QUESTIONS OF THE UTILIZATION OF THE DEAD-ARMS OF THE TISZA FOR FISHING PURPOSES PROBLEMS CAUSED BY POLLUTION

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Abstract

One of the possibilities for the development of fishing is the more intensive inclusion of the dead-arms of the rivers into fish-production. Because of the mass destruction of the fish which can occur in the dead-arms of the Tisza, however, fish-breeding there is risky. Such a loss of the fish has already taken place in practically all of the dead-arms, without pollution of extraneous origin. The cause of the destruction of the fish as a result of natural biological processes is hydrogen sulphide, formed as a product of sulphate reduction. It is also known that cases of such an origin do not occur in the dead-arms of the Danube, and thus the mineral composition of the mud, or more exactly the presence of lime, plays an essential role in the occurence or not of the lethal effects.

The dead-arms are at the same time important water reservoirs in the irrigation system. Accordingly, it can be understood that a problem of increasing importance recently is the pollution of the previously comparatively pure waters of the dead-arms. The waters discharged into the dead-arms include thermal waters used for the heating of factories and green-houses, which contain significant amounts of ammonium ion (5—10 mg/1) and phenol (1.7—2.3 mg/l).

Examinations were made to decide the question of whether the thermal waters can exert a direct or indirect deleterious effect on the quality of the water in the dead-arm, and harm the fish population. It was found that the above substances are diluted so much by the large mass of water in the dead-arm that the fish population is not harmfully affected, and the water is suitable for irrigation purposes. In those dead-arms where the eutrophication is in an advanced state, the destruction of the fish may be brought about by hydrogen sulphide, formed in the mud as a result of natural processes and released periodically, mainly as a consequence of climatic factors.

Possibilities of developing the area

There are two possibilities for the regional development of Hungarian fishing which have not yet been utilized to their full extent:

1. The conversion into fish lakes of sodic areas which are useless as regards agriculture, or at best are used periodically as pastures.
2. The more intensive utilization of the dead-arms for fishing purposes.

Although the two possibilities can not be distinguished sharply from each other with regard to the hydrobiological questions of the development, and indeed involve completely identical problems too, the present work deals with the hydrobiological questions of the utilization of the dead-arms only (these are restricted to the dead-arms of the Tisza), with the difficulties involved, and with the possible solutions.

Dead-arms of the Tisza

The waters of the dead-arms in the Hungarian section of the river Tisza occupy an area of several thousand hectares. Merely in the county of Csongrád the dead-arms at Csongrád, Felgyő, Mártély, Atka, Körtvélyes, Nagyfa and Gyála account for more than 700 hectares. The area of the three large dead-arms in the vicinity of Tiszaföldvár in the county of Szolnok is even larger. The colonizing and harvesting of fish is carried out on only in some of these dead-arms, and even not systematically. The main reason for this is that it is not guaranteed that the costs of the colonizing and harvesting will be returned. The maintenance of the fish life in the dead-arms has not been certain in the past; it is sufficient here to recall the repeated mass deaths of the fish in 1958 at Atka (DONÁSZY 1959) and in the dead-arm at Gyála. The risk involved in fish-farming is still further increased nowadays by the greater degree of pollution of the waters. The periodic destruction of the fish population has the greatest effect not on the sporting and recreational angler, but on the fishing-cooperatives.

A basic problem towards ensuring the maintenance of the fish life is the elucidation of the causes of the destruction. The clarification of these processes is an indispensable precondition in the activities of defence and avoidance.

Material and method

In the course of the investigations, use was made of the methods of MAUCHA (1930) and of the procedures given in the Collection of Water-examination Methods published in Jena in 1971. The Woker curves were used for the determination of free ammonia.

The establishment of the thickness of the iron sulphide-containing mud layer is an important factor in the determination of the total amount of hydrogen sulphide expected to be liberated from the mud. A thick-walled glass tube, 3.5 cm in diamater, was employed for this purpose. The tube was pressed vertically into the mud and then withdrawn with the mud inside it. The thicknesses of the upper, oxidized mud layer and the lower, black, iron sulphide-containing mud layer were measured, and samples were taken for the determination of sulphide (VÁMOS 1971).

Thin-layer chromatography was used for the demonstration of the organic compounds in the thermal waters.

Phenolic compounds which can give an unpleasant taste to the fish meat, were detected by the following procedure, as a direct method. A piece of the flesh, about 7—8 cm long and 1 cm wide, is cut from the side of the fish, put into a test-tube and covered with water. The test-tube is then heated over a gas flame. The vapour emerging from the tube after the commencement of boiling is tested by smell at frequent intervals; if the meat is contaminated by phenolic compounds, the smell of phenol is clearly perceived after 3—4 minutes.

Pollution of the dead-arms

Urbanization and the development of industry and agriculture have led to a significant increase in the quantity of waste waters. In many cases the outlets of the sewers are not in the living Tisza, but (perhaps fortunately as regards the quality of the river water) in the dead-arms. In such cases of course this pollution of external origin can be responsible for the death of the fish. However, such losses have also been known to occur (and recur) in dead-arms into which no waste water is discharged. Accordingly, in these cases the poisoning material must be produced in the dead-arm itself. That is, the natural processes taking place in the mud and water of the dead-arms can give rise to products harmful to the fish population. The

water courses flowing into the dead-arms can increase the eutrophication and enhance those processes which are of danger to the fish. Water courses able to enhance the eutrophic state are:

1. Thermal waters used to heat green-houses and industrial plants, the average oxygen consumption of which is 25—60 mg/l. They have a significant ammonium content of 10—14 mg/l, but their solid constituent contents are insignificant.

