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By G.G. Vinberg and V.P. Lyakhnovich

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THE FERTILIZATION OF FISH PONDS

by

G.G. Vinberg & V.P. Lyakhnovich

Preface

In pond piscicultural practice fertilization is one of the most effective methods of increasing the fish yield of ponds. Accordingly, much research has been devoted in recent years, both in the Soviet Union and abroad, to the study of various aspects of the complex effect of fertilizers. Hitherto, however, the data amassed have not been generalized or adequately utilized for the formulation of a theory of the effects of fertilizers. Such information is sorely needed by pisciculturists, who are concerned with discovering the most effective and economical ways of increasing production.

The sharp increase in the production of artificial fertilizers in the Soviet Union has given added urgency to the problem. By 1966 the output of artificial fertilizers in the USSR will be 39,200,000 metric tons, and towards 1970 the figure will be as much as 70-80,000,000 metric tons. Thus it will be possible to use fertilizers in much greater quantities to increase the productivity of pond fishes.

The development of the domestic artificial fertilizer industry, which is aimed at intensifying the production of food-stuffs is just as important for pond pisciculture as for agriculture. To make effective use of the new possibilities for intensifying fish breeding through the use of artificial fertilizers we must hasten to determine the scientific principles underlying the fertilization of fish ponds.

On the strength of the results of their own research and published data the authors have set themselves the task of showing what progress has been made with the problem and determining the direction of future studies and the prospects of pond fertilization. To achieve this aim it proved necessary to go beyond the piscicultural criteria of the effect of fertilization and to draw widely on the results of hydrochemical, hydrobiological and other research, which is of prime importance for an understanding of the laws governing the action of fertilizers in ponds. Great attention was devoted to generalization of the results of the research and pond fertilization practice in countries abroad, since this question has been insufficiently discussed in the Soviet literature.

Chapters I (sections 1-4), II and III were written by G.G. Vinberg, and chapters I (sections 5 and 6), IV, V, and VI by V.P. Lyakhnovich. N.I. Chigiri helped to write section 4 of chapter II.

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Authors

CHAPTER I

Pond Fertilization at the Present Time

1. Introduction

Artificial and organic fertilizers are one of the most important means of increasing the productivity of fish ponds. As fish culture is intensified the quantity of artificial and organic fertilizers added to the ponds grows, and hence it becomes increasingly important to gain an understanding of the laws governing the effect of these fertilizers on the fish yield of a pond. There is a growing need for a statement and generalization of the principal results of research conducted in this field to formulate a theory of the action of fertilizers. Such a theory would be a most effective guide to their use.

The early results of the use and study of pond fertilization in the USSR and the theories then entertained on the subject were discussed in the book by M.I. Arnold (1941), in the textbook by A.N. Eleonsky (1946), and in the well-known manual on general hydrobiology by S.A. Zernov (1934). At that not so remote time the main theoretical generalization was the theory taken from the Germans (Demoll) of non-nitrogenous fertilization of ponds, under the influence of which most attention was directed to the superphosphate fertilizer.

At the end of the forties the idea of "complex intensification of pond pisciculture" (Movchan, 1948) came into vogue in the Soviet Union and this stimulated the use of organic and mixed fertilizers in ponds, with denser stocking and intensified feeding. The achievements of the leading producers, and scientific studies in the post-war years, the chief results of which will be examined later, brought considerable success both in the construction of a theory of the effect of pond fertilizers and in fertilization practice in the Soviet Union.

The most important Soviet and foreign papers on pond fertilization published up to 1950 are cited in the paper by G.G. Vinberg (1952). A weighty, though bibliographically incomplete survey of the literature on the fertilization of /6/ ponds and lakes was published in England in 1954 (Mortimer). In the same year appeared a summary of the literature on the fertilization of lakes and ponds in the USA (Maciolek, 1954). The literature on the fertilization of ponds and related problems prior to 1955 was also cited by V.I. Zhadin (1959). In this book the author dwelt mainly on new achievements in pond fertilization and recent research. The use of fertilizers, and their study, developed chiefly on an empirical basis. Nevertheless, a certain role was also played by theoretical ideas on the principles underlying their action.

The theory of the fertilization of ponds, closely linked with its successful application in pond pisciculture, is at present under very intensive and fruitful study in the Soviet Union. Pond fertilization practice abroad and the theories devised reveal two main trends, one of which was established in the twenties in Germany and the other more recently in the USA.

The Germans devised the theory of non-nitrogenous fertilization of ponds, according to which ponds fertilized by superphosphate or other phosphorus compounds do not require nitrogenous fertilizers. It was assumed that phosphorus fertilizers intensify the bacterial fixation of free nitrogen to such an extent that there is no need to add nitrogenous fertilizers. Thus, superphosphate emerged in the role of the "universal fertilizer". In addition, the proponents of non-nitrogenous fertilization regarded artificial nitrogenous fertilizers as unprofitable, and not merely on account of their relatively high cost. They considered it pointless to add mineral compounds of nitrogen to the pond because of supposed intensive denitrification processes leading to the irretrievable loss of the nitrogen introduced into the pond. An important element of the theory of non-nitrogenous fertilization was formed by the speculative ideas advanced by German authors concerning the "soil laboratory", overemphasizing the role of the silt sediments of ponds in the useful effect of fertilizers. From these ideas flowed the practical recommendations typifying the German school, i.e. that mineral fertilizers should be applied to the bottoms of unfilled ponds, and the denial of the advantages accruing from repeated applications to the water.

Pond pisciculturists in Germany have also been using organic fertilizers (manure and others) for a long time, but the way in which they act has not been systematically studied.

In the USA the practice and theory of pond fertilization have developed quite differently. There, pond fertilizers began to be used much later than in Europe (about 1930), /7/ and the study of this question followed an independent path neglecting the experience of European countries. Typically, European fertilization practices and the corresponding theories in American piscicultural literature were first discussed in a review paper by Neess (1949) only thirteen years ago. In the same way Europe also ignored American practices and research, and they were examined even later (Vinberg, 1952).

In sharp contrast to the European traditions of non-nitrogenous fertilizers applied once or twice and in relatively small quantities, in the USA the prevalent practice is to use high doses of nitrogen, phosphorus and potash fertilizers, introduced repeatedly into the water. American theories of the action of fertilizers hardly take into account silt sediments and emphasize the direct effect of the fertilizers on the development of phytoplankton.

The methods of fertilization recognized in the USA are based on recommendations made by Smith and Swingle on the strength of the results of their experiments conducted since 1934 on trial ponds in the state of Alabama (Swingle, Smith, 1939, 1941; Smith, Swingle, 1939, 1940, 1941, 1942, 1943; Swingle, 1947).

Swingle and Smith, and subsequently the overwhelming majority of American authors (cf., for example, Rounsefell, Everhard, 1953), show a decided preference for artificial as against organic fertilizers, since it is easier to control their nutrient composition and they do not have undesirable side effects on the oxygen regime. Although liming is used in the USA to neutralize excessively acidic waters, it is not given the same importance as in the European countries.

The difference in the fertilization methods used in the USA and in European countries (Czechoslovakia, Poland and others) cannot be explained either by the natural conditions, which on the whole are fairly similar, or by the form of pond pisciculture, which, though differing strongly, does not alter the biological action of the fertilizers. Thus we have a picture

of an independent, predominantly empirical development of fertilization methods, which was determined in the USA by the wide use in agriculture of large doses of mixed fertilizers, different brands of which are produced by the chemical industry, and in pre-war Germany by a combination of a shortage of nitrogenous fertilizers and a developed superphosphate industry interested in promoting the use and sale of its products.

Until recently, the theory of non-nitrogenous fertilization of ponds was accepted in Soviet piscicultural literature. In 1952 G.G. Vinberg came out against this theory (1952, 1953) and showed it to be without foundation. On the basis of general theoretical principles and using the data of pond fertilization experience in the USA, the results of the research of A.Ya. Musatova and S.I. Kuznetsov (1951), and the initial data of his own experiments, he expressed the view that in many cases fish-breeding ponds have insufficient forms of nitrogen available to the phytoplankton, and that this limits their primary ~~gross~~ production and the fish yield . During the same years, i.e. from the beginning of the fifties, research was being performed by I.V. Baranov, V.I. Zhadin and some other hydrobiologists, who arrived at similar conclusions.

Summing up, in recent years substantial changes have taken place both in the treatment of the question of fertilizers in Soviet manuals on pisciculture (Martyshev, 1958) and in the practice of applying fertilizers in the USSR.

During the same period the theoretical views and fertilization practices described above have undergone little change in East and West Germany or the USA. Therefore an exposition of individual problems connected with pond fertilization should be prefaced by a brief description of the present research position and current fertilization practices in various countries. Naturally, a distinction will be drawn between the "European" school of thought on pond fertilization developed mainly in pre-war Germany, the "American" school of thought evolving in the USA, and, finally, the research and pond fertilization techniques successfully developed in the Soviet Union in recent years and in some of the peoples' democracies.

2. The Theory and Practice of Pond Fertilization in East Germany and West Germany

Both in East and West Germany the theory and practice of non-nitrogenous fertilization still reigns supreme. German researchers continue to ignore the practice of mixed fertilization accepted not only in the USA but also in many other countries. The general situation in East Germany may be summed up in the words of Schäperclaus (1961 b):

"Natural foods are the basis of all carp breeding. On their quantity and availability depends the degree of future intensification of carp breeding through denser stocking and fertilization. Therefore it is quite understandable that in East Germany a great deal of attention is devoted to increasing the production of natural food. In Lausitz there are ponds in which fish could not live without intensive annual

liming of the water. Some 750-1500 kg of $CaCO_3$ are added per hectare. In addition extensive use is made of phosphates in quantities of 30-35 kg of P_2O_5 per hectare. Since 1945 potash has hardly ever been used, since the water has enough potassium almost everywhere. Furthermore, potassium can be used to greater advantage in agriculture. This is even truer of nitrogen. Nitrogen-fixing bacteria, and particularly nitrogen-fixing blue-green algae, provide the ponds with sufficient quantities of nitrogen compounds. Therefore, we must continue to make use of non-nitrogenous fertilization. In view of the high nitrogen requirement of agriculture this is in the interests of the economy of the German Democratic Republic". Similar views and recommendations are expressed in the manual on pisciculture recently published (1961) by the same author.

As we see, compared with pre-war practice the only new development is that potash is no longer used for pond fertilization in the GDR. Furthermore, the East Germans have recently been paying more attention to organic fertilizers, especially pig manure.

In spite of the fact that frequent reference is made in fish-breeding literature to cases where phosphorus fertilizers have proved ineffectual, most German authors retain an unshakable belief that "phosphate fertilizers are always useful" (Rahn, 1962). Even new research work in the field of pond fertilization in the GDR is directed mainly towards a detailed study of the accepted system of non-nitrogenous fertilization. Tests are being made of various phosphorus fertilizers, the effectiveness of liming, the savings achieved through the use of different mechanical devices for spreading fertilizer, and so on. Furthermore, in accordance with the traditions established at the time of the Willenbach research station, the effect of fertilizers is judged only by piscicultural data. As a rule, no attempt is made to discover how fertilizers act and at best their initial effect is judged by the visual indices of water bloom.

In this connection one of the later papers of Schäperclaus (1961 a) stands alone. Taking six ponds on two farms where artificial and organic fertilizers and feed were used, he examines productivity factors, citing data on the composition and quantitative development of phyto- and zooplankton, the chemical composition of the water and the surface layers of the bottom and so on. Unfortunately, we cannot say that the fairly mixed material gathered by the author fortifies his views. Typically, the very high content of phosphates in the ponds (0.3-0.6 mg P_2O_5/l) failed to provoke any doubt over the advisability of using phosphorus fertilizers under these conditions.

Several reports in recent years have been devoted to the /10/ results of tests of various phosphorus fertilizers. Thus Schäperclaus (1954) concludes that it is possible to use magnesium and silicomagnesium phosphate, which, nevertheless,

are inferior to Thomas meal. In another paper by the same author (1956) he acknowledges on the results of its use in ponds that alkaline thermophosphate (Sinterphosphat) is more effective than the literature on pond fertilization indicates, it is difficult to accept as reliable those small differences in the productivity of the ponds on which the conclusions are based. In ponds with a natural yield of 156 kg/ha. fertilization with thermophosphate yielded 288.5 kg/ha. (plus 85%), whereas fertilization with Thomas meal yielded only 276 kg/ha. (plus 78%). In both cases 35 kg of P_2O_5 were applied per hectare. These figures, which differ so slightly and have not been worked up statistically, are hardly sufficient to serve as a reliable basis for conclusions concerning the advantages of one of the two phosphorus fertilizers.

Bank (1955), likewise on the strength of the results of using fertilizers when breeding for the market, considers that favourable results were obtained with Roechling phosphate, which, in effectiveness, occupies an intermediate position between superphosphate and Thomas meal. Bank, like other authors of the Wunder School, ascribes special importance to water bloom as an indication of the effectiveness of fertilizers. He speculates that the more favourable effect of Thomas meal as against superphosphate is due to its greater content of micro-nutrients, which, in his estimation, may be present in insufficient amounts in superphosphate.

In post-war East Germany the most thorough study of the effectiveness of liming and phosphorus fertilization of ponds was made by Müller (1954-61). The experiments were conducted in the ponds of the Königswartha experimental farm in Lausitz, i.e. a region which is the heart of East Germany's pond pisciculture. The ponds of this farm, which are located on light sandy soils poor in calcium and with an acid reaction (pH of salt extract 4.7-5.3), are filled with highly coloured water with an alkalinity of about 1 milliequivalent. In 1952 and 1953 different doses of calcium carbonate were added to the ponds, and in 1953 and 1954 unslaked lime. In 1956 the ponds were not limed (Müller, 1957). Phosphorus fertilizers were first used in the Königswartha ponds in 1957, and the results were described by Müller in 1958. Twelve finishing ponds, each with an area of 0.25 hectares, were divided into four groups: 1 - control ponds, 2 - limed ponds (600 kg/ha of CaO), 3 - ponds fertilized with double the normal dose of superphosphate, added twice (72.8 kg/ha of P_2O_5), and 4 - ponds limed and fertilized with superphosphate in the same doses. /11/ As the author himself notes, the results of the experiment are not very clear-cut. Both the lowest (128 kg/ha.) and the highest (330 kg/ha.) yields occurred in the control ponds. According to the average data for the different groups of ponds, the only statistically reliable criterion separating them was the average fish production of the six ponds without phosphorus fertilization (221.9 kg/ha.) and the six ponds fertilized with superphosphate (293.5 kg/ha.). In other words, there was no trace of whatever effect the lime may have had. Regardless of the relatively small

increase in fish production resulting from the introduction of the double dose of phosphorus fertilizer, amounting to 71.6 kg/ha, i.e. a total of 1 kg of fish per kg of P_2O_5, Müller acknowledges that it paid dividends. He regards as unexpected not so much the slight increase resulting from the use of superphosphate but the - in his opinion - high yield of the unfertilized ponds, and he directs the reader's attention to the relatively high content of phosphorus phosphate in the water of the water source (0.05-0.2 mg of P_2O_5/litre) and of the unfertilized ponds (0.01-0.08 mg of P_2O_5/litre). As usual, the content of phosphorus phosphate in the water of the fertilized ponds dropped rapidly, and on the 2nd of July, forty-one days after the second application of superphosphate, it was no higher than in the control ponds (0.015-0.04 mg of P_2O_5 per litre). It is possible that the phosphorus fertilizers, which proved ineffective under these conditions, would have been far more useful if used in conjunction with nitrogen.

Müller notes that water bloom was first observed in the ponds of Konigswartha farm in 1947 (he is apparently referring to the bloom of blue-green algae), but there was no clear connection with fertilization. Of those ponds fertilized with phosphorus, only three bloomed. For this reason Müller is inclined to regard bloom with circumspection as an index of the effectiveness of fertilizers (1957). However, let us note that the data cited by us show that of the six ponds fertilized with superphosphate the three in which there was no water bloom gave an average yield of 67.3 kg of fish per pond and the three in which there was yielded 78.1 kg, i.e. 16% more.

Other papers by Müller (1957, 1957b, 1961), in which he examined the effect of liming and, on the strength of his experience at the Königswartha farm, concluded that it brings little dividend, are studied later.

As regards technique, Müller's paper written in 1958 (1958b) is of special interest, since for the first time in the literature on the study of pond fertilizers he uses modern methods of statistical analysis on the data from the experiments, i.e. variance (dispersion) analysis, with the aid of which it is possible to estimate the degree of reliability of the differences between the values compared, yet at the same time determine /12/ the relative significance of the various factors involved.

Several authors (Neess, 1949, Mortimer, 1954, Vinberg, 1952, and others) note that a number of Soviet and foreign researchers concerned with pond pisciculture tend to neglect statistical methods of analysing the data of their experiments, and this results in incorrect planning of the experiments. Therefore many observations cannot be used as substantiated and reliable conclusions. In this respect fish breeding lags far behind agricultural and agronomical research, in which wide use is made of statistical methods for planning experiments and working up the results.

In research in the field of pond pisciculture it is often

impossible to repeat experiments many times. Frequently different versions of the experiments differ not in one but in several factors. Under these conditions the neglect of statistical methods specially designed for such contingencies becomes particularly reprehensible. The use of dispersion analysis, randomization in the staging of an experiment and other methodical devices must be recognized as essential.

The series of investigations conducted by Müller is also interesting in that it gives a clear idea of the general trend and level of study of artificial fertilization of ponds in East Germany and of the effectiveness of the accepted system of non-nitrogenous fertilization with phosphorus. The figures cited above do not necessarily relate only to the experimental ponds examined. On the whole they also reflect the position on the producing farms of East Germany. Estimated on the basis of the entire area of fish-breeding ponds in the GDR (14,000 hectares), in 1957 30 kg of P_2O_5 was applied per hectare, mainly in single doses of Thomas meal spread on the bottom of the pond in April. In addition, extensive use was made of pig's manure (4-6 m.t./ha). The natural yield on the poor sandy soils of Lausitz is 170-190 kg/ha. It is widely felt that this figure has been achieved as the result of systematic application of fertilizer (Przowlocki, 1960), but this is not borne out by the results obtained in experimental ponds at Königswartha. As we see, in spite of the prolonged application of high doses of phosphorus fertilizer and pig's manure the average level of natural fish productivity attained in East Germany is not high. Incidentally, in the early post-war years the average fish yield of ponds in East Germany was at a very low level (108 kg/ha in 1948). Then it rose steadily and by 1957, when the total pond area was approximately 14,000 hectares, it had reached 260 kg/ha (Schäperclaus, 1958). Let us note that in West Germany, with roughly the same area of carp ponds, the average crop in 1957 was only 115 kg/ha. (Schäperclaus, 1961). /13/

The theories and practice of pond fertilization in vogue in East and West Germany may also extend to fish culture in France and Belgium. The contents of the latest edition of the book by Huet (1960) - the main text-book on fish culture in French - would seem to suggest this. However, it is possible to come across individual statements by French researchers which conflict with German ideas on the fertilization of ponds and are closer to the American point of view. Thus, for example, Nisbet (1951), after fertilizing a pond with 500 kg of superphosphate and 150 kg of calcium nitrate, analyses his very incompletely described data and finds a rapid drop in the concentrations of phosphorus and nitrogen compounds. He therefore expresses himself in favour of repeated applications of fertilizers.

In France pond-fish culture is chiefly extensive in nature. Periodic aestivation of the ponds, liming and phosphorus fertilization are commonly used (Mann, 1954; Wurtz, 1956). No systematic study has been made of the effectiveness of fertilizers.

In the French literature on fish culture only a few short papers dating back to the thirties are devoted to the fertilization of ponds, and these are concerned mainly with the effect of liming (Féchant, 1960-1962). The criteria for judging the necessity for liming and the standard amounts to apply are the subject of a special study by Chimits (1949).

In this section we have given only a general idea of present position with regard to the fertilization of ponds in East and West Germany. The results of the researchers by German authors in connection with individual specific questions will be referred to more than once in the subsequent chapters of this book.

3. Fertilization of ponds in the USA and Israel.

In the USA they use N-P-K artificial fertilizers. When studying the problem of pond fertilization American authors invariably refer to the researches of Swingle and Smith, which were conducted in the thirties and at the beginning of the forties on the ponds of an experimental station in the state of Alabama. They recommend their method of fertilization and state that the necessity for regular applications of fertilizers can best be judged from the abundance of phytoplankton, or rather the reduced transparency of the water caused by the latter.

Initially Swingle and Smith, guided by the results of laboratory experiments in which they calculated the amount of phytoplankton developing in relation to the weight of organic matter (losses due to calcination), estimated that the /14/ most effective ratio of nitrogen to phosphorus was 4:1. When the fertilizers were tried in small experimental ponds chemical analyses revealed considerable adsorption of phosphorus by the bottom. As a result the nitrogen/phosphorus ratio was finally set at 4:2. With application of the fertilizers to the pond every four weeks the computed concentrations of nitrogen, phosphorus and potassium in the water of the pond were respectively 8:4; 2 mg/l plus 16 mg/l of $CaCO_3$.

Swingle and Smith cite comparative data on the growth of the organic matter of the plankton with monthly application of fertilizer and with weekly application of a quarter of the dose. In the latter case, starting with the tenth week, the biomass of the plankton was much higher (Swingle, Smith, 1939; Smith, Swingle, 1939, 1940).

As the result of their research Swingle and Smith recommended adding with each application of fertilizer approximately 45 kg of ammonium sulphate, 67 kg of 16% superphosphate, 5.6 kg of potassium chloride and 16.8 kg of calcium carbonate to every hectare of pond surface. In spring they advise fertilizing three times after the pond has been filled, at intervals of one week. After this, depending on the development of the phytoplankton, fertilizer should be applied as needed, usually every four weeks. All in all, during the season, which in the state of Alabama lasts from April to October, 8-10 applications of fertilizer are required. As the authors state in their first paper (1939), the use of this method increased the yield of the ponds from 150 to 648 kg/ha. Nitrogen fertilizers, like phosphorus fertilizers, failed to increase the crop when used alone in the experiments of Swingle and Smith.

The methods of fertilization devised by Swingle and Smith became standard practice in fish culture in the USA. In Edminster's short manual (1947) on fish culture in ponds he suggests fertilizing the ponds with a commercial mixture of 8-8-4, which signifies a content in 100 parts by weight of eight parts of nitrogen, eight parts of P_2O_5, four parts of K_2O and eighty parts of filler supplying the necessary calcium. For hard water he recommends using ammonium sulphate instead of ammonium nitrate. Of the organic fertilizers he only recommends manure.

According to Edminster, fertilizers should be applied repeatedly, in a dose of 112 kg/ha. (100 lbs per acre), at intervals of one week at the beginning of the season, and as needed, depending on the transparency of the water, after the appearance of bloom. The author states that the fertilizer should be added as soon as the visibility is reduced to twelve inches in ponds with colourless water and 8-10 inches in ponds with water coloured by humus. To determine visibility one /15/ should immerse an arm in the water as far as the elbow and see how easily visible the wrist is.

During the season no fewer than five applications are necessary, and only in rare cases should the number exceed ten. This means that during the season from 560 to 1120 kg/ha. of mixed fertilizer, or from 45 to 90 kg/ha. of nitrogen and the same quantity of P_2O_5, are added to the pond. Although special mixes are manufactured in the USA for the fertilization of ponds ("Hydro-Pok" and others), mixes intended for agriculture are also deemed entirely suitable. Such mixes differ in their percentage content of N, P_2O_5 and K_2O, possible combinations being 10-10-5, 12-12-4, 8-8-2. It is advisable to determine by experience which mixture is most suitable for a given body of water. The quantity of fertilizer applied per season varies considerably (ranging from 450 to 1350 kg/ha). The journal "Fish Farming" (1959) states that unfertilized ponds give an average yield of 56 kg/ha. and fertilized ones 224 kg/ha. (200 lbs per acre). Reid (1961) writes that in the USA unfertilized ponds yield 45-163 kg/ha, and fertilized ponds 224-560 kg/ha. Thus, fertilizers increase productivity by a factor of 3-4, i.e. their effectiveness must be recognized as high. When evaluating these productivity figures it should be remembered that they relate not to carp, which are not bred in ponds in the USA, but to several different species of fishes, mainly centrarchids, which are semi-predacious or predacious feeders. A predacious type of diet is associated with a longer food chain than is the case with the carp. Accordingly the yield of ponds stocked with predators must be lower, as will be the crop of fish per kg of fertilizer. One recalls that in the experiments of Swingle

and Smith (Swingle, Smith, 1941) the yield of ponds stocked with predators (168-224 kg/ha.) was five times lower than that of ponds stocked principally with plankton-eating fish under the same conditions (840-1120 kg/ha.).

In the USA they often add some extra component to the commercial mixes. For example, in the state of Connecticut for each application of fertilizer they recommend taking 90 kg of a 5-10-5 mix and 22.5 kg of sodium nitrate for each hectare of pond area ("Fishery Survey of the Lakes and Ponds of Connecticut", 1959). Let us note that, in spite of the wide use and, the apparent undoubted effectiveness of these methods of fertilization, in some cases the ponds failed to act to the fertilizer over a period of seven years. (Clark, 1952).

Since the basic research of Swingle and Smith only a few papers on fish culture have been published in the USA, devoted to the study of individual aspects of pond fertilization. Thus, for example, Zeller (1952) described his observations of the content of mineral and organic phosphorus in two fertilized ponds (1120 kg/hect. of 4-12-4 fertilizer per year) and four unfertilized ponds in the state of Missouri. Here the water of the unfertilized ponds was marked by a very low content of phosphates (0.010-0.016 mg P/litre) and a high content of nitrates (0.6-1.7 mg N/litre). After the application of the fertilizers the concentration of phosphorus in the water dropped swiftly. The quantity of plankton, which the author estimated from indirect data (the reduction in the transparency of the water, measured with a Secchi disk), was greater in the fertilized ponds. The fertilizers had a positive effect on the growth of the fish. Zeller feels that a particular quantity of fertilizer will be more effective if used in small and more frequent doses (weekly). The author describes the development of filamentous algae in one of the two fertilized ponds in the second half of the summer: the algae suppressed the development of plankton during this time.

In American fish breeding literature fears are often expressed that artificial fertilizers may lead to winter suffocation of the fish. This fear even induces certain authors who are fully aware of the effectiveness of fertilizers to refrain from recommending their use (Ball, 1952). Such views are linked with the fact that pond-fish culture in the USA is in its methods and the nature of the bodies of water used similar to lake culture. Therefore it is difficult to draw a precise line between data on the fertilization of ponds and the results described below of experimental fertilization of small "lakes" pursued on the same theoretical basis.

In the USA and Canada there is an unwillingness to resort to organic fertilizers, and artificial fertilizers are given greater emphasis. There have been cases where the application of artificial fertilizer was clearly unwarranted and unprofitable. This would appear to apply to attempts to fertilize rivers. As

long ago as the forties experimental fertilization of a river was attempted in the oligotrophic region of Nova Scotia to improve the conditions of growth of young salmon. At the end of July 1945 one hundred and seventy kilograms of a 4-12-6 mix were introduced into one of the affluents of Grand Lake, which has a slow rate of flow (0.2-0.3 m^3/sec), and 56 kg of the same mix were left in a river in a bag. In 1946 three bags weighing 56 kg each and containing the same fertilizer were again deposited in the river. In a very incomplete description of the experiment it is stated that the effect of the fertilizer, which was reflected in the intensified growth of filamentous algae and the accumulation of fish, made itself felt only at a point 135 metres downstream (Huntsman, 1948).

We also know of another case where a watercourse was fertilized. This time it was in Tennessee and the experiment was conducted on a large scale (Parson, Benson, 1960). The fertilizer used was a 9-6-3 mix, which was highly recommended /17/ by pond-fish breeders in the region. In July 1954 forty tons of fertilizer were applied in quantities of 300 kg per kilometre of a particular stretch of the river in which complete water replacement took thirty days. A year later another 31 tons of fertilizer was added. Before the fertilization of the river, in 1953, and after it, in 1956, rotenone was used to check the ichthyofauna. For five to six kilometres downstream the fertilizers produced abundant growth of filamentous algae, intensified development of mollusks, and, as the authors state (without citing any figures), an increase in the quantity of plankton. Mention is also made of the fact that the number of fish caught also rose.

The system of fertilization adopted in the USA and Canada has influenced application practices and research into the effect of fertilizers on bodies of water in Japan and several other Asian countries, including Israel.

In Japan, Matida (1953) experimented in the laboratory with N-P_2O_5-K_2O mixes in proportions of 3-3-4, 8-10-4 and 10-8-4. He found that the development of phytoplankton was stimulated most by 10-3-4 and 8-8-4 mixes, and used the latter mix for fertilizing fish ponds. The fertilizer stimulated the development of phytoplankton and the intensity of its photosynthesis. The results of measurements of the rate of photosynthesis, obtained by the bottle method, were used by the author for calculating the elements of the oxygen balance of the pond.

Other papers written by Japanese authors also contain references to the application of mixed artificial fertilizers. Thus, Shimadate et alia (1957), when analysing conditions of intensive carp culture, mentions changing from two to seven applications of fertilizer. Ito and Iwai (1960) described the changes in the character of an eel pond in which the water was originally highly acidic. Under the influence of liming and fertilization with calcium phosphate, bir lime and urea, abundant phyto- and zooplankton (rotifers) developed in the pond. Sulit et alia (1957) published the results of a successful experiment in the fertilization of a fry pond in the Philippines with an 8-18-4 mix applied in fractional doses. These examples show that the fish breeders of the Orient use N-P-K mixes, mainly following the American method.

The American method of pond fertilization became particularly widespread in Israel in the post-war years. Studies of pond fertilization conducted in Israel not only resulted in high yields in the specific conditions of that country but also led to interesting conclusions of a more general character. In Israel the limited scope for development of agriculture has stimulated the development of intensive forms of fish culture.

Pond culture in Israel uses intensive methods, is /13/ highly mechanized, differs strongly from pond-fish culture in the countries of the temperate zone, and may serve as an example of fish-breeding in the conditions of a subtropical climate. The high water temperatures and the long growing season mean that two and even three crops aan be obtained **every year.** For example, in the ponds of the Dor experiment fish farm in 1957 there were three periods of culture, i.e. from the 25th of February to the 29th of May, from the 6th of June to the 26th of August, and from the 29th of August to the 21st of September.

On the strength of their observations Israeli researchers consider that when the biomass of fish in the pond approaches a specific level marking the maximum carrying capacity of the the pond under the given conditions, the increase in the fish yield slows and even stops. Therefore it becomes unprofitable and pointless to increase the length of the period of culture. According to the figures for the period from 1953-1957, in the unfertilized ponds of the Dor experimental station, which had a low natural yield, the biomass of fish in each of the three periods of culture was 80-120 kg/ha., with an average of 100 kg/ha., for a high individual weight of the planting stock (30-60 grams). In these ponds, artificial nitro-phosphorus fertilizers greatly increased the carrying capacity, hence ultimately their yield. In the same years, the biomass of fish in the fertilized ponds had reached 368-453 kg/ha. by the time growth stopped during one period of culture, i.e. it was more than four times as large as in the unfertilized ponds. When carp were bred together with Tilapia even higher figures were obtained, for example 600 kg/ha. Under these circumstances the individual weight of the carp did not drop, the figures being 330-360 grams for the carp and 215-240 grams for the Tilapia (Yashouv, 1959). When the ponds were fertilized and the fish fed, the biomasses became even larger. Thus, according to the data for 1956, the biomass was 1530 kg/ha. for a carp monoculture and as much as 2683 kg/ha. for a mixed differently aged culture with Tilapia. Let us remember that these figures, which were obtained with the small ponds of an experimental farm, relate to a single period of culture, whereas there may

be three a year. Therefore the annual fish harvest is very high. According to the published data (Sklower, 1949, 1955), the average fish harvest over a period of eight years (1938-1946) from the experimental ponds was 3,451 kg/ha., with an overall range of 851 to 8,978 kg/ha. per year.

According to a description of the general state of carp culture in Israel given by Jones (1956), the total area of the fish ponds even at that time was in excess of 4,000 hectares and the average yield was 2,000 kg/ha., with fluctuations in various ponds of 1,000-4,000 kg/ha. The growing season in the finishing ponds lasted on average for 230 days a year, with the ponds being drained and harvested twice. The carp reached /19/
commercial weight (250-300) grams) in 100-110 days. In recent years the commercial weight has increased considerably. Thus, in 1961, sixty-eight percent of the carp delivered to the market weighed more than 480 grams (up to 1,000 grams) and only 7.5% had a weight of between 260 and 340 grams.

In 1961 the total area of ponds in Israel - equal to 4518 hectares - yielded a total of 9,205 metric tons, i.e. an average of 2,040 kg/ha. of fish, 96.2% of which was carp (Sarig, 1962).

Thus, fish culture in Israel is characterized by a high yield of fish per unit area of pond, and this due in large degree to the systematic application of artificial nitro-phosphorus fertilizers.

The artificial fertilizers used in Israel are superphosphate and ammonium sulphate, and the main organic fertilizer is bird lime. On the strength of the results of the initial research done at the experimental fish farm it was assumed that for each application artificial fertilizers should be used in quantities sufficient to raise the concentration of the active principles in the water to 1.5 mg N/litre and 0.5 mg P/litre. Initially it was assumed that the quantity of fertilizer necessary for this would be determined from the results of hydrochemical analyses of the water. For this purpose special laboratories were set up in the fish farming areas to make rapid analyses. Three years of analysis by these laboratories showed that two days after the artificial fertilizers had been applied the water in the large ponds (1-6 hect.) contained only 5-10% of the amount added, and the content of mineral forms of nitrogen and phosphorus had established itself at a specific level characteristic of the pond and region. This made it possible to close down the regional laboratories in 1955 and work from accumulated data when determining the standard amounts of fertilizer to use.

In accordance with these standards very large quantities of fertilizer were added to the pools. Even higher doses were applied during the first period of research begun in 1949. Thus, in 1951, 12.1-15.5 centners*/hectare of superphosphate and 17.9-20.7 c/ha. of ammonium sulphate per year were introduced into the experimental ponds of the station of Sde Nahum (Wirzhubski, Sarig, 1953). During a later period of research, which was conducted on new ponds in Dor, smaller, though still high doses were used (10-20 c/ha. per year), and their effectiveness was increased.

The effectiveness of the nitro-phosphorus artificial fertilizers became evident during the first few years of observations. The very first studies, which were conducted between 1949 and 1952 on the ponds of an experimental fish farm, showed that the natural yield of the ponds at Sde Nahum of 400-500 kg/ha /20/ per year rose to 750-1150 kg/ha after fertilization with nitrogen and phosphorus (Fisher, Rashkes, 1951; Reich, 1952; Wirzhubski, Sarig, 1953). These results were later confirmed by those obtained from the ponds at Dor.

During the four years of research (1953-1957) at the Dor experimental station six types of fertilizer were tested on twenty-two ponds. The standard adopted was fertilization once a fortnight in doses calculated to give concentrations of 2 mg of nitrogen and 0.5 mg of phosphorus per litre. It was shown that the addition of this amount of fertilizer once a week failed to give a higher yield (Yashouv, 1957). This extremely important conclusion is emphasized once again in a later paper by the same author (Yashouv, 1962) describing his research at the experimental station during 1961. In this paper Yashouv states that in 1961 experiments were staged to increase still further the number of applications of fertilizer by doubling the dose. Instead of the standard 60 kg of superphosphate and 70 kg of ammonium sulphate per hectare added every

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* Centner = 100 kg

fortnight, they took a double dose and applied it twice - at the beginning of each period of culture and thereafter at intervals of two weeks. Thus, during the two periods in 1961, 480 kg of superphosphate and 560 kg of ammonium sulphate were applied per hectare, and this led to a substantial saving compared with the standard rates of fertilization adhered to in Israel. In ponds fertilized by this novel (for Israel) method the fish grew even somewhat faster than in ponds fertilized by the conventional method. During the first period (of carp culture) the respective rates were 6.34 and 6.22 kg/ha. per day, and during the second period (joint culture of carp and Tilapia) they were 13.45 and 12.87 kg/ha. per day. The results of this experiment, which was to be continued, have not been published in full. If these interesting data are to be correctly understood and their significance properly appreciated we must remember that the ponds were filled with water with a very high content of nitrates during the period of culture to prevent a drop in the water level.

The results of the study of the fertilization of ponds in Israel have been generalized by Hepher (1962), and his data show that during five years (1950-1954) at the Sde Nahum station nitro-phosphorus mineral fertilizers raised the yield by an average of 77%.

The relative effectiveness of the action of mixed nitro-phosphorus artificial fertilizers proved much higher at the Dor fish farm than at Sde Nahum. According to the averages

for five years (1953-1957) the yield of the fertilized ponds was 732% of the yield of the unfertilized ponds. However, this is due not to the higher yield of the fertilized ponds but to the much lower yield of the unfertilized ones, which were /21/
fed not by the plankton-rich waters of the head pond as in Sde Nehum, but by ground water from boreholes. On average during the five years the rate of increase at the first station was 4.34 kg/ha per day in the fertilized ponds and 2.51 kg/ha per day in the unfertilized ones. The corresponding figures for the second station were 3.91 and 0.47 respectively. Let us note that the described results of the application of fertilizers to the new ponds of the Dor station completely contradict the widely held though unfounded view that artificial fertilizers can be effective only in "mature" ponds with sufficient silt sediment.

Particularly interesting data were obtained in experiments conducted in 1955 and 1956, when the effect of fertilization was studied in conjunction with feeding of the fish. To five 0.5 hectare ponds the researchers added feed in amounts sufficient to produce the maximum increment achieved by feeding in previous years. To five other ponds they added artificial fertilizers and the same amounts of feed. On average during these two years the increase in the yield of the fertilized ponds under these conditions was 88% as against the yield of the ponds where the fish were fed but no fertilizer was added. The most important point is that the amount of feed used fell from 3.5 to 1.9 kg per kilogram of fish.

We should like to point out that even the total amount of feed and fertilizer expended per kilogram of fish was less than the expenditure of feed in ponds where the fish were fed but no fertilizer was added. And the same sort of figures were obtained during the first years of fertilization studies (1948 and 1949) at the pools of the Sde Nahum station (Sarig, Vardinia, 1957).

Even larger yields were obtained by applying artificial fertilizers on farms producing for the market (Sarig, 1955). The ponds compared were divided into two groups (A and B) of 5-6 ponds each (Table 1).

Table 1

The effectiveness of artificial and organo-mineral fertilizers in ponds in Israel (Sarig 1955)

1 Год	2 Группа прудов	3 Удобрения 4 суперфосфат, кг/га	 5 сернокислый аммоний, кг/га	 6 птичий помет, м3/га	7 Общая продолжительность сезона, дни	8 Суточный прирост, кг/га	9 Годовая рыбопродукция, кг/га
1951	А	540	540	—	170	8,60	1460
	Б	—	—	4,7	170	9,84	1670
1952	Б	1160	1020	—	262	9,61	2520
	А	825	—	10,4	236	8,49	2000
1953	А	450	480	—	199	11,10	2210
	Б	425	—	9,0	237	7,91	1888

Key: 1. Year. 2. Group of ponds. 3. Fertilizers. 4. Superphosphate, kg/ha. 5. Ammonium sulphate, kg/ha. 6. Bird lime, m^3/ha. 7. Total length of season in days. 8. 24-hourly increase in kg/ha. 9. Annual yield of fish, kg/ha.

Note: The figures in the last column were obtained by multiplying the figures in the two preceding columns.

From the data of Table 1 we can judge the effectiveness of fertilization with bird lime, which, however, is less effective than fertilization with nitro-phosphorus artificial fertilizers. Of particular interest is the fact that double doses of artificial fertilizers in 1952 resulted in a comparatively small increase in yield. This fact, like the figures given above, is convincing proof of the existence of an upper limit for rational doses of nitro-phosphorus artificial fertilizers.

During the first stage of research at the experimental fish farm, begun in 1949, attempts were made to study all degrees of utilization of fertilizers with the aid of hydrochemical and hydrobiological methods (Fischer, Rashkes, 1951; Wirshubski, Sarig, 1953). In the first of these two papers it is stated /22/ that in the fertilized ponds the quantity of plankton and chironomids rose by 67% and 51% respectively, and the yield of fish increased by 68%. The authors of the second paper, which was based on data from 1951, found, contrary to their expectations, that the four fertilized ponds of the Sde Nahum experimental station, which yielded 843-1151 kg of fish per hectare during the three periods of culture, did not differ so very much from the control pond as regards the development of food organisms, especially zooplankton, although the harvest of the control pond was only 509 kg/ha. As is often the case with such investigations, the phenomena involved proved to be very complex, and the hydrobiological data accumulated could only be used for various arguments put forward by the authors.

More definite results were obtained in the hydrochemical part of the research. In spite of the weekly application of large doses of ammonium sulphate, the content of mineral forms of nitrogen in the water of the fertilized ponds, according to the data of analyses made every five days, settled at the same level as in the unfertilized ponds. After the application of fertilizer the content of phosphates in the water also suffered a rapid drop, although it was markedly higher on average in the fertilized ponds than in the unfertilized ones, the figures being 0.04-0.09 and 0.008-0.016 mg P/litre respectively. Consequently, the N:P ratio, which is very high in the waters of Israel because they contain large quantities of nitrogen nitrate and small amounts of phosphates, dropped perceptibly.

The high content of mineral nitrogen in the water source of the ponds in Sde Nahum (1.15-1.65 mg N/litre) is due mainly to the nitrogen nitrate (Vardinia, 1954). It is characteristic that, in both the fertilized and the unfertilized ponds, firstly the content of mineral forms of nitrogen was significantly /23/
lower than in the water entering the ponds (0.5-1.6 mg N/1 in the fertilized ponds, 0.35-1.45 mg N/1), and secondly ammonia nitrogen and not nitrate nitrogen predominated in the water of the ponds. In 1952 bird lime was introduced into two ponds in addition to artificial fertilizers. The water of these ponds contained far fewer mineral forms of nitrogen than did the control pond, and the proportion of nitrate nitrogen rose from 25% to 55%.

The factors governing the dynamics of phosphorus have been subjected to a thorough scrutiny by Hepher (1958a and 1958b, 1959, 1962a). The results of his studies, which are of great general interest, will be examined later (p. 71).

In 1962 Hepher published the results of studies of the gross plankton production of ponds, the magnitude of which is regarded as a good indication of the effectiveness of fertilization. At the present time such studies are being conducted on a large scale (Yashouv, 1962).

As we see, in Israel only the reconnaissance work of the first period was accompanied by "comprehensive" or "complex" studies of the ponds by hydrochemical and hydrobiological methods, which failed to yield clear-cut results. As they gained experience the workers at the experimental fish farm decided to switch to projects involving the study of individual problems connected with the fertilization of ponds, and this proved more fruitful.

For the fertilization of commercial ponds the Israelis use only nitro-phosphorus artificial fertilizers (ammonium sulphate and superphosphate), applied in large doses, sometimes in combination with bird lime. Together with the favourable conditions of the subtropical climate they have done a great deal to help raise the average yields of ponds in Israel to record levels.

