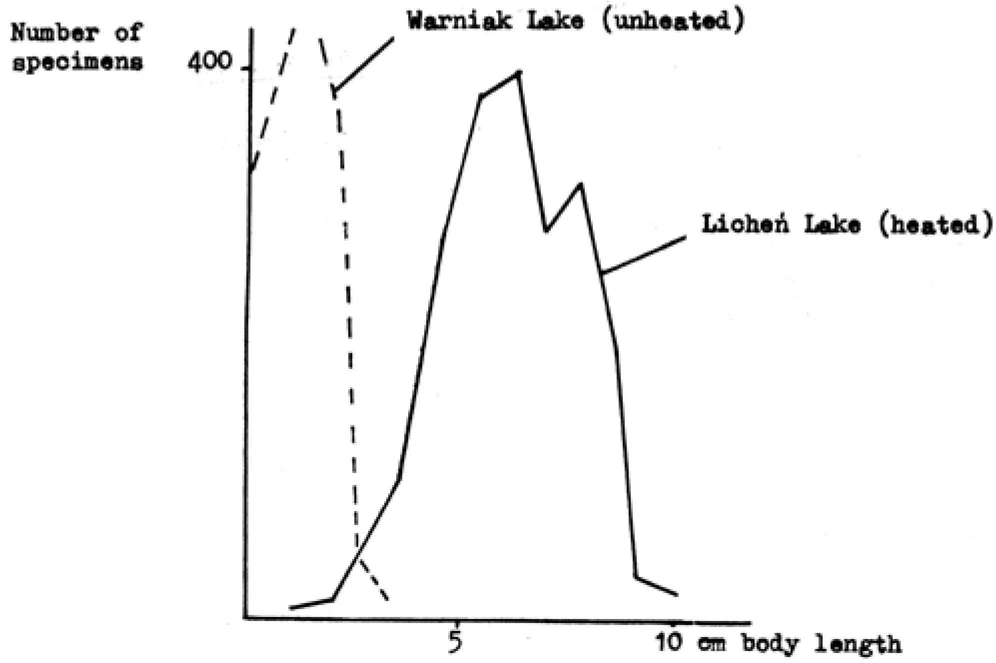

Fig.7 Body length of roach fry

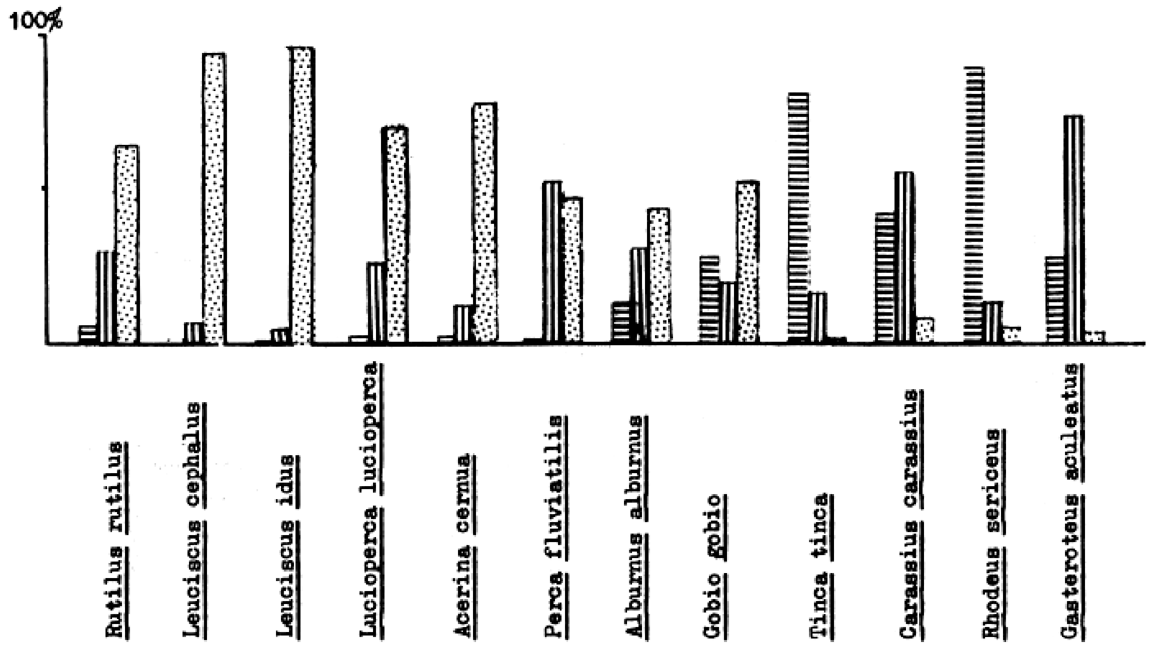

Fig.8 Comparison of catches (including fry) by species in 1966, 1967 and 1968. (Note 100% equals total catch of one species in these three years)