2. Water courses leading off industrial, town and agricultural waste waters: e.g. the Maty stream, which runs into the upper section of the dead-arm at Gyála. The pollution delivered by the Maty stream frequently includes material in the form of a fine industrial grease, which prevents the penetration of oxygen. This alone promotes the development of an anaerobic state.

3. The eutrophication can be increased considerably by nutrient materials such as nitrogen, phosphorus and potassium, washed in by rainfalls on the adjacent agricultural areas, and immediately utilized by the aquatic plants. The amounts of such nutrient materials are growing as a consequence of the more common use of artificial fertilizers.

Prior to a discussion of the increasing pollution, it is necessary to deal with the original water quality in the dead-arms. In this respect it is essential to understand the processes which can affect the quality of the water, and which determine it in those cases when no pollutants or nutrient material enhancing the eutrophication enter the dead-arm. The results of these investigations give the basis for a comparison of the effects caused by or attributed to the individual water courses in the event of the question of the responsibility of the water-pollution arising.

Original quality of the water of the dead-arms

The dead-arms came about on the regulation of the river, by the cutting-off of the larger bends and the construction of embankments. Two cases are possible for the connection of the river and the water in a dead-arm:

1. All contact between the river and the dead-arm ceased at the time of the regulation, but water from the river can enter the dead-arm on the occasion of flooding of the river. This can happen, for example, at Mártély and Körtvélyes.

2. When an appreciable amount of water, generally polluted, flows into the dead-arm from a sewer or stream, the surplus can only be passed on to the Tisza. The means of this depend on the level of water in the river. When the river water level is high, the transfer is accomplished by pump, but when it is low, the water is able to flow into the river by gravitation. Both forms of transfer are employed in the case of the Dead-Tisza at Gyála, which is mainly fed by water originating from Szeged, via the Maty stream.

After consideration of the utilization of the water and the most economical consumption of energy, the following practice has been adopted in the exchange of the water in the dead-arm at Gyála. During the winter, when the level of the Tisza is generally low, the water accumulated in the dead-arm is admitted into the river. At the time of the high-waters in spring, when the vast majority of the water, is the result of snow-melting, the dead-arm again fills up. This water, however, is excellently suited for irrigation purposes.

Today, therefore, the dead-arm can be regarded as a long standing-water, broken up by cross-dams, where exchange of the water is carried out annually. Culverts

and sluices ensure the movement of water across these cross-dams. The transfer of the water is never perfect, however. The mud here is not aerated to the sam extendt as occurs every year, systematically, in the case of a well-built and well-ehandle fish-lake. In those parts where the bottom of the bed remains covered by water, or the mud is saturated with water, the oxidation processes which are of extreme importance from the point of the aquatic life, including that of the fish, and which can be ensured only by the penetration of air, do not take place. As a consequence, the standing-water character of the dead-arm becomes more pronounced than that of the fish-lakes, and is more similar to that of natural lakes. The changes occurring in the standing waters, which govern the fishing activity and the provision of the nutriment for the fish, are closely related with the nature of the mud and its organic and mineral composition. The principle holds here that the fish lives in the water, but feeds from the mud. The fact that the mineral composition of the sediment is an important controlling factor in the intensity and regulation of the biological processes is demonstrated most strikingly in the dead-arms of the Tisza and the Danube. The natural mass-destruction of the fish such as is observed in the case of the dead-arms of the Tisza is never found in the dead-arms of the Danube. We shall see that this is connected with the mineral composition of the bottom of the bed

Mineral composition of the sediment in the river and the biological processes

The Tisza has cut and changed its bed in its own deposit; the bed became finalized only az the time of the regulation. However, there is an essential difference between the qualitative compositions of the alluvia of the Tisza and the Danube. It is necessary to know here that the limy alluvium of the Danube approaches the Tisza near Szeged (at Kiskundorozsma). In contrast with the Danube, which descends from the Alps, the Tisza contains no, or only a very little lime in its deposit. The deposit of the Tisza is much richer in iron, and with time the amount of iron passing into solution by the action of the electrons produced by the bacterial respiration is still further increased during the subsequent soil-formation. The quantity of iron washed in from the neighbouring, agriculturally cultivated areas is higher than ever observed in the mud of the dead-arms and in the soils formed on the deposit of the Danube. This large amount of iron plays a substantial role in the binding of the hydrogen sulphide produced by the action of bacteria in the mud, and in the accumulation of sulphide in the form of iron sulphide. These features, the abundance of iron and the absence of lime, exert a controlling influence on the biological processes, on the transformations of the products of these, and thus on the effects of the compounds formed on the life of the environment.

The process in which the effects of the mineral components are expressed most markedly is the bacterial sulphur cycle proceeding in the mud and in the water layer, i.e. the microbiological and the following abiotic transformations of the sulphur compounds. This process is closely connected to the cyclic turnover of the other organogenic elements and is one of the main regulators of the quality of the water.