4. Fertilization of Non-Draining Ponds and Lakes

A theory of pond fertilization can only be formulated on the basis of a deep understanding of the general principles governing the cycle of nutrients in the body of water. These determine the fate of the substances introduced into the pond and the effectiveness of their action. In this connection observations of the results of experimental fertilization of "lakes" are extremely important. We should say straight away that in most cases the lakes in question are small bodies of water with an area of a few hectares only, or even a few tenths of a hectare. They merit the designation "lake" only because they are natural pools and not artificial ones, and because they differ from the large non-draining ponds in being smaller.

However, observations conducted in connection with the fertilization of deeper heterothermous lakes are equally as important since they demonstrate certain important features of the initial effect of the fertilizers which would be difficult to trace immediately in shallow ponds, where they are obscured by the influence of the complex and highly variable interaction between the water mass and the bottom sediments.

Experimental fertilization of "lakes" has been pursued mainly in America, but one of the first and most interesting studies of this problem was undertaken in 1937 and 1938 in Germany, in connection with the small and thoroughly studied eutrophic Schleinsee (area 14.9 hectares, maximum depth 11 metres,

average depth 6.5 metres), situated on the north shore of Lake Constance. Careful and systematic analyses of the mineral and organic phosphorus and nitrogen in the water and in the composition of the plankton revealed the fate of the phosphorus which had been introduced into the lake (Einsele, 1941; Nümann, 1941). Superphosphate was first added to the lake and dissolved in the water of the epilimnion (0-2 metres) in the summer of 1937, and as a result the content of inorganic phosphorus, which was present in traces, rose to 50 mg/m^3. In the course of the next ten days all the phosphorus was taken up by the organic phosphorus and a considerable portion of it sank to the hypolimnion with descending particles. After four weeks the quantity of phosphorus in the lake was the same as at the beginning. The first addition had no perceptible effect on the production of plankton or the regeneration of the phosphorus in the hypolimnion. In 1938 phosphorus was added twice (on the 30th of May and the 30th of July) in doses of 47 kg, which, when calculated for the entire mass of water in the lake, corresponds to an estimated concentration of 100 mg/m^3. After the first application the content of inorganic phosphorus in the water rose from 0 to 80 mgP/m^3, but dropped back to 40 mgP/m^3 after four days because of the high rate of absorption by the plankton. The rapid absorption of the inorganic phosphorus was accompanied by a drop in its total volume in the trophogenous layer as the result of the sinking of particles to the hypolimnion.

It is particularly interesting that the rapid enrichment of the plankton with phosphorus was in no way due to an increase in its biomass. It was found that when the water was enriched with phosphorus there was a sharp increase in its relative content in the plankton, after which the content of phosphorus again diminished. On the 1st of August, i.e. on the second day after fertilization, the relative content of phosphorus in the dry substance of the plankton was 1.1%. On the 15th of August it was 0.52%, and on the 7th of September 0.30%. At a comparatively constant content of nitrogen (4-6%) the N:P ratio rose accordingly from 4.5 to 16.5. It was shown that in twenty-four hours the plankton is capable of absorbing twenty times as much phosphorus as it originally contained. /25/ The original N:P ratio of 20 then drops close to zero.

Evidently the accumulation of phosphorus was followed by propagation of the plankton, since in 1938, as the result of fertilization of the lake, plankton production, computed from the accumulation of CO_2 in the hypolimnion and by other methods, almost trebled.

Analyses showed that the absorption of phosphorus by the plankton was accompanied by a drop in the content of total phosphorus in the upper layers of water and in the lake as a whole because of its removal to the hypolimnion together with sinking particles. By the 1st of October, judging from the content and distribution of phosphorus in the water, the lake had reverted to its original state, and next season, but only at the beginning of summer, there was a small increase in the

total quantity of phosphorus in the water equivalent to 10% of the amount added the previous year. Thus, it was shown that at least in eutrophic stratified lakes a single dose of phosphorus produces only a very transitory effect and cannot materially effect the established cycle, which depends on the combination of conditions characterizing the lake.

The important data of Einsele and Nümann (1941), which were obtained at Schleinsee and published in the early years of the war in a German journal, were apparently ignored during the first uncoordinated attempts to fertilize lakes in the USA and Canada. As in pond-fish culture, mixed artificial fertilizers were used for the lakes in the USA. The results of the initial experiments at the beginning of the forties are known only in their general outline. Taylor in Canada (Quebec) added to a lake with an area of 15.4 hectares a 4-8-10 fertilizer at a rate of 7.5 mg/l. It is noted that the growth of brook trout was intensified that year. In 1943 King reported on the fertilization of an 8.5 hectare lake in the state of North Carolina. Roughly 4.5 tons of a 6-9-3 mix and 0.5 tons of sodium nitrate were added to the lake. There was a large harvest of perch, but the yield per unit of fishing effort did not increase (Smith, 1948).

A large-scale experiment in lake fertilization was conducted in the Algonquin National Park in Ontario. In 1946 one lake was fertilized, and in 1947 four lakes, with areas ranging from 22.5 to 230 hectares and depths of 9-27 metres. In all, some 600 hectares of water surface were fertilized and roughly 24 tons of 12-24-12 fertilizer was used. Two lakes were fertilized in three stages, and one in two stages, to produce an estimated concentration of the mix in the water of the epilimnion of 0.5 to 9 mg/l. in a season. It is reported that 3-4 weeks after the addition of the fertilizer the phytoplankton population increased on account of flagellates and diatoms. After reaching a peak, however, the numbers dropped /26/ rapidly again. After 3-5 weeks the numbers of zooplankton grew, mainly on account of rotifers. For reasons unknown, this was observed only after the first applicationof fertilizer (Langford, 1950).

In 1946 and 1947 experiments began on the fertilization of lakes in the state of Michigan (Ball, 1950; Ball, Tanner, 1951). The scientists chose one "salmon" lake (1.74 hectares, maximum depth 12 metres) and another "warm-water" lake (11.1 hectares, maximum depth 4.6 metres). 10-6-4 fertilizers was added every three weeks from June to September at a rate of 6 mg of mix per litre (in 1947 9 mg/l were added to the salmon lake). Judging by the figures cited, 500-600 kg/hectare were added during a season. In each case the control was a neighbouring lake of similar type. In the warm-water lake the fertilizer produced strong water bloom in the first year but not in the second, though there was vigorous development of filamentous algae. After the latter decomposed there were large amounts

of plankton. The authors note that the bloom did not reach the proportions cited by Swingle and Smith (very high) and that it always terminated before the addition of the next dose. In the salmon lake there was no bloom, but the transparency was reduced. In the opinion of the author, the data on the oxygen and temperature distribution indicate eutrophication of the lake. There was vigorous overgrowth and an improvement in the feeding and growth of the fish. In the second winter the fish began to suffocate in the two fertilized lakes as opposed to the unfertilized ones. This did not occur in the previous years. This case achieved widespread notoriety in the USA and gave rise to fears that artificial fertilizers might make winter oxygen conditions worse.

On the same and other lakes in the state of Michigan observations of the results of fertilization were continued by scientists at Michigan University (Barrett, 1953; Tanner, 1960). In June and July of 1949 and 1950, 6-10-4 fertilizer was added three times at three-week intervals to four small lakes of karstic origin, area 1.5-2.5 hectares, maximum depth 15-24 metres, average depth 10-17 metres). The quantity of fertilizer added during a season corresponded to an estimated concentration of the mix of 4-15 mg/l. In the fertilized lakes there was a sharp drop in the content of phosphates in the water and vigorous development of phytoplankton. After two years of fertilization no difference could be detected in summertime between the contents of total phosphorus in the waters of the fertilized and unfertilized lakes. The rate of reduction of the phosphate content was found to be inversely proportional to the alkalinity of the water in the epilimnion. In the hypolimnion, where the water contains more organic substances, the opposite was found - the concentration of phosphates was not inversely but directly proportional to the alkalinity. In 1949 and 1950 the thermocline in the fertilized lakes was higher, and the content of oxygen in the hypolimnion lower, than in 1948. In the unfertilized lakes, either there was no difference or the difference was much less noticeable. The authors consider that these phenomena are due to more vigorous development of the plankton in 1949 and 1950 as the result of fertilization. Their conclusions are made slightly less convincing by the fact that the two control lakes are characterized by lower alkalinity of the water than the fertilized lakes, the figures being 32 and 71 and 137-192 mg $CaCO_3$/l respectively. Therefore it is not impossible that the control lakes, with their lower yield, reacted more weekly to the meteorological differences between the various years. Nevertheless, there is no doubt that in sufficiently productive lakes the content of oxygen in the hypolimnion may be reduced under the influence of fertilizers. It is a well-known fact that the deficit of oxygen in the hypolimnion is directly proportional to the yield and degree of "eutrophication" of a lake (Hasler, 1947; Edmondson, 1951).

An instructive example of the consequences of "over-fertilization" is provided by lakes into which polluted waters bring large quantities of nitrogen and phosphorus. As we have already said (Vinberg, 1952), this is illustrated by the Wisconsin lake chain into which flows purified waste water from Madison city. According to the figures for 1944, 157, 661 and 328 kg of total nitrogen and 21, 99 and 66 kg of total phosphorus per hectare flow into the chain formed by lakes Monona, Waubesa and Kegonsa each year (Sawyer, 1947). If we ignore the flow of the lakes, these figures, for average depths of 8.4, 4.9 and 5.6 metres, correspond to estimated concentrations of 1.99, 13.4 and 7.1 mg of nitrogen and 0.254, 2.03 and 1.43 mg of phosphorus per litre. In spite of the large annual inflow of nutrients they are used up so completely that in summertime the concentrations of mineral forms of nitrogen and phosphorus in the water of the epilimnion are identical to those in the water of twelve other lakes in the area which receive no waste water. Thus, if we go solely by the results of chemical analyses of the water we might arrive at the paradoxical conclusion that these over-fertilized lakes with excessive development of phytoplankton require fertilization. In eutrophic bodies of water large quantities of nutrients are buried in the mud deposits. In 1944 for instance, the annual outflow of nitrogen in lakes Monona, Waubesa and Kongesa amounted to 49.8%, 54.9% and 61.4% of the inflow. It is quite evident that the available amount of nutrients available to phytoplankton in eutrophic bodies of water is determined chiefly by the conditions of nutrient regeneration and exchange between the bottom and the water in that basin. This is also true of ponds.

The figures quoted show convincingly that although /28/ the addition of artificial fertilizers to lakes produces characteristic and predictable consequences, the content of nutrients in the water and their seasonal dynamics, at least in eutrophic lakes, are a stable feature of each particular lake.

Initially it seemed that in low-yielding bodies of water whose cycle contains a small quantity of nutrients and whose metabolism is distinguished by a high degree of reversibility the situation was different. One might have thought that even a single application of fertilizer would easily change the content of nutrients in the waters of such lakes. Therefore the results obtained from the fertilization of originally oligotrophic lakes are of great interest. There is an example of this in the paper of Smith (1945). The lakes of New Brunswick, which are situated on granite, have a very low biological yield. The total biomass of the few species of fishes living there (brook trout, Fundulus, eel) weighs 20-40 kg/ha, yet the yield is less than 1 kg/hectare per year. For fertilization they close Lake Crecy (area 20.4 hectares, maximum depth 3.8 metres, average depth 2.4 metres), which has very low mineralization (3 mg of combined CO_2 per litre, pH 6.7). On the 19th of June 1946 one ton of ammonium phosphate

and 226 kg of potassium chloride were added to the lake, corresponding to 0.39 mg of phosphorus and 0.21 mg of nitrogen per litre. Towards the end of August, i.e. two months later, Anabaena began to bloom vigorously, which had never happened before. Soon after fertilization the zooplankton reached its peak. By the 27th of June the total phosphorus, which prior to fertilization had been at a level of 0.016 mg^P/l, had reached 0.183 mg^P/l. Then it began to diminish, but still it remained for a fairly long time at a higher level than before fertilization (26 July - 0.050 mg^P/l). Smith stresses that it proved possible to raise the biological yield of a lake with very low mineralization of the water without the addition of carbonate compounds. This fact is indeed of great general interest.

The following year a second lake of the same type was fertilized. This time the choice fell on Lake Gibson (24 hectares, maximum depth 6.1 metres, average depth 4 metres), which is situated in the same region. On the 22nd of July 1947 the lake was fertilized with 0.7 tons of potassium chloride and 6 tons of crushed limestone. Because of the larger volume of the lake only half the dose per litre was used compared with Lake Crecy. The lakes were fertilized a second time in June 1951. In both lakes blue-green algae began to bloom after each application of fertilizer, but an intensification of the development of the benthos and macrophytes and an increase in the rate of growth of the fish (Salvelinus fontinalis) were observed only

/29/

in Lake Crecy. In order to ascertain the influence of the fertilizers on the yield of fish the second application of fertilizer was associated with measures to count and limit the predatory fish (eel) and birds and stocking of the lakes, which, as was shown by earlier research, failed to produce results in these lakes without fertilization. Having carefully examined the effect of these measures, Smith came to the conclusion that the fertilization had increased the yield of fish only in Lake Crecy, whereas it failed to produce results in Lake Gibson. Emphasis is laid on the complexity of the conditions on which depend the ultimate effect of the fertilizers and the transitoriness of their action. These studies disproved the original assumption that it is possible by means of a single application of massive doses of fertilizers to alter the content of nutrients in the water of oligotrophic lakes for a long time.

Therefore great interest attaches to the long-term observations of systematic repeated fertilization of oligotrophic Bear Lake (49 hectares, maximum depth 7.5 metres, average depth 4 metres), situated on Kodiak island in Alaska. This lake, like the others on the island, is the dwelling-place of young red salmon (*Oncorhynchus nerka*). The lake was fertilized to check the supposition that the drop in the salmon yield was related to a deterioration in food conditions in the freshwater period of its life, which lasts on average for three years. The suggestion was made that this deterioration is in turn due

to a drop in the number of dead spawners remaining on the spawning grounds and a corresponding reduction in the amount of phosphorus and other nutrients entering the lake.

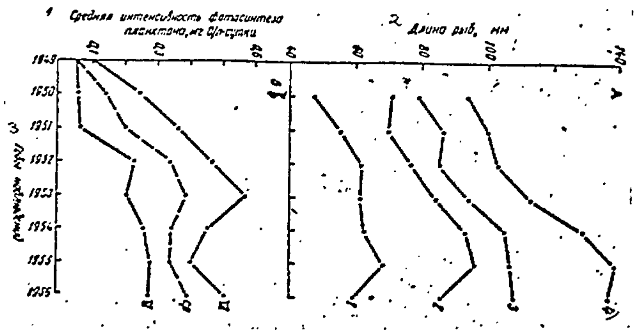
To determine the amount of fertilizer necessary and exploratory experiment was staged in 1949 using water from Bear Lake to which had been added various quantities of phosphorus and nitrogen salts. From the intensity of photosynthesis and the number of cells of phytoplankton developing in the test jars it was found that of the three fertilizers tested the greatest increase per unit was shown by the one with an addition of 0.05 mg of phosphorus and 0.25 mg of nitrogen per litre. These figures were taken as estimated concentrations for subsequent applications of fertilizer. Phosphate and nitrate salts were added to the lake every year, beginning in 1950. During the first two years the fertilizers were added once a season, but in subsequent years the dose was halved and given twice. Hydrochemical, hydrobiological and ichthyological investigations were conducted systematically. After fertilization the development of the phytoplankton lowered the transparency of the water, increased the oxygen content and made the water more alkaline. No marked regular variations in these factors was detected in different years. Highly interesting data were obtained as the result of measurements of the intensity of photosynthesis of the plankton by the bottle method, which, the authors conclude, is "the most direct existing method, which very quickly reveals the effectiveness of the fertilizer used" (Nelson, Edmondson 1955). When measurements are made by this method the figures for the gross yield can be expressed in absolute units. This made possible a quantitative comparison of the initial and end effect of fertilization and determination of the relationship between them. Figure 1 clearly shows that during the first four years of fertilization of the lake the average intensity of photosynthesis rose from year to year, and this revealed the cumulative effect, which could not be traced so distinctly by other methods. In subsequent years, notwithstanding the continuing fertilization of the water of the lake, the gross yield remained at the same level. Evidently, under the influence of the fertilizer there was also a progressive increase in the rate of growth of the young red salmon (Fig. 1, A). This tendency can also be detected in the increase in the average weight of the downstream migrant young, which yielded the following instructive series of figures (Nelson, 1959):

Year of investigation	Av. weight of one fish, in grams	Year of investigation	Av. weight of one fish, in grams
1950	3.35	1954	8.23
1951	4.83	1955	8.99
1952	5.59	1956	8.23
1953	6.54		

Thus, we are faced with one of a few examples where fertilization of a lake not only resulted in an initial effect but also, to some degree, led to the accomplishment of the ultimate aim - the improvement of the conditions of development

of the fish and an increase in productivity. Characteristically this was achieved in an oligotrophic homothermous lake. Of especial importance perhaps is the fact that in this specific case the original supposition that the fish yield is limited by the magnitude of the gross yield in oligotrophic lakes was borne out. Also important is the fact that the experiment demonstrated the cumulative effect of the fertilizers over a series of years, i.e. the possibility of raising the trophic level of an oligotrophic lake by prolonged fertilization. Of particular interest for the theory of the action of fertilizers is the fact that in the years 1950-1952 the rise in productivity had no effect on the composition and quantitative development of the zooplankton. As Nelson notes, this does not mean at all that the yield of zooplankton and other food organisms remained at the same level. With an invariable biomass of zooplankton, which is limited by the grazing of the fish, its yield could increase owing to a rise in fertility and a hastening of /31/ development under better trophic conditions. Judging by some data (McLeod, 1958), a certain increase in the yield of oligotrophic salmon lakes in Canada can be achieved with the aid of crab meal.

Lake fertilization is known to have been tried in other countries apart from the USA and Canada. In Australia for example the cold-water oligotrophic Lake Dobson, which is situated at an altitude of 1030 metres (area 5.85 hectares, maximum depth 6.1 metres, average depth 2.34 metres) and contains water of



1 mean intensity of photosynthesis of plankton, mg O/1-days

2 Length of fish in mm.

3 Years of investigation

Fig. 1. The effect of fertilization of Bear Lake on gross production and growth of young red salmon (after Nelson, 1959): A - Av. length of migrating fish of different ages; 1,2,3,4 - age in years; B - photosynthesis of plankton forty days after June (VI) and July (VII) applications of fertilizer and the mean intensity of photosynthesis (Co).

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very low mineralization (dry residue after heating - 21 mg/1), was, in the summer season of 1950/51, fertilized every month with some 800 kg of a mixture of salts (40% ammonium sulphate, 60% superphosphate, 5% potassium chloride and 15% lime). Later lime was added three times. It was found that after fertilization a sharp drop in the initially high content of phosphorus phosphate is followed by an increase in the amount of organic phosphorus in the water, and about a month later it reaches its peak.

The rate of growth of Myriophyllum was sharply stimulated. The rate of growth of the fish also increased (Weatherly, Nicholls, 1955).

Interesting results were obtained from phosphorus fertilization of the oligotrophic trout lake Loch Kinordochy /32/ (16 hectares, average depth 2.4 metres) in North Scotland. In the lakes of this locality the content of phosphates in the water is very low ($P-PO_4 < 0.5$ mg/m^3). In the summer of 1952 two tons of superphosphate were added and an initial concentration of 0.33 mg of phosphorus per litre was achieved. During the first fortnight the content of phosphate dropped in accordance with the logarithmic law and twenty weeks later it had reached analytical zero. Analyses failed to reveal any influence of the fertilizers on the content of NO_3, NH_4 and HCO_3 in the water (Holden, 1956).

The phytoplankton, which was subjected to systematic study 2½ years prior to the addition of the fertilizer, proved to be strongly affected by it during the following two years. Within a fortnight of fertilization the number of cells of Asterionella formosa, which had been very small, prior to fertilization, rose to 1030 per ml. This was accompanied by a drop in the content of silicon in the water to a very low level (0.1 mg SiO_2/1). This low content of silicon, which restricted the development of diatoms, was not found in neighbouring lakes. Prior to fertilization the content of SiO_2 in Loch Cairnardochi in summertime was approximately 1 mg/l. In the spring of 1953, after there had been a significant increase in the content of silicon compounds in the water during the winter, *Asterionella* reached its peak (2300 cells per ml). In summer of the same year the blue-green alga *Anacystis montana* developed - first in the plankton and then near the bottom.

In Scotland during the war years there was a widely publicized attempt to "fertilize the sea". This interesting experiment was performed in an almost completely isolated body of water connected with a sea bay by a narrow channel barred by a dam. In its size and depth the experimental water basin was in essence a small pool (area 7.4 hectares, average depth about 1 metre, maximum depth 5 metres) filled with sea water. For three years, from spring 1942 to spring 1945, this basin was fertilized with sodium nitrate and superphosphate. During the first two years the fertilizer was added 7-8 times a season. All in all, 233 kg of sodium nitrate and 177 kg of 20% superphosphate were added in 1942. In 1943 the quantity of sodium nitrate was increased (249 kg) and the quantity of superphosphate reduced (137 kg). In spite of the small doses of fertilizer their application had a marked effect. As a rule, the phytoplankton developed strongly during the first years, chiefly through the minute organisms of the nannoplankton and the peridinians. In some cases the fertilizer strongly stimulated the growth of Cladophora, and then there was no reaction on the part of the phytoplankton. It is interesting that in 1944 the phytoplankton failed to react to the first two applications of fertilizer, and not until the 4th of August, when almost ten times the dose was used (608 kg of sodium nitrate and 203 kg of superphosphate), did water bloom make an appearance.

It is very significant that the biomass of benthos /33/ had increased and the rate of growth of the fish (plaice) had been strongly accelerated as early as 1943. But because the mixing of the water in Loch Craiglie was greatly impeded by the freshening and heating of its surface layers, in 1944, in spite of the relatively small doses which had been used, adverse effects were noted. The oxygen deficiency near the bottom increased, hydrogen sulphide appeared near the bottom, and so forth. Owing to this the biomass of benthos and the rate of growth of the fish were not higher that year as they had been in 1943. In 1945, after the exchange of waters had been intensified, the biomass of benthos and the rate of growth of the fish increased strongly again. Observations showed that the fish maintained their good rate of growth in subsequent years too (1946 and 1947), when fertilizer was no longer being added. This example is interesting by virtue of the fact that small doses of nitro-phosphorus artificial fertilizers (30-35 kg/hectare of sodium nitrate and 18-24 kg/hectare of superphosphate per season) produced a marked improvement in the food conditions and increased the fish yield of the body of water.

Although the studies of the mechanism of the action of the fertilizers were conducted unsystematically they contain a number of interesting points. The reactions of the plankton to the application of the fertilizer differed greatly, and were in some cases non-existent. In spite of this, the content of mineral forms of nitrogen and phosphorus in the water, which was high after fertilization, invariably dropped rapidly in all seasons of the year. The zooplankton, which was very abundant in the first year of fertilization, dropped to a much lower level during the subsequent years, and this might have been due both to more intensive grazing and to the conditions created as the result of fertilization (pH up to 10, oxygen content up to 300% of saturation, and so on). The authors emphasize the great complexity of the phenomenon and the difficulty of analysing the mechanism of the action of fertilizers (Gross et alia), 1944, 1947, 1949; Marshall, Orr, 1948; Raymont, 1949)1 Special experiments conducted in winter, when there are no Cladophora, showed that the nitrate nitrogen of the sodium nitrate could be successfully replaced by ammonium nitrogen in the compounds $(NH_4)_2SO_4$, NH_4NO_3 and $(NH_4)H_2PO_4$. However, for reasons which are not clear, the application of ammonium chloride and urea failed to evoke a response from the phytoplankton (Marshall, Orr, 1948).

The authors referred to above also describe the results of the fertilization with nitro-phosphorus substances of another, more open part of the same sea bay. The experiments lasted

from the beginning of 1944 until July 1946. Our attention is drawn once more to a rapid drop in the concentration of nutrients in the water. Emphasis is also laid on the fact that the size of the biomass of phyto- and zooplankton cannot be used as a criterion to judge the effect of the fertilizers, since the increase in the biomass is constantly being eroded. The authors describe a strong increase in the biomass of the benthos which /34/ continued even in 1947, i.e. one year after fertilization had ceased (Gross et alia, 1944-1949; Raymont, 1947).

In Yugoslavia, on the island of Mljet, an interesting experiment was conducted in 1953 and 1954 under the supervision of Buljan. It involved the fertilization of the securely isolated end portion of the bay Mljet Lake, which is virtually a basin (area 183 hectares, maximum depth 46 metres, average depth 22.5 metres) filled with sea water (S °/oo equals 37) and connected with the bay by a shallow channel. The authors of this experiment (Buljan, 1953: 1957; Pucher-Petkovic, 1957, 1960) used an unusual method of fertilization. Because of the high cost of nitrogenous fertilizers, Buljan, relying on the stimulation of nitrogen fixation, selected superphosphate as the artificial fertilizer. However, in 1953 the lake was fertilized with a small quantity (2.27 tons) of cyanamide.

To avoid the sinking of the undissolved part of the superphosphate which occurred in the Scottish experiment the fertilizer was first dissolved in sulphuric acid diluted with sea water (to one centner of superphosphate 70-80 litres of water and 4.75 litre of commercial sulphuric acid with a specific weight of 1.68 and dilution to a volume of 200 litres). Earth was added to the solution as a source of micro-nutrients and supplementary growth factors. It is asserted that the introduction of an acid solution into a body of water can do no harm.

From the 20th of January to the 25th of September 1954 21.5 tons of superphosphate in nine doses were added in this way. A very careful check was kept on the effect of the fertilizer on the phytoplankton, which was studied in detail prior to fertilization, from March 1951 to March 1952 and in the same year as the experiment (Pucher-Petkovic, 1957, 1960). The first two applications in January and March had no effect on the phytoplankton. According to the authors this was because of stimulation of the growth of the benthos algae, which compete with the plankton. Subsequent fertilizations induced strong development of the phytoplankton. Before fertilization (1951-53) the quantity of phytoplankton in summer was 2-10 thousand per litre; after fertilization (1953) it was four hundred to five hundred thousand per litre. Typically, no increase in the quantity of zooplankton was observed in this particular case either. The rate of growth of oysters planted in the lake increased strongly, by a factor of 4.2. Due to the vigorous development of the phytoplankton the surface layers of water were supersaturated

with oxygen up to 200% and above during the year of fertilization, whereas the bottom layers developed a large oxygen deficiency. These phenomena were not noted prior to the fertilization of the lake.

Not without some justification Buljan considers that the creation of anaerobic conditions with the formation of H_2S at some very deep part of the demersal region has a /35/ beneficial effect, since the enrichment of the water with phosphates from the mud is facilitated in anaerobic conditions. He expresses his conviction that this method can also be used with success in freshwater lakes with an average depth not exceeding 10-12 metres.

The contents of this chapter show that the fertilization of lakes is still at the early experimental stage and that the experiments have not achieved their ultimate aim of increasing the fish yield. Nevertheless, they are of great interest since the observations accompanying them also enable us to arrive at certain conclusions of general significance in addition to the comments on individual topics made above.

The invariably observed initial effect of the application of artificial fertilizers showed that even in natural bodies of water in the most varied regions of the globe the development of plankton is limited by the content of nitrogen and phosphorus compounds in the water, and this applies to both oligotrophic and eutrophic lakes. In the case of oligotrophic lakes the possibility was shown of achieving the ultimate goal of fertilization, i.e. an increase in the fish yield.

At the same time it was found that not only in eutrophic lakes but also in oligotrophic ones it is difficult to change the established level of the content of nutrients in the water. After each application of fertilizer there is only a brief increase in their content, which then returns to its normal level for that particular body of water. However, there are grounds for thinking that, at least as far as oligotrophic lakes are concerned, systematic fertilization spread over a number of years may have a cumulative effect and increase the fish yield.

These conclusions are directly applicable to large non-draining fish ponds. There is no doubt that even in the case of draining ponds one must, when fertilizing them, bear in mind their trophic type and the intensity of their cycle, which depends to a considerable extent on the geographical location of the pond, and climatic and edaphic conditions. A correct understanding of the importance of these factors will help us to find the best way to alter the properties of the pond in the required direction.

5. Development of Research on the Fertilization of Ponds in the Soviet Union

In the post-war years pond fertilization research in the Soviet Union received a great boost, and in many ways led

the world in this field. Many Soviet research projects on pond fertilization are complex in nature, and this is completely justified by the complexity and multifarious aspects of the /36/ problem. In the Soviet Union hydrobiologists have played a prominent part in this research. The stress on productivity in Soviet hydrobiology has also been carried over into the study of questions relating to the fertilization of ponds, the task being to trace the entire intricate path from the initial effect of fertilization to the final link in the chain of this process - the culture of fish - and thereby ascertain the way in which fertilizers act and the principles underlying their action. Only in the researches of Soviet scientists A.G. Rodina, S.I. Kuznetsov, M.V. Mosevich and others has due attention been devoted to the special study of the microbiological processes involved in the fertilization of ponds. Soviet research has not been limited to the testing of individual types of fertilizer: rather has it been directed towards the development of a complex method of fertilization with the aim of achieving the maximum economic effect with the minimum outlay.

In view of the great diversity of soils, climatic and other natural conditions in the different parts of the country it is natural to suppose that the methods and doses of fertilization in fish culture, like those in field husbandry, cannot be uniform and universal, suitable under any conditions. Furthermore different methods must be used for intensifying the culture of the young of different species of fishes. Hence the diversity of the methods of fertilization which have been tested, developed and proposed and of the other means of intensifying fish culture.

Pond fertilization projects embrace virtually all the fish breeding regions of the Soviet Union and are on a massive scale. Numerous fish farmers and leading producers are taking part in the experiments.

In pre-war Soviet Russia pond fertilization problems were studied at the All-Union Lake and River Fish Farming Research Institute under I.N. Arnold and at the All-Russian Pond Piscicultural Research Institute under A.N. Lipin and A.N. Eleonsky.

Research on artificial phosphorus and potassium fertilization of ponds in the Ukraine was undertaken by M.K. Taran (1939, 1940). The same years witnessed the experiments of V.A. Movchan, the results of which are summarized in his book on the ecological principles of co-ordinated intensification of the growth of carp (1948).

This book by V.A. Movchan directed the attention of fish culturists to the advantages of co-ordinated intensification as against the desultory application of various methods of intensification.

After the second world war research into pond fertilization in the USSR was undertaken by the All-Russian Pond

Piscicultural Research Institute (VNIIPRKh), the State Lake and River Fish Farming Research Institute (GosNIORKh), the All-Union Research Institute of Fisheries and Oceanography (VNIRO), and the republican institutes of fish culture in the Ukraine, Belorussia and Latvia. A great contribution to the development of fertilization studies has been made by the institutes and laboratories of the Academy of Sciences of the USSR and the Academy of Sciences of the Ukrainian, Moldavian, Latvian and other republics, and the departments and laboratories of the universities of Belorussia, Moscow, Leningrad, Kiev, Dnepropetrovsk and many other institutions of higher learning and biological and agricultural institutes. /37/

A great deal of work on the fertilization of ponds is being done by fish breeders for the market who are directly concerned with finding the most effective methods of increasing the productivity of ponds.

Since 1950 over two hundred scientific papers specially devoted to pond fertilization problems have been published in journals and symposia. This number is greatly increased if we add the short notes and correspondence on new findings and other documents in local publications. Unfortunately, many of the results of experiments and investigations of the fertilization of ponds never find their way into print and are buried in the manuscript reports of piscicultural institutes and their branches, i.e. remain inaccessible to the wide circle of interested persons and specialists in other organizations.

As was mentioned earlier, after the war theories in the Soviet Union concerning pond fertilization and fertilization practice underwent a sudden change. The previously dominant theory of non-nitrogenous fertilization of ponds was finally refuted by Soviet scientists.

There were corresponding changes in practical recommendations. Great interest developed in nitro-phosphorus fertilizers and they were used in conjunction with organic fertilizers (combination or complex fertilization). Recommendations concerning the norms for the application of fertilizers also underwent great changes: instead of once or twice it is now recommended that artificial fertilizers be added to the water repeatedly.

The research performed by Soviet scientists is given wide coverage in the subsequent chapters of this book. Therefore the present chapter will be confined to a general outline of work on the fertilization of ponds carried out in the USSR, and a more detailed examination will be made only of the research which, for some reason or another, has not been allocated a place in the other chapters.

During the last decade a number of papers have been published on pond fertilization by scientists at the All-Russian Pond Piscicultural Research Institute. These papers take up again; as it were, the threads of the research begun before

the war, and the problems of pond fertilization are examined from preconceived points of view. Discussion of the conclusions of most of these papers is hampered by the fact that the effect of the various fertilizers used was obscured by the simultaneous use of concentrated foods for feeding the fish. This is a powerful method of increasing the fish yield. Moreover, the authors unfortunately failed to give even approximate estimates of the part of the yield which was due to natural food, calculating the consumption of artificial foods per unit of overall fish gain without reference to fertilizers and other means of raising productivity (Komarova and Musselius, 1959; Betenko, 1958; Bakhtina and Batenko, 1961; Mints and Khairulina, 1961 and others).

In 1951 experiments were conducted in the fertilization of six ponds at the Savvin experimental farm in the Moscow region using superphosphate (200 kg/ha.), lime (200 kg/ha.), manure (2 tons/ha.), peat (1.3-4 tons/ha.) and aquatic plants (2-6 tons per hectare). Half of these fertilizers was added while the experimental ponds were dry and the remainder in three doses after the ponds had been filled. During the growing season the development of the plankton and benthos, and the hydrochemical regime were observed, and the growth of the fish planted in the experimental ponds was checked for different densities of stocking. The authors (Il'in, Bakhtina, Erokhina, and Mamontova, 1956) came to the conclusion that the best effect is achieved with superphosphate and lime, and with these fertilizers in combination with aquatic plants. Peat proved quite ineffective as a pond fertilizer. However, it is difficult to judge the effectiveness of the fertilizers in these experiments because there was a very large loss of underyearling carp in the control pond, and the authors were obliged to take for comparison an estimated figure for the yield of this pond. The largest yield of fish in these experiments was 563 kg/hectare, with an average weight of the young of the year of 53 grams. In this particular case the authors used six tons/ha. of aquatic plants and two centners/ha. each of superphosphate and lime. The authors recommend adding the superphosphate and lime in the form of a solution poured into the water every ten days, and the aquatic plants in the same small doses 10-12 times during the growing season.

In 1952 V.M. Il'ich, A.N. Lipin, V.I. Bakhtina, M.P. Sheina, L.V. Erokhina, L.N. Mamontova and I.V. Komarova (1956) continued the experimental work by fertilizing 14 nursery ponds at the Zagorsk fish nursery and 9 finishing ponds at the Savvin farm. For these experiments the same mineral fertilizers as before - lime (150 kg/ha.) and superphosphate (150 kg/ha.) were used. The organic fertilizers selected were aquatic plants (1000-3000 kg/ha.) and vegetable meal (1000-3000 kg/ha.) and manure (300-500 kg/ha.) used in various combinations with artificial fertilizers. Regular observations were made of the temperature of the water and the content of dissolved oxygen, and an analysis was made of the salt composition of the water,

the development of the food supply of the fish (plankton and benthos), the feeding of the fish, their growth, and so on.

When assessing the effectiveness of the fertilizers the authors did not compare the yield of the fertilized ponds with the actual mean yield in the control ponds, but took for this purpose some estimated figure lower than the actual figure, and this led to a clearly overstated assessment of the effectiveness of the fertilizers. If we compare the experimental and control ponds from the standpoint of the actual yield of fish we obtain a negative result in four out of the twelve ponds. In the remaining eight ponds, which were fertilized with a similar complex of organo-mineral fertilizers, the yield was higher than in the control ponds.

It is interesting that the highest yield (415 kg/ha.) was obtained in the ponds fertilized only with vegetable meal at a rate of 3 t/ha. (in the control pond the yield was 268 kg/hect.). It was even slightly higher than in the other two ponds fertilized with the full range of fertilizers under test but with a smaller quantity of vegetable meal. From this we can conclude that if the mineral fertilizers in the form of lime and superphosphate had any influence on the yield in these experiments it was only very small.

A characteristic feature of these and other projects of that period is that numerous results of all kinds of hydrochemical and hydrobiological observations are cited, yet they are not used by the authors to draw any conclusions.

Simultaneously the same team of scientists followed a similar program to study the finishing ponds at the Savvin experimental farm. On seven ponds they tried various combinations of lime (150-200 kg/ha.), superphosphate (150-200 kg/ha.), aquatic plants (1-3 tons/ha.), manure (300-500 kg/ha.), and vegetable meal (1-3 tons/ha.). The ponds contained a mixed culture of yearling carp and trout (70% carp and 30% trout). The experiments also showed the greater effectiveness of organic fertilizers as against the superphosphate and lime. The results of these and several other studies by the Pond Piscicultural Research Institute in connection with the raising of the fish yield of carp ponds are summarized in the book by V.M. Il'in (1955).

The researches of I.V. Baranov, G.G. Vinberg, V.I. Zhadin and other Soviet scientists finally established the unsoundness of the theory of non-nitrogenous fertilization and proved the effectiveness of using nitrogenous and nitro-phosphorus fertilizers. After this, since 1957, the workers at the All-Russian Pond Piscicultural Culture Research Institute began experimenting with nitrogenous artificial fertilizers for fertilizing ponds. L.N. Mamontova, I.V. Komarova, and N.M. Kalish (1961), in their experiments to study artificial nitro-phosphorus fertilizers, used very high doses of nitrogen (up to 7 mgN/l) and frequent applications. The nitrogenous fertilizers were added daily at the beginning of the season and then every three days. The aim

was to maintain a constantly high concentration of mineral nitrogen in the water in order to prevent the development of blue-green algae, which L.N. Mamontova considers to be a trophic impasse, and which, in his opinion, cannot develop in a medium rich in mineral nitrogen. As a result the total quantity of ammonium nitrate in the experiments of Mamontova and her collaborators was increased to 27-30 centners/hectare. In the experiments Mamontova performed in 1961 the increase in the quantity of ammonium nitrate from 13.5 to 31.3 centners/hectare in the presence of similar quantities of superphosphate (roughly 7 cent./ha.) failed to provide any additional increase in the fish yield.

In recent years the All-Russian Pond Piscicultural Research Institute (VNIIPRKh) has been searching for methods of reducing the consumption of nitrogenous fertilizers per unit of increase in fish production and has begun experimenting in connection with problems relating to pond fertilization.

In GosNIORKh the research of I.V. Baranov merits special attention. He has made extensive use of biological tests to determine fertilizer requirements. I.V. Baranov advanced the idea of "combination fertilization" of water basins with mineral salts of nitrogen and phosphorus and higher aquatic plants. His experiments in the shallow parts of the Tsimlyansk reservoir showed in particular that with such a combination the intensification of the photosynthesis of the plankton eliminates the danger of an oxygen deficiency due to the decomposition of the vegetable fertilizer (Baranov, 1954).

Over a number of years (1951-1956) pond fertilization studies were conducted by an expedition from the Zoological Institute of the Academy of Sciences of the USSR under the supervision of V.I. Zhadin. From 1951-53 the experiments were conducted in the vimba-shemaia nursery in the North Caucasus, and from 1954-56 in the carp ponds of the Latvian SSR. A variety of specialists took part in the studies. Studies were made of the hydrochemical regime of the ponds, and the composition and quantity of the phyto- and zooplankton and zoobenthos. Under the supervision of A.G. Rodina an immense amount of work was done on the study of the microbiology of the ponds in connection with fertilization.

The fertilizers used in the experiments of this expedition were superphosphate, ammonium sulphate, potassium salt and partly-dried vegetation. The separate application of phosphorus or nitrogen fertilizer alone had only a slight /41/ effect. Much more effective was the combined application of nitrogenous and phosphorus artificial fertilizers in equal quantities, but the best results in the case of the ponds of the vimba-shemaia nursery were achieved with fertilization with vegetation using the zonal method and with mineral salts of nitrogen and phosphorus added every week to the water in the form of a solution (Zhadin, 1955). The weekly application of 40 kg/ha. of superphosphate and ammonium nitrate, 2-5 kg/ha. of potassium

salt and 500-750 kg/ha. of vegetation helped to raise the fish yield of the ponds from 60-80 to 300-449 kg/ha. V.I. Zhadin called this fertilization technique the complex method.

The same methods of fertilization were tested by the Zoological Institute's expedition on carp breeding ponds in the Latvian SSR. Here complex fertilization was again found to be comparatively effective, but it should be noted that the unusually low figure of 55 kg/ha. for the original natural fish yield was taken for comparison (Zhadin, 1958). This figure was obtained in a pond used as a nursery, although most of the experimental ponds with which it was compared were used as finishing ponds. The best total fish yield of the experimental ponds (including stickleback) was 418 kg/ha.

Experiments conducted with the ponds of the "Pirmrindnieks" collective farm in Latvia confirmed the previously obtained results, demonstrating the superior effectiveness of complex fertilization with mineral salts and aquatic vegetation (Pankratova, 1958).

Studies of the hydrochemical regime of the fertilized ponds of the vimba-shemaia* nursery and the carp ponds of the Latvian SSR (Ozertsovskaya and Smirnova, 1958, 1959a, 1959b) showed that as usual the addition of vegetation was accompanied by a drop in the content of oxygen dissolved in the water, an increase in the oxidizability of the water and a shift in the pH in the direction of acidity. The addition of the mineral

* Vimba vimba – Chalcalburus chalcoides

compounds N + P + K + Ca resulted in an intensification of the photosynthetic processes, and this led to a rise in the content of oxygen in the water and shifted the pH in the direction of alkalinity. The studies made by N.N. Khmeleva (1958, 1958a), N.N. Khmeleva and L.I. Tsvetkova (1959), and I.A. Kiselev (1959) of the development of phytoplankton in ponds in connection with their fertilization are examined in chapter III. The papers of N.A. Akatova (1957, 1958, 1959) and L.A. Kutikova (1958) devoted to the study of the zooplankton of fertilized ponds are, like the data of V.Ya. Pankratova (1957, 1959a, 1959b) on the development of the zoobenthos, examined in chapter IV.

A.G. Rodina who took part in these researches together with her pupils did an enormous amount of work on the study of microbiological processes in connection with the fertilization /42/ of the ponds. One of the most important results of these studies for pond fertilization practice was the discovery that "...when the fertilizers added are correctly selected....by far the greater part of the nitrogen fertilizers applied is very rapidly fixed biologically in the cells of the algae and microbes. The high saturation of the water with oxygen in conjunction with the mass development of phytoplankton also leads to a slowing of the denitrification process and fails to stimulate an increase in the population of denitrifying bacteria" (Rodina, 1958 a). This significant conclusion is an important milestone on the road to overcoming the notion rooted in the fish culture of many European countries that it is inadvisable to use nitrogen fertilizers on account of denitrification processes.

To determine the principles underlying the cycle of certain nutrients in connection with the fertilization of ponds the Zoological Institute's Baltic expedition staged aquarium experiments with radioactive isotopes of calcium (Shuvalov, 1959) and phosphorus (Zhadin, Rodina, Troshin, 1957; Rodina and Troshin 1954, 1959a; Khmeleva, 1959b).