3. MANAGEMENT MEASURES

3.1 Introduction of New Fish Species

3.1.1 Species introduced

The heating of the lakes increased the productivity and the investigations at an early stage indicated the necessity of introduction of new fish species, in order to avoid unwanted eutrophication effects (especially high content of organic matter affecting the cooling system of the thermopower stations) and to obtain maximum beneficial effects. Eels were bought from France and introduced to utilize the bottom fauna. As previously mentioned, eels do not spread from Lichen Lake. Carp (Cyprinus carpio) was introduced to utilize the bottom fauna and activate the bottom sediments. Grass carp (Ctenopharyngodon idella) was introduced to control the growth of aquatic plants. Bighead carp (Aristichthys nobilis) and silver carp (Hypophthalmichthys molitrix) were introduced to utilize and control the increased production of phytoplankton. Fry of the Chinese carps were obtained in 1964 from a Soviet hatchery and kept in the ponds at Zabieniec. In 1966, 500 kg of the two-year-old fish (average weight 0.8 – 1 kg) was introduced into Lichen Lake. The growth rate of the introduced fish was very high. After one year the average weight was 3.5 kg and thereafter the increase in weight has been about 3 kg per year. The introduced warmwater fish have remained in the heated lakes and not spread into the unheated lakes.

3.1.2 Results of introductions

The objectives of the introductions have been fulfilled. The macrophytes in the heated lakes are controlled by the grass carp to such an extent that those fish species laying eggs on plants /tench (Tinca tinca), crucian carp (Carassius carassius) and stickle-back (Gasteroteus aculeatus)/ have shown a decrease while other fish species proliferated also after the introduction (Fig.8). The plankton is utilized so that the transparency of the water has not decreased and the thermopower stations have had no problems with organic matter in the cooling water systems.

3.2 Use of Fish Culture

The heated effluents are also used for a fish culture station where the first stocking took place in 1968. The construction works were completed in 1970 and from this station it is expected to obtain 30 million fry per year of phytophagous fish. (The fish culture station has been described separately [1]).

[1] Thorslund, A., Thermopower effluents for fish culture in Poland. Vatten (1):36–9, 1972

3.3 Standards Proposed

One of the main objectives of the research work was to establish standards for the effluents from the thermopower stations. As the chemical composition of the water was not affected the only standard required was for maximum temperature. The thermopower plants are operating continuously; therefore it was not felt necessary to establish standards for variation of temperature. In order to maintain the diversified biological system necessary both for the fishery and for the cooling system of the power plants the maximum permissible temperature in the most heated lake shall not exceed 28.5°C. In emergency situations the temperature may, in summer, be increased to 31.0°C for the duration of one week.

The area around the lakes is scarcely inhabitated and no significant organic wastes are discharged into the lakes. No discharges of organic matter will be permitted in the future.

3.4 Continuing Studies

All the research work described above is continuing in order to follow up the situation and if necessary bring forward corrective measures.

The operation of the thermopower stations has run according to plans and no emergency situation has developed. The only problem encountered is that great fish losses occur at the pumping station pumping 40 m^3 per second from Licheń into Ślesin Lake during summer. This problem is being further investigated.

4. CONCLUSIONS

The success of the Konin Project clearly demonstrates that the so-called thermal pollution problem can in fact be converted into a valuable natural resource. When the common interests of the thermopower authorities and the fishery authorities are recognized it is possible to obtain a cooperation from which both parties benefit. In the Konin Project this was realized from the very beginning and the positive results obtained will be utilized for future thermopower stations, the next project commencing in 1972. It is expected that cooling water from future thermopower stations in Poland will not be discharged to rivers or to coastal waters but utilized in lakes with biological control methods as in Konin. The magnitude of future undertakings is illustrated by the following: in the next ten years the discharge of cooling water in Poland is expected to increase from presently 200 to 700 m^3 per second and 10 000 ha of lakes will be utilized for cooling purposes.

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