The bacteriological processes occurring in the mud at the bottom of the lake or deam-arm, and the mineral and organic matter composition of the mud, have previously not been sufficiently considered in the development of the quality of the water. Accordingly, the changes observed in the course of continuous water-

examinations have not been explained. Nor has light been thrown on the causes of the mass death of the fish.

Depending on the quantity and quality of the organic matter in the mud of the dead-arms, and also on the temperature, the oxygen-consumption of the bacteria multiplying there can give rise to anaerobic conditions. The electrons produced by bacterial respiration reduce the manganese and iron oxides in the mud, and in consequence the amounts of manganese and iron which can be dissolved by the mud solution increase (Figure 1). Where there is much manganese *Trapa natans*
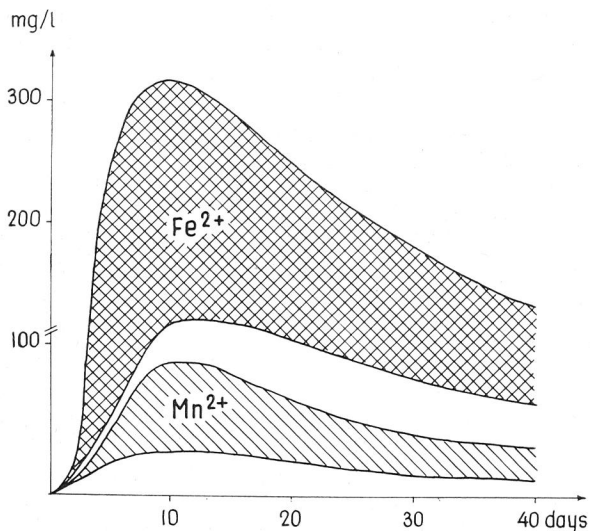

Fig. 1. Increase of the amounts of Fe^{2+} and Mn^2_+ in the mud of the dead-arms of the Tisza. Model experiment.

is extremely prolific; about half of the mineral content of the produce of this is manganese. In this environment, where the anaerobic decomposition mainly of plant residues proceeds at a redox potential of $Eh_0 \sim 0 \, mV$, the sulphate-reducing bacteria multiply, the oxygen demands of which are provided by the sulphate ions. The two products, sodium hydrocarbonate and hydrogen sulphide, are important factors from both pedological and limnological points of view as regards the further biological processes of the water. Thus:

1. On the decrease of the intensity of the decomposition of organic matter, and the accompanying decrease in the amount of carbon dioxide produced, the hydrocarbonate, which is converted to soda, increases the alkalinity of the water, i.e. the pH value. This circumstance indirectly promotes the formation of free ammonia which, as a respiration poison acting on the central nervous system, can lead to the death of the fish if it attains a concentration of 0.2 mg/l.

2. As a general cell, enzyme and nerve poison, the other product, hydrogen sulphide, can be harmful to the fish life both directly and indirectly. Via its poisoning action it reduces the fish population directly, while by destroying the living fish-food it can inhibit the growth of the fish.

Assessment of the changes in the waters of the dead-arms is facilitated by the fact that examination data obtained over several decades are available in this respect.

Perhaps the most valuable of the investigations relating to the earlier composition of the waters of the Tisza and the Körös are those of SCHICK (1934).

In 1955 the following results were obtained for the dead-arm at Gyála (which was cut of from the Tisza in the eighteen-nineties) and were compared with those for the water of the living Tisza. The results are worthy of attention, for at that time the industrial zone of Szeged beside the main road to Budapest did not exist, and thus the Maty stream delivered much less pollutant matter into the dead-arm. A proportion of the organogenic elements are washed into the dead-arm from the intensively cultivated gardens and agricultural land in the direct vicinity, by the action of the rainfall. As can be seen from the data of Table 1, there have been significant increases in the amounts of sodium, calcium, magnesium, hydrocarbonate and sulphate ions in the water of the dead-arm. Industrial contamination is not always necessary, therefore, for an increase in the amount of sulphate, as it can also appear as a consequence of a natural process. The more rapid increase in the quantity of sulphate ion to be found in the standing waters in Hungary today is rather a consequence of the industrial contamination. The presence of carbonate is a typical lacustrian hydrobiological phenomenon. All these changes are in the main the results of sulphate reduction. Unfortunately, the data relating to the mud from that period are not available.

The main factors involved in the changes taking place in the water of the dead-arm are the composition of the running water used to fill the dead-arm, the total organic matter content of the mud, and the temperature, which controls not only the evaporation but also the intensity of the decomposition of the organic matter.

Since the very small amounts of the products of nitrate and phosphate reduction are negligible in comparison with the products of sulphate reduction, from the point of view of fishing the quality of the water in the dead-arms is affected most by the above two products, soda and hydrogen sulphide.

The possibility of the destruction of the fish in the dead-arms of the Tisza due to the action of ammonia

In the evaluation of the qualitative effects, the first task is to assess the possibility of the danger of free ammonia.