The studies and observations made enabled the researchers to recommend fertilization with the following set of nutrients - P + N + K + Ca - in combination with aquatic bog vegetation. They recommend adding mineral compounds of nitrogen, phosphorus, potassium and calcium every week in equal portions in the form of a solution poured into the water in quantities of 40-60 kg of superphosphate, 40 kg of ammonium sulphate, 5 kg of potassium chloride and 15 kg of slaked lime per hectare in each application. The aquatic bog vegetation, which is preferred above all other types of organic fertilizer, should be added to the ponds by the zonal method of M.M. Isakova-Keo (Zhadin, 1959).

When the Zoological Institute of the Soviet Academy of Sciences had finished its work in Latvia the research on the fertilization of ponds was continued by workers of the Biological Institute of the Academy of Sciences of the Latvia SSR and the republican piscicultural research institute. Initially these investigations were aimed at determining the possibility of increasing the fish yield of ponds fed by bogs. In such ponds the application of fertilizers was preceded by liming (Matisone, 1958, 1959, 1962; Matisone, Volkova and Vadze, 1960). The complex used by V.I. Zhadin is recommended for fertilization. M.N. Matisone (1962) considers that it is sufficient to add the artificial fertilizers twice a month, and the vegetation every two-three weeks. The total consumption of fertilizer during the growing season is then (in kg/ha.) lime 1000-1200, superphosphate 1000-1200, ammonium sulphate 500, potassium chloride 50, and vegetation 1000-1200. According to the results of biological tests in the conditions of Latvia, neither Zhadin (1959) nor Matisone (1962) found any need for potassium fertilizers. In spite of this, the authors still judge it essential to add potassium chloride - apparently to complete the complex in the usual way.

In 1960 a group of workers from the Piscicultural Research Institute of the Latvian SSR made a comprehensive study of fertilized ponds at the Tukumsk fish farm. Phosphorus and nitro-phosphorus mineral fertilizers were tested on three ponds with a total area of 5-8 hectares after liming. Detailed observations were made of the development of the phytoplankton (Tsukurs, 1962), zooplankton and zoobenthos (Volkova, Bunkis, 1962) and the increase in the fish yield (Okhryamkina, 1962).

Systematic observations led to the discovery that there was a direct link between the quantity of fertilizers added to the pond and the biomass of phyto- and zooplankton. No link was

discovered between fertilization and the development of the benthic fauna. A larger quantity of fertilizer brought a lower yield of fish. The highest natural yield (350 kg/ha) was obtained from fertilization with 265 kg/ha of superphosphate, 544 kg/ha. of ammonium sulphate and 205 kg/ha. of lime. In these experiments the question of the use of potassium fertilizer was not even raised. The smallness of the doses of lime is probably due to the fact that the experimental ponds were fed not by bogs but by atmospheric precipitation. In all the experimental and control ponds the fish received ample food, and for this reason the authors were obliged to estimate the increase in fish production as the result of fertilization from the food coefficient of the artificial foods, which was taken to be constant. An objective assessment of the effectiveness of fertilization in these circumstances was difficult, since we know what a difference there can be in the consumption of artificial foods per unit of growth in figh production in different conditions.

In Belorussia the first post-war experiments in the fertilization of ponds were begun by the republican Piscultural Research Institute (BNIIRKh) in 1949 under the supervision of D.P. Poliksenov and in 1950 under G.G. Vinberg (Vinberg and Shchelkanova, 1953; Lyakhnovich, 1953). Initially the research was performed within the framework of a plan for comprehensive intensification, using the method of V.A. Movchan, on the ponds of the largest fish farm in the republic - the "Volma" farm in

Minsk oblast[*]. In later years the work was carried on by scientists from BNIIRKh in commercial ponds on the fish farms of the Polessk area.

The application of a complex of intensification measures, among which a certain role was played by artificial and organic fertilizers, made it possible to raise the total productivity of the finishing ponds on "Beloe" fish farm to 1007 kg/ha., while the yield due to natural foods amounted to 630 kg/ha. (Khomchuk, 1954). The same system of measures applied in respect of nursery ponds at "Krasnaya Zvezda" fish farm enabled an increase in fish production to 1397 kg/ha. (including 727 kg/ha. due to natural foods) (Lyakhnovich, 1961).

Starting in 1950, experiments to determine the fertilizer requirements of ponds were staged on several commercial fish farms by scientists from the Belorussian State University under the supervision of G.G. Vinberg.

Biological tests established that the water of the fish breeding ponds of various regions of the republic mainly required nitrogenous or nitro-phosphorus fertilization (Vinberg, 1952, 1953, 1956a, 1956b, 1957, 1958).

To test the results arrived at on the basis of biological

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[*] An oblast is an administrative unit in the USSR - Translator.

tests conducted between 1953 and 1955 on five experimental ponds at the "Shemetovo" fish nursery in Minsk oblast, experiments in the use of artificial fertilizers were performed. Superphosphate and ammonium nitrate were first tested separately and then together, in quantities ranging from 50-300 kg/ha. of ammonium nitrate and from 50-450 kg/ha. of superphosphate (Vinberg, 1958). The application of the phosphorus fertilizer alone failed to yield any benefit but the combined action of nitrogen and phosphorus was highly effective. The use of the nitrogen fertilizer provided a much smaller boost to fish production than the use of a mixture of nitrogen and phosphorus. As the result of repeated applications of artificial fertilizers in the form of a solution added straight to the water, the yield of the experimental ponds, which were being used as nursery ponds, was 3-4 times higher than in the control ponds.

Complex studies of the experimental ponds made in connection with this research revealed the influence of artificial fertilizers on the main links in the production process, i.e. the development of the phytoplankton (Kishchenko, Sokolova, 1958), the gross production (Vinberg, Kishchenko, 1958), the development of bacteria (Belyatskaya, 1958), and the zooplankton and benthos (Dunke and Dorozhkin, 1958; Dunke, 1958), and made it possible to determine the characteristics of the cycle of phosphorus when the ponds were fertilized by the method of tracer atoms (Vinberg, Godnev, Gaponenko, 1955; Vinberg, Gaponenko, 1958; Gaponenko, 1955, 1958).

In the experiments conducted by research workers from BNIIRKh between 1960 and 1962, under the supervision of V.P. Lyakhnovich, in the nursery ponds of "Volma" fish farm and the finishing ponds of "Izobelino" fish farm in Minsk oblast, they tested nitro-phosphorus fertilizers in the form of ammonium /45/ nitrate and superphosphate in a ratio of 2:1. The experiments showed the high degree of effectiveness of fertilizer added to the water in fractional doses at ten-day intervals. Using total quantities of up to 800 kg/ha. of ammonium nitrate and 400 kg/ha. of superphosphate during the growing season the scientists failed to detect any tendency towards reduced effectiveness of fertilization. The natural fish yield increases in direct proportion to the quantity of fertilizer added, and in the most favourable case reached a level of 847 kg/ha. (Lyakhnovich, 1963). In the experiments there was a sharp rise in the quantity of phytoplankton under the influence of nitro-phosphorus fertilization (Prosyany, 1963), an increase in primary production (Lyakhnovich, Surinovich, Prosyanik, 1963) and a considerable augmentation of the quantity of zooplankton food organisms for fish (Lyakhnovich, Korobchenko, 1963). Confirmation was also obtained a direct link between the biomass of food organisms and the fish crop of the ponds (for details concerning these ponds see chapter VI).

In the Ukraine after the war the study of pond fertilization problems was conducted chiefly by the Ukrainian Institute of Pisciculture (V.S. Prosyany, G.I. Shpet, M.B. Fel'dman et alia),

by the Ukrainian Piscicultural Amelioration Station (L.P. Braginsky) and the Hydrobiological Institute in Dnepropetrovsk (A.V. Evdushchenko). L.P. Braginsky, who used the method of biological testing for the fertilizer requirements of ponds and verified his observations on ponds, demonstrated that in the conditions of the Ukraine nitrogen must be assigned a large role in the fertilization of ponds (Braginsky, Frolova, 1959; Braginsky, 1961).

Valuable data were obtained by M.B. Fel'dman and Sukhovii (1961) from a study of the influence of fertilizers on the hydrochemical regime of ponds on the "Nivka" experimental farm. This research confirmed the effectiveness of applying nitro-phosphorus fertilizers as against phosphorus fertilizers on their own. When the dose was increased from 135 to 320 kg/ha. of ammonium nitrate and from 206 to 425 kg/ha. of superphosphate, added together in fractional doses to the water, the fish yield of the ponds grew in direct proportion to the quantity of fertilizer used, reaching 443 kg/ha. in the experiment with the largest amount of fertilizer (Fel'dman and Sukhovii, 1961). On the basis of the results of this study the Ukrainian Piscicultural Research Institute devised norms for nitro-phosphorus fertilization and suggested their adoption for commercial ponds. For repeated applications they recommended using in each case the following estimated concentrations of the active principles in the water of the ponds: 2 mg/l of nitrogen and 0.5 mg/l of phosphorus. /46/ In 1959 and 1960 these norms were tested by G.E. Korosteleva and L.S. Abramovich (1962) on carp ponds in Lvov oblast. The total expenditure of fertilizer was 500-800 kg/ha. of ammonium nitrate and 250-450 kg/ha. of superphosphate. As the result of the fertilization, the fish yields in these experiments rose by 57-167 kg/ha.

The experiments of L.P. Braginsky (1955, 1956 and others), D.E. Semenyuk (1956) and A.V. Evdushchenko (1955) served to prove the great effectiveness of organic fertilizers for pond-fish culture in the Ukraine. The use of vegetation for fertilization of the ponds was studied by V.A. Kononovy and V.S. Prosyany (1949) and V.S. Prosyany (1954).

The problem of the effectiveness of sowing ponds for fertilization was successfully tackled by A.A. Khomchuk (1948, 1950, 1954). Unfortunately, no work is being done in this field in the Soviet Union now.

All the papers examined have been connected with the raising of the productivity of carp ponds. Fertilizers are also used to improve the breeding conditions of young commercial fishes in hatcheries and in salmon ponds.

After the war there was a great deal of interest in the Soviet Union in the problem of the reproduction of valuable species of fish in hatcheries. Naturally, the exploitation of the largest areas of ponds in hatcheries required the elaboration of methods of raising the yield, including fertilization techniques.

An original method of organic fertilization of hatchery ponds was developed by S.I. Kuznetsov, G.S. Karzinkin and others. As we know, the hatchery ponds of the lower reaches of the Volga, Don and other southern rivers are very heavily choked with higher hydrophytes. The method of Kuznetsov and Karzinkin involves systematic clearance of the overgrown areas of the ponds and simultaneous securing of freshly cut floating vegetation as green fertilizer. In hot weather the vegetation rapidly decomposes and the water is enriched with nutritive substances and organic residues. S.I. Kuznetsov and G.S. Karzinkin were the first to prove that in these conditions rigid plants can be used as fertilizer without first being removed to the bank and dried in the sun. This method of fertilization on the "Yamat", "Azovo-Dolgii" and other fish farms yielded good results. During these experiments complex studies were made to determine the rate of decay of the rigid plants and its influence on the oxygen regime of the fertilized areas, the development of bacteria, phyto- and zooplankton, and on the growth of the fry and productivity. On and near the decomposing vegetation the /47/ observers noted intensified development of the food organisms of the zooplankton and benthos, and this accelerated the fattening of the valuable young commercial fishes being bred in the ponds (Kuznetsov, Karzinkin et alia, 1955; Karzinkin, 1955; Karzinkin and Kuznetsov, 1956).

In 1947 M.M. Isakov-Keo published data on the first experiment to increase the yield of whitefish ponds using a new method of "zonal fertilization", which was later called the zonal method of breeding live foods (Isakova-Keo, 1950). In essence the method involves placing organic fertilizer in a pond in zones in inlets or along dams on shoals. As the fertilizer decomposes in one spot it is piled up in other areas around the edge of the pond. M.M. Isakova-Keo (1950, 1952) recommends covering 1/3 of the margin with fertilizer at a time so that the ring of fertilizer is closed by the third application. The fertilizers used in Isakovo-Keo's experiments (1947, 1950, 1952, 1954, 1957) were hydrophytes and marginal vegetation, meadow grass and weeds, green branches of deciduous trees, manure, blood, fish entrails, boiled non-edible fish, and the like. The oxygen requirement was judged from the oxidizability of the water. If, in a sample of water taken 1 metre away from the point of fertilization, the oxidizability proved to be less than 12 mg 0/1 it was considered necessary to add the regulation dose of fertilizer.

The method of zonal fertilization of ponds with organic fertilizer suggested by Isakova-Keo was adopted by Ts.I. Ioffe, who, together with a group of fellow-workers from GosNIORKh, conducted pond fertilization researches on the "Sokolovo" fish farm in Novgorod oblast and the "Pelchi" fish farm in Latvia in 1949 and 1950 (Ioffe, 1950, 1954; Ioffe, Yandovskaya, Galkin et alia, 1955).

These experiments served as the basis for the formualation of biotechnical standards for the culture of salmon young of the year, which provide for two applications of manure in spring, and then, in the summer, fertilization with doses of 4 tons/ha. of vegetation every 30-35 days in the case of weeds, 5.5 t/ha. in the case of macrophytes, and 2 t/ha. for alder twigs. Before planting the authors advise drying all green plant fertilizer in the sun. If the water in the ponds exhibits an acid reaction it should be limed before the addition of the fertilizer.

Summing up our examination of the main trends in Soviet research on pond fertilization we should stress the general tendencies of the various methods employed.

1. Neither the scientists nor the fish farmers of the USSR deny the need for nitrogen fertilizers. It is rather a question of what forms of nitrogenous substances are most suitable as nitrogen fertilizers. /48/

2. There is general recognition of the advantage of fractional, comparatively frequent application of fertilizer as against one or two applications, irrespective of the form or quantity of the fertilizers used.

3. Ever wider use is being made of combination fertilization with mineral salts in combination with organic substances. As yet the forms of the combinations and the doses of fertilizer vary considerably.

6. Pond Fertilization in East European Countries

In the Polish People's Republic research on pond fertilization is being pursued in several directions. The first experiments after the war were concerned mainly with the effect of phosphorus fertilization on the regime of ponds (Wolny, 1956; Wrobel, 1960a; Stangenberg, 1959; Stangenberg-Oporowska, 1961). After comparing the data of chemical analyses of water following fertilization with superphosphate and Thomas meal, S. Wrobel (1960b) came to the conclusion that Thomas meal is the more suitable form of fertilizer since, when it is added, the content of phosphate in the water is maintained at a higher level than after the addition of the equivalent amount of superphosphate. The author does not cite any other data in support of this conclusion, apart from the results of phosphate determination.

P. Wolny (1956) considers that phosphorus fertilizers exert their full influence on the fish yield of ponds only in the second year after they have been added. In his opinion, phosphorus fertilizers stimulate the development of blue-green algae to a greater extent than representatives of other groups of phytoplankton, and since blue-green algae decompose very slowly they can only be used the next year.

Under the influence of Soviet research examining the theory of non-nitrogenous fertilization (Vinberg, 1952) scientists in Poland began to devote their attention to nitrogen fertilizers (Danieliewski, 1957; Wrobel, 1960). Danieliewski's experiment in the fertilization of experimental ponds at Ziabenec station near Warsaw with phosphorus and phosphorus in combination with nitrogen showed that after the addition of the nitrogen fertilizer the concentration of nitrites and nitrates in the water increased sharply, and then very quickly dropped to its original level.

Original thoughts on the use of nitrogen fertilizers in ponds were expressed by S. Wrobel (1960, 1962). He feels /49/ that ammonium sulphate should not be employed for nitrogenous fertilization of ponds because it is a physiologically acid substance, and the unavailable SO_4 anion, accumulating in the pond, reduces the alkalinity and displaces the CO_2 from the salts, as the result of which the buffer effect is diminished and conditions are created for sudden fluctuations of the pH. The author confirms these arguments with the results of his own experiments in the fertilization of ponds with ammonium sulphate which he conducted between 1957 and 1961 in the southern part of Poland ("Golysz" farm). During the first two years the addition of 250 kg/ha. of ammonium sulphate and superphosphate raised the yield to 360 kg/ha., which was three times higher than in the control pond. The accompanying phenomena were water bloom, a high oxygen content during the day, and so on. In the third year (1959) the yield of the ponds fertilized, as in the first two years, was only 140% of the yield of the control ponds, whereas the ponds which were fertilized with ammonium sulphate for the first time in the third year were more than twice as productive as the control ponds. On the strength of these data Wrobel feels that ammonium sulphate is an unsuitable source of nitrogen for prolonged fertilization of ponds. Obviously Wrobel's conclusion relates only to water of low or average mineralization and does not conflict with the successful application of ammonium sulphate in Israel, where, in highly mineralized waters, it must, for the same reasons, be regarded as the most suitable nitrogen fertilizer. Wrobel also casts doubt on the possibility of using ammonium nitrate for the fertilization of ponds because of the risk of denitrification. However, the author has failed to verify this point. Nevertheless, since Wrobel admits that the need for nitrogen fertilization is indisputable he suggests using ammonia water, consisting up to 20-25% of nitrogen and urea. Preliminary tests conducted at "Golysz" farm in 1959 showed that the addition to the pond of 150 l/ha. of 25% ammonia water caused alkalization of the water of the pond (the pH rose from 7 to 7.6), but as far as could be ascertained it had no detrimental effect on the fish. Wrobel considers that in future ammonia water and solutions of nitrogen-containing salts saturated with ammonia will be used as nitrogen fertilizers. Using the data of Soviet scientists, Wrobel (1962) tested fractional doses of nitro-phosphorus fertilizers added straight to the water over a period of four years (1958-1961) in the ponds of the "Golysz" and "Landek" fish farms. In these experiments, in 1960, the author used the bottle method of determining the primary production of the plankton of fertilized and unfertilized ponds. It discovered a positive link between the quantity of nitro-phosphorus fertilizer and the primary production, and also between the primary production and the fish yield of the ponds.

On "Golysz" farm several ponds were fertilized for many years in a row with superphosphate in quantities of 35 kg/ha. /50/ of P_2O_5. The fish yield of the ponds did not exceed 250 kg/ha. An increase in the amount of superphosphate failed to produce any further increase in the yield. It is extremely interesting that the yield of the same ponds was raised to 357-513 kg/ha. when nitro-phosphorus fertilization was used. One kg of $N + P_2O_5$ gave an additional increase of 1.3 to 2 kg of marketable carp.

In 1961 Wlodek and Danieliewski (1962) conducted production tests in the fertilization of ponds with ammonia water. Of thirty-two ponds belonging to nine state farms in central Poland, six were used for control purposes. Twelve were fertilized with superphosphate in quantities of 250 kg/ha., and fourteen were fertilized with superphosphate and nitrogen fertilizers, made up of twelve ponds treated with ammonia water in quantities of 500 l/ha. (100 kg/ha.) and two with an equivalent quantity of ammonium sulphate. The fertilizers were added every fortnight in equal portions from the middle of May to the middle of August. The estimated concentrations were 1.4 mg/l of nitrogen and 0.6 mg/l of P_2O_5. In the final assessment of the effectiveness of the nitrogen fertilizer seven ponds were ignored because the feeding of the fish in them was incorrectly organized. Out of nine ponds fertilized only with superphosphate, five had an average increase in yield over many years ranging from 9 to 196 kg/ha., and in the remaining four there was a drop of 14-78 kg/ha. Out of eleven ponds fertilized with phosphorus and nitrogen fertilizers, the yield was 38-140 kg/ha. above the average of many years in eight, and 30-85 kg/ha. below the average in three. Unfortunately, the authors do not cite any data on the control ponds, and they only indicate the relative increases or drops in production by comparison with the average of many years in the same experimental ponds. The authors emphasize that no water bloom was observed in the control ponds or the ponds fertilized only with superphosphate, whereas in most of the ponds fertilized with superphosphate and ammonia water bloom was caused by green and blue-green algae.

The authors traced the dynamics of the nitrogen when the ammonia water was added and showed that the high level of nitrogen does not persist; after five days it drops to lower levels than in the control ponds. In fertilization with ammonia water the loss of nitrogen occurs somewhat more rapidly than when ammonium sulphate is used. The authors recommend more frequent application of ammonia water than once every fortnight and doubling the dose of nitrogen fertilizer. The heightened interest shown by Polish scientists in liquid ammonia water as a source of nitrogen in the fertilization of ponds /51/ is due to the fact that, in terms of nitrogen, it is half the price of ammonium sulphate.

The tests of new types of artificial fertilizers conducted by Polish scientists are highly interesting. In the experimental carp fry ponds of "Ziabenec" station in 1963 experiments were staged to determine the comparative effectiveness of ammonia

water, urea, ammonium sulphate and ammonium carbonate (Wolny, 1964). All types of nitrogen fertilizer were tested twice against the same background of liming (1000 kg/ha. of lime) and phosphorus fertilization (330 kg/ha. of superphosphate). The ammonium carbonate was added to the ponds in nine doses in a quantity of 1000 kg/ha. The remaining nitrogen fertilizers were applied in quantities containing the same amount of nitrogen at the same times. The best piscicultural results were obtained from fertilization with ammonium carbonate. In second place was ammonium sulphate (269 kg/ha.). Under these conditions ammonia water and urea proved ineffective (ammonia water taken in large doses causes mass mortality of fry). Wolny feels that the effectiveness of the ammonium carbonate is due to the successful coupling in its composition of two elements of phytoplankton mineral nutrition - nitrogen and carbon.

In addition to the research on artificial fertilizers Polish scientists have been making a study of different forms of organic fertilizer. Wlodek even considers that "...organic fertilizer must be regarded as basic and artificial fertilizer as ancillary" (Wlodek, 1956), because organic fertilizer is more complete in its composition than artificial fertilizer, and the path from organic matter to the final object - the fish - is shorter than from mineral salts. In expressing this view Wlodek apparently forgets that organic fertilizer causes many side effects in ponds, such as depletion of the supply of oxygen in the water, which limit the scope for their application. On four of the ponds of "Ziabenec" experimental station near Warsaw, Wlodek (1957) tested manure taken in very large quantities (20 centners/ha. of dry substance). He studied the effectiveness of a single application before filling, and of five fractional doses spread over a period of 25 days. For comparison a crop of agricultural plants, which, as determined by the author, also contained 20 centners/ha. of dry substance, was also poured into one of the ponds. One pond was used for control. The increase in yield in the fertilized ponds as against the control pond was 29-45 kg/ha., i.e. the effectiveness of the fertilization was very low. The author considers that the best results were given by the fractional doses of manure and crops. Wlodek made an attempt to compare the quantity of food organisms for /52/ the fish, but he failed to obtain clear-cut results.

According to Wlodek, twenty centners/ha. of dry organic substance (70 centn./ha. of moist substance) failed to harm the gas regime of the ponds.

At the same experimental station (Ziabenec) a more detailed study was made of the effectiveness of sowing ponds with agricultural crops (Wlodek, 1957, 1958; Jasinski, Klimczyk, Rosol, 1957; Gurzeda, 1956; Paladino, 1954). The results obtained proved to be similar to the data of A.A. Khomchuk (1948), who made a study of the aestivation of ponds in the environs of Moscow and in the Ukraine. Some of the data from these papers are examined in the chapter devoted to organic fertilizer.

On the whole, fish culture in the Polish People's Republic in recent years has clearly switched from pure phosphorus fertilizer, copying the German fish culturists, to combined nitrogen and phosphorus fertilizer. Particular emphasis is laid on the role of nitrogen in raising the fish productivity of ponds, with references to the research of Soviet scientists (Gieraltowski, 1961). Instructions have been compiled on the use of lime and nitrogen and phosphorus fertilizers to suit the conditions of different parts of the country (Gieraltowski, 1961). It is accepted that in future fertilization rates must reach the following levels (in kg/ha.): N - 100, P - 50, and lime 750 (Wrobel, 1962).

In Czechoslovakia pond fertilization has, until recently, followed German methods. The mineral compounds used were lime, superphosphate and potassium salt. Artificial nitrogen fertilizers were never used. Fairly wide use is made of manure and various forms of green fertilizer. In recent years, under the influence of the work of Soviet scientists, the advisability of using artificial nitrogen fertilizer has been widely discussed (Lane, 1954; Bena, 1957; Havelka, 1960; Lanecek, 1961).

V. Susta (1953), drawing on a vast amount of statistical material, analyzed the effectiveness in Czechoslovakia of different combinations and doses of lime and superphosphate, and also manure for the fertilization of ponds. As his criteria he used the increase in fish productivity and monetary expenditure per centner of supplementary growth of the fish. According to his calculations, combined organo-mineral fertilization of ponds with manure, superphosphate and potassium salt raises the yield of fish by a factor of 2-2.5. The expenditure of fertilizer per unit of supplementary increase in the fish yield varies within very wide limits. Averaged data show that in Czechoslovakia some 4.5 centners of lime, 2.2 centners of superphosphate, /53/ 0.1 centners of potassium salt and up to 15 centners of manure are expended for each centner of additional fish production. Manure used on its own in a quantity of 29 centners also ensures the additional growth of 1 centner of fish.

In the experiments of F. Havlena (1956) 1 centner of pig's manure gave an increase of 2.6-2.9 kg of fish. The most suitable rate of application of the manure is considered by the author to be 50 centn./ha. The researches of other Czech authors confirm these data (Bena, 1957; Štedronsky, Pekar, 1958; Cernojev, 1954; Vaclavik, 1957).

In 1962-1963 workers at the Vodnany experimental station conducted comparative experiments in the application of nitrogen fertilizers in the culture of yearling carp (Janecek, 1963). Janecek stresses that prior to this artificial nitrogen fertilizers had not been used in Czechoslovakia and that their tests were begun under the influence of the successes achieved by Soviet scientists. The experiments were performed on small plots measuring 25 x 100 metres marked off in the ponds with the aid of polyethylene film. They tested ammonium sulphate

and calcium-ammonium nitrate against a background of liming and phosphorus fertilizer. Fractional weekly doses of fertilizer applied in the form of a solution poured into the water resulted in a direct correlation between the quantity of fertilizer added and the increase in fish production. The largest overall amount of fertilizer used was (in kg per ha): P_2O_5 - 144, N - 160. The maximum increase in fish production was 608 kg per ha, as against 70 kg per ha in the control. The difference in the effectiveness of the nitrogen fertilizers tested proved to be insignificant and was due primarily to the fact that the amounts of fertilizer used were not strictly equivalent with respect to nitrogen.

Much of the research performed by Czech scientists has been devoted to assessing the effectiveness of green organic fertilizer (Lane, 1955, 1957a, 1957b; Štedronsky, 1954a, 1954b, 1955; Kastak, 1957). These papers examine the effect of sowing the bottom of ponds with agricultural crops and then filling the pond. Recommendations are also made on the use of macrophyte shrubs in ponds.

Of particular interest are the methods devised in Czechoslovakia for the utilization of waste water from food factories in fish ponds. R. Pytlik and Z. Swec (1954) devised norms for the drainage of waste water from dairy factories into summer fish ponds. Then recommendations were made concerning the utilization of waste water from sugar factories (Pytlik, Votava, Benes, 1954), abattoirs (Pytlik, Dusek, 1956;

Pytlik, 1957) and starch factories (Pytlik, Lavicky, Kalina, Mytiska, Dvorak, 1957). These researches were aimed primarily at solving the problem of purifying the waste waters of food factories. At the same time, their utilization in fish ponds /54/ with observance of the appropriate norms of drainage, linked with obligatory abundant liming of the ponds (50 centners of CaO per ha), raises fish production to 600 kg per ha (as against 80-120 kg per ha in unfertilized ponds).

Judging by the data of papers by certain researchers (Frcek, 1957, Janacek V, Janacek V, 1958) combined carp and duck farming is very beneficial for fish culture. When ducks are bred on the ponds the fish yield rises by a factor of 4-5, reaching 500 kg per ha and over. This topic will be examined in greater detail in the chapter on organic fertilizers. It should be noted that in Czechoslovakia it has been suggested that composted peat could be used for the fertilization of ponds. But nothing has been reported on the effectiveness of this compost (Bena, 1957a).

In 1961 the mean yield of carp culture ponds in Czechoslovakia was 217 kg per ha (Zykmund, 1962).

In Hungary, manure, and especially pig's manure, is widely used for fertilizing fish ponds. According to the information available, it is deemed more sensible in Hungary to use artificial feed for feeding pigs than for feeding fish, and to fertilize fish culture ponds with manure obtained from

pig farms, especially as pig's manure is considered ineffective for fertilizing fields. Accordingly, it seems, the attention of scientists in Hungary has been directed primarily to the solution of problems connected with organic fertilization.

An original method of organic fertilization of ponds was devised by E. Woynarovich (1956a, 1956b, 1956c, 1957). The method consists essentially in diluting pig's manure with water and spraying the wash over the surface of the water with a motor pump. According to the observations of the author, a single application of 4-5 centners of manure per ha does not create a dangerous oxygen deficiency. The organic substance decomposes so rapidly in the aerobic conditions that the next dose of fertilizer can be added after 24 hours.

Woynarovich advanced and still defends the hypothesis that the main active principle of organic fertilizer in ponds is carbon. We shall examine this point in greater detail in the chapter of organic fertilizers.

As far as we know, the Bulgarian literature since the war consists only of two papers by M. Dimitrov (1959, 1961) devoted to problems of pond fertilization. They examine the advisability of using rigid plants as fertilizer. The author made interesting studies of the way submerged sheafs of plants were populated by groups of aquatic animals, estimated their numbers at various stages as from the time of introduction of the plants, and came to the conclusion, confirming the results /55/

of G.S. Karzinkin, S.I. Kuznetsov (1956) and other authors, that cut rigid plants can be used as organic fertilizer.

In Rumania papers on pond fertilization have been published in recent years (Busnita, 1958, 1960; Popescu *et alia*, 1961 a, 1961b; Rosca *et alia*, 1961), which, with reference to Soviet research, deal with the effect of complex fertilization of ponds.

Popescu and his co-authors report on the results of studies made in 1960 of two ponds at the "Balaria" fish farm, one of which, with an area of 10 ha, was overgrown with submerged vegetation, the other, with an area of 7 ha, was free from overgrowth. Lime was added to both ponds (0.5 tons per ha) and they were fertilized with relatively small doses of manure, cut vegetation and artificial fertilizers added once or twice at different times. In addition, on the 25th of June the first pond was treated with three litres of a suspension of *Azotobacter chroococcum* with a density of 158,000,000 cells per cubic metre and 8.45 kg of biomass of *Bac. megatherium* var. *phosphaticus* (phosphobacterin), containing 400,000,000 cells per gram. On the first of August 6 litres of a suspension of azotobacter (230,000,000 cells per ml) and 3.6 kg of phosphobacterin (250,000,000 cells per gram) were added. The authors give the results of analyses of the water and bottom and of qualitative studies of the phyto- and zooplankton and benthos. Sharp fluctuations were noted in the quantity of plankton and benthos. Because of the very large waste (81.5%) the harvested weight from the first pond (230 kg per ha) was 3.3 times higher than the planted weight. The harvest from the second pond, which was fertilized much less intensively (bacterial fertilizer was not added), was 535 kg per ha.

From the hydrobiological data obtained the authors try to discover the reaction of the population of the pond to each of the individual applications of various fertilizers, and at the end of the paper they even make some recommendations. But in spite of the vast amount of material collected the results still cannot be regarded as substantiated.

In the same year (1960) bacterial fertilizers were used at the Nucet fish-breeding station (Rosca et alia, 1961) in a small pond with an area of 200 m^2 which had been limed and fertilized with manure (5 tons per ha). Another pond with an area of 2.5 ha, which had been fertilized with manure and nitro-phosphorus artificial fertilizer, was used for control purposes. The authors give some estimates of the number of cells of azotobacter and *Bac. megatherium* in the water (azotobacter was found only once) and in the silt of both ponds, results of analysis of silts and estimates of the number of individuals in the different groups of zooplankton. The authors try to find in their data signs that the bacterial fertilizer added had a beneficial effect. However, such signs are completely unconvincing, since the experimental and control ponds are quite different in size and conditions. At all stages of the observations the number of all groups of zooplankton in the small experimental pond was 4-5 times greater than in the control pond. The biomass of benthos in the pond, to which biopreparations were added three times during the summer, was also higher than in the control pond, by a factor of nearly 5. When the ponds were drained and harvested it was found that the experimental pond yielded 504 kg of carp per ha, while the control pond gave 353 kg of carp per ha and 415 of crucian carp per ha. Therefore, the higher indices of the development of food organisms in the experimental pond cannot be regarded as the consequence of the action of the biopreparations. It is much more probable that they are due to other factors, such as less intensive consumption of food organisms. /56/

We can also discount the conclusions concerning the rates of fertilization which Popescu and his co-authors (1961 b) arrived at with completely unjustified boldness on the strength of a mere couple of attempts to use the biological testing method to determine the fertilizer requirement.

In Soileanu's paper (1960) on the results of three years of hydrobiological study (1957-1959) of five fish-breeding ponds he examines the question of the relation between the food source and fish yield of the ponds and the degree of development of phytoplankton, which is closely bound up with the study of the effect of fertilizers.

On the whole it must be confessed that the study of the fertilization of fish ponds in Rumania is still in its exploratory stages.

Thus, among East European countries the study of pond fertilization is most advanced in Poland, where the consequences of the theory of non-nitrogenous fertilization have been overcome and methods of combined artificial and organic fertilization have been successfully developed, and in Czechoslovakia, where great success has been achieved in the elaboration of techniques of utilizing industrial waster waters in fish farm ponds.

On the whole, the East European countries have been switching in recent years to complex fertilization of ponds under the influence of successes achieved in pond-fish culture in the Soviet Union.

CHAPTER II

The Use of Artificial Fertilizers in Ponds

1. Introduction

As was shown in Chapter I, pond fertilization practices differ widely in different countries. There are several methods of fertilizing ponds. Practical experience does not give a direct answer to the basic problem - i.e. what fertilizers are most sensible and profitable, and under what conditions? There is an urgent need to improve our theoretical knowledge of the influence of fertilizers on the productivity of bodies of water. The solution of this problem is beset with great difficulties.

The use of fertilizers in agriculture has long been studied by agronomists, scientists, and farmers. Corresponding research in piscicultural science was begun much later and is being conducted with far less expenditure. Nevertheless the effect of fertilizers on the fish yield of a body of water is based on much more complex phenomena than the influence of fertilizers on the fertility of soils.

A pond, like any other body of water, is a complex spatially dissected system in which the distribution and conversion of the substances added to it are governed by one set of laws and conditions in the water mass, with its population of organisms, and by another in the demersal region, and so on, all these phenomena being interrelated in a complex way.

In agriculture, fertilizers added to the soil serve directly as nutrition for the end product of agriculture - the crop. In pond pisciculture they can only affect the fish yield through complex trophic (food) interrelationships between the organisms populating the body of water. The first link in this food chain, or the first trophic level, is plants (phytoplankton and macrophytes), which provide the primary yield, i.e. the organic substance newly formed as the result of photosynthesis. The second link in the chain is plant-eating, water-dwelling animals, for example those forms of zooplankton which feed on phytoplankton. The third link of the chain is animals feeding on the creatures forming the second link of the chain. Such "peaceful"[*] fish as carp feed on organisms belonging both to the second and third links in the food chain. Of course, this greatly simplified scheme inadequately reflects the trophic interrelationships of the population of the pond. For example, it is not clear from the scheme that a large role is played in the feeding of many food organisms by bacteria developing as the result of dead organic matter. Finally, it is not only /58/ the primary production of the particular body of water which constitutes the original material and energy resources of the production process. In some cases an important part may be played by allochthonous substances, i.e. organic compounds which enter the pond and form detritus, dissolved substances, and so on.

Organic fertilizer enriches the pond directly with

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[*] i.e. non-predatory

allochthonous organic substances, whereas minerals fertilizers improve the conditions of the autochthonous synthesis of organic substances by plant organisms, mainly phytoplankton.

First of all we must examine artificial fertilizers, since their influence on the fish yield is exerted through the first link in the food chain - primary production - and is transmitted to the final link - the fish - through all the intermediate links in the food chain, i.e. it embraces the entire production process.

Fish farming is concerned with obtaining the greatest possible final yield, and with highly effective fertilizers. This means, firstly, that fertilizers must increase the primary production as far as possible, and, secondly, that the primary production must be utilized as fully as possible by food organisms, and the latter by fish. The effectiveness of the application of fertilizers in fish breeding, i.e. the influence on the fish yield, is compounded of the efficiency with which the substance is used and energy of the food in all the stages in the production process described above. The disturbance of any one of them may lower the final effectiveness of the fertilizers added to the pond, and even deprive them of any influence on the fish breeding process.

It should be noted that in practical experiments in the fertilization of ponds on fish farms the complexity of the problem is generally not realized. Usually the investigators

confine themselves to piscicultural indices of the effect of fertilizers, or undertake traditional "complex" studies in which they use descriptive hydrochemical and hydrobiological methods. It is not appreciated that the data obtained with the aid of these laborious methods are inadequate for determining the ways in which the phenomena described are connected. Poor use is made of physiological methods and ideas, and the results and possibilities of experimental methods of investigation. All this has deferred the formulation of an effective theory of pond fertilization.

The present book gives a brief resumé of our as yet very incomplete knowledge of the individual stages of the action of fertilizers, and examines the principles governing the physical and chemical conditions of utilization of fertilizers added to a pond, their effect on primary production, on the production of food organisms and on the fish yield. The initial effect of artificial fertilizers is to supply additional food to the /59/ phytoplankton and thereby facilitate its more vigorous development. When the addition of fertilizers to a pond does not result in an intensification of the development of phytoplankton or other plant organisms, i.e. when the initial effect is lacking, we cannot expect the fertilizers to have any effect on the fish yield. Hence, the initial effect of fertilizers is an essential condition of their piscicultural effectiveness.

An original view concerning the way in which artificial fertilizers act was put forward by G.S. Karzinkin and I.A. Shekhanov (1957). Under laboratory conditions, with the aid of a phosphorus radio-isotope, they demonstrated that fish are capable of absorbing mineral compounds of phosphorus directly from aqueous solutions. In view of this, the authors suggested that phosphorus fertilizers may have a direct beneficial effect on fish and thereby increase the yield of fish in a body of water regardless of the influence on primary production and food conditions in the pond. This view cannot be considered sufficiently substantiated.

The possibility of the absorption of ions of mineral compounds by the gills and scales of fish does not mean that fish feeding normally and receiving a great deal of phosphorus in their food and excreting it in large quantities with metabolic products, require additional phosphorus directly from the water of the pond, in which it is in any case contained in insignificant concentrations. Of course, we grant that under special conditions the absorption of mineral compounds of phosphorus by fish has some significance in nature also, although this has not yet been proved by anyone. But this curious physiological phenomenon in no way disturbs the basic view described above that the effect of fertilizers on the primary production and the subsequent utilization of the latter in the food chain lies at the basis of their piscicultural effectiveness.

The use of artificial fertilizers in ponds was originally

based on the successful application of fertilizers in agriculture, where the chief role is played by nitrogen, phosphorus and potassium. Therefore we need these same three elements in fish culture also.

In European countries, phosphorus and potassium fertilization of ponds has predominated for a long time. In spite of this, there are no convincing data proving the effectiveness of potassium fertilization of ponds, which has been always in doubt among a large number of fish breeders. Thus, for example, A.N. Eleonsky (1946) wrote: "It often happens that when potassium fertilizers are added to a pond the productivity of the pond is not only likely to rise, it may even drop". The belief in the necessity for using potassium fertilizer apparently stems from its use in agriculture, since it was not realized at first that fertilizer requirements and the principles underlying their action in the soil and in water may differ very substantially.

Artificial fertilizers exert a direct effect on /60/ phytoplankton. Therefore only those substances which phytoplankton requires in additional quantities under certain conditions can be used as fertilizers to raise the fish yield of a pond. As regards potassium, there are no experimental data or theorical arguments to show whether, in natural conditions, it, like nitrogen and phosphorus, limits the development of phytoplankton, and there are many reasons for believing that the opposite is the case. Thus, in his well-known study of the mineral nutrition of fresh water algae, Rodhe (1948) shows that a concentration of potassium in the water of approximately 1 mg. per liter is sufficient for the optimum growth of <u>Scenedesmus quadricauda</u>. Rodhe considers that a potassium concentration of 0.2 to 3 mg. per liter in the water of the lakes of Sweden is not too little, i.e. does not restrict the development of phytoplankton, which in these conditions is limited mainly by phosphorus and nitrogen compounds. Höll (1951) made a special examination of the content of potassium in the water of different types of lakes and showed that it ranges from 5.0 to 6.6 mg. per liter in strongly eutrophic lakes and from 0.85 to 1.9 mg. per liter in other European lakes. He also concluded that potassium, as a rule, does not restrict the growth of phytoplankton, although at times of vigorous algal development its content in the water drops. On the basis of data collected on a large number of lakes, the authoritative English limnologist Lund (1956), the author of classic works on the ecological physiology of fresh-water phytoplankton, compared the quantitative development of phytoplankton with the content of potassium in the water and came to the conclusion that there is no connection between these values. However, from his data we can see that vigorous development of phytoplankton occurs less often in lakes with a potassium content in the water of 0.04 to 0.4 mg. per liter than in lakes with a content of potassium of 0.4 to 2, and more than 2 mg. per liter. A colleague at the same laboratory, Mackereth (1956), after analysing data on the

ion composition of fresh water, came to the conclusion that potassium, like calcium, magnesium and sodium, does not limit production. Barrett (1957) points out that in fertilized Michigan trout lakes water bloom is often noted at a potassium content of around 1mg. per liter. This fact, and also the result of observations of the development of phytoplankton in vessels containing water enriched with various quantities of potassium, led him to conclude that potassium does not limit the development of phytoplankton.

We find data on the content of potassium in the water of fishfarm ponds in the detailed paper of Stangenberg-Oporowska /61/ (1961), who, on the basis of a large number of analyses, showed that the content of this element in the ponds of Poland ranges from 0.7 to 11.7 mg. per liter (in most cases 2 to 6 mg. per liter). The author notes that it is generally somewhat higher in ponds than in the waters feeding them and increases from spring to autumn. Thus, it might be expected that the water of ponds contains more potassium than lake water. There is all the less reason for considering that the supply may be inadequate when the content of potassium in the substance of the phytoplankton is small (0.5 to 1% of dry weight). Let us qualify this by saying that the foregoing comments on the content of potassium in water relate to waters of the hydrocarbonate class with low and average mineralization, the range of which embraces the main areas of European and North American pond culture. Naturally in waters of another composition, for example in waters of the chloride type, the ratios may be different and the content of potassium much higher.

The problem of the importance of potassium as a component part of artificial fertilizers has been tackled in yet another and perhaps more convincing way, i.e. with the aid of biological tests to determine the phytoplankton's nutrient requirements. The principle and method of these tests have been allocated a special place in Chapter III.

The results of biological tests systematically carried out in 1950 in many ponds on three fish farms situated in different areas of Belorussia in which the water was enriched with K_2SO_4 to a concentration of 4 mg. of potassium per liter, showed that the addition of potassium to pond water both unenriched and enriched with nitrogen and phosphorus fails to stimulate the viability and development of the phytoplankton, and even has a adverse effect (Vinberg, 1953). E.P. Braginsky (1951, 1958, 1961), who used the same method of biological testing on Ukrainian fish ponds, confirms the results obtained from the Belorussian ponds. Similar results were yielded by biological tests conducted on the ponds of the Vimba and Shemaia Nursery in Krasnodar region by N.N. Khmeleva and L.I. Tsvetkova (1959) and on Latvian ponds by M.N. Matisone (1962).