When filled up at the time of the spring flood, the water of the dead-arm has a pH of 7.0—7.2. Depending on the decomposition of organic matter and on the intensity of the reduction processes, this value can rise to about 7.5—7.8 in the course of the summer. The data available indicate that in the nineteen-sixties the pH approached a value of 8.0 only in rare cases, while in the period 1955—1958 the pH remained successively below 7.8. Since the Woker curves show that at a pH of 7.8 and a temperature of 20 °C in summer 3 % of the total NH_4 is converted to free ammonia, the water should contain 7 mg NH_4 per litre in order that the free ammonia might attain a toxic level. However, such conditions have not developed to date; in summer there has never been such a high water pH or such a high NH_4 ion content in the water of the dead-arms that the destruction of the fish has been attributed to the formation of free ammonia. The amount of NH_4 ion measured in the dead-arms in summer varied in the range 0.6—1.1 mg/l. This relatively low ammonium ion content can be explained by the nitrogen uptake of the algae and the high-order aquatic plants. The lowest ammonium ion concentrations,

0.3—0.4 mg/l, were measured in May—June, the periods of vegetative development of the aquatic plants. Since the destruction of the aquatic plants, the so-called reed-grass destruction, in the dead-arms does not attain the extent characteristic of certain fish lakes, the destruction of the fish in this indirect way is not a threat either.

The destruction of fish by the action of hydrogen sulphide in the dead-arms

Th other product of sulphate reduction, hydrogen sulphide, reacts with the iron ions in the mud solution and, as long as the solution contains iron, is immediately bound. The resulting iron sulphide colours the mud layer black (Figure 2). The

Fig. 2. The bank-side mud, black from iron sulphide, is covered by a thin, oxidized layer.

thickness of the black layer therefore indicates the accumulated iron sulphide, and from a knowledge of this the amount of hydrogen sulphide liable to be liberated can be estimated.

The sulphide content of the iron sulphide layer is on average 10—30 mg S^{2-}/100g. There are cases, which are particularly frequent in the dead-arms of the Körös, when it attains, and even exceeds 100 mg S^2/100 g. This usually occurs, however, only at the upper end of dead-arms into which waste water is introduced, or where organic refuse matter is used to fill up the dead-arm.

The hydrogen sulphide thus accumulates in the mud in the form of iron sulphide. In this form it is not harmful to living creatures, and the worms in the mud, including *Tubifex*, develop undisturbed. It only becomes dangerous when molecular hydrogen

sulphide is released in large masses from the iron sulphide. In the case of the dead-arms, there are two main periods for this:

1. One of these is the summer, or more exactly the second half of August, when the first rapid cooling-down and air-pressure decrease occurs following a prolonged hot period of uniform air pressure. One typical example of this is the destruction of fish at Atka on 18—23 August 1958 (DONÁSZY 1959), but at the same time there was a similar occurrence in a section of the dead-arm at Felgyő. The rapid temperature and air-pressure decreases on 18 August 1958 also promoted the release of hydrogen sulphide and the resulting poisoning of the fish elsewhere, for instance in the fish lakes at Kelebia and in the lake at Palics.
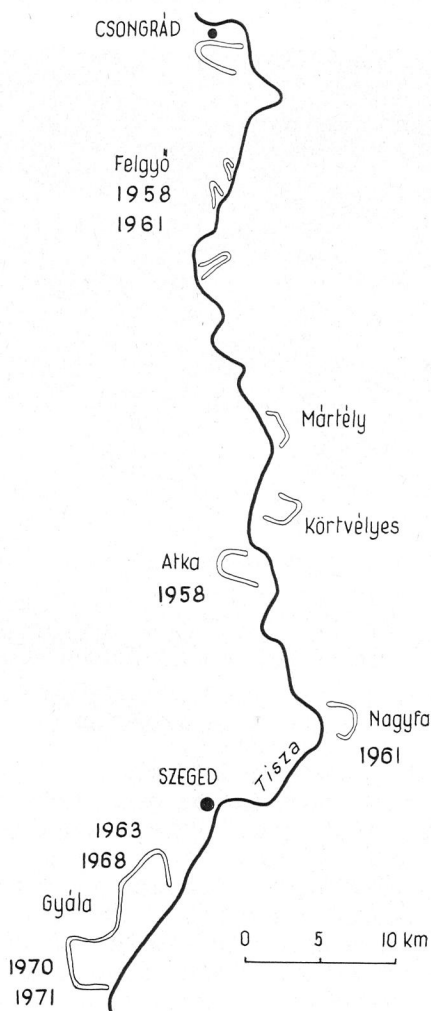

Fig. 3. Dead-arms of the Tisza in the county of Csongrád. The years are those involving destruction of the fish.

2. The other period is the beginning of winter, when the temperature suddenly falls from the comparatively high 6—10 °C to below the freezing point. The surface of the water freezes, and thus the hydrogen sulphide released from the mud can not escape into the atmosphere. Such a case was involved in the destruction of the fish in the lake at Grébics, the weather factors of which were described by VESZPRÉMI (1964).

In both cases, therefore, fish destruction can occur, the onset of this being closely connected with the weather conditions. It has been observed only in certain years, when the weather had been favourable for several years with regard to the accumulation of a considerable amount of iron sulphide, and similarly the conditions which arose permitted the release of a large mass of hydrogen sulphide at a high rate. The two main factors in the weather which play an important role in the formation, release and accumulation of hydrogen sulphide are the changes in air pressure and temperature (VÁMOS 1964).

On the basis of our experience to date, it can be concluded that the iron sulphide accumulates in the mud as the product of several years' bacterial sulphate-reduction. The reason is that on the cooling-down in autumn and winter not all of the sulphide is oxidized. The rate of the oxidation also depends on the proportions of the clayey constituents of the mud. The larger the quantity of clay, the more protracted the drying-out, and hence the slower the change in the anaerobic → aerobic conditions. An iron sulphide zone always remains in mud saturated with water. When continuously hot summers follow one after another, and there are no significant differences in temperature and air pressure, the thickness of the reduction layer increases, and with it the amount of sulphide in it. Under such conditions, and depending on the weather changes, the occurrence of the mass death of the fish is to be expected. It is understandable that it is now known when the destruction of the fish occurs en masse in almost every dead-arm of the Tisza. Similar phenomena also occur in the dead-arms of the Körös. One of the most extensive such poisonings of the fish by hydrogen sulphide took place in the dead-arm of the Körös at Endrőd in 1968. Figure 3 shows the dead-arms of the Tisza in the county of Csongrád, together with those years in which the mass death of the fish ensued in them.

The course of the destruction of the fish
in the dead-arms

Study of the destruction of the fish by hydrogen sulphide is much more fruitful in the dead-arms than in the fish lakes. The beds of the dead-arms are about 100 m wide, and my be even 5—10 km long. Observations to date indicate that the destruction of the fish does not begin at the same time everywhere throughout the entire bed section, but generally commences at the upper end and proceeds in the direction of the earlier flow. As it spreads further it gives the impression of being caused by some infectious microbe. The destruction thus takes several days, that at Atka, for instance, lasting for 5 days. All five sections of the dead-arm at Gyála, which is split up by cross-dams, count as separate lake-units, and the destruction of the fish in these has taken place in different years and in different seasons. The penetration of the oxygen required for respiration, and the escape of hydrogen sulphide, are inhibited at the time of the death of the fish in summer by the oxygen consumption of the algal mass on the surface of the water (water-blooming), and in the winter

by the ice cover. In winter, however, when the oxygen content of the water is high, the hydrogen sulphide is oxidized and the elemental sulphur is precipitated in a colloidal form resembling milk, which colours the bottom of the ice or the water a characteristic sulphur-yellow (Figure 4).

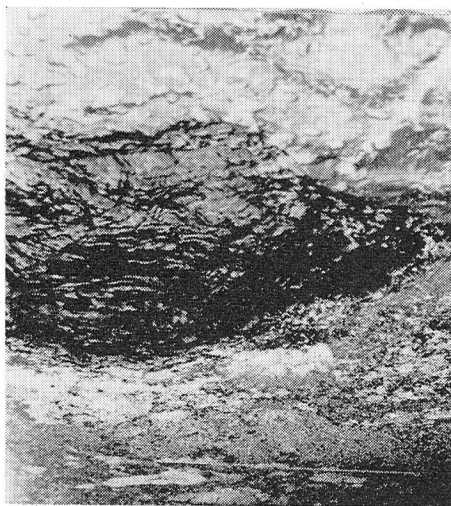Fig. 4. The separation of sulphur colours the water a yellowish-green.

Fig. 5. The mud contains gases even in the middle of the bed.

The role of the air-pressure decrease

On the rapid decrease of the air pressure, the gases in the mud (CO_2, N_2, CH_4, H_2S) rise to the surface. The ascending gas bubbles carry up fine particles of mud with them (Figure 5) and the water becomes disturbed. As the fisherman then says "The bottom of the water is upset". The oxygen content of the water decreases. The fish float about under the surface and then begin to gasp for breath.

The accumulation of hydrogen sulphide in the water layer

Our observations so far indicate that the gaseous hydrogen sulphide can accumulate in the mud and enter the water layer in two ways:

1. Climatic effects lead to the rapid release of hydrogen sulphide from the iron sulphide formed as a result of sulphate reduction.

2. In iron-poor mud the hydrogen sulphide accumulates in the form of gas bubbles, and only on the fall of the air pressure or the artificial disturbance of the mud does it rise into the water layer and from there into the air, where its smell becomes apparent. This phenomenon is characteristic only of lakes with alkaline water and limy soil, e.g. at Kunfehértó.

In the dead-arms of the Tisza only the first process is known, i.e. the rapid release of the gas from iron sulphide. The cooling-down, which is a regular fore-runner of the release of hydrogen sulphide, is accompanied by the oxidation of the

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Table 1. *Analysis of the waters of the river Tisza and the dead arm of Tisza at Gyála, from the time when there was no water-exchange*

	Dead-arm at Gyála	River Tisza	
	1954	1931	1954
		mg/1	
Ca^{2+}	51,49	37,0	28,5
Mg^{2+}	28,58	4,5	7,7
Na^+			
K^+	137,82	20,0	23,06
Fe^{2+}	0,26	2,5	0,33
Cl^-	41,20	17,5	7,20
SO_4^{2-}	146,28	17,0	25,15
CO_3^-	19,05	—	—
HCO_2^-	408,58	137	119,26
PO_4^{3-}	0,03	—	0,01
SiO_2	10,40	—	0,05
Total organic matters	10,96	—	3,59
Total salts	880,00	—	210,00
pH	7,6	—	7,2

surface iron sulphide to sulphuric acid, and it is this strong mineral acid which sets the gas free (VÁMOS 1964, STARKEY 1966). The death of the fish always begins in the more shallow end of the dead-arm. This is understandable, for this is where the hydrogen sulphide is liberated first as a result of the earlier oxidation of the iron sulphide in the shallower water, while in addition the smaller volume of water present means that the hydrogen sulphide attains a lethal concentration more quickly.