Thus, we may conclude that in spite of the important role played by potassium in the composition of agricultural fertilizers there are no grounds for considering it an essential element in artificial fertilizers for ponds. This shows how different are the principles of fertilization of ponds and farm land.

Let us recall that in pre-war Germany, phosphorus-potassium fertilizers were used for fertilizing ponds, whereas after the war potassium salts were no longer used for this purpose (p. 9). In the American method of mixed fertilizers potassium is included in the composition of the fertilizing mixes, but this is merely a carry-over from agricultural practices and not because its presence has been proved essential./62/

As there is no justification for using potassium salts as artificial pond fertilizers we shall ignore potassium fertilizers in the rest of this book.

As regards mineral compounds of phosphorus and nitrogen, there is no doubt that their content in the water limits the development of phytoplankton. Many authors have shown that the addition of phosphates and nitrogen compounds to water results in intensified development of phytoplankton. Hence in the overwhelming majority of cases these two particular elements occur in minimal quantities in different types of lakes. Experience in the use of artificial fertilizers for fish culture has helped to confirm this general principle of the theory of the biological productivity of bodies of water.

2. Phosphorus Fertilizers and the Phosphorus Cycle in Ponds.

Years of experience in the use of phosphorus fertilizers for ponds would, one might have thought, have led to quite definite recommendations on the methods and rates of application and shown under what conditions they are most effective. In actual fact, however, the piscicultural literature shows a division of opinion on these questions. For example, as recently as 1953 F.M. Sukhoverkhov stated that "now the view that fertilizers must be added to the water in individual portions several times during the summer has been repudiated", whereas V.M. Il'in (1955) at approximately the same time wrote: "phosphorus fertilizer, like lime, must be added to ponds as often as possible, but not less than once every ten days". At the present time, there is a marked tendency to add fertilizers several times, but this important question has by no means been finally solved.

Many contradictory opinions also exist concerning the conditions under which phosphorus fertilizers are most necessary and useful. For example, according to V.M. Il'in (1955), "on podzolic and waterlogged soils and sandy, sandy-loam, loamy and argillaceous soils such phosphorus fertilizers as super-phosphate are less effective than on black soils". At the same time, A.I. Isaev (1948) considers that phosphorus is required by "almost all types of soils, but particularly sandy-loam, argillaceous-loamy, peaty and podzolic soils". This lack of uniformity in the recommendations reflects contradictory results of the

application of phosphorus or phosphorus-potassium fertilizer, which, as is now clear, did not always answer the fertilizer requirements of ponds. /63/

At the present time, when the previously prevalent phosphorus-potassium fertilization is being replaced by other systems of fertilization and increasing use is being made of other methods of intensifying pond culture, the productivity of which is increasing from year to year, the conditions under which fertilizers act are undergoing radical change. The rates and methods of application of fertilizers, devised under conditions of extensive farming for a low yield, are unsuitable for intensive pond culture with a high yield of fish. The new conditions require the development of new criteria for judging the advisability of applying fertilizers and assessing their effectiveness. For example, the experimental ponds of the "Shemetovo" fish farm did not respond to phosphorus fertilization, and reacted very weakly to nitrogen fertilization and very strongly to nitrogen-phosphorus fertilization (Vinberg, 1957). In other words, under these conditions superphosphate on its own proved unnecessary, and, moreover, was quite superfluous in the same ponds as a component in mixed fertilizers.

At the present time only the general principles of the newer and more highly perfected systems of fertilization are known and it still remains to determine in what forms they are most beneficial to different types of ponds situated in the different soil and climate zones of the Soviet Union. Therefore it is particularly important to discover the general principles underlying the cycle of the individual elements forming the active principle of fertilizers, and this means in the first place phosphorus and nitrogen. After having determined the exact way in which the individual nutrients help to create the fish yield of a pond we can discover what conditions are favorable for each of the components of the fertilizers. This will enable us to determine the forms of fertilizer necessary in the specific conditions of particular ponds, farms and regions, and will facilitate future study of special problems concerning the compositions, times, and rates of application of fertilizers under different natural and commercial conditions.

Let us examine from this standpoint the part played by phosphorus in raising the productivity of ponds.

The necessity for phosphorus fertilizer arises from the low content of phosphorus compounds in the water. Therefore it is natural to assume that the phosphorus fertilizer requirements can be judged from the results of chemical analyses of the water to determine its content of phosphorus compounds. In the Soviet Union and abroad frequent more or less detailed hydrochemical examinations have been made of unfertilized and fertilized fish ponds. By now a very large volume of hydrochemical data has been accumulated, but unfortunately only some of it has been published. /64/

In spite of the large scope of the studies conducted, manuals on fish breeding do not indicate the exact manner in which the data of chemical analyses can be used to determine the fertilizer requirements of ponds. There is no indication, for example, what content of phosphates in the water of a pond necessitates recourse to phosphorus fertilization, or what content of phosphates is adequate, thus rendering fertilization unnecessary. This seemingly paradoxical analyses to judge a pond's fertilizer requirements. Of course, when the water contains an unusually large or unusually small amount of mineral phosphorus, some not very accurate conclusions can be drawn from the data of the analyses of the water. In the overwhelming majority of cases however when the content of mineral phosphorus in the water of ponds remains within normal limits (hundredths or a few tenths of a milligram per liter), it becomes extremely difficult to draw any conclusions whatsoever concerning fertilizer requirements from the chemical composition of the water.

Many authors have shown that the addition of a phosphorus fertilizer - usually superphosphate - to a pond merely leads to a very brief increase in the content of phosphates in the water, which after a few days drops once again to a characteristic level for the given body of water, which hardly differs from the original level (Gaponenko, 1958; Vinberg, 1958; Ozeretskovskaya, Smirnova, 1959a; Fel'dman, Prosyany, Sukhovii, 1961; Nisbet, 1951; Zeller, 1952; Hepher, 1958a; Müller, 1958a; Wrobel, 1960; Stangenberg-Oporowska, 1961).

An experiment in bulk analysis conducted by five special laboratories in Israel showed that after fertilization with phosphate phosphorus, with the concentration being brought to 0.5 mg. of phosphorus per liter approximately 1% of the initial concentration of mineral phosphorus remains in the water after 1 to 2 days (Hepher, 1958a). As in other such cases, this drop in the concentration of mineral phosphorus can be due only in very small part to its consumption by phytoplankton. The water in the ponds of Israel has an alkaline reaction and is highly mineralized, and this facilitates precipitation and combination of phosphorus. In other conditions the mechanism of the removal of phosphorus from solution is quite different, but the rapid drop in the concentration of dissolved phosphorus after the addition of fertilizers is a common phenomena observed everywhere.

Under certain conditions the content of phosphates in the water of fertilized ponds may be even lower than in unfertilized ponds. This occurs for example when nitrogen-phosphorus fertilization stimulates vigorous development of phytoplankton, which very rapidly consumes phosphorus compounds (Fel'dman, Prosyany, Sukhovii, 1961). This example clearly shows that the content of phosphates in the water reflects only the relation between the rate at which they enter the water and the rate at which they are consumed and absorbed. A change in the content /65/ of phosphates in the water shows that the relation of these processes has changed, but it does not enable us to estimate the rates at which they take place, which for one and the same

content of phosphates in the water may be low (in low-yield lakes) or high (in lakes with an intensive cycle, which results in high productivity). The total content of phosphorus present at any given time in the water of a pond is very small by comparison with the quantity contained in the composition of the substance of hydrophytes, bottom-dwelling animals, and, particularly, in bottom sediments. According to Stangenberg (1959), poor bottoms in ponds contained less than 0.1% phosphorus, whereas rich bottoms, for example peaty soils, contain from 0.2 to 0.5% and more (percentage taken from a dry weight and expresses the content of phosphorus and not P_2O_5!). If the bottom contains only 0.15% phosphorus and its moisture content is 90%, then a layer of soil 20 cm. thick in 1 hectare of pond contains 300 kg. of phosphorus. Even at such a high content in the water as 0.1 mg. of phosphorus per liter, the water in a pond 1 meter deep contains only 1 kg of phosphorus per hectare. As a rough guide, it is useful to compare with these values the quantity of phosphorus in a harvested fish. According to the data of various authors the content of phosphorus in the body of a fish is 0.2 to 0.6% of the raw weight. Assuming 0.4%, we find that for a harvested weight of 1,000 km per hectare the bodies of the harvested fish contain 4 kg per hectare of phosphorus.

And so, as we see, one hectare of pond bottom contains hundreds of kilograms of combined phosphorus, whereas the water usually contains fractions of a kilogram, i.e. many hundreds of times less. This fact enables us to understand better why it is necessary every year to add a large quantity of artificial fertilizer. For example, on many farms in the German Democratic Republic every year for a number of years 30 kg. of P_2O_5 have added with superphosphates, i.e. 13 kg. of phosphorus per hectare. Compared with the total quantity of phosphorus in the soil this is not so very much, therefore a large part of the phosphorus added easily combines with bottom sediments and only a small part is available to the phytoplankton.

As we mentioned earlier, even more fertilizer is added every year to the ponds of the United States and Israel.

That small part of the total stock of phosphorus in the pond which at any given moment is present in the form of phosphate phosphorus dissolved in the water participates intensively in the cycle. Each individual phosphorus-containing molecule or ion is in a dissolved state for a limited period from the moment it emerges from the composition of the organic substances of the live bodies of organisms or silt deposits until the time it is included once again in the composition of the body of phytoplankton or other plant organisms prior to precipitation and combination with the bottom deposits. /66/ The phosphorus combined with bottom sediments is excluded from the active cycle, or rather participates in it at a far slower rate. However, the bottom sediments contain hundreds of times more phosphorus than the water of the pond. Therefore, the quantity of phosphorus dissolved in the water at any given time and available to the phytoplankton depends primarily on the

conditions of phosphorus exchange between water and bottom. When the conditions favor the combination of phosphorus with the bottom its content in the water drops, in the contrary case it rises.

In recent years our information on the principles underlying the phosphorus cycle in bodies of water has become far more complete owing to the use of the phosphorus radio-isotope P^{32}. The tracer atom method enables us to trace the distribution of the phosphorus added to a pond and to obtain quantitative data on the rate of the phosphorus cycle under different conditions. The latter problem cannot be solved with the aid of ordinary analyses. If, for example, the content of phosphorus in the water remains at the same level for a long time this only means that the rate of removal of the phosphorus from its dissolved state and the speed at which it enters the water are equal, but analyses do not show what these speeds are and how often the quantity of dissolved phosphorus present is renewed. The answer to the latter question is easy to obtain if we add P^{32} to the pond. Measurements of the radio-activity at different times after the introduction of P^{32} yield data from which we can judge what part of the radio-active phosphorus added still remains in solution and at what speed it is being removed from solution. In its chemical properties the phosphorus radio-isotope does not differ from non-radio-active phosphorus. Therefore the speed of its cycle reflects the steady speed of the phosphorus cycle under given conditions.

Interesting results obtained during the study of the principles underlining the phosphorus cycle in bodies of water with the aid of P^{32} are generalized in the paper by Hayes and Phillips (1958). These authors examine the concentration of mineral phosphorus in water as the sum total of continuous exchange with phytoplankton and bacteria, with zooplankton, with phosphorus-containing organic compounds dissolved in the water, with macrophytes, and, finally, with bottom sediments. In all these different directions the exchange with dissolved mineral phosphorus takes place at different speeds. It is emphasized that the exchange of dissolved mineral phosphorus with phytoplankton and bacteria takes place particularly quickly, the "transfer" time being astonishingly small - roughly 5 minutes. Still fast, but not so fast, is the exchange with higher hydrophytes is still slower, the "transfer" time of phosphorus being a few days. The exchange with the bottom of the pond is slowest, since the phosphorus is retained most strongly. /67/

Figure 2 illustrates an experiment in which the phosphorus radio-isotope was added to a pond. The experiment was staged in 1953 in small (roughly 0.1 hectare) experimental ponds on the "Shemetovo" fish farm in Belorussia (Vinberg, Godnev, and Gaponenko, 1955). The results of the experiment are shown in the figure in the form of a semilogarithmic graph. The points indicating the initial phase of the experiment lay along a straight line on this graph. This means that in the first week the drop in the concentration of P^{32} took place at a steady speed.

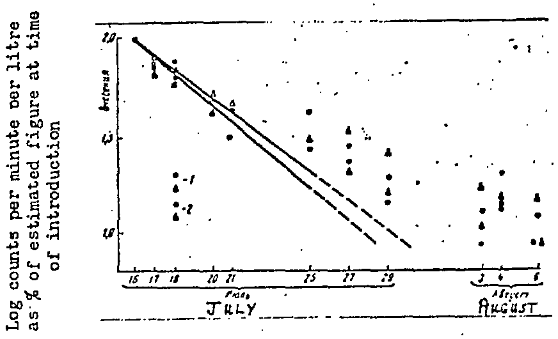

Fig. 2 Total radio-activity of the water of experimental ponds after the introduction of the phosphorus radio-isotope P_{32} (after Vinberg, Godnev, Gaponenko, 1955);

1- pond no. 3; 2- pond no. 5 (the small circles indicate the samples taken near the left bank of the ponds, and the triangles those taken near the right bank).

In 24 hours the concentration dropped by 15.7% in pond no. 3, and by 17.2% in pond no. 5. Since the total concentration of phosphorus remained approximately the same during this time the indicated rate of decline of the content of P^{32} in the water corresponds to the "transfer" time of the phosphorous, which equals 6.4 days in pond no. 3 and 5.8 days in pond no. 5. Subsequently, and apparently as the result of the reverse process of the emergence of the absorbed P^{32} into the water, its content in the water dropped more slowly and considerable quantities of P_{32} remained for a long time in solution. Later, in 1954, the experiment was repeated, but P^{32} was added to the water only in pond no. 3, whereas in the case of pond no. 5 granulated superphosphate containing P^{32} was scattered over the bed of the empty pond (Gaponenko, 1958). As in the previous year, in pond no. 3 considerable quantities of P^{32} remianed in the water for a long time. For example, after two weeks the water contained approximately 20% of the amount of P^{32} added. By contrast, in pond no. 5 only a small quantity of P^{32} - not more than 3% of the dose added - emerged into the water. Eighteen days after the pond has been filled there was no trace of P^{32} /68/ in the water. These data show that when phosphorus fertilizers are scattered over the bed of a dry pond, a much greater proportion of them is retained by the bottom than when the fertilizer is poured into the water.

Of course, the first experiments with radio-active phosphorus have not yet solved the complex problem of the forms in which the phosphorus fertilizer should be added to the ponds, but they indicate the great possibilities of this method, which deserves wide application in the study of many problems associated with the fertilization of ponds.

The mechanism by which the dissolved mineral phosphorus combines with the bottoms of ponds may vary. This complex phenomenon which depends on many conditions has been poorly studied and no light has yet been shed on many of its important aspects.

The absorption of mineral soluble compounds of phosphorus

by the bottom sediments of ponds is governed by chemical and physicochemical sorption processes, and by biological fixation of the phosphorus entering the bodies of micro-organisms. The absorptive capacity of silts is the greater, the finer its component particles and the greater its total surface area, and also the more mineral and organic colloids the silts contain. Of great importance are the chemical composition of the mineral part of the silt, the reaction of the silt solution and the redox conditions prevailing in it. Acid soils combine firmly with phosphorus, the phosphorus in this case combining with sesquioxides (aluminium, ion) to form aluminophosphates for example. In view of this, we must, as pointed out by Nenec and Fastova (1941), expect that the productivity of the pond will, all other things being equal, depend not on the absolute content of phosphorus in the bottom, but on the ratio of P_2O_5 to Al_2O_3. More explicitly, the main role is played by the ratio between the /sic/ content of phosphorus and the total of sesquioxides (R_2O_3), since many bottoms contain more iron than aluminum, and it plays an important role in the combination of the phosphorus. Many fish-breeders have noted that phosphorus fertilizers have no effect in ponds with a bottom that is rich in iron.

The combination of phosphates with sesquioxides is particularly pronounced where there is an acid reaction, as soil scientists will know. As regards the adsorption of the phosphates dissolved in the water on ferric hydroxide, this was demonstrated experimentally by Ohle (1937). Where there is an acid reaction the phosphorus also combines with humic acids.

When the reaction of the silt solution becomes more alkaline, a change takes place in the physicochemical conditions of the combination of phosphorus with sesquioxides and humic acids, and the phosphorus easily passes into solution. Accordingly, equilibrium between the absorbed and dissolved phosphorus is achieved not at low concentrations of phosphorus in the water, as for an acid reaction, but at much higher concentration. /69/ This is well illustrated by figure 3, in which, on the basis of the results of Mackereth's experiment (1953), is shown the concentration of phosphate-phosphorus in water after agitation of 250 ml. of surface silt from Lake Windermere and 3.5 liters of water giving different reactions.

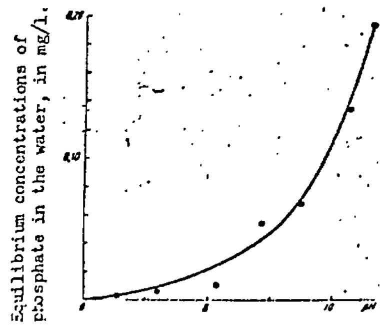

Fig. 3 The influence of the pH reaction on the exchange of phosphates between mud and water according to the observations of Mackereth (1953) on Lake Windermere.

Under these conditions, at a pH of 6.8 to 7.0 equilibrium is achieved at an insignificant level of phosphorus in the water (approximately 0.1 mg per liter), whereas for an alkaline reaction, as can be seen from the curve, it is achieved at a concentration of 0.1 mg of phosphorus per liter and above. The same thing, and this time only in connection with pond silt, was demonstrated by M.B. Fel'dman, V.S. Prosyany and A.V. Sukhovii (1961), when they agitated air-dried silts and buffer solutions and found that a minimal amount of phosphorus passed into solution at pH 6. As in the experiments of Mackereth, when the water gave an alkaline reaction, the quantity of phosphorus in the solution increased sharply. Thus, the neutralization and alkalinization of acid soils makes it easier for the phosphorus combined with the soils to pass into solution, and this is achieved in practice on fish farms by liming acid pond bottoms. We find an illustrative example of the effect of liming in the paper of Waters (1957). The author notes that after the liming of a small swampland pond (area 0.7 hectares) with very low mineralization and an acid reaction of the water (pH approximately 5) the content of total phosphorus in the water increase sharply, after which water bloom occurred and the concentration of dissolved phosphorus dropped again (fig. 4). The laboratory experiments of the same author showed that the addition of an extra amount of /70/ lime to the water facilitated the transfer of phosphorus from silt to water.

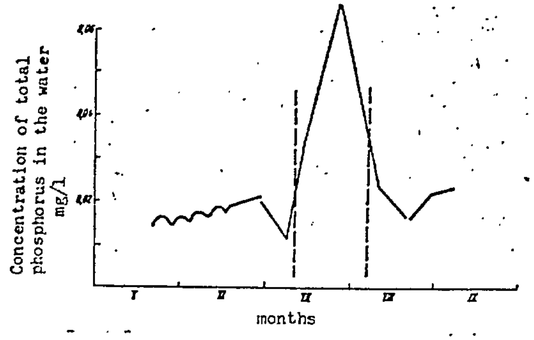

Fig. 4 The effect of liming on the enrichment of water with phosphorus from the bottom according to the observation of Waters (1957) on a dystrophic lake with an acid reaction. (the vertical dotted lines indicate the time of liming).

However, alkalinization of the water and increasing the content of calcium only facilitates the passing of phosphates into solution when they do not exceed a given level. In alkaline highly mineralized waters containing much calcium the opposite occurs. Very strong alkalinization of the water may be caused by photosynthesis of hydrophytes. For example, it takes place as the result of vigorous water bloom, when abundantly developed phytoplankton consumes the free CO_2 and bicarbonate ions (HCO_3'), causing an increase in the concentration of CO_3 ions. Under these conditions, in sufficiently highly mineralized* waters, the Ca and CO'_3 ions may become soluble and the poorly soluble calcium carbonate is precipitated, i.e. biogenic decalcification

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*i.e. rich in mineral salts

of the water begins. Settling on the bottom, the $CaCO_3$ particles enrich the bottom sediments with calcium. This is accompanied by a sharp drop in the content of phosphates in the solution, since they are precipitated in the form of weakly soluble tricalcium phosphate, $Ca_3\ (PO_4)_2$. Hepher (1958), after making /71/ a detailed examination of the conditions of the physicochemical balance of the phosphate ions and calcium ions at different pH values, calculated the maximum possible concentration of phosphate phosphorus in relation to the content of calcium and the pH. The result of his computations as shown in fig. 5.

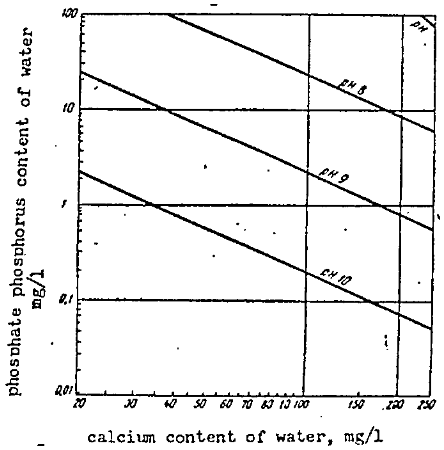

Fig. 5 Maximum concentrations of phosphate phosphorus in the water for different contents of calcium and different water reactions. (The straight lines indicate the estimated maximum possible concentrations of phosphorus in solution at different pH values). (Hepher, 1958).

As we see, at pH 8 a relatively large concentration of phosphate phosphorus is still possible, at pH 4 quantities of more than 0.1 mg. of phosphate phosphorus per liter are possible only with a low calcium content, while at pH 10, even at a low content of calcium, the water cannot contain more than a few hundredths of a milligram of phosphorus per liter. These computed values coincide with the results of the laboratory experiments of Hepher. According to Hepher, in the fish ponds of Israel, in which the pH is often as high as 9.2 to 9.4, the sharp drop in the content of phosphorus in the water after the addition of fertilizers is due mainly to the factor we have just examined. Thus, the ponds in Israel, the water and bottoms of which are both typically alkaline, not only do not require liming, but tend in fact to suffer from an excess of lime. Therefore, Hepher (1958) suggests that it may be possible to replace /72/ superphosphate, with which approximately half its weight of calcium sulphate is added, by other phosphorus fertilizers ("monophos, phosphoric acid").

Since, under the conditions described, insoluble phosphorus-calcium compounds form when there is an alkaline reaction acidification of the water through enrichment with free carbon dioxide must help to keep the phosphorus in solution. In this way Hepher explains a high concentration of phosphate phosphorus which he observed in the bottom layers of water of a pond which was higher than the content of phosphorus near the surface of the pond. In this case the carbon dioxide released

by the bottom acidifies the water and facilitates the accumulation of soluble phosphates. Hepher links this with the high content of phosphorus in the water of ponds to which organic fertilizers are added in addition to phosphorus fertilizer.

It seems to us that the direct effect of carbon dioxide on the physicochemical conditions can only partially explain these extremely interesting observations. We must also take into consideration the fact that micro-organisms play a very important role in the cycle of phosphorus. In the paper of A.T. Rodina (1958a), N.V. Mosevich, V.N. Danilevich (1955) and D.Z. Gak (1958, 1960) it is shown that two groups of bacteria play a particularly large part in the cycle of phosphorus in ponds, on the one hand facilitating the transfer of phosphorus from water-insoluble compounds to soluble compounds, for example from tricalcium phosphates to soluble phosphates, and on the other facilitating the conversion of organically combined phosphorus into mineral phosphorus. Studying the dynamics of the population of bacteria of both groups in the ponds of the "Rita-Ausma" and "Pirmrindnieks" (Latvia) fish farms, which ponds were fertilized by various methods, D.Z. Gak found that the activity of the bacteria of both the third and second group is strongly stimulated when organic fertilizer is added to the pond in the form of decomposing vegetation. Hence, organic fertilizers, like organic bottom sediments, promote a high content of phosphorus in the water not only by virtue of the fact that the decomposition enriches the water with free carbon dioxide, but also because the presence of easily assimilated organic substance fosters the activity and propagation of phosphate - dissolving bacteria.

The characteristics of the cycle of phosphorus in highly mineralized alkaline waters with a high calcium content, which have been studied in detail by Hepher, must in some degree also occur in the ponds of the southern zones of the Soviet Union, where the waters are highly mineralized and the phytoplankton of the ponds develops vigorously. /73/

In the central zone of the Soviet Union, where the waters are of average or low mineralization and the bottoms acid, as we have already noted, the exchange of phosphorus between bottom and water is quite different. In addition to the factors already examined (content of sesquioxides in the bottom, the pH of the water and bottom, the calcium content), the combination and release of phosphorus by the bottom are strongly influenced by the oxidation and reduction conditions.

As far as the oxidation and reduction conditions are concerned, submersed soils, i.e. the bottom sediments of water basins, differ greatly from unsubmersed soils in that a far greater part is played by anaerobic processes. Therefore, when examining this aspect of the problem we cannot rely on the ideas formulated by soil scientists, since we are confronted with phenomena specific to bodies of water, which have so far been inadequately studied.

In submersed soils, especially in deposits of silt rich in organic substance, the free oxygen is quickly consumed owing to intensive microbiological oxidation of the organic substances. Hence anaerobic, i.e. reduction conditions, prevail in silts. The substances taking part in the redox reactions in silt sediments become reduced - for example trivalent iron becomes bivalent iron. As the result of anaerobic decomposition of the organic substances, the nitrogen incorporated in them is released in the form of an ammonium ions (NH_4^{+}), and sulfur is released in the form of hydrogen sulphide (H_2S). When conditions ensure profound anaerobic decomposition of the organic substances, the result is the formation of methane (CH_4), in which carbon is present in its most reduced form, and gaseous free nitrogen (N_2).

As a consequence of the relatively low speed of diffusion in the aqueous medium and intensive absorption of oxygen, even when the surface of the silt is in contact with water saturated with oxygen, it is only in the thin surface layer of the silt that oxidizing conditions prevail. As soon as mixing of the water in the bottom region diminishes and stagnant conditions are created, the content of oxygen in the layer of water directly adjacent to the silt drops and often falls to zero. In that case reduction processes take place in the surface silt and the boundary between the areas of reduction and oxidation shifts into the mid-water. As we know, in sufficiently deep eutrophic bodies of water the bottom layers of water are deprived of oxygen for the entire period of winter or summer stagnation. In shallow bodies of water such prolonged periods with stable stratification of water do not generally occur. But even in shallow ponds on windless summer days more or less long periods easily occur when there is some slight difference in temperature between the warmer surface layers and bottom layers. In these conditions mixing is difficult, and for a while anaerobic conditions are created in the layers /74/ of water directly adjoining the bottom. In the life of the pond this phenomenon may be very important since the conditions of exchange with the bottom differ fundamentally, depending on whether the water adjacent to the silt contains oxygen or not. We shall illustrate this important principle by taking the example of the link between the cycles of phosphorus and iron.

As we know, bivalent ferrous iron forms compounds which are easily soluble in water (ferrous hydroxide $Fe(OH)_2$, ferrous iron salts, etc.), whereas compounds of trivalent ferric oxide - for example, ferric hydroxide $Fe(OH)_3$ - are much more difficult to dissolve and are easily precipitated from aqueous solutions in the form of sediments. Under oxidizing conditions, i.e. in the presence of oxygen, iron is oxidized and may remain in solution only at high pH values (fig. 6). With a neutral and weakly acid reaction, for example pH_6, trivalent iron in the form of hydroxide ($Fe(OH)_3$) is deposited from the solution. As already mentioned, when this happens phosphate ions are adsorbed and precipitated together with the iron.

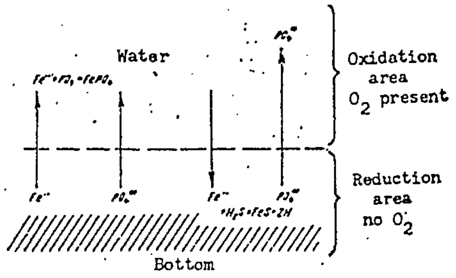

Fig. 6 Diagram explaining the effect of iron on the exchange of phosphate ions between water and bottom sediments in relation to oxidizing and reduction conditions.

This same process may be represented as the formation of a poorly soluble salt $FePO_4$, which is deposited from the solution. Descending into the reduction area, i.e. into layers of water without oxygen or silt deposits, the trivalent iron is again reduced into easily soluble ferrous iron, thereupon releasing phosphate ions. As a result, conditions are created in which bivalent ferrous iron and phosphates can accumulate in the oxygenless layers of water near the bottom.

When hydrogen sulphide is present in the silt /75/ solution or in the bottom water, the ferrous iron combines firmly with the sulfur to form insoluble ferrous sulphide. As a result the ion concentration of the ferrous iron drops, while the phosphate ion remains in solution. As soon as mixing becomes more vigorous, the ions accumulated in the bottom water, phosphate ions in particular, are again distributed throughout the water of the pond. The weakening and intensification of mixing in shallow bodies of water is due to variable meteorological conditions, and this is one of the most important, though not always duly considered, causes of the familiar instability of the hydrochemical indices in ponds.

Hence, when the silt is in contact with waterrich in oxygen and the surface layer is oxidized, conditions favour the combination of dissolved phosphorus. However, when the surface layers of silt are reduced and oxygenless water lies above them, conditions favour the dissolution of the phosphate ions.

Let us qualify this by saying that not in every case will an anaerobic medium, regardless of other conditions, facilitate the emergence of phosphorus into the water. Thus, for example, in the laboratory experiments of Hayes (1955), the rate of consumption of the phosphorus radio-isotope P^{32} by silt in anaerobic conditions, with nitrogen bubbled through the water was slower than in aerobic conditions with air bubbled through the water. These same experiments showed that microbiological processes play an important role in the absorption of phosphorus in aerobic conditions, since the rate of absorption was much slower when an antibiotic was added. Furthermore, it was confirmed experimentally that it is not only the thin surface layer of silt which takes part directly in the exchange with the water. During the two weeks of the experiments, the

absorbed P failed to penetrate more than 1 ml. into the silt. Of course, in the conditions of a lake the layer of silt participating in the exchange is thicker. Of great interest in this connection are the data of Holden (1961), which were obtained after an analysis of the results of fertilization with phosphorus of a small lake in Scotland and accompanying laboratory tests.

According to Holden, the rate of combination of the initially water-soluble phosphorus added to the lake must follow a logistical curve, described by the equation

$$\frac{dm}{dt} = K'\left(\frac{S - m}{S}\right)\left(\frac{aV - m}{V}\right)$$

where K' - is a constant;

m - is the quantity of phosphorus removed by time t, per unit of surface of the silt;

S - maximum value of m when the silt is saturated; /76/

a - initial concentration of phosphorus in the water;

V - volume of water per unit of surface of the silt.

The equation is greatly simplified when m is very small in relation to S, which often happens in practice.

According to calculations made by Holden under laboratory conditions, S for the silt examined by him, which contains 12.7% of dry material, proved to be equal to 0.14 mg. of phosphorus per milliliter of raw mud. This means that a layer of mud with a maximum thickness of 1 cm. can absorb all the phosphorus dissolved in a column of water 10 metres high, with a content of phosphorus in the water of 0.14 mg. per liter. Taking into consideration this figure and his investigations of the rate of decline of the concentration of phosphorus in the water after fertilization with superphosphate, Holden calculated that the absorbing layer of silt is 10 to 15 mm. thick, which is no more than the layer of oxidized silt which, according to Holden, measured approximately 2 cm. Direct observations of the distribution of phosphorus at different levels in a column of silt showed that after the addition to the body of water of 30 kg. of phosphorus per hectare the phosphorus in some cases penetrated the silt for at least 150 mm. The author attributes this to mixing of the silt by the animals dwelling in it.

Let us note that the conditions influencing the mixing of water above the silt and the silt itself are of prime importance for the question under study. Both Holden and Hepher (1958) in laboratory experiments obtained a lower rate of consumption of phosphorus by the surface of the silt than in the conditions of the pond. Of interest is the observation of Hepher, who stated that, all other things being equal, the rate of decline of the content of phosphorus in the water of a pond stocked with fishwas perceptibly higher than in a pond without fish. But it cannot be concluded from this that intensification of the mixing of natural water and muddying of the water, always lead to a drop in the concentration of phosphorus in the water. In most cases, where the concentration of phosphorus in the water is lower than the value at which, under given conditions, equilibrium with the silt is achieved, mixing will have the reverse effect, i.e. the water will be enriched with phosphorus. Only in these circumstances can we expect an increase in productivity from harrowing the bottom of a filled pond (Kopet, 1955). It follows that this method may indeed lead to an increase in the content of nutrients in the water in some circumstances, whereas in others the content may be reduced.

In the paper referred to above Holden showed that only 6% of the total quantity of phosphorus combined with the silt passed into solution in a decinormal hydrochloric acid extract. This led him to conclude that most of the phosphorus entering the silt is fixed biologically, i.e. enters into the composition of the bodies of micro-organisms. It is impossible to agree with this since not all the mineral phosphorus passes into 0.1N. hydrochloric acid. Nevertheless it must be acknowledged that organic forms of phosphorus play an important role in its overall cycle. Unfortunately, the hydrochemical research connected with the study of pond /77/ fertilization is, with a rare exception (Stangenberg-Oporowska, 1961), limited to analyses to determine the content of mineral phosphorus in the water and total phosphorus in the soils. Therefore, very little is known about the connection between mineral and organic phosphorus in the water and soils of ponds. In the silts of a number of small lakes in the

Velikiye Luki and Novgorod oblasts[x] and Lake Ladoga the content of organic phosphorus was in most cases 15 to 30% of the total phosphorus, but in some cases, for example in the marginal areas of Lake Ladoga, it constitutes as much as 45% (Mosevich, 1954). Clearly we must expect a higher percentage of organic phosphorus in pond silts than lake silts.

Usually organic phosphorus is determined by the difference between total and mineral phosphorus. There are grounds for believing (Fatchikhina, 1948) that this difference is not always due only to organic phosphorus.

Figure 7 depicts the results of examinations of total /78/ and phosphate phosphorus in the water of two ponds on the "Shemetovo" fish farm (Belorussian SSR), into the water of which, on the 15th of June 1953, was poured superphosphate (Vinberg, Godnev, Gaponenko, 1955). As we can see, the phosphate phosphorus remained at a low level for the first month° after the addition of the fertilizer, and it was not until the second month° that its content increased. Without data on the content of total phosphorus in the water it would be natural to conclude that the phosphorus added was initially adsorbed by the silt and that its appearance in the water in the second month was the result of exchange with the bottom. In actual fact, as was shown by analyses for total phosphorus, the content of phosphorus in the water was high after fertilization, but

then gradually dropped. Knowing this, it was natural to arrive at a completely different conclusion. It is most likely that in this particular case the total phosphorus in the water was not only organic phosphorus but also the phosphorus of unprecipitated tiny particles which was not revealed by the normal method of determining phosphate phosphorus. Apparently, processes - possibly microbiological processes - occurred which gradually converted this phosphorus into soluble mineral phosphorus. Analyses for the total phosphorus in this case provided a better understanding of the dynamics of the phosphate phosphorus in fertilizer ponds.

Unfortunately, because of the absence of data it is difficult to determine whether such conditions occur frequently, but the example given is sufficient for us to conclude that the laws of phosphorus fertilization cannot be understood if we continue to confine ourselves to determining the mineral water-soluble forms of phosphorus and ignore analyses for the total phosphorus of suspended particles.

From what has been said it follows that when large doses of phosphorus fertilizer are added to the ponds the quantities of phosphorus involved represent only a small part of its reserves, which are present mainly in the bottom sediments and participate to some extent or other in the biotic cycle of phosphorus in the pond. At any given moment the water contains very little phosphorus in the form of soluble compounds directly available to the phytoplankton. The daily replacement of these forms of

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[x] Administrative unit in the USSR — Translator.

° From fig 7 it would appear that month should be week phosphorus, on which the initial effect of fertilization directly depends, both in fertilized and unfertilized ponds, is governed by the speed of the phosphorus cycle, and especially by the conditions of exchange between the bottom and the water of the pond. This process is dependent on both the physico-chemical and microbiological factors common to submersed and unsubmersed soils (content of sesquioxides, pH, calcium content, influence of pH on microbiological processes), and on factors specific to submersed soils, in connection with the particularly large role played in them by anaerobic processes. To understand the conditions under which the use of phosphorus fertilizers /79/ is most effective we require a more profound systematic study of the factors involved in the cycle of phosphorus in ponds.

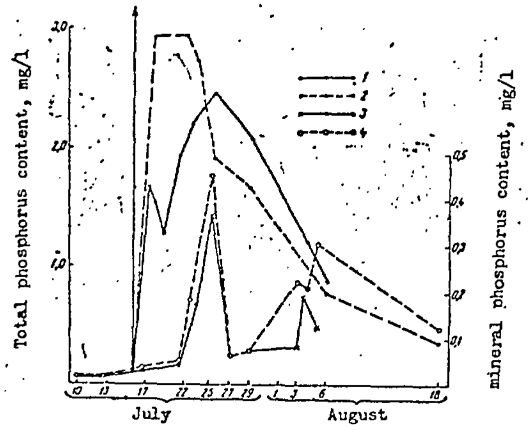

Fig. 7 Content of total phosphorus (1 and 2) and mineral phosphorus (3 and 4) in the water of a fertilized pond. (Time of application of superphosphate indicated by vertical arrow) (after Vinberg, Godnev and Gaponenko, 1955).

3./Nitrogen Artificial Fertilizers and the Cycle of Nitrogen in Ponds.

Until recently nitrogen artificial fertilizers were not used in pond culture in the Soviet Union. After Soviet hydrobiologists (S.I. Kuznetsov, G.G. Vinberg, V.I. Zhadin, I.V. Baranov et alia) demonstrated the effectiveness of repeated applications of nitrogen-phosphorus fertilizers at the begining of the fifties (page 126), this method of fertilization was tested at VNIIPRKh/All-Union Pond Piscicultural Research Institute/(Mamontova, Komarova, Kalish, 1959; Mamontova, Komarova and Kalish, 1961; Mamontova, 1961, 1962; Batenko, 1959; Batenko and Bakhtina, 1961, 1962; Bakhtina and Batenko, 1961), at the Belorussian NIRKh/Fish-Breeding Research Institute/ (Lyakhnovich, 1963a, 1963b; Lyakhnovich, Surinovich and Astapovich, 1963; Lyakhnovich, Surinovich and Prosyanik, 1963; Prosyanik, 1963; Faktorovich, 1963), at the Ukrainian NIRKh (Fel'dman, Prosyanii and Sukhovii, 1961) and at the Latvian NIRKh (Tsukurs, 1962; Volkova, Bun'kis, 1962; Okhryamkin, 1962). The research performed by these institutes confirmed the effectiveness of nitrogen-phosphorus fertilization of ponds. This method is now being introduced on a wide scale on fish farms. Some authors have even lost their sense of proportion where nitrogen fertilizers are concerned and recommend using them in unjustifiably high doses (Mamontova, 1961, 1962).

As mentioned earlier, whereas the Americans are certain of the effectiveness of nitrogen-phosphorus fertilizers, all

European text-books and manuals on fish culture invariably say that insufficient is known about the conditions under which nitrogen fertilizers may be effective, that contradictory results have been achieved with them, and that they are relatively expensive and in short supply. To a considerable extent these statements reflect the fundamental principles of the theory of non-nitrogenous fertilization of ponds. Adherence to these dogmatic principles has hampered research into the real factors involved in the action of nitrogen fertilizers and has led to unjustified recommendations, acceptance of which has concealed the useful effect of nitrogen fertilizers. We shall content ourselves with citing just one highly typical example. A book published in 1955 by V.M. Il'in, who considered that "all ponds require phosphorus", contains the following sentence: "Ammonium nitrate is added to the ponds only once during the entire season". How are we to understand such a recommendation which runs completely counter to the successes achieved in recent years with fractional and multiple joint applications of nitrogen and phosphorus? Undoubtedly it is an echo of the views of the /80/ German school of Hofer and Demoll, who greatly exaggerated the danger of nitrogen loss as the result of denitrification. Without any experimental data it was assumed on the basis of mere speculation that the rapid drop in the concentration of the nitrogen compounds when they are added to the water is due entirely to denitrification. Hence the strange conclusion was drawn that artificial nitrogen fertilizers must be added in winter, when the low temperature prevents denitrification. It is impossible to understand what prevents denitrification when summer arrives, if, of course, we do not naively assume that the nitrogen will be used biologically at the low temperatures and remain in the "used" state. In actual fact, of course, during the growing season the atoms of nitrogen repeatedly leave the medium and reenters the cycle of biotic transformations.

Unfortunately we have at present only the most general information on the principles governing the cycle of nitrogen in the pond and we are still far from being in possession of the detailed knowledge necessary for an understanding of the mechanism of the effect of nitrogen fertilizers and for substantiation of practical recommendations concerning their use. To a considerable extent this is due to the fact that attention has been devoted mainly to fish-breeding indices and their ultimate effectiveness, whereas hardly any special study has been given to the general principles of the action of fertilizers.

At any given time in the active biological cycle the pond contains a small part of the total reserves of nitrogen. The quantity of nitrogen in the bottom sediments is very large. The composition of the ash-free organic substance of the bottom sediments generally contains approximately 4% nitrogen (Kuznetsov, Speranskaya and Konshin, 1939; Stangenberg, 1949). Let us take by way of example silt containing 40% organic substances and having a moisture content of 85%. In this case the top ten centimetres of silt alone in an area of 1 hectare contain 2,400 kg of nitrogen. At the same time, even when plankton develops at a rate of 50 mg of dry weight per litre, plankton containing 8% nitrogen dry weight will, for a mean depth of the pond of one metre, contain only about 40 kg of nitrogen per hectare, the body of fish (1,000 kg per ha) about 25 kg, the organic substances dissolved in the water, with their fairly high total content (40 mg per litre for 5% nitrogen), roughly 20 kg, and the hydrophytes during their period of peak development approximately 25 kg of nitrogen per hectare. All in all, the active biotic cycle in this particular case includes 110 kg of nitrogen per hectare. It is interesting to compare this figure with the possible total quantity of mineral compounds of nitrogen dissolved in the water. Even if we take as high a figure as 1 mg/l for the sum of /81/ ammonium and nitrate nitrogen, it will correspond to only 10 kg of nitrogen per hectare for a mean pond depth of 1 metre, and this is less even than the removal of nitrogen in harvested fish.

Of course, for this rough calculation we could have taken other initial figures for the content of plankton, fish yield, and so forth, but this would not alter the overall result that the mineral compounds dissolved in the water contain tens of times less nitrogen than the live organisms, whereas the latter in turn contain tens of times less nitrogen than the bottom sediments.

Hence we are faced with the problem of how to mobilize the reserves of nitrogen and how to use them more effectively. In piscicultural practice the solution adopted is to create better conditions for the mineralization of the organic compounds by way of liming, aestivation and other methods. Unfortunately, very little study has been made of the way in which these measures affect the nitrogen cycle.