For the assessment of the danger of hydrogen sulphide release, it is indispensable to determine the thickness of the mud layer containing iron sulphide. The thick-walled glass tube described in the Methods section is excellently suited for this. From the analysis of the samples it was established that the sulphide content below the redox level is always higher than in the deeper levels. The decrease, however, is not always gradual. An important factor in this may be the organic matter and total nitrogen content of the mud. This can be exemplified by the analyses of samples taken in two different places (Table 2).

Table 2. *Vertical decrease of the amount of S^{2-} in two mud samples*

Deepness cm	Dead-arm at Gyála	Dead-arm at Mártély
	S^{2-} mg/g	
0,5—1	7,8	3,5
1—3	6,6	2,8
3—5	4,9	2,4
5—8	2,7	0,7
8—11	2,1	0
11—13	0,4	0

The physiological effect of hydrogen sulphide

The amount of hydrogen sulphide which leads to the death of carp within a short time is about 0.4—4.0 mg/l. Unfortunately, there are no data referring to predatory fishes. The sequence of sensitivity is the following: bream, pike, pike perch, silurus, tench, carp, crucian, bull-nosed pout, loach. A number of factors affect the lethal concentration: the state of health, the pH of the water, its temperature, its oxygen and salt contents, the quantity of suspended colloids, etc. It is to be understood, therefore, that it is a difficult task to denote an exact lethat concentration of general validity. Hydrogen sulphide primarily paralyzes the respiratory centres. As a result, the gills of fish suffering from the effects of hydrogen sulphide are a lilac colour because of the accumulating carbon dioxide. If a fish which has recently sunk to the bottom is placed in fresh, oxygen-rich water, it regains consciousness and remains alive. The open gill-covers of unconscious fish sinking head-downwards to the bottom are often impaled (like an arrow) in the mud, and hamper the ascent of the decomposing fish to the surface.

If the hydrogen sulphide does not attain the lethal concentration, the carp reacts in a different way to the continuous poisoning effect. Before this is described it is necessary to know that in pure tap water the carp loses its appetite at an oxygen concentration below 4 mg/l. Under conditions of insufficient oxygen supply the toxic concentration of hydrogen sulphide is lower. Because of the inhibiting effect of hydrogen sulphide on the respiration, the fish may be observed gaping on the surface even when the oxygen content of the water would be enough for respiration.

It was also found that as a result of the continuous effect of sublethal concentrations of hydrogen sulphide the red blood cell count progressively decreases. A count of about 6—700,000, in place of the normal 2.1—2.3 million, is the minimum that the fish can still endure for a prolonged period. As a consequence of the considerable anaemia and blood-supply disturbances, the internal organs lose their colour completely.

It was established that at a hydrogen sulphide content above 2 mg/l the carp does not spawn. Since hydrogen sulphide has never been observed in the waters
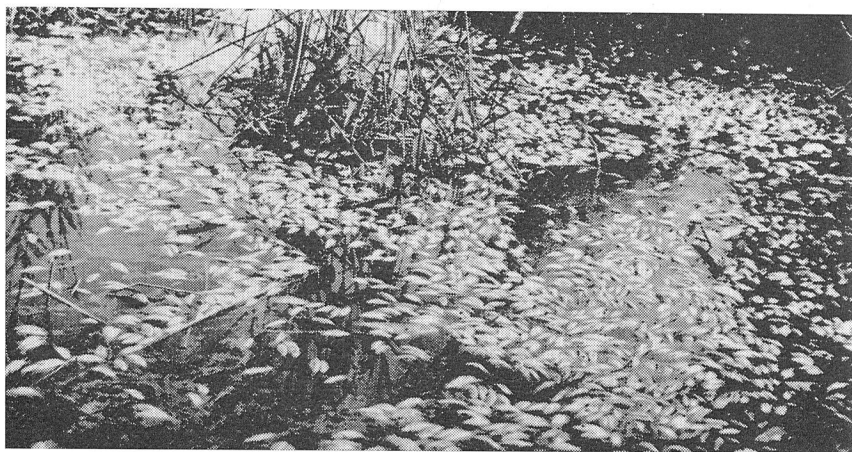

Fig. 6. Mud particles containing iron sulphide adhere to the gas bubbles ascending from the disturbed mud.

of the dead-arms at the time of the spring spawning, the latter is not disturbed in any way.

The different fish species are not uniformly sensitive to hydrogen sulphide. It follows from this that, depending on the concentration of the poison, there can be various levels of destruction. For example, a case is known from the upper section of the dead-arm at Gyála when only the bream died, but all the other species survived. At the same place, but in a different year, however, not only large numbers of bream were destroyed, but also the predatory fish, among them the pike perch. In the case of apparently total destruction, the carcases of practically every type of fish can be seen on the surface of the water, mainly near the banks or washed in among the reeds (Figure 6).