Let us examine the main stages in the nitrogen cycle. The water of the pond generally contains a very small quantity (for example tenths of a milligram per litre) of mineral compounds of nitrogen in the form of ammonium cation ($NH_4^{\cdot}$) and nitrate anion ($NO_3^{'}$). Both these ions serve as the chief source of nitrogen in the nutrition of the algae of the phytoplankton and other hydrophytes.

The bulk of the nitrogen of the organic compounds goes to form proteins, or more specifically amino acids, from which the proteins are constructed. In the amino acids the amine radical contains (NH_2) in a reduced state. The protein nitrogen can only be reconverted to the mineral form as the result of far advanced processes of disintegration or mineralization of the protein molecule, which occur microbiologically in nature.

The nitrogen cycle differs greatly from the phosphorus cycle since these two elements participate in completely different ways in the metabolism of the live organisms. The biochemical processes of energy exchange include constant repeated linking and division of remnants of phosphoric acid from organic compounds. Because of the lability of the phosphorus links, a considerable, and often large part of it, during a very short spaced time after the death of the cells, sometimes measured in minutes, is easily liberated as the result of fermentative autolysis processes and transferred to the surrounding medium in the form of phosphates. Golterman (1960) showed that after as little as five hours of fermentative autolysis in sterile conditions, without any aid from microorganisms, 49% of the total content of phosphorus in the protococcal alga Scenedesmus quadricauda is transferred to the water, mainly in the form of phosphate phosphorus. Later the autolytic splitting of the phosphorus proceeds more slowly, but even so, within a few /82/ days 70-80% of it has passed into the water. Only a small part of the phosphorus, forming part of the nucleic acids and proteins, fails to separate during autolysis. As against this, only 20-30% of the total content of nitrogen is liberated during fermentative autolysis. The nitrogen in the organic substances is attached by much stronger bonds than the phosphorus. Therefore conversion of most of the nitrogen into a mineral form is possible only as the result of profound microbiological destruction of the organic molecules.

As we have seen, microbiological processes also play a certain role in the phosphorus cycle, which depends to a large degree on physico-chemical conditions. In the nitrogen cycle the microbiological processes are definitely in the

forefront, and the importance of such physico-chemical phenomena as the differing degress of solubility of the various nitrogen compounds, sorption, and so on, is much less than in the case of the phosphorus cycle.

In a body of water the protein compounds, under aerobic and anaerobic conditions, are decomposed everywhere by various scattered saprophytic ammonifying bacteria. In the process, part of the nitrogen of the proteins is released into the medium in the form of ammonium ion and part of it goes into the construction of the bodies of the bacteria. What proportion of the nitrogen passes into the bodies of the bacteria and what proportion is liberated in the form of ammonium nitrogen depends in the first place on the relative content of nitrogen in the decomposing material and on the carbon: nitrogen ratio in it. When the decomposing substances contain much nitrogen (C:N less than 20) the excess nitrogen is released in the form of ammonium nitrogen. If the reverse holds true, i.e. if there is an excess of carbon, for example when a considerable quantity of hydrocarbons enters the composition of decomposing substances of vegetable origin together with proteins (C:N greater than 20), all the nitrogen will be used in the construction of the bodies of the bacteria. As was shown by the researches of V.D. Konshin (1939), the lower the ratio of assimilated forms of carbon and nitrogen (C:N) in silts, the more of the total nitrogen occurs in them in the form of ammonia. The ammonifying function is fulfilled by many species of anaerobic and aerobic saprophytic heterotrophic bacteria.

Organic substances are mineralized most fully and most rapidly in the presence of oxygen, i.e. under aerobic conditions. With full mineralization the organic nitrogen is released in the form of NH_3. In ponds, aerobic conditions prevail in the mid-water and in the thin surface layer of silt. In the main mass of the silt anaerobic processes bring about the decomposition of the organic substances, to the accompaniment of the generation of ammonia gas. The ammonium nitrogen entering the water from the bottom sediments is an important source of replacement of the nitrogen compounds dissolved in the water. Hence, rapid decomposition of the organic substances in the bottom sediments fosters high pond /83/ productivity. The rate of mineralization is determined by many conditions. An acid reaction of the medium, an insufficient content of calcium, phosphorus and other elements essential to the ammonifying bacteria, retard this process. Therefore the quantity of ammonifying bacteria in the water and bottoms of ponds may vary greatly. In ponds with an acid water and soil reaction the ammonifiers may be very few in spite of the presence of large quantities of organic substances in the form of difficulty assimilable humic compounds. The addition to the pond of easily oxidizably substances in the form of organic fertilizers leads to a very strong increase in the quantity of ammonifying bacteria. Liming and harrowing of the bottom of a pond in conjunction with aestivation improve the conditions of mineralization of the organic substances and foster ammonification, i.e. the recycling of the combined nitrogen of the silt deposits.

The ammonium nitrogen (NH'_4 ion) entering the water is immediately consumed by the algae of the phytoplankton, many of which prefer this form of nitrogen to the nitrate nitrogen. This is in line with the successful application of the ammonia form of nitrogen in the shape of ammonium sulphate in Israel, or ammonia water, which is just being introduced in pond culture (page 51).

The presence of free oxygen in the water makes for nitrification, i.e. the conversion of the reduced ammonium nitrogen into its oxidized nitrate form. This process takes place microbiologically as the result of the activity of nitrifying bacteria, which absorb the ammonium ion and oxidize the ammonium nitrogen first into the trivalent nitrite form and then into the pentavalent nitrogen of nitrates. The first phase of the nitrification process is controlled by the nitrite microbe Nitromonas, the second by the nitrate microbe Nitrobacter. During the oxidation of the nitrogen a certain amount of energy is liberated which is used by the nitrifying bacteria for their work. Therefore they do not need to feed on organic substances, i.e. they belong to the autotrophic microorganisms. It is frequently pointed out that the organic substances even hamper their development, but this applies only to large concentrations of organic substances in media for the cultivation of heterotrophic bacteria. Far smaller concentrations of organic substances, such as may occur in natural waters, promote the development of the nitrifiers rather than restrict it, since the decomposition of the organic substances, for example organic fertilizers, is accompanied by ammonification, and this creates the necessary conditions for the development of the nitrifying bacteria. Therefore the number of nitrifiers and the intensity of the nitrification process increase when organic fertilizers are /84/ added to the pond. Nitrification, together with other biological processes, is stimulated particularly strongly when artificial fertilizers are added in combination with the organic forms. The nitrification leads to a drop in the concentration of ammonium nitrogen and a corresponding increase in the content of nitrates, which, like the ammonium nitrogen, are eagerly consumed by the phytoplankton. The nitrifying bacteria are very difficult to isolate in a culture, and this greatly hampers study of the conditions favouring nitrification. Nitrifying bacteria, especially *Nitrobacter*, are relatively insensitive to the reaction of the medium. The development of *Nitrobacter* is possible within a wide range of reactions from pH 5, and even lower, to pH 12 and above. Conditions are at their best for the activity of *Nitrobacter* when the reaction is slightly alkaline. *Nitromonas* develops best when the reaction is neutral, and the pH limit for this species does not lie so far in the direction of alkalinity as with *Nitrobacter*. Judging by the data of laboratory experiments in which were traced the consequences of the decomposition of

plankton and other organic substances of animal origin, nitrification is strongly linked with the content of calcium in the water, is sharply depressed even at 20-40 mg/1 of Ca, and practically ceases at 10-15 mg/1 (Kuehl, Mann, 1955). These data confirm that liming - when it leads to an increase in the content of calcium in the water, of course - besides stimulating ammonification must also have a similar effect on nitrification. In soils, nitrification, which results in the accumulation of nitrate nitrogen, increases fertility and is therefore one of the beneficial processes. The importance of nitrification to the productivity of ponds is less clear. On the one hand the nitrate form of nitrogen, as the negatively charged anion, unlike the cation NH_4 hardly undergoes sorption and cannot escape from the body of water into the atmosphere like ammonium nitrogen when the water is alkaline. On the other hand, and this is very important, nitrate nitrogen unlike ammonium nitrogen can be lost through denitrification.

As the result of denitrification, i.e. the process in which nitrate nitrogen is reduced, the nitrogen of the nitrates is converted into inert molecular nitrogen (N_2). In practice denitrification leads to the loss of nitrogen.

The first phase in denitrification - the reduction of nitrate nitrogen to nitrite nitrogen ($NO'_3 \longrightarrow NO'_2$) - may be due to the activity of many different bacteria. However, the reduction of the nitrates and nitrites to molecular nitrogen is caused by a few specific bacteria - denitrifiers (*Pseudomonas*, *Achromobacter*, *Chromobacterium*), which are heterotrophic saprophytic bacteria, i.e. require to feed on organic substances. /85/ They have the ability, for the oxidation of organic substances (respiration), to use either free oxygen, like other heterotrophic organisms, or the oxygen of nitrates and nitrites. Therefore, when respiration can take place at the expense of the free oxygen present in the medium, denitrification, while possible, is strongly depressed. Under anaerobic conditions, on the other hand, denitrification is stimulated. As A.G. Rodina (1958) stresses, "in nature, where denitrification takes place in an extremely complex environment, a necessary condition for the process of nitrate reduction is inadequate aeration". The question is further complicated by the fact that, for example, the content of oxygen dissolved in the water may be high, whereas at the same time conditions of a reduced oxygen content, fostering denitrification, may be created within the decomposing particles suspended in the water. The importance of such "microzones" was demonstrated experimentally by Jannasch (1960, 1961). With the aid of a heavy nitrogen isotope (N^{15}) he found that when molecular nitrogen was generated in the presence of suspended particles in a culture of *Pseudomonas* Stutzeri, mixing of the medium intensified absorption of oxygen and depressed nitrification.

Denitrification is strongly linked with the reaction of the medium. Denitrification occurs most intensely when the

reaction is nearly neutral and slightly alkaline (pH 7.0 - 8.2), and practically ceases at pH 6.1 and 9.5. Hence neutralization of a strongly acidic medium coupled with liming also creates favourable conditions for denitrification, which of course can in no way be compared with the beneficial effect of liming on the fish yield, since denitrification is always undesirable.

For the solution of the main problems connected with the application of artificial fertilizers it is extremely important to know about the quantitative aspect of denitrification under the conditions obtaining in fish ponds, i.e. to be able to estimate how much nitrogen is lost as the result of denitrification. Unfortunately, no answer has yet been found to this question, since the quantitative side of denitrification in fish ponds, as indeed in other bodies of water, remains unknown. There is a pressing need for the organization of appropriate special studies.

In spite of the absence of specific data, the opinion was long expressed, first in German and later in Russian manuals on fish culture, that denitrification in ponds proceeds at such a rate that it is senseless to apply nitrogen fertilizers. A.G. Rodina (1958a), after thorough microbiological investigations of fish ponds in various regions (Krasnodarsk region, Latvia, Leningrad oblast) convincingly demonstrated the incorrectness /86/ of this extreme view, the unsoundness of which had been pointed out earlier in the literature (Vinberg, 1952).

Rodina showed theoretically that the number of denitrifiers increases only when nitrates are added, whereas the addition of ammonium sulphate generally does not, i.e. does not result in intensification of denitrification. Strictly speaking, this is only to be expected, since the addition of ammonium nitrogen can affect the denitrification process only after the ammonium nitrogen has been converted into nitrate nitrogen as the result of nitrification. From this follows the important practical consequence that as regards possible losses due to denitrification there is a great difference between ammonia and ammonium fertilizers on the one hand and fertilizers which contain nitrogen in the nitrate form on the other.

Actually, according to the data of Rodina (1958), after the application of nitrate fertilizers to warm-water southern ponds the number of denitrifiers is substantially increased (Fig. 8). Hence denitrification is also intensified to some extent. In spite of this Rodina comes to the conclusion that: "The addition of sodium nitrate usually stimulates the denitrification process, but this stimulus is more often than not insignificant. Intensification of the process to the point where it might result in catastrophic losses of nitrogen from the salts added was not observed. It is impossible to speak of the destruction of the fertilizers by bacteria when sodium /87/ nitrate is added". The process of denitrification in bodies of water is usually restricted by a deficiency not only of nitrates but also of easily assimilable organic substances.

Furthermore, when the fertilizers act effectively phytoplankton flourishes, and this leads to an increase in the content of oxygen in the water and to an alkaline reaction on the part of the water, i.e. it creates conditions unfavourable for denitrification, which in these cases is unable to prevent the rapid assimilation of nitrates by the vigorously developing phytoplankton. We must agree with these observations and recognize that there are no grounds for attributing too much importance to the nitrogen losses of fertilizers due to denitrification.

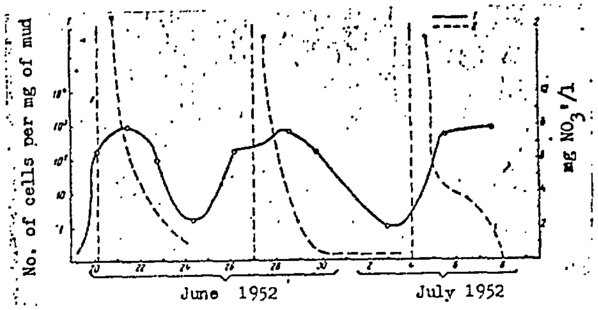

Fig. 8 Fluctuations of the numbers of denitrifying bacteria after fertilization of ponds with sodium nitrate (after Rodina, 1958):
1 - No. of denitrifying bacteria, 2 - content of NO'_3 ion in the water. (Time of application of the fertilizers indicated by the vertical dotted arrows).

And yet it is incorrect to consider the problem completely solved. We must reckon with the fact that the addition of nitrate nitrogen leads to a strong increase in the number of denitrificates, which is particularly evident when artificial and organic fertilizers are added once only. Special studies are required to determine the importance of the denitrification process in the fertilization of ponds, not only indirectly from the number of denitrificates but also with the aid of methods giving a quantitative estimate of the intensity of this process under different sets of conditions.

When conditions permit denitrification, the process takes place mainly in the mid-water and possibly in the uppermost oxidized layers of silt. In the main mass of the bottom sediments where there is no oxygen and there are far more denitrificates than in the water, which, it would seem, promotes denitrification, this process is unable to develop, since there are no nitrates in the reducing medium of the bottom sediments.

Under certain conditions, in bottom sediments rich in easily assimilable organic substances and nitrogen, a completely different process may occur, i.e. anaerobic fermentation of the nitrogen-containing substances, which, like denitrification, results in the loss of nitrogen in the molecular form. This phenomenon can be seen in certain highly productive and fairly deep ponds, in which, with intensive feeding of the fish and dense stocking, the from the bottom sediments emission of bubbles of gas can sometimes be observed. This gas may contain a considerable amount of free nitrogen. Rough calculations done by S.I. Kuznetsov (1952) for highly eutrophic small lakes - lakes Beloye and Chernoye - in Kosino showed that considerable quantities of nitrogen can be lost in this way. However, in correctly exploited fish ponds which are drained every year nitrogen losses of this sort would be important only in a few apparently rare cases.

Free nitrogen can only be included in the biotic cycle because of specific characteristics of the metabolism of a /88/ few microorganisms, i.e. nitrogen-fixers. Among the aquatic bacteria this ability is possessed by aerobic bacteria of the genus Azotobacter and the facultatively anaerobic bacteria Clostridium pasterianum, which are capable of developing under both aerobic and anaerobic conditions. In spite of the fact that Clostridium is found more easily and in greater quantities than Azotobacter in the water, and especially in the silt deposits, it is considered that Azotobacter plays the main part in the fixation of nitrogen in bodies of water (Kuznetsov, 1952; Rodina, 1958).

The nitrogen-fixing bacteria are heterotrophic, i.e. they need to feed on organic substances. Accordingly, organic fertilizers stimulate the development of nitrogen-fixers, provided the other necessary environmental conditions exist. Azotobacter can only develop within a narrow range of pH values, from 6.5 to 8.0. Even at pH 6.0, i.e. in a weakly acidic medium, nitrogen fixation stops. It is evident that neutralization of the medium coupled with liming also intensifies this function of the microbial population of the pond.

Apart from the nitrogen-fixing bacteria, certain species of blue-green algae may also assimilate free nitrogen. So far this ability has been detected in more than three dozen species. About twenty of them occur in the Soviet Union, but only a few of them are planktonic (Shtina, 1962). The ability to fix nitrogen is encountered most commonly among forms of Nostocales. Among the planktonic forms this ability is shared by some (but not all) species of the common genus Anabaena, and Gloeotrichia. It is very important to remember that one of the most common forms of Nostocales - Aphanizomenon flos-aquae - which often develops in masses in fish ponds, lacks the ability to fix nitrogen. This incapacity is also shared by the widely distributed mass species of planktonic blue-green algae Microcystis aeruginosa, which causes water bloom no less frequently than Aphanizomenon flos-aquae (Fogg, 1953).

The rough calculations of Kuznetsov (1952) show that blue-green algae may play an important role in the balance of nitrogen in a body of water. However, there is no quantitative information on their active role in this respect under natural conditions. It is possible that in some cases it may be great. Thus, for example, Japanese scientists consider that blue-green algae are highly important for the fertility rice fields. To increase the rice harvest attempts have even been made to breed blue-green algae and "algalize" rice fields with them. It appears

that free nitrogen fixation in paddy fields occurs as the result of a peculiar symbiosis of nitrogen-fixing bacteria and blue-green algae with the same ability.

Although the literature contains references to the /89/ effect that when blue-green algae bloom the content of nitrogen in the water rises (Aleev and Mudretsova, 1957), it should nevertheless be remembered that for the most part blue-green algal water bloom in ponds is due to the development of Aphanizomenon and Microcystis, i.e. species which lack the ability to assimilate free nitrogen.

The biochemical mechanism of nitrogen fixation has proved to be very similar in both blue-green algae and bacteria. In particular this function is in both cases strongly linked with the presence of sufficient quantities of molybdenum in the medium. For Anabaena cylindrica the optimum conditions for nitrogen fixation in a nitrogenless medium exist at concentrations of 0.2 mg Mo/l and above (Fogg, 1953).

Nitrogen fixers, like other microorganisms, need calcium, phosphorus and several other elements. Therefore, when conditions are favourable for their development, and there is insufficient phosphorus, the addition of phosphorus fertilizers is bound to intensify the development of nitrogen fixers and increase the rate of fixation. Phosphorus fertilizers do not always have this effect by any means; it only happens in those cases where it is an insufficiency of phosphorus and not other substances which is holding back the fixation of nitrogen. When the phosphorus stimulates the development of phytoplankton, and hence the synthesis of organic substances, this must also have a beneficial effect on the fixation of nitrogen. But even in these cases there is no proof that the fixation of nitrogen can increase so strongly that a pond no longer requires nitrogen fertilizers. Moreover, there are many reasons for believing that this does not occur. For example, biological tests to determine the fertilizer requirements of the water of ponds (page 26) revealed that there was a particularly strong need for nitrogen fertilizers in ponds fertilized with phosphorus (Vinberg, 1953).

Of great interest are the data shown in Fig. 9. They

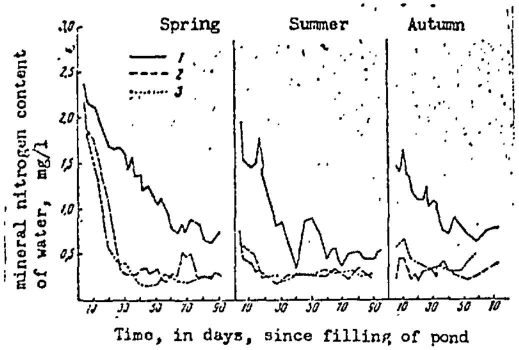

Fig. 9 Content of nitrogen in the water of unfertilized ponds on Israeli experimental station (1), ponds fertilized with phosphorus (2) and ponds fertilized with nitrogen and phosphorus (3) in three breeding seasons (after Hepher, 1952).

represent the results of four years of systematic studies of ponds in Israel. As we see, the addition of phosphorus resulted not in an increase, but in a drop in the content of nitrogen compounds in the water of the ponds. This is easily explained by the growing consumption of nitrogen by the phytoplankton, which developed vigorously under the effects of the phosphorus fertilizers. It appears that in this particular case the fixation of nitrogen could not compensate for its consumption. However, the impact of this example is weakened by the fact that the concentration of mineral compounds of nitrogen is very high in the ponds of Israel. Under these conditions the nitrogen-fixing microorganisms are albe to satisfy their nitrogen requirements not only from the free nitrogen but also from the mineral forms of nitrogen. When the water contains sufficient mineral compounds of nitrogen the fixation of nitrogen becomes, as it were, superfluous.

The suggested depression of nitrogen fixation by /90/ mineral compounds of nitrogen, together with other reasons, has been used as an argument against the advisability of applying artificial nitrogen fertilizers. It is impossible to deny that artificial nitrogen fertilizers may to some extent depress the fixation of nitrogen, but evaluation of the significance of the effect depends on the role played by nitrogen fixation in the overall nitrogen balance in the pond. The unsubstantiated view that nitrogen fixation in ponds fertilized with phosphorus is intensified to such an extent that the need for nitrogen is entirely obviated has been refuted by recent research and experience in the application of artificial fertilizers. Therefore it is clear that nitrogen fixation cannot completely eliminate the need for nitrogen in ponds. Unfortunately we still have no idea what role nitrogen fixation plays, quantitatively speaking. This problem, too, requires special studies of ponds fertilized in different ways.

As we can see, microbiological phenomena play a very important role in the nitrogen cycle. This fact has been used as a basis for attempts to raise the yield of a pond with the aid of bacterial fertilizers. Particularly high hopes in this regard have been entertained by nitrogen-fixing microorganisms, for example Azotobacter, since they can be relied on to help increase the quantity of nitrogen in the biotic cycle at the expense of the universal excess of molecularnitrogen. In addition to this it would be very important to accelerate the /91/ microbiological processes of the cycle of phosphorus and other nutrients, for which such beneficial fertilizers as phosphobacterin are used.

So far only a few uncoordinated experiments have been made in bacterial fertilization of ponds. These experiments were not always sufficiently sound, nor were the results properly checked in every case. Earlier, when we were describing Rumanian research, we gave an example where unsound bacterial fertilization of ponds failed to produce a definite effect.

A serious study of bacterial fertilization of ponds was made by A.G. Rodina and her pupils, who in a series of experiments added "azotobacterin" and other bacterial fertilizers to ponds. Unfortunately, the effect of the fertilizers was determined only from the number of cells of the relevant bacteria, which increased in the area of the fertilizer. Rodina reaches highly important conclusions. She considers that, firstly, only special preparations prepared from strains isolated not from soil but from an aqueous medium are suited to the conditions of a body of water, and secondly that bacterial fertilizers can be useful only in cases where the conditions ensure the development of the species of bacteria added. For example, Azotobacter requires a neutral or weakly alkaline medium, the presence of sufficient quantities of calcium and, in particular, of easily assimilable non-nitrogenous organic substances.

The proposition that bacterial fertilizers may be effective not always but only in conditions ensuring the development of the appropriate bacteria is of fundamental importance. Azotobacter, like other microorganisms, are found in greater or smaller quantities everywhere. It would appear that when conditions exist which favour the development of a particular species of bacteria, this species achieves its maximum possible density in the medium within a short space of time. If we considered this argument alone we should come to the facile conclusion that bacterial fertilizers have nothing to offer and that all our effort should be concentrated on the creation of conditions favourable to bacteria whose activity needs to be intensified to increase the productivity of a pond. There is a grain of truth in this, but in actual fact the problem is much more complex. Under natural conditions the various forms of microorganisms are linked by diverse and complex symbiotic and antibiotic relations which determine the relative size and role of different physiological groups, i.e. ammonifiers, nitrifiers, and others. In these complex circumstances the addition of massive doses of bacteria of the required species may apparently in certain cases be one of the ways of shifting the balance in the necessary direction, or at least accelerating this process.

/92/ As we know, various bacterial fertilizers (nitragin, azotobacterin, phosphobacterin, and others) have been suggested and used to increase the fertility of the soil. The experience gained from the application of bacterial fertilizers, or mineral fertilizers, in agriculture cannot be automatically applied to the essentially different conditions of an aqueous medium. The soil is a medium which, if not completely immobile, at least offers the particles limited scope for movement. On the other hand, an aqueous medium in shallow ponds is constantly undergoing intensive mixing, which must certainly facilitate the rapid diffusion of all species of bacteria for which the conditions are favourable. The latter argument persuades us that conditions under which bacterial fertilizers may be

effective occur less often in an aqueous medium than in soils.

It should be noted that in agriculture too, apart from intragin - a preparation of nodule bacteria which has completely vindicated itself, but which cannot be used in ponds, the effectiveness of bacterial preparations is assessed very differently. Summing up the use of bacterial preparations in agriculture, E.N. Mishustin (1962) writes: "Azotobacterin and phosphobacterin in bulk give a very small increase in the yield of field crops", and mentions that these preparations frequently prove ineffective, but that when they do have an effect the increase in the yield is no higher than 10-13%. On soils which are rich in organic substances, such as kitchen gardens, bacterial fertilizers are most effective. In addition the author states that bacterial fertilizers cannot be regarded as analogues of, or be used to replace, artificial fertilizers, but must be used in conjunction with other types of fertilizer.

These arguments obviously also apply to pond culture. The effectiveness of bacterial fertilization of ponds requires further study. Under certain conditions it will probably prove useful in conjunction with other methods of raising the yield of ponds, but as far as we know at present there are no grounds for thinking that bacterial fertilization may acquire the importance of a basic method of increasing pond productivity.

The cycle of nitrogen, as of any other individual element, does not exist in isolation, but is merely a component part of the single and integral process of the cycle of matter and energy in a body of water. This means that it is impossible to understand the principle underlying the cycle of nitrogen in a body of water by examining it separately from the cycle of phosphorus. It is quite obvious that when a large amount of nitrogen and an insufficient quantity of phosphorus enter the cycle the former cannot be fully utilized and it will prove to be in excess. The reverse will happen if a large amount of phosphorus and an insufficient quantity of nitrogen enter the cycle. Let us stress that we are talking here of entry into the cycle, which is not necessarily the same as entry into the body of water. It often happens that because of the conditions prevailing in the body of water the phosphorus or any other biogenous element entering it is quickly adsorbed, deposited or removed in some other way from the biotic cycle. /93/

Similarly, the cycle of phosphorus is connected with the content of assimilable nitrogen in the medium. In the experiments of V.I. Gaponenko (1958) the drop in the content of radioactive phosphorus in the water occurred much more slowly in the cases where no nitrogen fertilizer was used than when mineral compounds of nitrogen were added simultaneously, since in the latter case more rapid consumption of the phosphorus by plankton was ensured. Likewise, filamentous algae also consumed P^{32} much more rapidly in the presence of ammonium nitrate.

A striking example of the connection between the cycles of phosphorus and nitrogen is provided by the fish ponds in Israel, the chemistry of which has been thoroughly studied (see Fig. 9). Here the waters supplying the ponds have a very high content of nitrogen, mainly nitrate nitrogen. As can be seen from the figure, the content of nitrogen in the water of the ponds drops throughout each of the breeding seasons. Particularly characteristic and instructive is the fact that the nitrogen content in unfertilized ponds remains at a relatively high level, whereas in ponds fertilized with phosphorus it rapidly drops to much lower values. This is easily explained since the nitrogen is quickly absorbed by the plankton when the phosphorus deficiency is remedied. It is particularly interesting that the nitrogen content also dropped rapidly in the ponds to which very high doses not only of phosphorus but also of nitrogen fertilizer were added every two weeks. Let us remember that the hydrochemical picture described relates to ponds whose fertilization resulted in rapid development of phytoplankton and ultimately led to a high fish yield. This instructive example tells us a great deal. With such a high content of nitrogen compounds in the source water as 2 mg/l, it might be thought that nitrogenous fertilization would be superfluous. A special analysis of the role of nitrogen and phosphorus made by Hepher (1962) on the basis of the results of four years of study of the ponds of the Dor experimental station (Israel) led him to conclude that "nitrogen has an indubitable effect on the fish yield of ponds" under these conditions also. At the same time it was noted that the nitrogen is effective in the spring and autumn seasons and almost ineffectual in the summer season. Hepher explains this by saying that water rich in nitrogen was added in summer and that blue-green algae were growing in the ponds. It seems to us that, apart from this, importance could be attributed to the acceleration of the mineralization processes and the nitrogen cycle at high temperature. Nevertheless, as can be seen from Fig. 10, in the ponds of Israel the greatest effect is produced by phosphorus, which is entirely natural with such a high nitrogen content in the feeding waters and under the unfavourable conditions of the phosphorus cycle described above.

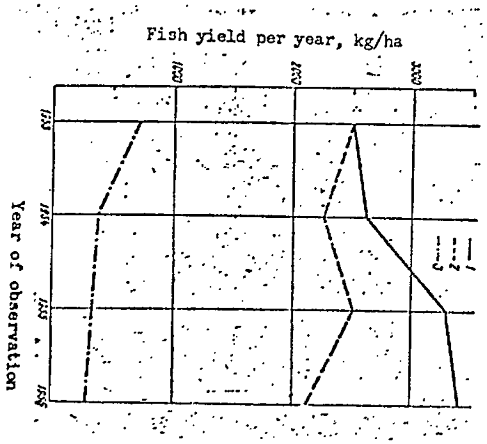

Fig. 10 Comparative effectiveness of nitrogen and phosphorus fertilization of ponds at an Israeli experimental station: 1 - fish yield of ponds fertilized with nitrogen and phosphorus; 2 - yield of ponds fertilized only with phosphorus; 3 - yield of unfertilized ponds. (After Hepher, 1962).

It has several times been mentioned that the high content of ammonium and nitrate nitrogen in the water after the addition of artificial nitrogen fertilizers very soon drops. At the same time it often happens that in intensively fertilized ponds with vigorously developing phytoplankton the content of mineral forms of nitrogen in the water soon after fertilization is not higher but lower than in unfertilized (control) ponds (Wiebe, 1930; Vinberg, 1958; Fel'dman, Prosyany, Sukhovii, 1961).

These examples show how difficult it is merely on the basis of the results of hydrochemical analyses to judge /95/ a pond's fertilizer requirements. At any given moment the concentration of nitrogen compounds in the water of the pond reflects a specific correlation between the outflow and inflow rates of nitrogen, which are governed by many causes and conditions. A high content of nitrogen or any other nutrient in the water is evidence primarily that under the given conditions that element cannot be effectively used. Hence, when a high content of nutrients is maintained in the water with the aid of large doses of artificial fertilizers, this means that the fertilizers being added to the pond are not being used effectively. Frequently fish farmers underestimate the complexity of the phenomena of the biotic cycle of the nutrients determining the first stages of the production process, and various methods of increasing the yield of the pond are suggested without sufficient justification. This ultimately leads to a vain waste of effort and means.

After our examination of the main points of the cycle of nitrogen in the pond it would be a good idea to list the chief processes of which this complex phenomenon is composed.

1. The consumption of mineral (ammonium and nitrate) nitrogen by phytoplankton and other plants and the conversion of mineral nitrogen into organic nitrogen.

2. The consumption of phytoplankton and other plants by planktonic and benthic animals with subsequent biochemical changes in the assimilated nitrogen-containing organic substances.

3. The various biochemical processes involved in the metabolism of the plant and animal organisms, as the result of which some of the nitrogen returns to the medium in the form of ammonium ion or some other relatively simple compounds available to the plants.

4. Bacterial decomposition of faeces and dead bodies of plant and animal organisms in the mid-water or bottom sediments, as the result of which some of the nitrogen is converted into the ammonium form (ammonification) and some passes into the composition of the bodies of the bacteria, which in their turn may be consumed by animal filter feeders and detritus eaters.

5. Nitrification, i.e. bacterial oxidation of ammonium nitrogen into nitrate nitrogen.

6. Denitrification, taking place under certain conditions and leading to loss of nitrogen, i.e. to a drop in the quantity of nitrogen present in the biotic cycle.

7. The reverse process of free nitrogen fixation, which brings the nitrogen back into the biotic cycle.

Although we already know plenty about the conditions on which the various stages of the conversion of nitrogen in ponds depend, it is still impossible to assess the quantitative /96/ aspect of these processes. Because insufficient study has been made of the cycle of nitrogen, and, incidentally, of other nutrients also, we are not yet in a position to control these complex phenomena and direct them as we require. The solution of this problem would enable us to increase the yield of ponds substantially without recourse to fertilizers, or at least permit us to use smaller doses.

By adding nitrogen fertilizers we strive to influence a particular stage of the nitrogen cycle in a particular direction. The success of such attempts depends on how well we know the process which we hope to influence. Hence, fish farming interests demand systematic and profound studies directed towards the formulation of scientifically substantiated conceptions of the principles underlying the biotic cycle of nitrogen in ponds.

In spite of our lack of knowledge of the nitrogen cycle, and hence of individual stages of the effect of nitrogen fertilizers on the fish yield, the experience which has been acquired in their application enables us to draw certain general conclusions. There are no serious grounds for thinking that artificial nitrogen fertilizers can achieve a great effect under normal, i.e. the most commonly encountered, conditions unless they are used in conjunction with phosphorus fertilizers. This conclusion is confirmed by the results described below of biological tests to determine the fertilizer requirements of water in ponds. Thus the practice of applying mixed nitrogen and phosphorus artificial fertilizers is fully justified.

Theoretical arguments can also be adduced to support the practice of fractional multiple doses of nitrogen-phosphorus fertilizer. It is supposed that with this method of application a considerable part of the nitrogen compounds added is swiftly absorbed by the phytoplankton, i.e. is most fully utilized, that no high concentrations of nitrates are formed to promote denitrification, and that the phytoplankton receive "liquid dressing" throughout the entire growing season. Let us note however that this tendency towards repeated application of nitrogen-phosphorus fertilizers is based chiefly on theoretical considerations and not on experimental data. The comparative effectiveness of single, double or multiple doses of nitrogen-phosphorus artificial fertilizers has as yet barely been studied.

Such studies should therefore be instituted on an appropriate scale in connection with highly productive ponds.

The complex, though highly important, problems surrounding the application of nitrogen-phosphorus artificial fertilizers in conjunction with organic fertilizers, coupled with simultaneous feeding of the fish, will, together with the question of fertilizer doses, be touched on in later chapters on the initial /97/ effect of the application of fertilizers and their influence on the food supply and fish yield of ponds.

The rates and methods of fertilization must be established on the basis of a knowledge of the general principles governing the action of fertilizers in conformity with the natural historical characteristics of ponds, the level of intensification of pond culture reached, and the ways in which the ponds are managed.

4. The Effect of Fertilization on the Oxygen Regime of Ponds.

So far we have not touched on the importance of artificial fertilizers as a means of improving the oxygen regime of ponds, which is often a great need with intensive forms of pond culture. In highly productive ponds, particularly when the fish are fed intensively, the consumption of oxygen by bacterioplankton, phytoplankton and especially bottom sediments may result in a large drop in the oxygen content of the water. Highly eutrophic and effectively fertilized ponds are characterized by pronounced daily fluctuations in the content of dissolved oxygen in the water.

Fig. 11 illustrates one of the many examples to be found in the literature. When these pronounced daily fluctuations occur there is a real danger of morning oxygen starvation of the fish. After examining this question, V.M. Il'in and his coauthors (1958) come to the conclusion that "with an annual increase in the density of stocking in carp ponds and intensification of culture in the summer months the ponds inevitably become deficient in oxygen. Thus, in highly intensive culture the oxygen regime is the main factor restricting further intensification and augmentation of the fish yield of ponds".

This necessitates the institution of special expensive studies to develop various methods of artificial aeration of the water with the aid of sprinklers, bubbling (Il'in et alia, 1958) or other mechanical aeration techniques (Sphet and Fel'dman, 1961). Meanwhile, artificial fertilizers may be a powerful means of maintaining a favourable oxygen regime. Comments to this effect have already been made in the literature (Barantov, 1953, Mamontova, 1961). However, no special study has yet been made of this problem, nor has it been examined from the quantitative angle.

We shall not touch on all the factors of the oxygen regime of fish ponds, which are discussed in papers specially devoted to this topic (Sphet, Fel'dman, 1959, 1961; Shpet, 1961; Il'in et alia, 1958), nor shall we stop to analyse the causes of the daily fluctuations in the oxygen supply, which has been done in another paper (Vinberg, 1955, 1960). Instead we shall

confine ourselves to an examination of some ideas which will /98/ help us to assess the importance of fertilizers to the oxygen regime of ponds.

The fish breeder is faced with an immediate problem when the oxygen content drops in the morning hours to very low values or even close to zero. During the night the oxygen content of the water falls because of the cessation of the photosynthetic aeration of the water, which in the daylight hours is compensated by the continuous process of oxygen consumption by the microflora in the water and surface layers of the bottom, by plankton, and so on. It is less well known that the cessation of photosynthesis is not the sole reason for the drop in the oxygen content during the night. In highly eutrophic ponds with vigorous planktonic growth and intensive absorption of oxygen by the bottom sediments the daytime continually brings a pronounced vertical stratification of the oxygen content, pH and other hydrochemical components (Olifan, 1928; Sivko, 1961 and many other sources). This well-known fact shows that on sunny days in summer, when the surface layers of water are heated by absorption of solar radiation energy, the mixing of the water is rendered so difficult, even in shallow ponds, that pronounced stratification of the water occurs. Owing to this stratification, in daytime on sunny days gaseous exchange with the atmosphere and the bottom sediments is greatly reduced, and in extreme cases practically ceases. There is no doubt that under these conditions "arrears of oxygen" accumulate in the surface layers of the bottom sediments and the adjacent water, creating a strong deoxidizing medium.

At night there is thermal and well as wind mixing of the water due to the cooling of the surface layers, which extends deeper and deeper in the course of the night. The thermal mixing facilitates gaseous exchange with the atmosphere, which, therefore, given the same deficit or supersaturation of the water with oxygen, proceeds much faster at night than during the day (Vinberg, 1955). The depth to which thermal mixing extends in calm weather during the brief summer night depends primarily on how pronounced the thermal stratification is during the day, and on the meteorological conditions, which determine the radiation balance. When the daytime vertical stratification of the temperature is sufficiently distinct nocturnal thermal mixing reaches a depth of only a few decimetres (Vinberg, 1940). When the thermal mixing extends to the bottom, contact is established between the mixed water and the surface of the bottom sediments, which are then able to absorb a large amount of oxygen, and the drop in the oxygen /99/ content of the water becomes very rapid. This is particularly marked in those cases where a series of calm hot days is succeeded by a cold spell, or the wind strengthens, and the water is thoroughly mixed. In these cases the rapid loss of oxygen from the watermay be due to the fact that in the warm windless days preceding the cold spell the nocturnal thermal mixing did not extend to the bottom (this even occurs in shallow

ponds), so that large "arrears of oxygen" accumulated in the space of a few days in the upper layers of silt and the adjacent water. Apparently the mechanism in question plays a large part in the creation of oxygen starvation phenomena, which, as has been pointed out more than once, occur when the weather changes. Only a few authors (Newell, 1957) have noted that the mixing of the water may result in suffocation.* Frequently these phenomena have been described without an explanation of their true nature. Thus, for example, V.M. Il'in and his co-authors (1958), after observing summer suffocation,* note: "The windless sunny weather in the second half of August helped to create a state of suffocation* in the body of water on the 20th and 21st of the month, and this was accompanied by losses of fish". From Table 2 in their paper it can be seen that cooler weather arrived on the 20th of August. In the same paper we find a description of a case in which the oxygen content in the water of a pond suddenly dropped and within ten minutes "there was an abrupt change in the weather; a strong wind rose and a thunderstorm threatened. In the ponds the oxygen content dropped to 2 mg/l as against 3.7 mg/l. This may have been the result of a sudden change in pressure". It is impossible to see how a drop in pressure could have had anything to do with it, but it is quite natural to assume that in this case too the main factors were mixing with the oxygen-deficient bottom layers of water and the contact established with the bottom sediments.

When suffocation* begins to occur after a change in the

* Deoxygenation

weather it is usually assumed that cooling or some other effect caused the "death of the phytoplankton", which in turn led to a sudden burst of bacterial oxidation. Such phenomena are apparently possible, but nobody has yet succeeded in detecting them through measurements of the rate of consumption of oxygen by the water, or other data of direct observations.

As we see, in each individual case morning suffocation of fish is due to a combination of a number of factors which await specific analysis, taking into account the conditions influencing the activity of the phyto- and bacterioplankton, the degree of stability of the water, which determines the value of the constants of the exchange with the atmosphere, the rate of absorption of oxygen by the bottom sediments, and so on. A clear understanding of the mechanism of the occurrence of suffocation will assist us to devise and apply counter measures when suffocation is both possible and probable. A discussion of this special problem is beyond the scope of this book. However, we must examine the more general question of the extent to which it is possible to create with the aid of artificial fertilizers conditions under which it is impossible for morning suffocation to occur.

Fig. 11 shows the published results of G.I. Shpet and M.B. Fel'dman (1961) of observations of the daily fluctuations in the level of oxygen dissolved in the water of two ponds on the "Nivka fish farm. In both cases the daily variations were of practically the same magnitude, but as can be seen from the figure there was no danger of suffocation in pond No. 4, since the average saturation of the water with oxygen in twenty-four hours was much higher than in pond No. 6, in which the right combination of circumstances made suffocation both possible and probable.

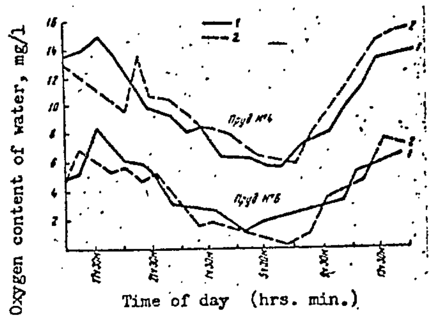

Fig. 11 Daily fluctuations in the content of oxygen in the ponds of "Nivka" fish farm with 2.5 times normal stocking density (pond 4) and 12.5 times normal s stocking density (pond 6) (after Shpet and Fel'dman, 1961):
1 - at point where food introduced, 2 - away from point where food introduced.

This instructive example illustrates an extremely important general principle. The possibility of the occurrence of suffocation is determined not only by the spread of the daily fluctuations, i.e. by the magnitude of the difference between the maximum and minimum contents of oxygen during twenty-four hours, but also by the average oxygen content during the same period. When the mean daily saturation of the water with oxygen is sufficiently high, the danger of suffocation is removed or improbable.

Hence we must discover what the mean daily oxygen saturation level depends upon and determine whether it can be kept sufficiently high by the application of fertilizers. /101/

Let us recall that the mean daily saturation of the surface layers of water with oxygen determines the direction and rate of exchange with the atmosphere. When saturation exceeds 100% the pond gives up a certain amount of oxygen during the day, but when it is less than 100% the pond is enriched with oxygen from the atmosphere[1].

It is quite evident also that the ponds give oxygen to the atmosphere when the sum total of photosynthesis in the course of twenty-four hours is greater than the sum total of all the oxidation and destruction processes. Hence, when on average the pond yields up oxygen to the atmosphere during the day this means that newly-formed organic material has accumulated in it in an amount strictly proportional to the excess quantity of oxygen. However, when on average during the day the water is undersaturated with oxygen and the pond receives oxygen from the atmosphere, destruction processes are in the ascendant, i.e. a negative balance of organic materials prevails.

A negative balance of organic materials is possible only when organic materials enter the pond and are destroyed there. This happens in fish ponds when organic fertilizers are added and the fish are fed. But in these same ponds phytoplankton is developing intensively, and this is coupled with the formation of new organic material as the result of photosynthesis. To be able to understand these complex phenomena we must first examine the general direction of the conversions of matter and energy in two extreme ideal cases; first, when the fish yield of the pond is based solely on autochthonous formation of organic substances (primary production) and natural foods, and second, when it is due solely to artificial foods or in general to allochthonous substances.

With the autochthonous production process the phytosynthetic assimilation of carbon dioxide and the consumption of mineral salts results in the formation of the substances of the bodies of the plant organisms and the release of an equivalent volume of oxygen. In the subsequent links of the food chains a large part of the primary production is subjected to oxidation in the energy exchange processes of the heterotrophic organisms, while a certain part is transformed into the substances of the bodies of heterotrophic microorganisms,

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[1] Strictly speaking it is not quite correct that the direction of the gaseous exchange changes at a mean daily saturation of 100%. If we bear in mind the lower values of the gaseous exchange constants in the daytime (see above) it is easy to see that the direction of the gaseous exchange during twenty-four hours alters at a saturation level of slightly above 100%.

zooplankton, zoobenthos and fish. If, as the result of these processes, the total quantity of organic substances in the body of water remains the same as before, i.e. when all the newly-formed organic matter undergoes destruction, the same amount of oxygen is expended on oxidation as was generated during the photosynthetic construction of the oxidized substances, i.e. the pond is neither enriched with oxygen nor depleted. It is enriched when there is an increment in the biomass of organisms populating the pond, i.e. when a certain proportion of the newly-formed organic substances remains unoxidized and when the total volume of destruction is less than the primary production during the same period.

The enrichment of the water with oxygen as the result of photosynthesis is inevitably accompanied by an increase in the total quantity of organic substances. This certainly does not mean that the biomass of plant organisms increases. Moreover, the accumulation of unconsumable plant organisms may even bring undesirable consequences. When the primary production is not consumed for some reason or other and it helps to swell the biomass of phytoplankton, the water is heavily oversaturated with oxygen and a considerable part of it is given off into the atmosphere. When large biomasses of phytoplankton or other plant organisms accumulate, they may begin to die and decompose at a given time, and this will be accompanied by heavy consumption of oxygen.

When the primary production is fully utilized, the entire increase in the phytoplankton is completely consumed by animals, and the production of the latter is fully consumed by the fish; only the biomass of the fish increases. For example, suppose that the primary production under these circumstances is equal to 10 kcal/m^2 and the increase in the biomass of fish during 24 hours is 0.5 kcal/m^2, while the remaining 9.5kcal/m^2 is dispersed in the process of exchange with the fish, food organisms and bacteria. When the enrichment of the water with oxygen is (0.5 kcal/m^2): (3.4 kcal/gO) equals 0.15 gO/m^2, i.e. at a mean depth of the pond of one metre, it will be equal to 0.15 mgO/litre per day /i.e. 24 hours-translator/.

Now let us imagine that the increment in the biomass of fish is due not to the primary production and natural foods but to an inflow of allochthonous organic substances, for example artificial foods added to the pond. Let us assume by way of example that the energy of the increase in the fish is 25% of the energy of the assimilated food, while 75% of the energy of the assimilated food, i.e. three times more, is dispersed in the process of energy exchange. If the increase due to the feeding is equal to 5 kg/ha per day, i.e. 0.5 kcal/m^2 per day, then the consumption will be 3.0.5 kcal:3.4 kcal/gO equals 0.44 gO per square metre per day. As we see, the increase in the biomass of fish due to artificial foods is accompanied not by enrichment of the pond with oxygen, but by depletion.

Let us note that the estimated quantity of oxygen consumed (0.44 g) was three times greater than the amount of excess oxygen (0.15 g) found above for the same biomass of fish when /103/ it is due to an autochthonous process, i.e. primary production and natural foods. In addition, with artificial feeding considerable quantities of oxygen are expended on microbiological oxidation of the portion of food unconsumed by the fish and of their faeces.

In real conditions in ponds where feeding and organic fertilization are practised photosynthetic processes also take place simultaneously, ensuring aeration of the water. The mineralization products (CO_2, NH_4, etc.) of the foods or other organic substances added to the pond may serve, and to a certain extent do serve, as the raw material for the photosynthesis and formation of new organic materials. This is evidently one of the chief reasons why "the higher the degree of intensification and density of stocking with fish the more vigorous the water bloom" (Il'in et alia, 1958). The photosynthetic assimilation of the mineralization products of foods and organic fertilizers partially offsets the expenditure of oxygen on their oxidation, increases the amount of natural food and thereby tends to increase the degree of utilization of and the return for the artificial foods. One could even imagine that all the mineralization products of the foods are used over and over in photosynthesis. In this case, and only in this case, photosynthetic aeration would compensate fully for the oxygen consumed during the oxidation and mineralization of the foods. With such a completely reversible cycle and "repeated" utilization of the substance of the foods, the foods added to the ponds would practically pay for themselves. We are well aware that this does not occur and that the real figures for the financial benefits derived from the foods under the most favourable conditions are not much greater than when the substance of the food is used only once. Hence, the partial assimilation of the food mineralization products by the phytoplankton, which undoubtedly occurs and increases the quantity of natural foods, is on a relatively small scale. Therefore there are no grounds for considering that the expenditure of oxygen on the oxidation processes accompanying the mineralization of the foods may be compensated for by photosynthetic assimilation of the mineralization products. Hence, under real conditions the feeding of the fish is inevitably accompanied by consumption of oxygen and a corresponding drop in the mean level of its content in the water.

This undesirable effect may be offset if artificial fertilizers are used in conjunction with feeding. As was shown earlier, the necessary quantity of oxygen is obtained most rapidly and economically when the biomass of the photo- /104/ synthesizing organisms themselves - unconsumable algae - increases. But a useful effect of this nature can only be achieved for brief spells, whereas for long periods we should require absurdly large accumulations of phytoplankton. A long-term effect can only be obtained if the biomass of fish increases at the expense of the primary production and natural foods.

In other words, we arrive at the important conclusion that in ponds where intensive feeding is practised the saturation of the water with oxygen through the application of artificial fertilizers can only be maintained on condition that the fish yield due to the artificial fertilizers is sufficiently great and at least comparable to the fish yield obtained as the result of feeding. Hence, the conditions which ensure the greatest effectiveness of artificial fertilizers, in the sense of providing an increase in the natural yield of fish, at the same time also ensure the greatest effectiveness in respect of prolonged maintenance of a favourable oxygen regime.

So far, in an effort to avoid complicating matters, we have not dwelt on the importance of the different elemental and chemical compositions of the organic substances added to the pond and the body materials of the organisms produced, as though assuming that they have the same composition and caloricity.

Now we must make the necessary corrections.

Let us imagine that a certain quantity of organic matter enters the pond with the food or fertilizers and undergoes destruction, and the mineralization products (CO_2, NH_4 and others) are fully utilized by the photosynthesizing organisms and serve for the construction of new organic substances. If the nitrogen-rich organic substances (food or fertilizer) added to the pond are characterized by a lower C:N ratio than the organisms being produced, more nitrogen accumulates in the medium than is necessary for the assimilation of all the carbon of the mineralization products. This excess of nitrogen enables the phytoplankton to construct more organic substances than were added to the pond, but this requires, in addition to the carbon of the mineralization products, the assimilation of a certain amount of the free carbon dioxide dissolved in the water, or bicarbonates. Accordingly the water will be enriched with oxygen, the content of CO_2 and HCO_3 will drop, and the reaction of the water will shift in the direction of alkalinity.

The opposite changes will be observed in the medium when material with a low nitrogen content is added the pond, i.e. material with a higher C:N ratio than the material of the newly forming organisms. This case is of particular interest since it approximates the conditions arising when the fish /105/
are given feed poor in nitrogen, such as oilcake, or when the ponds are fertilized with plant fertilizers with a high C:N ratio. Then, mineralization of the substances added to the pond liberates less nitrogen than is necessary for the photosynthetic assimilation of all the carbon of the mineralization products. Under these conditions the photosynthetic construction

of the organic substances will be limited by the insufficiency of nitrogen, and the content of oxygen in the medium will drop. Thus, for the fullest possible utilization of the carbon of the mineralization products by the phytoplankton, and hence for the strongest possible photosynthetic aeration, we must add the missing quantity of nitrogen in the artificial fertilizers.

To ensure the fastest and fullest mineralization and utilization of artificial fertilizers and a normal oxygen regime, it is necessary that the total ratio of carbon, oxygen, nitrogen and other nutrients in all the mineral and organic substances entering the cycle should be as close as possible to the ratio of these elements in the substance of the organisms produced. Therefore, the addition to the pond of organic substances with a lower relative content of nitrogen and phosphorus must be accompanied by the addition of nitrogen-phosphorus artificial fertilizers. In addition, to increase the effectiveness of the nitrogen-phosphorus fertilizers they must be accompanied by a source of replenishment of free carbon dioxide such as nitrogen-deficient organic substances.

There is no doubt that the phenomena in question do not depend only on the C:N ratio. A role may also be played by differences in the level of oxidation of the substances being destroyed and produced. This can be determined for example from the corresponding magnitudes of the coefficient

of respiration (CR equals $CO_2:O_2$), i.e. the ratio of the volume (number of molecules) of carbon dioxide gas generated with full oxidation of the substance in question to the volume (number of molecules) of oxygen consumed during oxidation. Only when the CR's of the substances oxidized and produced are equal are the generation and absorption of CO_2 and O_2 during oxidation and synthesis compensated. However, the possible differences in the CR's are relatively small.

The ratios we have been discussing can be summed up briefly by saying that a mean daily saturation of the water with oxygen of close to 100% corresponds to a state of balance in the processes of synthesis and destruction of the organic substances, i.e. a considerable degree of reversibility of the biotic balance; while large deviations from 100% saturation correspond to a sudden predominance of the processes of primary production or destruction, which is always undesirable.

Of course, the general arguments put forward fail to convey an idea of the overall complexity of the actual processes /106/ taking place in the body of water, where at any given moment the relation of production to destruction may depend to a considerable degree on the different speeds of these processes and not on the final states which have just been discussed. Nevertheless, the theoretical analysis made has demonstrated the deep organic connection between the oxygen regime and the processes of synthesis and destruction of the organic substances in a body of water, through which the artificial and organic fertilizers achieve their effect.

All this leads us to the important conclusion that the conditions ensuring the best utilization of the substances added to the pond to increase the yield of fish and the conditions necessary for maintaining the normal content of oxygen in the water coincide. To maintain a favourable oxygen regime for the fish very cheaply through the use of artificial fertilizers in the face of heavy oxygen consumption due to dense stocking and the addition of large quantities of foods or organic fertilizers, we must ensure that the fish yield obtained through the use of artificial fertilizers is the same as or greater than that obtained with the aid of feeding.

5. The Importance of Liming for Pond Fertilization

Artificial fertilizers produce a useful effect only in ponds which have been previously prepared for culture. They are brought to this state by the usual ameliatory measures (control of excessive plant growth and marshiness, aestivation of the ponds and liming of the bottom, etc.). Here there is no opportunity or need to examine each of them, and we shall deal only with liming, since it has a close bearing on the fertilization of ponds. Often, especially in the German literature, there is mention of "calcium fertilization" (Kalkdüngung). This term and the ideas which it connotes are also found in Soviet manuals (Martyshev, 1958).

Liming is used in a variety of ways and for different purposes. Its effect is complex and a distinction should be drawn between the various consequences. Many authors are prone to view liming on the one hand as an ameliorative measure, helping to improve the physico-chemical conditions of the medium, and on the other as fertilization, i.e. the addition to the body of water of a lacking nutritive element. The latter is justified by the fact that aquatic organisms need calcium salts, since the body of water is lacking in food value without them. Some hold the view that the fish being bred remove a great deal of calcium from the pond. A statement to this effect is to be found in the latest edition of the /107/ authoritative manual on pond culture by F.G. Martyshev (1958), in which we read: "Every year, organisms remove a vast quantity of calcium from the pond which often cannot be replaced by the amount of the element contained in the water feeding the pond from the catchment area." The impression is created that there may be a lack of calcium in the pond and that one of the purposes of liming is "calcium fertilization", i.e. the replacement of the missing amount of calcium. All this is the result of a misunderstanding rooted in the literature.

It is quite impossible that the water feeding the pond should bring with it less calcium than is removed in the composition of the bodies of fish and other organisms leaving the pond. This is shown by the following calculation. Let us suppose that the water contains only 2mg-equ. of calcium, which corresponds to a low alkalinity. Let us suppose that, in spite of the low alkalinity of the water, the yield of fish is high and amounts to 1,000 kg/ha. With a mean depth of the pond of one metre the water will contain 560 kg CaO per hectare. If the 1.25% of the live weight of the bodies of the fish consists of CaO, the total quantity of CaO in the high yield of fish selected for the example will be 12.5 kg, i.e. no more than 2% of the quantity present in the water.

In calcium carbonate waters, the range of distribution of which embraces the main regions of European and North American fish culture, calcium predominates above all other cations. Therefore a lack of calcium can be assumed only in waters of very low mineralization. But the low yield of such waters can be explained with equal justification by the still smaller content of other substances or by a low concentrations of bicarbonates.

The generally known fact that the best waters for fish culture are those of average mineralization, for example with an alkalinity ranging from 2-5 mg-equiv./litre, is also only indirectly connected with the calcium content. Not only calcium but also other hydrochemical elements are positively correlated with such indices of the total mineralization of the water as the alkalinity.

In the overwhelming majority of cases, except perhaps for waters with an extremely low content of calcium, which, however, hardly ever occur in carp breeding ponds, there are no grounds for thinking that the fish, like the other organisms, receive insufficient calcium from the water and foods. In general there are no convincing arguments in favour of the necessity for "calcium fertilization". Hence, liming must be regarded as a measure to improve the water and bottom of ponds. The increase in the content of calcium is only a side-effect, and not the main purpose of liming.

In spite of the great importance of liming in the /108/ system of measures for the intensification of pond culture, the theory of its effect and scientific proof in support of the doses of lime to be used lag far behind practical requirements. We are compelled to agree with M.B. Fel'dman and N.P. Rudakov (1958), who wrote: "In spite of considerable experience in the augmentation of productivity through the liming of ponds, lime is added not so much because of the peculiarities of the particular body of water as because of the entrenched conventional view that it is undoubtedly useful, and this results in considerable wastage of lime, and in some cases leads to a deterioration in the conditions under which the aquatic organisms live."

In the German Democratic Republic and the Federal German Republic, as in other central European countries, liming is a customary measure of many years standing, which is of fundamental importance to ponds with acid bottoms and water. As noted by Schäperclaus, without the neutralization induced by liming of acid bottoms, pond culture would be impossible on the whole in certain areas of Lausitz. In these extreme cases there is no doubt of the necessity for liming. But in pond culture practice liming is resorted to much more often. In spite of this, its mechanism and action have barely been subjected to special duty. In recent years interesting papers have been published by Müller (1957b, 1961a, 1961b) in which the author discusses the importance of liming from a new angle, on the basis of the results of research performed over a number of years at a farm in Königswartha, situated in the main fish breeding region of East Germany - Lausitz.

Noting the "astonishing result" of the experiments conducted at the Königswartha farm, which showed that liming does not lead to an increase in the harvest and has no perceptible effect on the chemical properties of the water, Müller comes out decisively in favour of terminating the practice of liming ponds in Lausitz. It should be added that Müller is not opposed to the neutralization of acid bottoms and water with lime in ponds in which, without liming, fish culture would be impossible. Nor does he deny, of course, the use of lime as a sanitary measure. He has in mind the liming systematically practised on the fish farms of East Germany as calcium fertilization to increase the fish yield of ponds, in accordance with the views of Schäperclaus, Bunder and others. Müller states, not without justification,

that there are no data in the literature to prove the effectiveness of "calcium fertilization", whereas there are, on the other hand, references to its failure to produce results (Wurtz, 1956; Wunder, 1949, 1956).

In the USA and in countries where American experience is followed in matters relating to the fertilization of ponds, liming is hardly ever used, and culturists remain satisfied with the amount of lime contained in commercial fertilizer mixes. Swingle (1947) even found that the application of lime to ponds fertilized with organic fertilizers (urea, ammonium sulphate, sodium nitrate and mixed fertilizers), led in all cases to a drop in the yield of fish. Apparently he is referring to ponds with water of fairly high alkalinity, in which no beneficial effect could have been expected in the first place. /109/

In recent years, however, the American literature has included isolated examples of successful liming, some of which have already been discussed above. Zeller (Zeller, Montgomery, 1958) report that the liming of twenty-two ponds in Georgia, which had previously failed to respond to fertilization, helped to increase the general hardness and pH of the water and fostered the development of plankton. Snow and Jones (1961) describe the effect of the addition of 0.4-3 tons/ha of slaked lime to twelve small ponds (0.3-1.3 ha) in a fish nursery in the state of Alabama. They note the possibility of determining the necessity for liming from the metabolic acidity of the bottom. It is suggested that the effect of liming can be judged six months after it has been done, as the pH of strongly acid bottoms returns to its original value after 18 months.

Interesting data obtained under very unusual conditions in 36 ponds in Malacca (Malaya) are reported by Fish (1961). These ponds, measuring 1 acre, are characterized by a very low initial natural yield (some 20 kg/ha) and very low mineralization of the water (content of calcium in the water no more than 3-4 mg/litre), a strongly acid reaction of the water (pH 3.5-4) and a low oxygen content. The author studied the effect of adding to the pond powdered lime in six different doses (up to five tons per hectare). In the ponds which had been limed and fertilized with ammonium phosphate the alkalinity and calcium content rose, the pH increased to 7-8, and oxygen saturation of the water was raised to 100% and over. The biological productivity of the ponds and the harvest of fish also rose. The greatest fish yield was obtained for the highest doses of lime, but the author considers that 2.5 kg/ha is sufficient. Here we are faced with an example of the use of lime for the neutralization of water of high acidity where the useful ameliorative effect of liming is most evident and indisputable.

Liming neutralized the acid reaction of the water and increases the content of calcium and bicarbonates in it, i.e.

it increases the alkalinity of the water. Therefore we should regard the rise in the alkalinity of the water as the specific feature of liming, and this is caused mainly by an increase in the content of bicarbonate ions and their accompanying calcium ions. When powdered lime, i.e. $CaCO_3$, is used for liming, it is incapable on its own of perceptibly /110/ influencing the alkalinity[1] because of its very low solubility (about 0.06 mg-equ./l) at 20°C. The alkalinity of the water rises only as the result of the formation of easily soluble bicarbonates when the calcium carbonate reacts with carbon dioxide: $CaCO_3 + CO_2 + H_2O = Ca(HCO_3)_2$.

Hence, when $CaCO_3$ is added the alkalinity of the water can increase only when, under given physicochemical conditions (aggressive), excess carbon dioxide is present, or when there is a source to enrich the water with free carbon dioxide, for example decomposing organic substances.

The addition of slaked lime $Ca(OH)_2$ to water without dissolved carbon dioxide leads only to a sharp shift in the direction of alkalinity. The pH of the water may easily reach values fatal for the fish and all living creatures. When $Ca(OH)_2$

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[1] In carbonate waters the alkalinity of the water (carbonate alkalinity) is basically proportional to the content of bicarbonate ion (HCO_3). It is usually expressed in milligram-equivalents of CO_2. The reaction of the water (pH) for a given alkalinity depends on the content of free carbon dioxide and carbonate ion (CO_3) in the water.

is added to water containing free carbon dioxide the pH of the water changes more weakly, and the alkalinity of the water rises as the result of the formation of bicarbonates in the reaction $Ca(OH)_2 + 2CO_2 = Ca(HCO_3)_2$.

However, when there is an excess of $Ca(OH)_2$ over CO_2 the effect of liming may be not an increase in the alkalinity of the water but a drop as the result of the formation and precipitation from solution of difficulty soluble carbonates in the reaction $Ca(OH)_2 + Ca(HCO_3)_2 = CaCO_3 + 2H_2O$.

Hence, the addition of slaked lime to the water of ponds requires great care and should only be done in small doses.

At first sight it seems that, knowing the content of free CO_2, we can easily calculate the necessary quantity of CaO from the equations above, bearing in mind that 1 mg-equ. of CaO is 28 mg, $Ca(OH)_2$ 37 mg and CO_2 44 mg. In actual fact, however, as the free CO_2 enters a system of physicochemical equilibrium with the bicarbonates (HCO_3' ion) and hydrogen ions ($H^{\cdot}$), more lime (CaO) is required in highly alkaline water than in weakly alkaline water if the pH of the water is to be brought to any predetermined value.

The view has been expressed (by I.V. Baranov) that the oxidizability of the water is also important when liming. When the water is highly oxidizable more lime has to be used to achieve a given change in the pH.

It is equally inadequate to estimate the necessary amount of CaO from the alkalinity alone, as is suggested by /111/ Chimitz (1949). He considers that liming must bring the alkalinity to 3 mg-equ./litre and suggests that the calculation be based on the difference (3-a), where a is the present alkalinity of the water in mg-equ. This calculation is correct if the water contains a sufficient quantity of free CO_2, and in practice natural waters contain far less. Therefore, the extent of the increase in the alkalinity will depend primarily on the amount of free CO_2 present.

Thus, special significance is acquired by such sources of enrichment of the water with free CO_2 as the decomposition of the organic substances of bottom deposits, unconsumed food and organic fertilizers.

These arguments fit in with the results obtained by M.B. Fel'dman and N.P. Rudakov (1958) from a study of the effect of liming on the hydrochemical regime of experimental ponds on "Nivka" farm. Samples taken from the peaty bottoms of these ponds before filling revealed a reaction of a salt extract tending in the direction of acidity (in five ponds the pH_c ranged from 5.2-5.9, and in the two remaining ponds from 6.4-6.8), the reaction of an aqueous extract being close to neutral (pH 6.2-7.1). The pH of the water of the ponds ranged from 7.4-8.2, i.e. the water had a weakly alkaline reaction. To seven out of fourteen ponds four doses of lime were added to give a total quantity for the season of 4-12 centners per hectare. Contrary to the expectations of the authors they could not detect any sign that the liming affected the content of calcium or, in general, the salt composition and pH of the water.

The result of this experiment clearly shows that liming on its own is still insufficient to raise the calcium content, and hence the content of bicarbonates, in the water of a pond. In this particular case, where the reaction of the water was alkaline and there was hardly any free carbon dioxide, such an effect should not have been expected.

Hence, if the aim is to increase the alkalinity of the water, liming must be accompanied by the application of organic fertilizers. On the other hand, liming of the water can eliminate the accumulation of carbon dioxide and acidification of the water when organic substances decompose. This is one of the reasons for underlying the practice of fertilizing ponds with manure and lime, which is bound to lead to an increase in the content of bicarbonate ions in the water.

The importance of carbon dioxide as a sine qua non for increasing the alkalinity of water through liming has been convincingly demonstrated by Müller (1957a). Initially this was shown in laboratory experiments in which various doses of calcium carbonate were added to aquariums with and without soil. Prolonged measurements of the alkalinity of the water revealed /112/

that, regardless of the dose, the calcium carbonate, in virtue of its low solubility, has on its own no perceptible effect on the alkalinity of the water. It increased only in those aquaria in which the water was enriched with carbon dioxide generated by the silt.

In Königwartha the ponds, which are situated in light sandy soils, are filled with highly coloured water of low mineralization and an alkalinity of approximately 1 mg-equ./litre. As already mentioned (page 108), special experiments failed to disclose any sign that liming had a positive effect on the fish yield (Müller, 1958). This prompted the experimenters to discover how liming affects the alkalinity of the water. It was found that in this respect ponds to which 5-10 centners per hectare of lime had been added every spring for a number of years in no way differed from unlimed ponds (Müller, 1961a, 1961c). Apparently, the sandy soils of these ponds, which are poor in organic substances, produced so little carbon dioxide that the lime added to them had hardly any effect.

These experiments and observations confirm once again that the carbon dioxide produced by the bottom is one of the chief factors governing the success of liming of the water. At the same time liming of the bottom increases the rate of decomposition of the organic substances and hence the rate of production of carbon dioxide. Thus there is a close link and interdependence between the effects of liming the bottom and the water.

Liming of the bottom of the pond achieves its full effect if it neutralized the acidity of the bottom. The result is firstly a change in the physicochemical conditions of exchange between the bottom and the water of the pond, and secondly the creation of more favourable conditions for the activity of its microflora, which are in turn of fundamental importance to the cycle of nutritive elements.

In acid soils hydrogen ions predominate among the absorbed ions. When liming occurs they are replaced by calcium ions and there is a corresponding drop in the acidity of the bottom. When the bottom is neutralized, the linkage of the phosphates with sesquioxides is weakened and the release of phosphate ions into the water is facilitated. This promotes the utilization of phosphorus fertilizers by phytoplankton and ultimately has a beneficial influence on their effectiveness.

Apart from the immediate change in the physicochemical conditions it is of no less importance that the neutralization of the bottom has a strong influence on the microbiological processes, which are largely depressed at low pH values. All that was said earlier about the dependence of the microbiological phenomena in the soil on the pH also applies in respect of the bacterioplankton. Thus, for example, the data of Brandt and his co-authors (Brandt, Klust and Mann, 1956) showed that the rate of decomposition of cellular tissue, which was determined from the loss of strength of cotton threads placed in a body /113/

of water at a particular time, is also clearly dependent on the pH and calcium content of the water. In ponds with a low pH of the water (5.4-5.6) no decomposition of cellular material was noted during a period of one month, whereas in ponds with a higher pH (6.0-7.6) and a higher content of calcium it occurred very rapidly. The authors express the opinion that the rate of decomposition of the cellular material may be used as a good integral index of the productivity of bodies of water.

When the bottom exhibits an acid reaction the processes of decomposition and mineralization of organic substances are sharply retarded by a lessening or cessation of the activity of bacteria of the most varied physiological groups. As a result, there is a sudden slowing down of the regeneration of nutrients, which in turn leads to a drop in the speed or intensity of their cycle. Liming creates more favourable conditions for the development of bacteria in the bottom sediments and thereby intensifies the cycle of nutrients and promotes the mobilization and utilization of their stocks in the bottom sediments, the fixation of free nitrogen, and so on.

By stimulating the development of the bacterioflora, liming of pond bottoms apparently improves the conditions of bacterial nutrition of the bottom food organisms, although direct proof of this is still lacking.

Not all ponds need liming. Different doses and techniques of application must be used for different conditions. There arises the question of the principles of the determination of liming requirements.

In spite of the fact that submersed soils differ from unsubmersed soils in many respects, in the fish-breeding literature the problem of liming requirements and the doses of lime to be used are examined mainly in the light of agronomical experience, on which are based the doses of lime recommended for different soils by Schäperclaus and other, later authors. There is no need to list these recommendations here, since they are not very often followed in fish breeding practice. Various authors, on the strength of extremely diverse data stemming from liming practices, cite sharply differing figures, ranging from 0.5 to 30-40 centners per hectare of unslaked lime. References to the need to take into account the acidity of the soil are insufficiently precise, since they are, strange though it may seem never accompanied by an indication of which method of the several employed in soil science is being used for measuring and expressing the acidity of the soils (Wunder, 1949; Sukhoverkhov, 1953; Martyshev, 1958; Il'in, 1955; Pakhomov et alia, 1958). In this connection too we run up against inadequate analysis of theoretical concepts, and this makes it impossible to issue quite definite and scientifically based /114/ recommendations for fish culturists.

Accordingly it is appropriate here to set out some

of the results of the researches of N.I. Chigirin, conducted between 1957 and 1959, on the liming of ponds. Thus far these results have not been published.

Apart from the neutralization of the free organic acids contained in the bottoms of ponds, the result of liming is that the calcium ions displace the hydrogen ions adsorbed by particles of soil, thereby lowering the so-called latent or potential acidity of the bottom.

The number of calcium ions which must be added to achieve this effect depends firstly on how many cations are capable on the whole of combining with the soil in question, i.e. it depends on the latter's characteristic total capacity for absorbing cations, and secondly on the extent to which this capacity has already been utilized, i.e. on the degree to which the absorbing complex of the bottom is saturated with the cations of calcium, magnesium, potassium, etc. which it has adsorbed. The answer to these questions may be obtained by determining the total cation absorption capacity (T) and hydrolytic acidity (H) in samples of the bottom. These values are normally expressed in mg-equ. per 100 grams of dry soil. From these figures for T and H we can compute the degree of saturation of the bottom with base cations as a percentage of the total cation absorption capacity using the formula

$$V = \frac{T - H}{T} 100.$$

Pond bottoms are characterized by high absorption capacities. Thus, M.B. Fel'dman and N.P. Rudakov (1958) found that the peaty soils of the pond of "Nivka" fish farm (Kiev oblast) have an absorption capacity (T) of 29.5-46.6 mg-equ. per 100 grams when heavily impregnated with bases (84-98%). H in this case ranged from 0.75 to 7.8 mg-equ. per 100 grams. According to the data of Chigirin (Table 2), the T value of the bottoms of ponds in Velikiye Luki, Shipulino and Opochka lay between 20 and 49, while H fluctuated from 0.2 to 11.3 mg-equ. per 100 grams.

The lower the percentage of impregnation of the absorbing complex of the bottom with base cations the more calcium ions, relatively speaking, it can still absorb and the more acutely will the bottom be in need of liming. On the other hand, when the absorption capacity is largely taken up with cations, there is no necessity to lime the bottom.

Another index of the necessity for liming is the pH_c value, which reflects the potential acidity of the bottom and its content of free acids and acid salts. The connection between the values V and pH_c is apparently complex, but a comparison of a series of determinations of the two values in different soils reveals that they are clearly related. As was shown by Chigirin, this relation in the ponds investigated by him can be expressed by the equation

$$V = 1.667 + 0.047\ pH_c.$$

Although the relation expressed by this equation is not universal and requires amendment for different ponds in different pedo-geographical zones, it indicates the possibility of using the pH_c values for practical purposes to assess the degree to which ponds require liming. The advantages of pH_c over V are that it is more stable and that the method of determination is simpler and more straightforward.

Table 2

Results of the determination of pH_c[1], the degree of saturation with bases, hydrolytic acidity and doses for liming of pond bottoms in 1957 (data of N.I. Chigirin)

Pond	pH_c	V	H	T	CaO, cent./ha
Velikie Luki					
nursery pond No. 1	6.2	94	1.8	30	4.1
nursery pond No. 2	5.0	88	4.6	38	13.5
Shipulino					
nursery pond No. 1	4.1	77	10.3	45	19.0
nursery pond No. 2	4.7	77	11.3	49	20.0
Opochka					
nursery pond No. 1	6.0	94	2.3	38	5.6
nursery pond No. 2	5.8	89	4.3	39	9.2
whitefish pond No.1	6.7	97	1.2	40	2.3
fry pond No. 1	6.5	95	1.9	38	5.3
fry pond No. 2	7.3	99	0.4	40	1.5
spawning pond No. 8	6.0	93	2.9	41	8.1
hibernating pond No.2	7.6	99	0.2	20	0.8
Sebezh					
fish nursery	6.8	97	0.9	30	2.2

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[1] pH_c - pH value of salt extract from the bottom (using potassium chloride solution).

On the strength of an analysis of data from ponds in the north-west of the USSR N.I. Chigirin suggests that we let ourselves be guided by the following estimates of the liming requirements of pond bottoms, depending on the results of measurements of V or pH_c.

Need for liming	V	pH_c
Great.............	under 80	under 5
Moderate..........	80-90	5-6
Slight or non-existent....	over 90	over 6

As was noted earlier, we can judge from the figures /116/ for V and pH_c whether it is necessary to lime the bottom of a pond, but they do not give us any idea of the quantity of lime to be applied to the bottom to saturate the absorption capacity with cations.

This quantity can be estimated from the hydrolytic acidity, expressed in mg-equ. per 100 grams of dry soil. Having determined the hydrolytic acidity of a sample of the bottom and knowing that 1 mg-equ. of the latter corresponds to 28 mg of CaO, and also having made allowance for the natural moisture content of the bottom, we can compute the quantity of lime needed for neutralization and saturation of the absorbing complex with cations in a layer of the bottom of a given thickness with an area of 1 hectare. If we assume that the effect of the lime extends under natural conditions to a depth of 10 cm, then, according to the calculations of N.I. Chigirin, we obtain quantities of lime close to those recommended on the strength of practical experience. The data in the last column of Table 2 on the quantity of CaO need to lime the ponds were computed by the method described above for layer 10 cm thick.

We can ensure that the effect of the lime extends to a given and constant depth by harrowing, or some other method of breaking up the soil of the bottoms.

In the main, three types of lime are used for the liming of ponds: unslaked or burnt lime, which is calcium oxide (CaO), slaked lime or calcium hydroxide ($Ca(OH)_2$), and limestone or similar rock, consisting mainly of calcium carbonate ($CaCO_3$). The most convenient form for adding to a pond is slaked lime, which is a fine powder. It acts quickly, and care must be taken to control the dosage and check the results. Finely ground limestone is frequently used. It acts much more slowly than slaked lime, and therefore the danger of an overdose does not exist. Ground limestone is also suitable for application in small annual doses to sufficiently cultivated ponds. Unslaked lime acts similarly to slaked lime. It is best applied by aerial top-dressing. In addition to the forms of lime already mentioned we can also use marl, limestone tuffs, lake-lime, and ash.

The various forms of lime have different neutralizing capacities. If we assume that this capacity is unity for pure unslaked lime, it would be 1.3 times less for slaked lime, and 1.8 times less for limestone. Therefore when we are estimating /117/ the doses of lime to be added to the pond, the computed quantities of CaO must be multiplied by the corresponding coefficients of the neutralizing capacity of the form of lime being used.

Furthermore, the lime used in practice is normally polluted with admixtures such as unburnt rock, clay, or sand, which to a greater or less extent reduce its neutralizing capacity.

To avoid gross miscalculations of the size of the dose because of these complicating factors we must determine the neutralizing capacity of each batch of lime added to the pond.

Liming of the bottom of pond does not necessarily require the full dose calculated from the hydrolytic acidity. Some benefit will be derived from part of the required dose, which will reduce the necessity for liming.

Chigirin tested the methods he recommends for determining liming requirements and the dosage on ponds in Shipulino in 1959. The tests showed that the results came up to expectations. From the hydrolytic acidity of the bottom (pH_c), which in three ponds with a clay-peat bottom ranged from 5.0-5.3, and in a fourth, with a peat bottom, was 4.1, he computed the necessary quantities of CaO. To the first pond, which required an estimated 20 centners/ha of CaO he added 20 centners/ha, to the second, which required an estimated 21 cent./ha, he added 15, to the third, which required 12, he added 10, and to the last, which required 20, he added 10. After two months the pH_c values were 6.4, 5.7, 6.7 and 5.4 respectively. These pH_c values indicate a somewhat higher residual CaO requirement than was expected from the calculations, i.e. 5, 8.5, and 14 cent./ha of CaO. This may be due to the fact that the dose of lime calculated was rather lower than the amount needed to eliminate all the acidity of the bottom, or it may have been the result of an intensification of the decomposition of the organic substances in the soil of the bottom under the influence of the liming.

Thus, before embarking on liming we must determine the necessity for it from measurements of the pH_c value. In greatest need of liming are pond bottoms with a pH_c of less than 5. The procedure is to determine the hydrolytic acidity of the bottom and then compute from this the dose of lime required for liming.

The main conditions for effective liming of pond bottoms are even distribution of the lime in the form of the finest powder possible and good interaction between the particles of lime and soil, which is achieved by loosening /118/ the soil and working the lime in to a given depth.

The effectiveness of the liming can be verified by regular determination of the pH_c value. A substantial drop in the pH_c signifies the necessity for repeating the liming process. Ponds acutely in need of lime must have a full dose applied to the dried bottom. If the ponds are fed by water with an alkalinity of more than 2 mg-equ./litre, there is no need to lime the water then the bottom is limed in the normal way. If the alkalinity of the water is low it is advisable to add small doses of quenched lime, at the same time keeping a close watch on the reaction of the water (pH must not exceed 8.2-8.4). Liming of the water should be accompanied by the addition of organic fertilizers easily stirred up in the water, but the consumption of oxygen by these fertilizers should be taken into account. It is very important to make allowance for the reaction of the lime with the different types of fertilizers added to the pond. Errors creeping in owing to an inability to understand this point are often the cause of serious failures and disappointments.

The principles of the methods described for determining liming requirements are taken from soil science. Submersed soils are peculiar in many respects. Accordingly doubts have been expressed about the applicability to submersed soils of the methods used in soil science (Müller, 1961). Müller points out that, unlike submersed soils, arable soils, on being washed by rains, lose their bases (cations), thereby enriching the drainage water with calcium. This drainage water then flows into the ponds. This means that submersed soils are heavily saturated with bases. According to Müller, the practice borrowed from soil science of determining the pH_c value from exsiccated samples gives an incorrect notion of the reaction of the damp bottom of a pond. According to his data, in fresh samples of bottom sediments the reaction is always clearly linked to the pH of the water, and at high pH values of the water, even in ponds which have never been fertilized, the

actual pH value of the bottom is always greater than 7, whereas measurements of pH_c give much lower values (4.75-6.45). Thus, in the opinion of Müller, the pH of the water acquires special significance when we are determining the necessity for liming.

These arguments are valuable in so far as they concentrate attention on the close connection between the reaction of the water and bottom and the necessity of specific methods for studying submersed soils, methods which have not yet been devised. But Müller does not indicate what we should take as our yardstick for determining liming requirements and the doses of lime to be added to ponds with an acid reaction of the water and bottom, where the need for liming is patent. Therefore, the methods outlined above are not diminished in value, but they must be applied with an awareness of the /119/ conditions attached and the results obtained must be checked.

The effect of lime added to a pond must be viewed not in isolation but in relation to the conditions prevailing in the pond. Here we once again run up against the close interdependence of the individual manifestations of the single process of the cycle of matter and energy in a body of water.

In ponds containing poorly mineralized water with low carbonate alkalinity, when the bottoms are weakly saturated with bases and contain little CaO, as against sesquioxides, liming facilitates the transfer of combined phosphorus to the water and thereby helps to accelerate its cycle, increase the effectiveness of the utilization of phosphorus fertilizers, and reduce the amounts of these fertilizers necessary.

In the opposite case, with high carbonate alkalinity of the water, for example above 3 mg-equ./litre, and bottoms saturated with bases, liming is superfluous and may even be harmful. Under these conditions an increase in the quantity of the calcium merely leads to precipitation from the water and fixation of phosphates in the bottom in the form of insoluble tricalcium phosphate.

The importance of liming for the nitrogen cycle and effectiveness of nitrogen fertilizers consists above all in the fact that liming eliminates the acid reaction of the medium which prevails in soils weakly saturated with bases and which depresses the microbiological processes of ammonification, nitrification and nitrogen fixation. As a result the nitrogen cycle is speeded up and there is a corresponding increase in the effectiveness of nitrogen fertilizers.

The fact that successful liming of the water, i.e. the augmentation of its alkalinity, requires a source of free carbon dioxide, which normally takes the form of the microbiological and biological processes of the destruction of the organic substances, in turn stimulated by the liming, is of fundamental importance. It compels us to acknowledge that liming will be most successful when the necessary scale of decomposition of the organic substances is ensured, for example

by the application of manure or vegetable organic fertilizers in conjunction with artificial fertilizers or with intensive feeding, when the unconsumed part of the food decomposes, and so on. The interdependence between liming and the intensity of the biotic cycle also shows that each of the active principles of the fertilizers can be expected to be more effective when they are combined together in organo-mineral fertilizers.

CHAPTER III

THE INITIAL EFFECT OF ARTIFICIAL FERTILIZERS ON PONDS. /120/

1. General conditions of development of phytoplankton in ponds.

As we have already stated more than once, the initial effect of artifical fertilizers in effectively fertilized ponds is to stimulate vigorous development of phytoplankton.

The species composition of the phytoplankton of fertilized and unfertilized ponds is the same. No species are found in fertilized ponds that are not found in unfertilized ponds. This is not unexpected since the hydrochemical conditions-for example the content of nutrients are not so very different in fertilized and unfertilized ponds. This was also emphasized earlier on. Hence we can merely speak of the influence of fertilizers on the relative numbers of the different forms of phytoplankton.

At the present time this is a very confused topic. Only rarely have papers on the study of pond fertilization been accompanied by a qualified study of the phytoplankton. Often the authors confine themselves to extremely general comments on "vigorous" or "weak" water bloom due to green or blue-green algae, and so on. On the other hand, some fairly detailed algological research on fish ponds has, unfortunately, been done without reference to the conditions under which these ponds are used (Sretenskaya, 1961). Also almost unusable are data on phytoplankton relating to specimens collected with a plankton net. Such catches contain only large forms, the importance of which in the creation of primary production may be much less than

that of smaller species which can only be captured by more comprehensive methods (centrifuge, membrane, sedimentation). Finally, not much benefit can be derived for practical purposes from the results of the study of phytoplankton which merely refer to the number of individuals, the number of cells (Khemleva, 1958; Tsukurs, 1962), or even the number of"items per litre" (Il'in et alia, 1956). All this greatly restricts the number of papers which can be used to answer this problem of how phytoplankton actually changes under the influence of fertilizers.

/121/ There is no doubt that the species composition of phytoplankton which has developed as the result of fertilization is of importance for its later utilization and the ultimate effectiveness of the fertilizer. But so far, it is not clear what composition of phytoplankton is most favourable for the creation of a high natural fish yield in ponds. At present different and even contrary views exist on this subject. It is widely felt that it is necessary to promote the development of small species of algae, primarily Protococcaceae, which can be easily consumed by zooplankton. Blue-green algae are recognized to be undesireable components of phytoplankton since they are not immediately consumed. These ideas stem from the theoretical formulations of certain hydrobiologists who regard the development of blue-green algae as a "trophic blind alley" (Gaevskaya, 1947).

A completely different assessment of the role of blue-green algae has been arrived at by authors working from pond culture practice and generalizing studies of commercial ponds. Thus, Wunder, after years of study of the fish farms of Silesia, distinguishes three categories of ponds: 1 - ponds with the lowest fish yeild, in which the water is colourless or brown all year long; 2 - ponds with a greater yield in which brief water bloom can be observed mainly in spring or at the beginning of summer; 3 - the most productive ponds, in the best of which vigorous and prolonged bloom lasts all summer. In the last category of ponds it is, according to Wunder, already possible to distinguish two types of water bloom with the naked eye, i.e. uniform bloom by "punctate" algae (chiefly *Anabaea*) and bloom by "falcate" algae (*Aphanizomenon*.) The best-quality ponds are distinguished by two forms of bloom which breeders should strive to stimulate in practice. Wunder thinks that a single application of a large dose of fertilizer induces prolonged bloom whereas multiple applications have only a transitory effect. In summer, bloom begins roughly two weeks after the application of the fertilizer (Wunder et alia, 1935; Weiman, 1935a, 1935b, 1944).