In spite of appearances, however, not all of the fish are destroyed, for the hydrogen sulphide does not attain the lethal concentration in the whole of the dead-arm at the same time. The release of the poisonous gas is not instantaneous, and this is the reason why certain of the fish remain alive even when it appears that the destruction is complete in the dead-arm and that all the fish are dead. The growth of the fish which remain alive after hydrogen sulphide poisoning is faster than at other times, in contrast with cases of ammonia poisoning, after which the growth is always more drawn-out.

The effect of hydrogen sulphide on the taste of the fish meat

In several cases of the poisoning of fish by hydrogen sulphide, examinations were made to determine whether hydrogen sulphide can cause a perceptible change in the meat of the fish, detectable on its consumption. As it has no charge, hydrogen sulphide can penetrate the cell wall almost without hindrance. It diffuses in the tissues about 100 times more quickly than does oxygen. Our experience to date on the effects on the taste of the fish meat is as follows:

When the destruction occurs in winter, when the respiration is slow, the absorption of the hydrogen sulphide is more protracted. The fish can endure a given concentration of the poison for a longer time in winter than in summer. The cause of this is presumably that the amount of oxygen dissolved in the cold water is at least double (8—10 mg/l) that to be measured in the summer. At such time no unpleasant side-taste can be detected in the meat of the fish.

On the cooling-down in summer, on the other hand, it can happen that the fish stir up the mud of the fish-bed, and may then spend even several days in this hydrogen sulphide-containing slime until they are removed. The death of the fish can then easily occur, but even in the case of the fish remaining alive, the danger exists that the meat of the fish will absorb hydrogen sulphide and other compounds dissolved in the mud. This can give rise to the meat having a characteristic swampy taste, which in many cases is confused with the taste of phenol. Such a case occurred in the dead-arm at Gyála in December 1972, when the fish remained in hydrogen sulphide-containing water in the dead-arm about 3—4 weeks. This long period entailed such a large quantity of hydrogen sulphide penetrating and being accumulated in the meat of the fish, that its later consumption afforded no pleasure. During the first 14 days of the fishing the meat and its taste were of an excellent quality.

If a young fish undergoes the shock of hydrogen sulphide poisoning and successfully recovers, then later it does not succumb to a similar concentration of the poison.

The effect of thermal waters on the quality of the water in the dead-arms

Deep-borings carried out for various purposes in the vicinity of the Tisza have produced significant quantities of thermal waters varying considerably in composition. These are used in part as medicinal bathing waters, but also to heat houses, factories and green-houses. These waters are excellently well suited for this, as their temperature often exceeds 80 °C.

A still existing problem in connection with the utilization of thermal waters, however, is the leading-off and disposal of the "spent water" from the heating system. If these are admitted to a reservoir, such as a dead-arm, where there is a fish population, they may give rise to changes endangering the fish, or even kill them. In certain cases changes and unpleasant tastes in the meat of the fish have been attributed to the effects of thermal waters.

Sinces disputes have arisen between plant-producing cooperatives utilizing the thermal waters and the fishing cooperatives which make use of the dead-arms into which the thermal water is discharged, it appears necessary to clarify this question. For instance, the death of the fish in the dead-arm at Gyála in December 1972 was ascribed by the fishing cooperative there to the properties of the thermal water.

Examinations were therefore carried out to decide the question of whether the physical and chemical properties and the amount of the thermal water entering the dead-arm can lead to changes in the health of the fish and in the taste of the meat, or even bring about their death, and if so, then to what extent.

The results and experience emerging from these examinations can be classified into three groups:

1. The original properties of the "spent" thermal water, established from samples taken from the channel section prior to the outlet into the dead-arm.

2. The original properties of the water in the dead-arm or reservoir, and the periodic changes in these.

3. The physical, chemical and biological changes to be attributed to the thermal water in the water of the dead-arm, and which can be interrelated with the harmful effects on the fish.

The subject of a dispute is overall connected with the above changes. Our examinations to this end, and similarly our experience relating to the utilization of the dead-arms will be summarized below.

The examination of thermal waters

Although the already reported quality of the initial water of the reservoir is the most important factor as regards the fish life, analysis of the thermal water discharged into the dead-arm provides information not only on the components which are present in larger amounts, but also on the small quantities of organic compounds which give perhaps an unpleasant taste to the meat, and which are much more difficult to detect when diluted by the large mass of water into which they are discharged.

The data of an examination of the thermal water flowing into one dead-arm, the analyses of samples taken from the effluent tap at the end of the heating system, are given in Table 3. Although the water discharged from the heating system in

Table 3. *Exhange of the thermal water in the heating system*

Samples	pH	Ca^{2+} mg/l	Fe^{2+} mg/l	CO_2 mg/l	Total hardness $G°$	O_2 con-sumption mg/l	SO_4^{--} mg/l	S^{2-} mg/l	Alkalinity m-val/1	NH_4^+ mg/l
Original thermal water	8,0	7,00	0,06	36	1,2	64,0	76,7	0,36	49,2	13,2
At the wastepipe	8,3	3,45	0,26	18	0,48	60,3	29,6	1,7	48,0	9,7

many cases reaches the Dead-Tisza arm at Gyála only after passing through several kilometres of channels, the changes reported below are those which occurred in the first step, i.e. in the heating system itself.