Of special importance is the statement by Wunder concerning the positive value of bloom due to *Aphanizomenon flos-aquae*. Wunder suggests that mass development of this species be regarded as a criterion of the good condition of ponds and the effective action of fertilizers. It is interesting to note that Wunder's disciple, the famous connoisseur of phytoplankton, Utermöhl (1936), on the basis of his studies of the phytoplankton in the ponds of Silesia, accepts the method suggested by Wunder for classifying the ponds by the development of the phytoplankton, and also considers that positive significance should /122/ be ascribed to mass development of *Aphanizomenon*. In his paper, he, like other authors, stresses that the same species of

phytoplankton are found in both fertilized and unfertilized ponds, but he goes on to say that when the phytoplankton develops in greater quantities, the number of component species in fertilized ponds is far smaller. In the most heavily fertilized ponds only *Aphanizomenon* develops, which in many cases dominates the plankton, displacing all other species by, according to Utermöhl, chemical activity. Utermöhl notes that in no other ponds is *Daphnia* found in such great quantities as in those in which this algae is vigorously blooming. Utermöhl summarizes his observations thus: "The aim of fertilization must be the development of blue-green algae, especially *Aphanizomenon*".

Other authors arrive at the same conclusion. Fott(1952), after examining the phytoplankton of fish ponds in Czechoslovakia in connection with their fish yield, divides the ponds into five groups: 1 - those without water bloom, 2 - those with blooming green algae and diatoms, 3 - those with blooming green algae and flagellates, 4 - those with blooming green algae, flagellates, diatoms and blue-green algae (*Anabaena*, *Microcystis*) 5 - those with blooming *Aphanizomenon*. In his conclusions Fott makes special note of the fact that many well fertilized and limed ponds give a small yield of plankton. Let us remember that he is referring to phosphorus fertilizer, the only type being used at that time in Czechoslovakia. Nevertheless, he considers that the grouping of ponds according to their phytoplankton reflects the intensity of fertilization. The fifth group includes the most heavily fertilized highly productive ponds. When *Aphanizomenon* blooms the development of nannoplankton is depressed, but large *Cladocera* flourish. Fott observes that it is not yet clear whether blue-green or green algae are more desirable in fish ponds.

F. Havlena (1956), when investigating the effectiveness of using pig's manure for fertilizing ponds, observed mass development of large *Daphnia* (*Daphnia pulex*, *D. longispina*) in fertilized ponds. *Daphnia* was particularly abundant where there was vigorous water bloom due to *Aphanizomenon*, when the biomass of algae reached 300 kg/ha of dry matter.

Novak (1961) made a special study of the consequence of vigorous water bloom in the fish-breeding ponds of a Czech fish farm caused by *Aphanizomenon* with a very large biomass (9.2 mg/litre of dry matter in 1957 and 46.9 in 1958). At times of maximum bloom there is suppression of other forms of phytoplankton and many forms of zooplankton, but at the same time /123/ there is abundant development of large *Cladocera* which are valuable in the food sense (*Daphnia pulex*). After blooms cease, the variety of the species composition is quickly restored. Therefore Novak concludes that there are no grounds for fearing that water bloom due to *Aphanizomenon* will reduce the fish yield of ponds.

Of particular interest are the studies conducted between 1950 and 1956 of more than 100 fish ponds in Belorussia. As the result of these studies, it was found that "it is those ponds in which prolonged persistent bloom is observed, with predominance of *Aphanizomenon*, that give the maximum natural yield of fish of 400 - 700 kg/ha" (Lyakhnovich,1958a). On the basis of his own and published data, V. P. Lyakhnovich includes *Aphnizomenon* among the indicator organisms whose mass development serves a reliable indication of a high natural fish yield in a pond.

Later, Lyakhnovich and L. V. Prosyanik (1962), in a conference paper devoted to the role of blue-green algae (Sept., 1962), summarized the data from 40 finishing ponds on five farms in Belorussia and showed that as the natural fish yield of ponds increases under the influence of intensification measures the biomass of phytoplankton also increases, and at the same time there is a parallel increase in the percentage of blue-green algae in the total biomass. The largest biomass in ponds with the highest yield normally occurs when there is water bloom due to blue-green algae. The authors came to the conclusion that "in the ponds of this group it is the blue-green algae which constitute the material and energy base which leads to the high fish yield".

Lyakhnovich and Prosyanik note that their material does not reveal the suppressive effect of blue-green algae on algae of other taxonomic groups. A similar conclusion was arrived at by T. M. Mikheeva (1964), who examined the phytoplankton the lakes of Belorussia in a paper read at the same conference. Other reports and speeches also noted a positive link between mass development of blue-green algae and high fish yields of ponds and reservoirs.

Interesting information to the effect that a high fish yield was obtained from the ponds of the "Para" fish farm in Rostov oblast in 1953 and 1954 in the presence of strong water bloom due to blue-green algae and Protococcaceae is contained in a paper written by workers of VNIIPRKH (Il'in et alia, 1958). The authors assert that the "intensity of water bloom (particularly when due to blue-green algae) increases from year to year with intensive culture".

/124/

At first glance all these data are in striking contrast to the widely held views concerning the undesirability ~~of~~ and even "harmfulness" of water bloom formed in ponds by blue-green algae and the absolute preferability of protococcal plankton, which is easily consumed by zooplankton. Nevertheless, there still seems to be a way of reconciling these two extreme points of view. Generally speaking, the opinion regarding the advantages of protococcal algae was originally not based on the results of observations of ponds but arrived out through speculation, arguing from the ease of consumption by zooplankton, whereas blue-green algae, it was thought, are not eaten by zooplankton. Of course, the difference in food value and consumability between protococcal and blue-green algae is not absolute.

Let us recall the important data of O. N. Rusina (1956), who showed that larvae of Chironomus dorsalis eagerly feed on dying cells of Aphanizomenon, whereas Protococcaceae are unsuitable as food for them. There is no doubt that blue-green algae are also consumed by the large Daphnia.

Protococcal plankton apparently enjoys an advantage when efforts are being made with artifical fertilizers or some other method to increase the production of ponds in the same season. It is to be expected that when there is an equal biomass of blue-green algae, which affects the yield of fish in a more roundabout way, the piscicultural effect of fertilization in the same season will be less.

However, these ideas concerning the superiority of protpcoccal algae become less convincing if we take into account the fact that not only are the food organisms, and ultimately the fish yield, dependent on the phytoplankton, but that the reverse

also holds good, i.e. that the species composition and quantitative development of the phytoplankton depend on it consumers. Strange though it may seem, this fact is often forgotten. If we take this aspect of the matter into consideration we can understand why the largest biomasses of pond phytoplankton occur when there is development of blue-green algae. In actual fact, if the propagation of the zooplankton is not restricted in any way, its biomass will in a short time reach such a magnitude that the rate of consumption of the Protococcaceae will be higher than the rate of increase and their biomass will rapidly diminish. That this is in fact the case was convincingly demonstrated by investigations of biological cleaning ponds in Minsk. These ponds are periodically drained and refilled with run-off water, in which within a few days, masses of Protococcaceae develop. In summer, when the temperature favours the development of rotifers, they multiply on a vast scale (tens of thousands per litre) after the development of the phytoplankton and rapidly destroy the protococcal plankton (Galkovskaya, 1961; Sivko, 1961). This same phenomenon was described for the eel ponds of Japan by Ito (1955). It is /125/ a well-known fact that the development of rotifers, cladoceran crustaceans and other consumers of phytoplankton is a difficult obstacle to the mass cultivation of algae in the open (Vinberg, 1957). Hence it follows that large biomasses of Protococcaceae and other easily consumed algae can only be maintained for a prolonged period in cases where increase in the biomass of zooplankton is limited by intensive consumption of the latter by fish, or in some other way. This means that dense stocking of fish ponds is bound to facilitate the development of phytoplankton. Confirmation of this can be found in the data of Soileanu

(1960), who, after observing the fish ponds of Rumania, came to the conclusion that consumption of zooplankton by fish promotes the development of water bloom. By this he explains the strong water bloom in ponds stocked with an estimated 80,000 underyearlings per hectare. From this point of view, when large does of fertilizer are used it is rational to anticipate dense stocking. In the absence of factors restricting the development of zooplankton, large biomasses of phytoplankton may be created only if species develop which cannot be consumed, or are not easily consumed, by zooplankton. This is confirmed by the data of three years of study by N. I. Sretenskaya(1961) of thirty-one ponds on three Belorussian fish farms, including both low-producing and high-producing effectively fertilized ponds. In the table drawn up by Sretenskaya, out of 76 average seasonal results of measurements, the biomass of Protococcaceae exceeded 5mg./l in only nine cases and was greater than 10mg/l in only three. A large biomass of phytoplankton was achieved only because of the development of blue-green algae, the biomass of which was greater than 100mg/l (maximum size 578 mg/l) in eight cases.

It is because blue-green algae are not immediately consumed by most of the forms of zooplankton that they are able to develop in masses and give the maximum primary yield, which through bacterial decomposition and other channels is included in the biotic cycle and raises the productivity of the pond. If systematic fertilization over a number of years causes intense water bloom due to blue-green algae we can be sure that it leads to an increase in the natural yield of the pond.

The ideas expressed still need to be subjected to experimental verification. Nevertheless, it is already clear that the degree of development of phytoplankton consumers, the density of stocking, and other biotic factors influence the composition and quantitative development of the phytoplankton no less than do the physical and chemical conditions of the medium, for example the temperature of the water of the content of nutrients, which are usually the only factors taken into consideration.

/126/

An oversimplified idea of a complex natural phenomenon retards research and prevents the discovery of ways in which the phenomenon can be controlled. Therefore, even the primary effect of fertilizers must be studied with awareness of the great complexity and obscurity of the conditions governing the development of phytoplankton and the primary production of ponds. Recently it has been discovered that many algae, for example Euglenoidina, require not only mineral nutritive elements but also vitamins. Mackereth (1953) showed that *Asterionella*, in an artificial medium prepared with distilled water, is incapable of accumulating phosphorus from NH_4PO_4, whereas in lake water, where there are much smaller concentrations of phosphates, phosphorus accumulates in its cells. When 20% lake water is added to the artificial medium the capacity for the accumulation of phosphorus is restored. On the other hand, S. I. Kuznetsov (1945) and N. B. Zavarzina (1955) found that the water of lakes may contain some substances as yet unstudied which suppress the development of phytoplankton. Let us not forget too the antibiotic relations between various species of phytoplankton, which undoubtedly exist although they have barely been studied. We still know little about all these phenomena, but we know enough to beware of simplified notions on the basis of which it is impossible to determine the principles governing the initial effect of fertilizers.

2. The Development of Phytoplankton in Relation to the Content of Nutrients in the Water.

The development of phytoplankton depends on many factors, of these, the content in the water of the nutrients serving as the active principles of artificial fertilizers are of particular interest.

It is often thought that it is necessary to maintain a specific concentration of nutrients in the water of a pond with the aid of fertilizers. Thus, for example, on the strength of the results of three years (1958-1960) of research on the ponds of the "Nivka" experimental fish farm (Fel'dman, Prosyanii and Sukhovii, 1961), the Institute of Fish Culture of the Ukranian SSR devised norms for the use of nitrogen-phosphorus artificial fertilizers in ponds and recommendations for their application. They recommend adding mineral salts every fortnight until the desired concentrations of 2 mg of nitrogen per litre and 0.5 mg of phosphorus per litre are reached, the doses of fertilizer being determined from the results of hydrochemical analyses, revealing the required amounts of nitrogen and phosphorous to be added. The same norms have been adopted in Israel. L. N. Kamontova (1959, 1961) considers it necessary to constantly maintain a very high concentration of mineral nitrogen /127/ in the water of ponds (for example, 5 mg N/1) and a substantial content of phosphorous (0.3 mgP/1), which, according to her recommendations, can be achieved by adding very large doses of artificial fertilizers every three days. Simultaneously she recommends denser stocking. In the view of Kamontova, (1959, 1961) these conditions facilitate the development of green algae and suppress the development of blue-green algae.

As we can see, the recommendations for practices leading to heavy consumption of artifical fertilizers are based on the necessity for achieving the initial effect of fertilization, these very crucial conclusions being based on definite ideas concerning the ecological and physiological characteristics of different algae of the phytoplankton. It would seem that these basic premisses must be well-founded. In point of fact, however, no attention is usually paid to the physiology of the phytoplankton when the fertilization of ponds is being studied. Therefore many of the ideas on the physiological characteristics and chemical composition of algae which have become rooted in pisciculture turn out to be unsubstantiated or improbably, while modern ecological and physiological knowledge and methods remain unused. It was this that induced us in the present chapter to examine those basic ideas on the physiological characteristics of fresh-water plankton which must be examined in the first place for a better understanding of the initial effect of pond fertilization.

It is evident that for rational fertilization of ponds we must use those fertilizing substances which are most needed, and in quantities which will ensure that they are drawn into the biotic cycle.

It is difficult and often impossible to judge the fertilizer requirements of a pond from the results of hydrochemical analyses, i.e. to determine which of the active principles of the fertilizers must be added in each individual case. This point has already been discussed before. As far back as 1900

Zuntz and Knauthe (1900) suggested judging the fertilizer requirements of ponds by the results of observations to determine which of the various fertilizing substances induced the most vigorous development of phytoplankton in vessels containing water from the pond under investigation. This method is invariably described and even recommended in fish-breeding manuals, but it has not been widely applied.

Regardless of this, and without reference to the interests of pond culture, A. V. Frantsev (1932) suggested the "hydrobiological productivity method" in which cells of the protococcal alga Scenedesmus quadricauda are added to the water under study to see which of the salts added appears to cause the greatest increase. Frantsev's method was used by A. Ya. Musatova and S. I. Kuznetsov (1951) during a study of experimental ponds on the Chiralovsk fish farm (Moscow region) in the summer of 1938. /128/ Both unfertilized ponds and one fertilized with superphosphate revealed the need of nitrogen and the joint application of nitrogen and phosphorous. According to the results of tests, in the period from the 29th of May to the 3rd of September ten applications of nitrogen-phosphorous fertilizer were made until estimated concentrations of 0.4 - 0.8 mg/litre of nitrogen and phosphorus were achieved. The application of the fertilizers invariably caused an intensification of the development of first the phytoplankton and then the zooplankton, whereas in pond. no 11, which was fertilized only with superphosphate, planktonic development was even weaker than in the control pond. The results of the research by Musatova and Kuznetsov, which became known to a circle of specialists long before their publication in 1951, were of great theoretical importance, since they shook the belief current at that time that ponds do not require nitrogen fertilizer.

S. I. Kuznetsov used the same method (1956) when making a study of ponds on the "Ust-Koisug" fish farm (Rostov oblast). Through biological tests performed on the 22nd and 30th of May and the 5th of June, he discovered a pronounced need for nitrogen. In this particular case nitrogen-phosphorous fertilizers added to the pond stimulated the development of filamentous and periphytonic algae and failed to induce vigorous development of phytoplankton. Nevertheless the rate of growth of the fry was higher in the fertilized pond.

A very similar technique was employed by Lotash (1956) in his year-long study in 1951 of two ponds in the state of New York. He used a culture of another species of Protococcaceae-Kirchneriella subsolitaria. From the results of daily counts of the number of cells in the experimental vessels he computed the assymptote of the logistic curve of growth, which also served as an indications of the limit of growth under the given conditions. It was found that phosphorous was at a minimum in the winter months, but that after March nitrogen was the factor limiting growth. The author notes that the method used by him can be used for studying fertilization of ponds.

In 1949 and 1950 Frantsev's method was used by S. S. Baslavskaya and his colleagues (1953) in research on ponds in the Kamyshkin region of the Volgograd oblast and compared it with another form of biological testing in which the influence of the different fertilizer materials is determined directly from the reaction of the phytoplankton in the pond in question. Although there was general agreement between the results obtained by the two methods, preference was given to the second, which was then adopted for the study of pond fertilization.

The reaction of the plankton to the addition of a particular substance was determined either from the increase in the number of cells in the course of the experiment, or from the intensity of photosynthesis of the plankton, which can be judged in the simplest case by the content of oxygen in the water in the experimental bottle towards the end of the experiment. The latter method, which was adopted by I. V. Baranov (1949) during observations in 1948 of the Artem'ev pond on the "Ropsha" fish farm (Leningrad oblast), and later used by other authors (Baslavskaya et alia 1952, 1953; Matisone, 1962), proved most practical. It is simple, gives a rapid answer to the question posed, and unlike the counting does not require examination of plankton which is possible only with a qualified algologist. The counting method, in addition to its laboriousness in the face of the complex composition of the phytoplankton, gives a very confused picture, from which it is by no means always possible to arrive at a definite conclusion concerning the effect of the substance on trial on the function of the plankton as a whole. As against this, for any species composition it is possible to obtain from the rate of generation of oxygen directly comparable quantitative data relating to that chief function of the plankton - primary production - to stimulate which the fertilizers are being used.

The procedures followed by the different authors for their biological tests varied both in the length of the experiment and concentrations of the salts added, and in the compostion of the salts and the plan of the experiment. The most extensive biological tests for the fertilization requirements of ponds were conducted between 1950 and 1952 on many ponds of the "Volma", "Krasnaya Zvezda", "Beloe", "Alba" and "Shemetovo" fish farms situated in various parts of Belorussia (Vinberg, 1953, 1954,

/129/ 1956a, 1956b, 1956c, 1958; Vinberg, Kishcenko, 1958). In these experiments salts were added to the water until the following concentrations were reached: 2.7 mg of nitrogen, 1.3 mg of phosphorus and 4 mg of potassium per litre. These concentrations are close to those which can occur when artificial fertilizers are used, but they are apparently markedly higher than the minimum concentrations sufficient to reveal the fertilizer requirements. In special tests staged to clear up this problem in 1951 on the "Volma" and "Al'ba" fish farms, Ya. P. Salei and V. I. Gaponenko (Vinberg, 1956a) found that after 48 hours of exposure the maximum effect was being achieved with the addition of as little as 0.3 mg of nitrogen per litre in the form of calcium nitrate. The result of the experiments was basically the same for different concentrations of the salts added and different lengths of the experiments (2, 3, 6 days). Nevertheless, it must not be considered that it is a matter of indifference under all conditions how long the bottles are exposed for during the biological tests. This question requires further study. Apparently, with weakly developed /130/ phytoplankton it is advisable to expose the bottles for longer periods and, perhaps, to use smaller concentrations of the salts added.

Research on the ponds in Belorussia led to completely clear-cut results. In all the ponds examined on the various fish farms the activity of the phytoplankton was stimulated either by nitrogen or by nitrogen and phosphorus together, the need for nitrogen being much more marked in the ponds fertilized with phosphorus. Only in rare cases was there evidence of a weak need for phosphorus. The same results were obtained by S. S. Baslavskaya and her co-authors (1952, 1953) in biological tests performed on ponds in the Volgograd oblast, by A. A. Egorova (1954) on the bayous of the Volga delta, by M. N. Matisone (1962) on the Latvian fish farms, by L. P. Braginsky (1955, 1956, 1957, 1961) on the ponds of fish nurseries of Kiev oblast and certain other oblasts of the Ukraine, and by N. N. Khmeleva and . I. Tsvetkova (1959) on the ponds of the vimba-shemaia nursery in Krasnodar region.

S. I. Kuznetsov (1945) and N. B. Zavarzina (1955), on using the method of Frantsev, found that the lakes they were studying near Moscow (Beloe, Svyatoe, Nerskoe, Dolgoe, Krugloe, Bol'shoe and Maloe Medvezh'i) mainly display a need for nitrogen.

I. V. Baranov, one of the first to use biological testing and to have fully evaluated the data obtained in this way, employed this method systematically for hydrochemical research on many bodies of water (Baranov, 1948, 1949, 1952, 1953, 1954, 1958, 1960, 1961, and 1962). In the first and second papers, in which he used the data of 1946, he showed that the phytoplankton of Artem'ev pond on the "Ropsha" fish farm in Leningrad oblast reacted only to the addition of phosphorus and failed to react to nitrogen. In this case the pronounced need for phosphorus and the analogous data for Nikol'sky pond situated near Petrodvorets (Baranov, 1953) are due to the fact that the bodies of water of the Silurian plateau of Leningrad oblast are fed by glacial waters with a very low content of phosphates. It might be added that in alkaline waters of high mineralization the conditions described above foster the combination of phosphorus. These observations are of great interest, since they were made on ponds which, unlike the overwhelming majority of the bodies of water studied, are characterized by a marked and persistent need of phosphorus due in all cases to the special features of their hydrochemical regime. Let us remember that the first experiments in phosphorus fertilization of

ponds, which were widely known in their time and of great significance, were made by N. I. Arnold between 1929 and 1931 on the ponds of the "Ropsha" fish farm, which, as is now clear, now occupy a quite special position as regards fertilizer requirements. /131/

As early as 1952, I. V. Baranov found that the very first biological tests of water of the Vlasov, Batrachek and Mayachny bayous in the Volga delta clearly revealed a marked need of nitrogen. Baranov suggested applying nitrogen fertilizers as an element of the "combination" organo-mineral fertilization recommended by him, which is also examined in his paper of 1953. On the strength of this, ammonium sulphate was used as early as 1952 for the fertilization of the Batrachek bayou (Mil'shtein, 1957).

In subsequent research Baranov used the same method of biological testing, to find that the need for nitrogen or nitrogen and phosphorus was characteristic of the lakes (Onega, Chuzhkovskoye, Kuibyshevskoye) studied by him. Only in isolated cases did he discover a weak need for phosphorus as a temporary or seasonal phenomenon (Kuibyshevskoye reservoir in 1957 and 1958).

Thus the method of biological testing used on many bodies of water in different zones of the Soviet Union showed convincingly that it is usually nitrogen or nitrogen and phosphorus compounds that are needed to stimulate the development of phytoplankton. This proved that application of mixed nitrogen-phosphorus fertilizers is sound practice.

It is particularly important that the strongest effect in biological tests is generally obtained from the joint application of nitrogen and phosphorus, whereas in many cases, for example in the "Shemetovo" experimental ponds (Vinberg, 1958), the phytoplankton failed to react on the whole to separate application of these elements. These facts show that the cycles of nitrogen and phosphorus are very closely linked. As we know, the ratio of the concentrations of nitrogen and phosphorus in the natural waters (on average N:P equals 10) is generally close to the average ratio of these elements in living organisms, and this reflects the balance achieved between the constructive and destructive processes of the biotic cycle in nature.

From this follows the important conclusion that the separate application of both phosphorus and nitrogen fertilizers can only be adequate in special, apparently rare, cases. As a rule, these two components are most effective only when used together.

The important results achieved with the biological testing method should not lead us to overestimate its possibilites. In the form in which it was used by the authors mentioned above it can only give a clear idea of which of the elements is required by /132/ the phytoplankton of a particular body of water at a particular time. When biological tests show that the plankton requires a specific nutrient this fact still does not, in itself, prove that the corresponding fertilizer should be added to the pond. Thus, for example, when phytoplankton develops excessively it also displays a "need" of nitrogen or phosphorus, which might lead to a senseless increase in the biomass and production of the phytoplankton with possibly undesirable consequences.

We cannot expect biological testing to supply an answer to the question of how much of the necessary element must be used for fertilization. In this connection quite unacceptable recommendations are made by Popescu (Popescu et alia). Since there were only two experiments, in each of which ammonium nitrate was used in four different concentrations, it cannot be accepted that the results of the biological tests conducted (which, incidentally, were not very clear-cut) permit the recommendation of specific doses of fertilizer. The amounts of fertilizer necessary and sufficient depend not only on the processes which take place in the main body of the water between the dissolved substances and the phytoplankton which can to some extent be ~~taken into consideration~~ measured in the biological tests; they are also dependent to no less degree on the exchange between the water and the bottom, the macrophytes, and so on. Therefore, to determine and test the applicability of the results of biological tests to the body of water as a whole we must conduct appropriate experiments on the ponds.

In one and the same body of water, but in different seasons, the phytoplankton may display substantially different requirements as regards nutritive substances. Thus, for example, in 1951, research on the ponds of the "Volma" fish farm in Belorussia at the beginning of summer, when the phytoplankton was still weakly developed, revealed a need of phosphorus, which was later replaced by a clearly marked need of nitrogen. Apparently, here as in other similar cases (Potash, 1956), was manifested the absence of phosphorus and nitrogen cycles referred to above. By virtue of the more labile links, the feed-back of the phosphorus, at least within the limits of the water masses, must be greater than that of the nitrogen, the liberation of which requires more thorough decomposition of the organic substances. Therefore, we should expect that rather more nitrogen than phosphorus will be immobilized in the organic remnants, not yet decomposed, in the annual cycle during the growing season. Such arguments have already been adduced to explain the decline in summer of NO_3:P ratio in New York harbour after fertilization with pollutants (Jeffries, 1962).

L. P. Braginsky (1961) also states that in ponds "in spring (in May and the beginning of June)....there is a slight increase in the need for phosphorus; later there is a persistent need of nitrogen and NP", but he is inclined to put a different interpretation on the seasonal differences in the results of biological tests and to regard them as the consequence of replacement of the dominant species of phytoplankton. /133/

According to his observations of the composition of the phytoplankton developing in experimental bottles during biological tests, L. P. Braginsky makes an interesting attempt "to show how variations in the species composition of the phytoplankton are linked with variation in its "need" of nutritive elements, as determined from the intensity of photosynthesis". The computed concentrations of the main nutritive elements in his experiments, as in the experiments of G. G. Vinberg, were 2.7 mg of nitrogen, 1.2 mg of phosphorus and 4 mg of potassium per litre. Having summarized the material of many experiments , L. P. Braginsky came to the conclusion that "it is possible to observe a definite similarity in the reactions of phytoplankton to fertilizers of the same type, particularly nitrogen fertilizers." *Protococcaceae*, especially *Scenedesmus* and some *Euglenoidina* (*Trachelomonas*), react with intensified multiplication to the addition of nitrogen fertilizers *in vitro* or in the pond. L. P. Braginsky suggests calling these species nitrophils. "Diatoms (*Pinnularia* sp. sp., *Navicula* sp. sp.) and some blue-green algae (*Merismopedia puntata*, *M. tenuissima*) react in the same way to the addition of phosphorus" (phosphorophilous species); "forms of desmidian algae from the genera *Closterium*, *Cosmarium* and *Staurastrum* react slowly to potassium, there being no resultant increase in the intensity of photosynthesis".

It seems that Braginsky suggests that the result of the biological tests also depends on what algae achieve dominance in the test bottles, since, for instance, in his view, Protococcaceae will require nitrogen, blue-green algae will need phosphorus and so on. Braginsky, like some other authors (K. A. Guseva) appears to ignore the fact that the term "requirement" or "need" used of phytoplankton in connection with a particular element may be understood in two quite different senses. In the ecological sense it means the optimum concentration in the medium for the development of a given species, and this is the way Braginsky interprets the term, distinguishing nitrophilous, phosphorophilous and other species. The other meaning of "requirement" is the particular quantity of a nutritive element necessary for the production of a certain biomass of phytoplankton of a given composition.

There is no doubt that different species of algae develop best under different environmental conditions. K. A. Guseva (1952) showed that diatoms cultivated by her grew best at a nitrate nitrogen content ranging from 0.01 (*Tabellaria fenestrata*) to 0.4-0.8 mg N/litre (*Synedra acus*), whereas the maximum development of Protococcaceae was achieved at 5 mg of N/l, and the peak development of Volvocina (*Eudorina*, *Chlamydomonas*) at not lower than 2-5 mg of N/l. /134/ The same effect was achieved with approximately 10 times smaller concentrations of ammonium nitrogen. In respect of blue-green algae Guseva notes that some species in this group give their maximum increase at the same concentrations as the diatoms mentioned earlier (*Aphanizomenon flos-aquae*, *Anabaena Lemmermannii*), whereas other species do so at nitrogen requirements similar to those of green algae. Let us note that in other groups too the needs of various species undoubtedly differ just as much, which is in complete conflict with the feeding characteristics of large groups of algae that have come to be accepted in hydrobiology.

Having demonstrated thoroughly that different species develop best at different contents of nitrogen in the medium, Guseva attempts to connect the different nitrogen requirements of the species studied by her with the fact that "according to need" they differ in the content of nitrogen in dry matter. This seems to us unconvincing, since many data show that the chemical composition of the organic matter of the most diverse algae is very similar. In this case a given increase in the biomass requires a given quantity of nitrogen, and in this sense the various species of algae will not differ in their nitrogen requirements. As we can see, a clear distinction must be drawn between the two possible meanings of the term "requirement". Let us explain this by another example. Let us imagine that "phosphorus-loving" species, i.e. species which require for their normal development relatively high concentrations of phosphates in the medium, do not differ in their chemical composition from the nitrogen-loving species. In such a case the same quantity of nutritive substances will be required for a given increase in the biomass of each of these species. Let us suppose that there is a large excess of phosphorus in the medium and that the phytoplankton accordingly consists of phosphorus-loving species. However, if there is an excess of phosphorus, the upper growth limit of the biomass will be determined not by the phosphorus but by nitrogen. Hence, during biological tests these phosphorus-loving species display a need of nitrogen. Thus, the final result of the biological tests will indicate the nutritive element which is in insufficient supply to ensure growth, i.e. that element which is present in the smallest quantities and which determines the limit of the possible development of the total biomass of phytoplankton for any given species composition.

Hence we must clearly differentiate between the two meanings nutritive elements and the need of fertilizer. The first, or ecol-

ogical meaning is uppermost when an analysis is made of the conditions of the medium ensuring the possibility of development of a given species. The second meaning is paramount when a study is made of the conditions ensuring the possibility of an increase in the total biomass of the phytoplankton as a whole. The requirements as determined by the method of biological testing, in the form described earlier in which such integral functions as the intensity of photosynthesis or growth of the biomass are used as the criterion of the activity of the plankton, should be understood mainly in the second sense.

Let us note that the requirements of the plankton are on the whole far less specific than those of its component species, taken separately. For example, a lack of silicon or vitamin B_{12} may limit the development of a particular species, but it cannot restrict the growth of the biomass of phytoplankton as a whole, if it is made up of species which do not need silicon or vitamin B_{12}. This appears to explain the generally uniform picture emerging from the biological tests, according to which the development of the phytoplankton of the most disparate bodies of water is limited by nitrogen and phosphorous. As against this there is no doubt that the development of individual species of algae may be limited by many different factors, such as micronutrients, vitamins and many others.

Artificial fertilizers, by supplying lacking nutritive elements, help to increase the yield of phytoplankton, with the active principles of the fertilizers, primarily nitrogen and phosphorous, entering into the composition of the bodies of the algae. From this it is clear that accurate ideas of the chemical composition of the phytoplankton are of prime interest for an understanding of the way in which fertilizers act and of the conditions determining the maximum possible initial effect of their application.

The similarity between the main indicies of the chemical composition of the organic matter of different algae has been confirmed again and again by many recent studies. This does not mean, however, that there is a certain invariable chemical composition of algae independent of the conditions of growth; it merely means that the differences in the chemical composition of the organic matter of one and the same species under different conditions may be no less than in a comparison of data relating to different species. This important principle, which was enunciated 25 years ago (Ketchum, Redfield, 1949), has been verified by many authors. At first sight it contradicts the oft repeated statement that, for example, blue-green algae are "rich in nitrogen", whereas diatoms contain less nitrogen and hence, protein, the quantity of which, as we know, is calculated from the quantity of nitrogen. In point of fact, the content of nitrogen in diatoms, expressed as a /136/ percentage of the dry weight, is lower than the content of nitrogen in the dry matter of green or blue-green algae. However, this difference is fully explained by the fact that diatoms are characterized by a high ash content due to layers of silicon (up to 50-70% of the dry weight). When calculated for ashless (organic) substance the content of nitrogen in comparable conditions is the same as in other algae.

The extent of the similarity between the composition and chief biochemical characteristics of different algae is clear, if only from the results of a careful study of the accumulation of fat in cultures of algae from the most diverse taxonomic classes. The study failed to reveal any "substantial" differences in fat accumulation in representatives of Chlorophyceae, Eugleninae,

Xanthophyceae and Bacillariophyceae. The authors note that "the generally accepted view that accumulation of fat is characteristic of certain classes of algae is based on insufficient data" (Collyer, Fogg, 1955).

Let us point out that it is the chemical composition of the organic matter and not the dry matter that determines the food value of algae, as indeed of other organisms, and that it is the organic matter which contains the energy and the major part of the nutritive elements. Therefore, for the purposes of biological production and fish breeding it is the chemical composition of the ashless and not dry matter which is of greatest interest in the overwhelming majority of cases.

The composition of algae reared in a culture may differ strongly from that of phytoplankton in bodies of water. Nevertheless, for the purposes of comparison it is interesting to cite certain data. On the strenght of extensive cultural experience it is assumed that the normal requirement of *Chlorella* per 100 parts by weight of carbon is: N - 15, P - 5, Mg - 2.5, K - 1.8, S - 1.6, with carbon normally forming 51-56% of the ashless matter. Let us note the unusually high content of phosphorus, which should evidently be ascribed to the high content of phosphates in the culture medium.

The extent of the possible difference in the chemical compositions of the cells of the same species reared under different conditions is shown by the widely known data obtained from *Chlorella* cultures. Depending on the conditions of cultivation, the content of nitrogen in the cells of *Chlorella* may, according to the well-known paper of Spoehr and Milner (1949) range from 1.2-14%, which would correspond to 7.3-88.2% of protein. The relative content of many other components may also fluctuate within similarly wide limits. Therefore, there is sense in citing collated data of the results of analyses of the composition of different algae (Krauss, /137/

1958), relating mainly to cells grown in cultures. (Table 3)

Table 3 also contains data obtained under extreme conditions of cultivation. For comparison we give in the last column average data of analyses of algae, chiefly Protococcaceae, bred on municipal drainage water, i.e. under conditions of a restricted carbon diet and a good supply of nutritive elements (Gotaas et alia, 1954).

Table 3 gives only a general idea of the range of variation of the content of individual components. The range of the content of phosphorus has been greatly compressed, as it is very variable and may be higher than 1.5% or lower than 0.94% dry weight. However, it is marked by great steadiness and in the overwhelming majority of cases it constitutes 50-55% of the ashless substance.

Unfortunately there are only a few data characterizing the chemical composition of fresh-water planktonic algae bred under natural conditions. The nitrogen content in the dry matter of diatoms of fresh-water plankton ranges under natural conditions from 1.6-3.1%,. The corresponding figures for green algae and blue-green algae are 2.4-8.3% and 6.3-9.2% respectively (Guseva, 1952). Let us remember that these differences are obliterated when reckoning on the basis of ashless matter. According to Guseva, the phosphorous content in the dry matter in different algae of fresh-water phytoplankton ranges from 0.19 to 0.55%.

TABLE 3

Range of fluctuation of elementary composition of monocellular algae of various taxonomic classes bred under different conditions.(as % dry weight).

Element	According to Krauss (1953)	Bred on drainage water, according to Gotaas.(1954)
C	49.51-70.17	44.9
O	17.40-33.20	25.7
H	6.57-10.20	7.69
N	1.39-10.98	8.92
S	0.91	1.11
P	0.94-1.51	1.00
Ca	0.00-1.55	1.2
K	0.04-1.44	-
Mg	0.26-1.51	0.35

The great differences referred to in the chemical composition of the cells of specific species occur under different conditions of cultivation. The extreme values, for example the particularly low content of nitrogen, which was accompanied by a high fat content, /138/ were observed under special conditions, with nitrogen starvation and strongly retarded growth. In nature such cells are incapable of competing. It appears that in a population of phytoplankton made up of many species each species can remain in the composition of the plankton and not be replaced by species more attuned to the given combination of environmental factors only in circumstances permitting more or less normal development of the species in question. Therefore the fluctuations that may occur in the chemical composition under natural conditions are bound to be much smaller than those observed in monocultures in extreme conditions. This gives rise to the idea of a "normal" chemical composition which is steadfastly preserved in actively growing populations.

The determination of the "normal" chemical composition of the various algae of the phytoplankton is beset with many difficulties. Extremely interesting data have been obtained for *Microcystis aeruginosa* (Gerloff, Skoog, 1954). Careful examinations of cultures of this species led the authors to the conclusion that the "normal" or "critical"content of nitrogen in *Microcystis* was 5% of the ashless matter, since this content of nitrogen ensures the maximum speed of growth. Under cultural conditions the "normal" content of nitrogen in the cells (5%) is achieved at approximately 10 mg of nitrate nitrogen per litre of medium while the maximum content (8%) is achieved at 15 mg of nitrate nitrogen per litre of medium. At the same time, under natural conditions, *Microcystis* develops splendidly with a far lower content of nitrogen in the medium.

It is noteworthy that in nature a high content of nitrogen and phosphorus's in the cells of *Microcystis* is achieved at concentrations of these two elements in the medium at which the cells in cultures experience acute nitrogen and phosphorus starvation and have a low nitrogen content. In material collected in nature the nitrogen content ranged from 5.64-8.68, with an average of 6.83%, and the phosphorus content varied from 0.52-0.98%, with an average of 0.69%. This example shows once again how difficult it is to judge the trophic conditions for phytoplankton in bodies of water from data obtained in cultural conditions.

Frequently the results of physiological investigations on cultures prove to be in conflict with the views which have been formed by hydrobiologists. Thus, for example, a study of the conditions ensuring the greatest speed of growth of *Microcystis* in cultures revealed that it is achieved only at a very high content (not less than 13.6 mg/litre) of nitrogen in the medium. (Gerloff, Fitzgerald, Skoog, 1952). On the strength of this, the "normal" nitrogen content in the culture medium would be 20.4 mg/litre(!). In absolute contradiction of the idea that blue-green algae are phosphorus-loving, the concentrations of phosphorus adequate to /139/ ensure maximum growth proved to be comparatively low (0.18 mg/litre). The authors conclude that of the elements forming the mineral diet of *Microcystis* "there is most reason why nitrogen should be the factor limiting growth".

Although these data, which were obtained on cultures, cannot

be applied without qualification to natural conditions, we cannot ignore them either. These data, like the material of many authors who have successfully cultivated different species of planktonic and blue-green algae on media containing mineral compounds of nitrogen in considerable concentrations, show how insecurely based are those ideas that the development of blue-green algae is, so to speak, excluded when the medium contains about 5 mg of mineral nitrogen per litre. Therefore it is no surprise that in some cases water bloom due to blue-green algae (*Microcystis* and others) has been observed in ponds in which a high content of nitrogen compounds has been maintained in the water through the application of large doses of nitrogen-phosphorus fertilizers.

The study of the chemical composition and trophic requirements of phytoplankton is also greatly impeded by the fact that planktonic algae may accumulate phosphorus, and to a lesser degree nitrogen, beyond the "normal" content of these elements. Therefore they prove able to grow in media which do not contain these nutritive substances, where they can complete several subsequent divisions due to a drop in the relative content of nitrogen and phosphorus in the cells (Frantsev, 1932; Rodhe, 1948). The ability is particularly marked in respect of phosphorus and less marked in the case of nitrogen. Thus, for example, *Microcystis* in a medium without nitrogen gave a 100% increase in dry weight, whereas the increment was much greater in a medium without phosphorus. The increment was 308% for cells bred at 1.8 mg of P per litre, 177% for those bred at 0.18 mg P/l, and 102% for cells bred at 0.09 mg P/l (Gerloff et alia, 1954).

Accordingly, the relative content of phosphorus is particularly variable. The ability of the cells of phytoplankton to accumulate "excess" quantities of phosphorus is of prime importance to a study of the effect of fertilizers. As long ago as 1941 Einsele (1941) noted, on the strength of the results of a study of the consequences of fertilization of ~~lake~~ the Schleinsee, that the content of nitrogen in the net plankton of the lake was relatively stable (4.2 - 6.0%) whereas the content of phosphorus fluctuated much more strongly (0.33 - 1.1%), as the result of which the N:P ratio also varied widely (4.5 - 18.2).

Planktonic algae are also able to accumulate phosphorus when its content in the medium is very low. In this connection the data of Mackereth (1953) are exceptionally interesting. He showed that the diatom *Asterionella formosa* can accumulate phosphorus /140/ at insignificantly small concentrations of phosphate phosphorus in the water down to 0.0001 mg P/litre. In the lake studied by Mackereth, particularly favourable conditions for the accumulation of phosphorus exist already in wintertime. This ensures rapid propagation of *Asterionella* in the spring. The content of phosphorus in the cells of Mackereth's observations dropped very heavily when the number of cells, both in cultures and in natural conditions, increased. For instance, in a culture in which the original content of phosphorus in the medium was 0.001 mg per litre there were initially 1.5 micrograms, but bu the time the maximum number was reached there was only 0.06 micrograms of phosphorus per million cells. According to the data of Lund (1950), who in his classic research projects conducted in the same laboratory on ~~Lake~~ Windermere made a detailed study of the life cycle of *Asterionella*, the content of phosphorus in the cells of this species varies within even wider limits - from 0.06 to 4.2 micrograms per million cells. However, we must take into account the fact that after subsequent divisions the volume of the cells of diatoms may diminish substantially.

It would appear that many planktonic algae, whose physiological characteristics in natural conditions have not been studied, differ from *Asterionella* in several ways, for example they need large concentrations of nutritive elements in the medium. However, it is a well-known fact that phytoplankton of the most varied composition vegetates successfully and develops en masse at low concentrations of nutritive elements and is capable of reducing their content in the water to analytical zero, i.e. to insignificantly small concentrations which cannot be detected by chemical methods. Therefore there are no grounds for thinking that a high content of nutritive elements - some several mg of nitrogen per litre or several tenths of a mg of phosphorus per litre - can stimulate the development of phytoplankton the more, the lower the concentrations of these elements. Most probably, to achieve the maximum speed of propagation of at least the overwhelming majority of species of algae it is sufficient to maintain moderately high concentrations, for example up to 0.1 mg of phosphorus/l and up to 1 mg of nitrogen/l. The lengthy presence of large concentrations of nutritive substances must be regarded as proof that under the conditions in question they cannot be utilized, i.e. as an indication of lack of effectiveness of fertilizers.

3. Phytoplankton As An Index of the Initial Effect of Fertilizers.

Investigation of the degree of development, and in particular measurements of the primary production, enable us to express the initial effect of artificial fertilizers in quantitative terms and /141/ to find the connection between primary production and the fish yield of fertilized and unfertilized ponds. When such comparisons are made the species composition of the phytoplankton should be taken into account, since it is quite possible that when there is a predominance of Protococcaceae, for example, fertilizers may be most effective for a smaller biomass and lower phytoplankton yield than when blue-green algae predominate. The biomass achieved due to the development of *Volvox* will not give such an effect as might be obtained, shall we say, with a smaller biomass of *Chlamydomonas*, and so on. Unfortunately, there is no way at present of differentiating between these different aspects of the problem, so we have to compare the fish yield with the total biomass and primary production of the phytoplankton regardless of the species composition of the latter.

Several methods have been used for making a quantitative estimate of the degree of development of phytoplankton. Among these the most widespread is the counting method, which is indispensable when it is necessary to follow the dynamics of the development of individual species. But material on the number of cells, or coenobia, does not enable us to compare the general development of phytoplankton of different species compositions. To overcome this difficulty we have to resort to computing the biomass from the total volume of cells. In this way we obtain values for the total biomass of phytoplankton which are at first sight quite comparable, irrespective of the species composition. To a certain extent this is the case, but even the figures for the biomass computed from the volume of cells are not free from many qualifications. The same biomasses of diatoms, say Protococcaceae, may differ in their content of dry or organic matter, caloricity, etc. - In spite of this there is some point in comparing the available material on the biomass of the plankton of fish ponds with the fish yield of those ponds.