Increase of the pH

The increase of the pH is partly a consequence of the decrease of the carbon dioxide pressure, but it is presumable that a more important role here is played by the sulphate reduction. The increase of the pH can be seen clearly in the case of 5 water samples taken from thermal water used to heat green-houses. The rise in the pH of the thermal water samples, taken from different sites, on standing for 30 days at room temperature, is shown in Table 4.

Table 4. *Increase of the pH of thermal water in contact with the air*

	pH			
Number of sample	0	6	18	29
	days			
I.	7,4	8,2	8,9	9,5
II.	7,5	8,4	9,0	9,6
III.	7,5	8,5	9,1	9,7
IV.	7,6	8,5	9,1	9,7
V.	7,4	8,4	8,8	9,4

The reason for the alkalinification to be observed in the Table is that the sodium hydrocarbonate is gradually converted to sodium carbonate, which undergoes dissociation to yield sodium hydroxide. Later, in the open system, where the carbon dioxide can escape moro easily, only the transformation of hydrocarbonate to carbonate is responsible for the rise in the pH value.

The decrease of ammonium ion observed in the pipe system is presumably a consequence of the nitrogen-consumption of the sulphate-reducing bacteria. The ammonium ion is the only source of nitrogen for these bacteria, for they are unable to utilize nitrate nitrogen, which in fact is a poison for them.

Decrease of the sulphate ion, and formation of hydrogen sulphide and sulphides

The most striking change within the closed system is the decrease in the amount of sulphate ion; the initial sulphate content, 60—80 mg SO_4^{2-}/l, is more than twice the sulphate concentration of the water discharged from the system. The cause of

this is bacterial sulphate reduction. As a consequence of this, samples taken from those parts of the heating system where the water stagnates of flows only slowly contain 2.3—7.7 mg S^{2-}/l, mainly in the form of iron sulphide. The sulphate-reducing bacteria (Desulphomaculum nigrificans) multiplying here can endure temperatures in excess of 80 °C (POSTGATE 1966), and reduce sulphate in order to satisfy their oxygen requirements. A role may be played in the food-supply of the sulphate-reducing bacteria by the dissolved organic matter content of the water, which frequently exhibits an oxygen consumption of 50—60 mg/l, but an even more important role may be that of the polarized water molecules on the surface of the metal. The sulphate-reducing bacteria are able to use the hydrogen atoms of this water as an energy source.

A chromatographic procedure revealed indole derivatives in the initial water, these being responsible for the unpleasant taste and smell of the water.

It can be concluded from the above results that the changes occurring in the heating system are not sufficiently large for exception to be taken to the original water from an ichthyophysiological aspect after its dilution by the great mass of water in the dead-arm.

Appropriate utilization

Independently of whether the thermal waters discharged into the dead-arm contain compounds harmful to the fish, possibilities arise for the utilization of the water by both plant producers and fishermen.

The gardeners begin the heating for the production of their early fruit and vegetables at the end of October and in November. By this time, however, the fishermen have generally completed their harvesting. One factor making this difficult is the high level of the river in autumn, for this prevents the discharge of the wa er in the dead-arm and, similarly as in fish lakes, this is the procedure employed in the fishing of the dead-arms, when possible. Fishing in the dead-arms must be performed earlier than in the fish lakes, for the bottom of a dead-arm is not very uniform. In addition, frost and an ice-cover involve many more difficulties than in the fish lakes.

In the lakes of the dead-arm at Gyála, the letting-out of the water is considerably promoted by the trench at the middle of the dead-arm, dug out parallel to the bank. This facilitates not only the lead-off of the water, but also the catching of the fish.

When the dead-arm at Gyála is filled up with the excellent water from the Tisza in spring, the thermal water is diluted by a minimum of 650—850 million litres of river water. After such a considerable dilution, the ammonium content of the thermal water (initially 6 mg/l) is no longer harmful, but it does improve the poor nitrogen-supply of the Tisza water. The daily amount of ammonium nitrogen contained in the thermal water discharged into the dead-arm section is 7—11 kg, which (calculating for an area of 30 hectares) corresponds to a weak fertilization. In spring the ammonium content of the water of the Tisza is at most 0.4—0.6 mg/l. The favourable nitrogen-supply is an important factor in the multiplication of the zooplankton serving as living fish-food. The unexpectedly large multiplication of the zooplankton in fish lakes filled with Tisza water and treated with ammonium sulphate (Szeged State Farm) led to the increase of the natural yield. A detailed study of this is in progress, but requires examinations over a number of years.

With regard to the pH and ammonium ion concentration in the period of

feeding and development of the fish in the dead-arm at Gyála, our investigations indicate that these do not and can not attain levels toxic for fish. The death of fish due to ammonia poisoning has not been observed in the dead-arms. The same holds, but to a greater extent, for the phenolic derivatives descharged into the dead-arm with the effluent waste-water. The dilution of the phenol content of 1.7 mg/l means that it can never attain the lower limit of toxicity, 4—5 mg/l, and nor can it be the source of a perceptible change in the taste of the fish.

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