On the basis of the results of an investigation of 69 fish ponds in Belorussia in June and July in 1958 and 1959 E. L. Chernyakova (1961) divided all the ponds examined into four categories according to the biomass of phytoplankton: I - those with a biomass of less than 1mg/litre (28% of the total number of ponds examined); II - those with a biomass of 1-10 mg/l (48%); III - those with a biomass of 10-100 mg/l (20%); IV - those with a biomass of over 100 mg/l (only two ponds). These data show that the ponds investigated are characterized by weak development of the phytoplankton. The data of V. P. Lyakhnovich and L. V. Prosyanik (1962) reproduced in Table 4 demonstrate this.

TABLE 4

Average sizes of the biomasses of phytoplankton during the growing season and the natural fish yield of ponds in Belorussia (after Lyakhnovich and Prosyanik, 1962).

1 Группа	2 Число прудов	3 Рыбопродуктивность, кг/га		Биомасса фитопланктона, г/м³ 6		7 Процент синезеленых от общей биомассы фитопланктона
		4 средняя	5 минимальная и максимальная	4 средняя	5 минимальная и максимальная	
I	16	150	100—200	9,5	1,4—23,8	22
II	8	235	200—300	39	3,0—159	76
III	9	375	300—400	118	5,5—276	68
IV	7	550	>500	207	6,4—433	80

KEY: (1) Group. (2) No. of ponds. (3) Fish yeild in kg/ha. (4) mean. (5) Minimum and maximum. (6) Biomass of phytoplankton in g/m³. (7) Number of blue-green as percentage of phytoplankton.

Without any attempt at selection the table includes all the final results of systematic studies of the ponds of Belorussian fish farms between 1950 and 1960. As we see, the ponds, which are /142/ grouped according to their natural fish yield, also clearly differ as to the mean biomass of phytoplankton for each group of ponds, determined from the average data of observations extending for the entire length of the growing season. The higher the fish yield, the higher the mean biomass of phytoplankton of the ponds of the corresponding group. Such strictly regular results can only be obtained on the basis of the mean data of systematic studies of a large number of ponds. The wide fluctuations in the mean biomasses for individual ponds, as reflected in the table, show that no clearcut connections can be expected between the development of the phytoplankton and the fish yield when we compare the results of a few observations.

Lyakhnovich and Prosyanik (1962) note that in Belorussia in recent years increasing eutrophication of fish ponds has been observed everywhere, and this is connected with the growing intensity of farming. Observations of the same ponds revealed that at the beginning of the fifties the biomass of phytoplankton in them was only 8-10 g/m^3 and over. Accordingly, the fish yield has risen from 150 to 600-800 kg/ha. From the data given in Table 4 Lyakhnovich and Prosyanik estimated how many kilograms of biomass of phytoplankton went to produce 1 kg of fish in the ponds of each of the four groups, and obtained the following figures: Group 1 - 0.63, Group II - 1.67, Group III - 3.15, Group IV - 3.76. The impression is created that when there is an increase in the biomass the effectiveness of the utilization of the primary production is reduced, but we should bear in mind that the aquatic vegetation was more strongly developed in ponds with poorly developed phytoplankton, and this vegetation could have served as an important /143/ source of primary production. It is interesting to note that if we exclude the blue-green algae from the biomass of phytoplankton we obtain for the ponds of all four groups a figure of 0.40-0.76 kg of phytoplankton per kg of fish yield.

It is still difficult to say how typical these figures relating the biomass of phytoplankton to the fish yield are. In particular we need data on the biomass of phytoplankton of ponds situated in the southern regions of the Soviet Union, where the figures should be higher. However, it is doubtful whether the mean even for the southern regions exceeds 500 mg/l.

As already noted, the biomasses of phytoplankton calculated from the volume of cells are very relative, depend on the methods of measuring the cells and making the computations, have different significance for different species compositions of the phytoplankton,and so on. It is preferable to express the biomass of phytoplankton directly in terms of dry weight, and even better to do so in terms of the dry weight of the ashless, i.e. organic, matter, since the food value and energy content of the cells of the phytoplankton depend primarily on the quantity of organic matter, which is formed as the result of photosynthesis (primary production) of the plankton.

Unfortunately, only in a few cases was the biomass of phytoplankton expressed in these units. Swingle and Smith (1939) and other papers in their celebrated investigations of the effectiveness of artificial fertilizers, came to the conclusion that there is a direct link in fertilized ponds between the degree of development of phytoplankton and the fish yield. This is clearly illustrated by the graph in Fig. 12, which was constructed from their data. Swingle and Smith consider that an effort should be made to maintain the development of phytoplankton in the ponds at a level of 15-30 mg of ashless matter per litre. They note that when the biomass is larger overvigorous development of phytoplankton may have adverse consequences. For example, they mention a case of suffocation of fish as the result of the decomposition of phytoplankton which had accumulated on the surface of ponds, the total

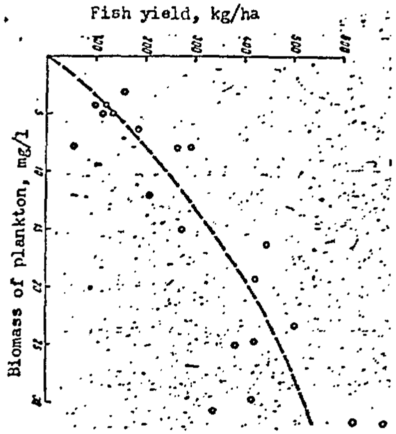

Fig. 12 - Link between mean biomass of phytoplankton of experimental ponds and their fish yield (based on data of Swingle and Smith, 1939).

biomass of this phytoplankton being 76.1 mg of ashless weight per litre.

Research on the ponds of Belorussia (Vinberg, Leshina and Vasil'eva, 1958) revealed that the total biomass of plankton can be estimated with almost sufficient accuracy from the bichromate oxidizability of seston collected on a membrane filter covered with powdered glass. Of course, this figure, like the ashless weight of "plankton" of Swingle and Smith, includes both detritus and zooplankton. However, in the unfertilized ponds with weak development of plankton the content of seston did not exceed 2-2.5 mg of ashless matter per litre, whereas in fertilized ponds it was much higher, reaching 14 mg/l. Hence, the difference in the bichromate oxidizability of seston in control and experimental ponds provides us, /144/ through this easy and simple method, with valuable information on the biomass of plankton in fertilized ponds, expressed in absolute units of weight or energy[1].

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[1] Let us remember that it is easy on the basis of the results of the bichromate oxidizability to express the content of seston in calories by using the oxycaloric coefficient 3-4 cal/mg of O. Having taken a specific value for the caloricity of the seston, e.g. 4.5 cal/mg of ashless matter, we can express the quantity of oxidized substance in mg of ashless matter also. To do this we must multiply the bichromate oxidizability, expressed in mg of O, by some coefficient, in our example 3.4/4.5 equals 0.75 mg of ashless weight/mg of O. Knowing the ash content, we can easily proceed from the ashless to the dry matter. Having allowed for a certain incompleteness of oxidation or organic substances during bichromate oxidations, such as was later verified by A. P. Ostapenya (1963), and for the ash content, G. G. Vinberg and his coauthors (1958) considered it permissible to assume for simplification of rough calculations that the bichromate oxidizability expressed in mg of O is numerically equal to the dry weight expressed in mg.

Finally, a particularly promising index of the biomass of phytoplankton is the content of chlorophyll, and more especially chlorophyll "a", in the plankton. On the basis of his own data and data in the literature, G. G. Vinberg (1960) made a study of the chlorophyll content in pond plankton. Here we shall merely /145/ cite the following conclusion drawn by Vinberg: "In the plankton of fish ponds with different natural yields of fish the content of chlorophyll usually ranges from 5-100 micrograms per litre, but during odd periods of vigorous development of the phytoplankton it may reach 500 micrograms per litre and over. It is clear that in ponds with highly productive phytoplankton such high levels may be maintained for a long time."

Since the biomass of phytoplankton can be expressed in different ways there is a need for conversion factors which could at least be used for rough comparisons of biomasses expressed in different units. This is difficult since, for example, the content of ashless matter in the wet weight of phytoplankton, found from the estimated volumes of cells, may vary widely. Furthermore, the content of chlorophyll in the dry matter of plankton also fluctuates, even if only within narrow limits, and so forth. Nevertheless, even approximate mean estimates are useful.

In hydrobiology it is usually assumed that the content of dry matter in the wet weight of plankton is 10%. In actual fact the content of dry matter in the wet weight of the cells of many algae, for example Protococcaceae, is much higher (20-30% and more). However, the biomass of phytoplankton estimated from the volume of the cells may deviate strongly from the true wet weight. Therefore there are inadequate grounds as yet for rejecting the conventionally accepted assumption that the dry weight of phytoplankton is 1/10th of the computed wet weight . The conditionality of the determination of the dry weight from the computed wet weight and the low content of ashes in all algae apart from diatoms mean that we can assume the dry weight equals the ashless weight when making rough calculations. The mean content of chlorophyll in the dry matter of planktonic algae can be assumed equal to 2.5%. The content of chlorophyll in seston, and not in the pure phytoplankton, fluctuates strongly, and it is usually much less than 2.5%, for example 1% or lower.

Bearing in mind these figures and other published data, we can, as a rough guide, note the following gradation of the degree of development of phytoplankton in fish ponds.(Table 5)

TABLE 5

Rough indices of the degree of development of phytoplankton.

Biomass	Computed wet weight, mg/l	Dry Weight mg/l	Chlorophyll content,g/l
Low......................	0.4-4	0.04-0.4	1-10
Medium...................	4-40	0.4-4	10-100
High.....................	40.400	4-40	100-1000
Very high................	400	40	1000

These figures are very tentative and particularly rough guide, useful only as an initial working basis, and they must be checked and corrected on specific material.

When fertilizing ponds one should strive for a "high", but not "very high", biomass of phytoplankton, since the latter would lead to less effective utilization of the primary production, and the consequences of overvigorous development of the phytoplankton might be deleterious.

/146/ The number of cells of the phytoplankton and its biomass, no matter how it is expressed, only convey the degree of development of the phytoplankton at any given time. These statistical values do not reflect the production of the phytoplankton directly, and without knowing this we cannot judge its functional role in the biotic cycle and the productivity of the pond. During the growing season the phytoplankton of a pond produces ten times more organic substances than its biomass contains at any one time, i.e. the production of the phytoplankton is ten times greater than its biomass. Therefore, to understand the mechanism of the initial effect and utilization of fertilizers it is extremely important to know not only the biomass of the phytoplankton but also its production , on the basis of which the food supply of ponds and, ultimately, their fish yield is created.

The phytoplankton production is formed in the process of photosynthesis. Therefore, to determine the magnitude of the primary production we must measure the intensity of photosynthesis of the plankton. This is usually done with the aid of the so-called bottle method. Darkened and undarkened bottles are filled with the water to be tested, which contains a given amount of oxygen. These bottles are placed for a certain period, normally twenty-four hours, in a body of water, where they are in natural conditions of temp-

erature and light. After exposure the content of oxygen in the water of the bottles is measured. The drop in the oxygen content of the darkened bottle during the period of exposure indicates the rate of expenditure of oxygen on the respiration of bacteria, phyto- and zooplankton, i.e. the rate of respiration, and hence destruction, of organic substances (D). The difference between the content of oxygen in the light and dark bottles after their exposure is proportional to the true photosynthesis, or gross primary production (F), whereas the difference as against the initial oxygen content in the light bottle is proportional to the apparent photosynthesis, or the *net* primary production (F - D). With the aid of factors derived from the equation describing the photosynthetic balance /147/
($6CO_2 + 6H_2O = C_6H_{12}O_6 - 674$ kcal/mol),
and the coefficients of respiration and photosynthesis, quantities F and D, which were initially expressed in units of oxygen, can be expressed in calories, for example by multiplying them by the oxy-caloric coefficient 3.4 cal/mg of O, or in conventional organic matter ("glucose"), or in organic carbon, and so on.

The bottle method, starting with the first observations in 1932 of ~~Lake~~ Beloe Ozero in Kosino, was used initially by G. G. Vinberg and later by other authors for determination of the primary production of the plankton of lakes, but by 1934 it was being used by V. S. Ivlev (1939) for observation of the primary production of the experimental ponds of Mosrybvtuz, and then in 1935 by Vinberg (1937) in connection with ponds fertilized with superphosphate and unfertilized ponds on Obiralov (Savvin) fish farm in Moscow oblast. Since then this method has been employed by many authors for the study of ponds (Baranov, 1948), (Vinetskaya, 1953a, 1953b, 1956; Baslavksaya and Rusina, 1950; Vinberg and Shchelkanova, 1953; Vinberg, Leshina and Vasil'eva, 1958; Matida, 1953; Ishimura, 1954). The main results of these papers are examined in the book by G. Vinberg (1960), where it is shown that there is a close link between the primary production of the plankton and the fish yield of ponds. Papers published later (Matisone, 1961; Lyakhnovich, Surinovich and Kazanova, 1961; Wrobel, 1962a) confirmed this on new material.

There is every reason for considering that the application of the technically simple, easy, yet accurate bottle method is "the most direct way of determining the initial effect of artificial fertilizer" (Vinberg, 1937). A similar conclusion was reached by Wrobel (1962a), who used different methods of assessing the effect of fertilizers and estimating the productivity of ponds in his experiments in Poland.

He wrote: "The most suitable method of estimating the effect of fertilizers and the productivity of the ponds proved to be measurement of the primary production of the phytoplankton with the light and dark bottles". Even single measurements by this method, made at the right time, often give a clear idea of the initial effect of fertilization. Such a case is illustrated in Fig. 13 on the basis of the results of measurements of the photosynthesis of plankton in experimental ponds of the "Shemetovo" fish farm fertilized with different doses of nitrogen-phosphorus fertilizers. No less illustrative are the data obtained by V. P. Lyakhnovich and his colleagues (1961) on investigating collective farm and state farm ponds in Belorussia in July 1958 and 1959. Only one examination was made of each of the 56 ponds. From the results of these observations the ponds were divided into four groups according to the level of primary production. It was found that the fish yields of the ponds in the different groups also differed accordingly. (TABLE 6)

TABLE 6

Primary production of plankton and natural fish yield in ponds of collective and state farms in Belorussia.
(after Lyakhnovich and Kazanova, 1961).

Group	No. of ponds	Gross primary production of plankton (F), mg O/1·days	F:D	Fish yield of ponds, kg/ha.
I	8	1	1.2	50-70
II	23	1 - 3	1.4	80-85
III	14	3 - 10	2.1	100-120
IV	11	10 - 22	6.9	250-300

From the data in Table 6 we can see that, when the gross production of plankton (F) grows, the ratio of production to destruction (F:D) also increases. This means that when production is low the net production of the plankton is particularly small, while at high values of F, which are generally achieved when blue-green algae develop, since they are hard to consume, a considerable part of the production is realized in the form of net production (increment) of plankton. High values of F:D signify a smaller degree of utilization of the gross primary production. This accords well with the fact that, according to the figures in Table 6, the boundary values for the gross production differ by a factor of more than 20, while the range of the net production is even wider, yet the boundary values of the fish yield differ only by a factor of 6.

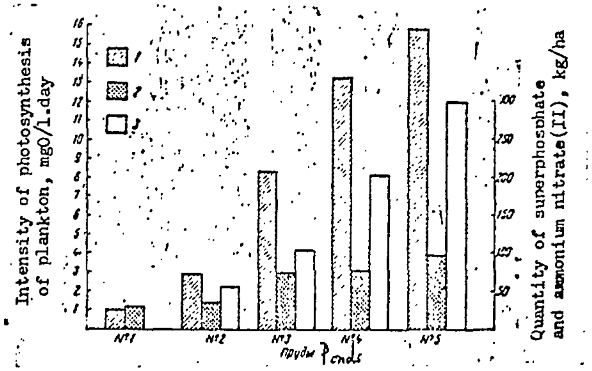

Fig. 13 – The intensity of photosynthesis (1) and respiration (2) of plankton and the quantity of fertilizers added (3) in five experimental ponds on "Shemetovo" farm. (After Vinberg and Kishchenko, 1958).

Having examined the data published prior to 1959 on the primary production of ponds, G. G. Vinberg (1960) came to the conclusion that "in ponds of different yields the mean seasonal values of F (gross primary production of plankton) usually lie between 0.5 and 5 g O/m^2·days". When the season in the nursery ponds lasts for 100 days the corresponding values will be "50-500 gO/m^2 or 175-1750 kcal/m^2 for the breeding season." Let us note that it appears that the largest values for the gross primary production in the most productive ponds may be much higher than the upper limit indicated, /149/ possibly rising to 2500 kcal and more per season, which, however, has not yet been confirmed by observations.

To be able to compare the primary production with the fish yield Vinberg determined from the intensity of exchange of the fish the total energy of the food assimilated (not consumed) by the fish during the entire breeding season in the nursery ponds and found that the figure was three times greater than the content of energy in the bodies of the harvested fish[1].

[1] In the finishing ponds, when the relative growth rate is slower rather more must be expended on exchange, and it would evidently be more correct to take a factor of 4 in this case.

Having set the limits of natural productivity at 50-500kg/ha, equivalent to 5-50 kcal/m^2, which corresponds to an expenditure of energy of 15-150 kcal/m^2 per season, Vinberg compared these figures with the limits given above for the gross primary production of the ponds (175-1750 kcal/m^2) and came to the conclusion that "in ponds, the expenditure of energy by the fish is about 8% of the energy of gross primary production." He adds that "this is only a rough mean figure and larger deviations must be expected from individual ponds."

Of great interest are the results of the systematic observations of V. P. Lyakhnovich on the primary production of seven experimental finishing ponds on the "Izobelino" fish farm. These ponds were fertilized with various doses of nitrogen-phosphorus fertilizers. Using the bottle method the author established that both the primary production of the phytoplankton and the fish yield of the ponds were directly linked to the doses of fertilizer (Fig. 14). From these data, using the method of least squares, he computed the equation of the straight line best conveying the position of the empirical points:

$$y = 271 \& 123x,$$

where y is the fish yield in kg/ha and x is the mean seasonal gross /150/
primary production expressed in g O/m^2 per day.

Bearing in mind that the season lasted for 177 days, we find that 123 kg/ha of fish per g O/m^2 corresponds, given the figures used in the calculation above[1], to a utilization by the fish of 6.1% of the gross primary production of plankton. If, for the finishing ponds, we assume that the total expenditure of energy during the growth of the fish is not three, but four times greater than the content of energy in the bodies of the harvested fish, we obtain a

figure of 8.2%.

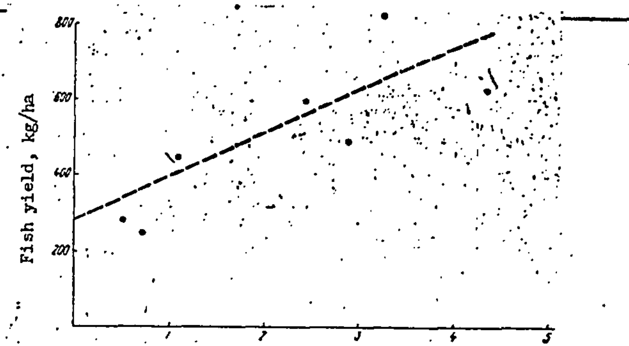

Fig. 14. - The mean intensity of photosynthesis of the plankton in relation to the fish yield in the experimental ponds of "Izobelino" fish farm. (after Lyakhnovich).

The fact that the computed curve did not start near the origin of the coordinates, but showed instead that for zero primary production the fish yield was 271 kg/ha, is apparently not accidental. In the ponds used for control purposes intensive feeding was practised in the preceding years and only ceased in the year the observations were made (1961). Under these conditions it is reasonable to assume that part of the fish yield was formed on the basis of the use of organic substances already present in the ponds. This part of the fish yield /151/
must actually have been less than 271 kg/ha, since the real relationship between the fish yield of the ponds and the primary production was probably not linear.

There is insufficient data as yet for us to judge what kind of a relationship between the energy of primary production and the energy expenditure on fish production must be regarded as best, but it is

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[1] 1 kg of fish = 1,000 kcal, 123 kg/ha = 123,00 kcal/ha. 1 g O/m^2 = 3.4 kcal/m^2 = 34,00 kcal/ha. This is during twenty-four hours, but for 177 days the figure is 6,018,000 kcal/ha. The expenditure of energy by the fish is 3 X 123 = 369,000 kcal/ha.
Hence $\frac{369 \times 100}{6,018} = 6\%$.

quite certain that this relationship concerns the main principles underlying the action of fertilizers and therfore merits special study. The ratio between primary production and the fish yield is an objective quantitative index of the efficiency with which the primary production is used, and it can be employed as a basis for determining the optimum doses and regularity of application of fertilizers. Therefore, to simplify evaluation of the values obtained in the experiment it would be sensible to determine the maximum value of the ratio of the fish yield to the primary production of plankton, which will only be attained under ideal conditions. The maximum utilization of the primary production will occur when it is fully consumed by the food organisms, and when, in turn, the entire production of these plant-eating food organisms is consumed without any waste by the fish. In conditions favourable for the development of phytoplankton, 10-15% of the gross primary production (true photosynthesis) will be expended on average per day on the respiration of the phytoplankton, and the effective production or increase in the biomass of phytoplankton will at best be equal to 90% of the gross production.[1]

At a given level of primary production the production of the food organisms* will be higher the greater the assimilability of the food $\left(\frac{1}{I}\right)$ and the greater the coefficient of utilization of the assimilated food for growth (K_2)[2]. Given a very high assimilability of $\frac{1}{I} = 0.90$ and a high value of $K_2 = 0.40$, we find that of the consumed food, i.e. of the effective primary production, 36% ($K_1 = K_2 \times I = 0.40 \times 0.90 = 0.36$) is used on the growth (production) of the food organisms. Earlier it was assumed that the effective primary production was 90% of the gross primary production, in which case the production of the food organisms will be 0.90×0.36, i.e. 32% of the gross primary production of the plankton.

Given that the fish also assimilate 90% ($1/I = 0.9$ of the natural foods, and assuming that they consume all of the production of the food organisms, we find that all the energy of the assimilated part of the food, i.e. the total energy expended by the fish on exchange and gain, equals $0.9 \times 32\% = 28\%$ of the gross primary production of the plankton.

There is no need to prove that the real values of the ratio of the energy of the primary production of the plankton to the energy expended by the fish must be smaller than those computed for the optimum and ideal conditions of maximum values. In actual fact, not all of the primary production is consumed by the food organisms. In addition to the fish yield there are other processes in which the primary production is used up, for example those which result in the departure from the pond of chironomids and other heterotopic insects. Furthermore, not all the food organisms are vegetarian. Bearing all

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[1] Here we are talking about the respiration and effective production of phytoplankton, and not the respiration (D) and net production (P-D) of the plankton as a whole, which can only be determined with the aid of the bottle method. The respiration of the phytoplankton is not determined directly by the bottle method and, as a rule, it represents only a small part of the respiration of the plankton as a whole (D).

[2] The coefficient of the utilization of assimilated food for growth is $K_2 = P:(P+T)$, where P is the increment and T the expenditure on exchange, expressed in cal. per unit of time or in other equivalent values. The coefficient of the utilization of consumed food for growth is $K_1 = P:R$, where R is the ratio expressed in the same units as P. $R = N+P+T = I(P+T)$, N being the unassimilated part of the food. I, like K_1 and K_2, is a dimensionless coefficient. It is easy to see that $K_1 = \frac{1}{I} K_2$ or $K_2 = IK_1$. We obtain K_1 by taking the reciprocal of $\frac{1}{I}$ the food coefficient multiplied by the ratio of the caloricity of the food to the caloricity of the increment (the caloricity is the number of calories per unit of weight).

*i.e organisms which serve as food for other organisms

Footnote 2 — p. 260

this in mind, the figures cited above, which were obtained during the first attempts to compare the primary production of ponds with their fish yield, may even be regarded as too high. It should be noted, however, that as the result of many years of piscicultural practice conditions have been established in the pond which ensure intensive use of the yield of food organisms by fish. The results of comparisons between the primary production and the fish yield create the impression that the production of phytoplankton is also efficiently utilized by the food organisms. Further research is necessary in this direction to determine the relationship between the initial and final effect of fertilization and the conditions under which this relationship is optimum, i.e. ensure that they are used with the greatest efficiency.

/153/

CHAPTER IV

ORGANIC FERTILIZATION OF PONDS

1. Introduction

The term "organic fertilization" can be used of any method which uses organic substances to enrich the habitat of hydrobionts with nutritive substances and increase the yield of fish. Many forms of organic fertilizer were being used on bodies of water long before the application of artificial fertilizing salts, by analogy with fertilization practices in agriculture.

In practice the following forms of organic fertilizer are being used for ponds: manure, compost and other organic substances, green fertilizer in the form of fresh plants added to the ponds, obtained either from the ponds themselves or from outside them, the sowing of the bottom with land plants followed by submersion of the greenery of the culture, the breeding of waterfowl on ponds, and household and certain industrial waste waters.

Undoubtedly a large role is also being played by artificial seeds of vegetable origin which are not utilized by fish, particularly when they are cut up very small. This means primarily cake and oil-seed meal, which are the most widely used items for feeding fish in the Soviet Union. To what extent these foods are directly consumed by the fish, and what part of them serves as fertilizer, is as yet uncertain. This complex problem merits careful and special investigation, but only the first few steps have been taken in this direction (De Bont, 1952; Lobacheva, 1959; Kirpichnikov, 1960; Lyakhnovich, 1962).

Some authors (Wlodek, 1956) consider it possible to link organic fertilization with such measures as the harrowing of the bottoms of ponds or loosening the bottom sediments. This would be an unwarranted extension of the concept of "organic fertilization" and render it less specific.

It is incomparably more difficult to assess the role of organic fertilizers in ponds and understand the mechanism of their effect than to have to deal with artificial fertilizers, because organic fertilizers are themselves mixtures of complex compounds, and their addition to the pond produces a series of secondary and sometimes undesirable biochemical and physical processes which complicate understanding of the effect of /154/ organic fertilizers. After finding its way into the body of water organic fertilizer can either decompose to form mineral compounds of the nutritive elements, which will then act on a level with artificial fertilizer as the nutritive substances of autotrophic plants, or be immediately consumed by the detritus-eating forms of small aquatic animals, i.e. be used directly by heterotrophic organisms. An intermediate case would be the utilization of organic fertilizers in the heterotrophic phase of conversions through the bacterial link. It is a well-known fact that many freshwater invertebrates consume bacteria.

Finally, part of the dissolved organic matter of the fertilizer may be assimilated by algae and thus be used in the first link of the chain without preliminary mineralization.

But organic fertilizers also have their drawbacks, and unless we keep these in sight we shall derive not benefit but harm from their use in fish breeding. In the first place we must mention the increase in the biochemical consumption of oxygen for bacterial oxidation of organic substances. This means that the addition of a large quantity of organic matter to a pond may sometimes cause such a large drop in the content of dissolved oxygen in the water that the fish suffocate. So far organic fertilizers have only affected the oxygen regime of ponds when applied in large doses.

2. Manure

Manure is one of the most widely used forms of organic fertilizer. The quality of the manure and its composition depend to a large degree on the species of animals, the quality of the foods, and the quantity and type of bedding, its chemical and physical properties, and the methods used to store the manure. Referring to analyses conducted at the All-Union Research Institute for Fertilizers, Agricultural Practices and Agropedology, and other institutions, I.P. Mamchenkov (1955) gives the following sample composition of fresh manure (Table 7).

Table 7

Percentage composition of fresh manure

1 Составные части	16 Навоз на соломенной подстилке					22 Навоз на торфяной подстилке	
	17 смешанный	18 конский	19 крупного рогатого скота	20 овец	21 свиной	23 конский	24 крупного рогатого скота
2 Вода	75,0	71,3	77,3	61,6	72,4	67,0	77,5
3 Органическое вещество	21,0	25,4	20,3	31,8	25,0	—	—
4 Азот (N)							
5 общий	0,50	0,58	0,45	0,83	0,45	0,60	0,60
6 белковый	0,31	0,35	0,28	—	—	0,48	0,38
7 аммиачный	0,15	0,19	0,14	—	0,20	0,28	0,18
8 Фосфор (P_2O_5)	0,25	0,23	0,23	0,23	0,19	0,25	0,22
9 Калий (K_2O)	0,60	0,63	0,50	0,67	0,60	0,53	0,48
10 Кальций (CaO)	0,35	0,21	0,40	0,33	0,18	0,44	0,45
11 Магний (MgO)	0,15	0,14	0,11	0,18	0,09	—	—
12 Сера (SO_3)	0,10	0,07	0,06	0,15	0,08	—	—
13 Хлор (Cl)	—	0,04	0,10	0,17	0,17	—	—
14 Кремний (SiO_2)	—	1,77	0,85	1,47	1,08	—	—
15 Окись железа и алюминия (R_2O_3)	—	0,11	0,05	0,24	0,07	—	—

Key: 1. Constituents. 2. Water. 3. Organic matter. 4. Nitrogen (N): 5. total, 6. albuminous, 7. ammoniacal. 8. Phosphorus (P_2O_5). 9. Potassium (K_2O). 10. Calcium (CaO). 11. Magnesium (MgO). 12. Sulphur (SO_3). 13. Chlorine (Cl). 14. Silicon (SiO_2). 15. Iron and aluminum oxide (R_2O_3). 16. Manure on straw bedding. 17. Mixed. 18. Horse's. 19. Cattle's 20. Sheep's. 21. Pig's. 22. Manure on peat bedding. 23. Horse's. 24. Cattle's.

V.A. Movchan (1948), in his experiments in complex intensification of the growth of carp, made extensive use of manure and obtained a positive result, reflected in a rise in fish production from 50 to 205% compared with unfertilized ponds. This author recommends adding manure in several applications throughout the growing season, placing it in small heaps along the banks of the pond. In Morchan's experiments 18-70 units by weight of fresh organic fertilizer in the form of manure, compost and liquid manure were expended per unit of growth of fish /155/ production (compared with the control pond).

Wunder (1949) emphasizes that an important prerequisite for the effectiveness of manure is the absence from the ponds of rigid plant overgrowth.

Wolny (1956b) mentions that manure must be added in quantities of 20-30 t/ha, being distributed in small heaps over the bottom. The manure is capable of increasing the fish yield by 100%. Liquid manure is more effective than ordinary manure in increasing the food supply of the fish.

Summarizing the rich experience in the use of manure in pond-fish culture in Czechoslovakia, Dyk, Podubsky and Stedronsky (1956) note that the manure must be added to the ponds immediately before filling and thereafter be poured into the water at intervals of one month. The manure must be placed in heaps projecting above the surface of the water, in shallow well-heated places. The authors assert that the amount of ordinary or liquid manure used must be determined according to the productivity of the pond, to the content of humus in the soil, and to the type of fertilizer employed, but they do not give specific recommendations on this point. Eight to fourteen centners of manure are added per hectare of pond surface, which gives an increase in fish yield of 80-150 kg/ha. In such case one unit of additional /156/ growth in yield would require the application of 10 units by weight of manure, and this seems unlikely. In the view of these authors, the application of manure is an necessary prerequisite if artificial fertilizers are to be effective. However, the results of numerous experiments show that artificial fertilizers are found to be effective even when organic fertilizers are not added first. It appears that when organic and artificial fertilizers are used correctly they will have an added effect.

In the experiments of Havlena (1956) in the fertilization of ponds with pig's manure using doses of 18-100 centner per hectare, the fish yield was raised by 31-417 kg/ha, or 9-167%. On average the increase in fish yield per centner of fertilizer used was about 2.5-3 kg. In fertilized ponds mass development of the blue-green alga Aphanizomenon flos-aquae was observed, the biomass of which in individual cases was 300 kg of dry matter per hectare. The author came to the conclusion that the best dose was 50 centners of manure per hectare, and best method of application to distribute the manure in heaps in the water. Economic calculations show that the use of pig's manure for fertilization of ponds not only pays for itself but even increases the profitability of the farm.

Similar calculations, but on more extensive material taken from various authors, were made by Susta (1953), who showed that the use of manure for the fertilization of ponds is economically profitable.

An original method of applying manures was devised by Woynarovich (1956a, 1956b, 1956c, 1957). In his view organic fertilizer added to a body of water must be oxidized as soon as possible in the aerobic conditions of the water to molecular carbon dioxide, and if possible it should not settle on the bottom of the pond, where little oxygen is available and anaerobic conditions are easily created. To this end the author recommends mixing the manure with water (1 m^3 of water to 1 centner of

fresh pig's manure) and spraying the liquid manure thus formed over the surface of the pond with a motor-pump and hose. In this way the bulk of the manure decomposes within 24 hours. The author recommends adding 2 centners of fresh manure per hectare every week, and 3-4 centners per hectare at a time during the warmest part of the summer. At the beginning of August fertilization must cease. According to the observations of Woynarovich this method of adding fertilizer obviates the danger of the occurrence of an acute oxygen deficit, which with other methods frequently prevents an increase in the dosage. This method of applying manure so that the fertilizing substances are rapidly included in the biotic cycle merits serious attention.

Woynarovich calls his method "carbon fertilization". /157/ He considers that the main point in using manure is to enrich the water with carbon dioxide. In his view the carbon added in the manure improves the conditions of carbonate nutrition of plankton, and it is this that he regards as the main point of organic fertilization. By way of proof in support of his theory he cites the well-known formula for the combination of carbon dioxide gas and organic matter during photosynthesis and emphasizes that one centner of pig's manure contains eight kilograms of pure carbon. Since other nutritive elements such as nitrogen, phosphorus, potassium and calcium are present in smaller quantities in the manure Woynarovich considers the idea that organic fertilizer is a supplier of these nutritive elements to be outmoded.

It is impossible to agree with this. In actual fact, the enrichment of the medium with carbon dioxide does under certain conditions hasten the growth of algae, as has been repeatedly demonstrated in experimental conditions, but if we assume the carbon is the principal factor limiting the production process in the pond it is impossible to explain the great effect of the use of artificial nitrogen and phosphorus fertilizers. Also we should not forget that combined mineral carbon in the form of bicarbonate ions (HCO_3') readily available for photosynthetic assimilation are always present in natural water in large quantities, whereas the content of mineral nitrogen and phosphorus in the water often drops to analytical zero. Assuming the mean alkalinity of the pond water to be 2 mg-equ., this gives 122 mg of HCO_3' per litre, and for a mean pond depth of 1 metre we have 1220 kg/ha. Converting to mineral carbon, we obtain 240 kg/ha of carbon, which is thirty times more than in one centner of pig's manure. The alkalinity of pond water is often greater than 2 mg-equ., and furthermore it contains the carbon of dissolved carbon dioxide, so that it is hardly likely that "carbon starvation" of phytoplankton will occur in fish ponds under normal conditions.

The great importance of carbon dioxide for the liming of ponds has been noted in the papers of Müller (see section on liming), but this in no way tallies with the theoretical views of Woynarovich on "carbon fertilization".

The times recommended by various authors for adding manure to ponds can be grouped as follows:

a single application of the entire quantity of fertilizer prior to the filling of the pond;

Repeated applications of manure in individual portions throughout the entire growing season or some part of it.

A generalization of accumulated experience inclines us to the conclusion that the fertilizers can be added to the ponds repeatedly in small portions. Although this means more work and material, the results obtained are far better than with /158/ a single application.

As regards methods of adding manures, these differ greatly. For a single application of manure before the filling of the pond some authors recommend spreading the manure evenly over the entire bottom, others say work it in to a certain depth. Some authors consider that the manure should be placed in small heaps, distributed evenly all over the bottom and then sprinkled with soil.

There is an even greater variety of recommendations on the addition of manure to filled ponds. In practive the following methods are most commonly employed: distribution of the manure in small heaps in the vicinity of the bank along the water's edge; laying the manure behind the barriers separating the dikes of the ponds from the pounding of the waves; distribution of heaps of manure all over the pond or at its shallower points, so that part of the heaps projects above the surface of the water; mixing the manure with water and spraying the mixture over the pond. The last method is also used when the bottom of the pond is fertilized prior to filling.

The choice of dosage and method of fertilization is governed by the particular features of the farm in question. In all cases, however, certain general principles and procedures and must be observed. Thus, the fertilizer must be spread evenly over the entire area of the pond suitable for fertilizing. It is no less important that organic fertilizer should not reduce the content of oxygen in the water to a critical level. Finally, the method of fertilization must be technically progressive. In the light of these considerations the technique devised by Woynarovich is the most suitable for adding manure, liquid manure and other forms of organic fertilizer which lend themselves to dissolution in or dilution by water.

In the conditions of the Non-Chernozem Belt, where manure is used extensively for fertilizing field and garden crops, it has limited application for the fertilization of ponds. Hence the pond-fish culturist is faced with the task of finding and using other forms of organic fetilizer. One possibility is vegetable compost, which can be prepared on any farm from higher aquatic plants, which grow abundantly in the shallows. The plants, having been prepared in the water or out of it, are placed in compost heaps in a mixture with manure, liquid manure and lime. The matured compost is used for fertilizing ponds equally with manure. In its effectiveness and the technique of its application the mature compost is practically the same as manure. The technique of preparing compost is described in all textbooks on pond-fish culture (Martyshev, 1954; Kononov and Prosyany, 1949; Dyk, Podubsky, Štedronský, 1956; Vaclavik, 1957; Gurzeda, 1956). /159/

In the experiments of Štedronský (1954a) in Czechoslovakia, 1 centner of mature compost raised the fish yield of a carp pond by 15-20 kg. Štedronský considers that compost yields the best results in ponds in which the bottom sediments are poor in organic matter. In some cases fertilization with compost produces better results than the application of manure in the same quantities. From the viewpoint of hygiene and sanitation, compost is superior to manure for pond fertilization.

However, the preparation of compost involves a greater expenditure of labour. Therefore composts have been prepared and used in limited quantities on pond-fish farms, particularly after it was shown that aquatic plants (the main material for the preparation of composts) can be used successfully in ponds as green fertilizer.

3. Green Fertilizers

There are at least two basically different forms of green pond fertilizer. The first is the analogue of green manuring in agriculture and has been taken from horticulture. It involves sowing the bottom of the pond with farm crops of grasses after the bottom has been suitably prepared. At the present time this form of green fertilization is limited mainly to nursery ponds, since the finishing ponds, when not allowed to aestivate, are used for fish breeding throughout the entire growing season. In addition to this, the finishing ponds in many parts of the Soviet Union are not always drained sufficiently, even in the aestivation period, for land plants to be sown.

When the bottom of the pond has been sown with farm crops and the latter have been covered with water, the green fertilizer acts on the pond as follows.

1. The cultivated plant mass enriches the pond with organic matter.

2. After the sowing of leguminous plants the rhizobia living in symbiosis with them accumulate nitrogen, thereby increasing the stocks of nitrogen in the bottom in accessible forms.

3. The plant roots, penetrating deep into the ground, assimilate nutritive substances and convey them to the surface from the deep layers of soil. This process is especially important for fish ponds because the reserves of nutritive elements in the bottom sediments of ponds are extremely large.

4. Preparation of the bottom of the pond before sowing /160/ hastens the processes of mineralization of the organic matter in the bottom sediments and promotes the liberation of nutritive substances from them.

In practice part of the crop is usually removed and only comparatively rarely is the entire crop grown covered with water, particularly when the bottom of the pond has been sown all over, since there is a danger that the fish will suffocate as the result of vigorous decomposition of the vast mass of plants.

Research on green fertilizer has been conducted since 1954 at the Institute of Hydrobiology of the Polish Academy of Sciences. They are studying the effectiveness of sowing

carp ponds with a mixture of winter crops. Ploughing in of the after-harvest remains before filling the ponds failed to produce a beneficial result. When the plants were cut at the filling level of the ponds (60 cm) and the after-harvest remains were inundated without ploghing in, abundant development of zooplankton was observed and the fish yield increased by 45% compared with the control ponds (Jasinski, Klimczyk, Rosol, 1957).

The inadvisability of turning in the green mass of the crop is also commented on by Wlodek (1957, 1958). The author conducted a series of experiments on the ponds of an experimental pond farm in Zabieniec (near Warsaw) in order to determine the maximum quantity of greenery which could be inundated without risk of suffocation of the fish. It was found that a green mass of rye or a mixture of winter rye and vetch in quantities of 75 centn/ha inundated during the blooming stage does not cause a dangerous oxygen deficiency in ponds and that green fertilizer in the form of the inundated crop yields better results than manure added to the pond in the same quantities.

Most contemporary authors recommend sowing the bottom of the pond not with one crop but with a mixture, which must include leguminous plants, which help to enrich the pond with nitrogen to a greater extent than other plants. The crops in the mixture must be selected with an eye to their rate of decomposition after filling of the pond, so that both rapidly and slowly decomposing species of plants should be included. As a result the process of decomposition will be extended over a longer period, there will be less danger of suffocation, and the fertilizing effect of the inundated crops will be more lasting. In the Soviet Union the most widely used crop in a mixture of vetch and oats. In other countries various mixtures of both spring and winter crops are used (Lane, 1957a).

On the whole the work done on this problem confirms the conclusions arrived at in his time by A.A. Khomchuk (1948). His studies of the effectiveness of sowing the bottom of the /161/ pond with green fertilizer, which were conducted on the ponds of the Lenin fish farm near Moscow and on ponds in the Ukraine, remain the most complete and thorough which have ever been done. In his experiments in ponds in which a mixture of vetch and oats was sown on the bottom before filling, the food organisms of the plankton and benthos used by the fish were observed to develop abundantly. Particularly numerous were larvae of chironomids on the decomposing plants of the vetch-oats mixture. The fish yield of the ponds fertilized in this way rose on average by 63% compared with the control ponds.

The second form of green fertilization was based on the use of banks of macrophytes cut from ponds. In this case the green mass is used on a smaller scale and it is prepared outside the ponds. Many authors consider that only the so-called "soft plants" and grasses are suitable for the fertilization of ponds. However, the experiments of S.I. Kuznetsov and G.S. Karzinkina (1955) on the spawning and nursery ponds of the Volga delta showed that "hard plants" can also be used effectively, especially if they are cut before blooming and fruit-bearing, i.e. before the stems of the plants have had

time to lignify. The authors recommend cutting the hard plants in comparatively small areas and leaving uncut strips between these areas to prevent removal of the plants by the wind and the formation of large accumulations of the plants, which might have an adverse effect on the oxygen regime of the pond. Thus, we eliminate the very laborious task of collecting the cut plants and securing them in specific places in the pond.

The *littoral* aquatic plants in the ponds develop very intensively and yield a great quantity of greenery. S. Dorokhov (1958) states that for 1 hectare of water area the biomass of the overgrowth may amount to 40-60 tons/metric tons – translator/ of water thyme (Elodea), 50-90 tons of hornwort (Ceratophyllum sp.), up to 50 tons of pondweed (Potomageton sp.), and up to 120 tons of ivy-leaved duckweed (N. trisulca). Control of the growth by cutting (2-3 times during the growing season) permits the preparation of a vast quantity of greenery which can be used successfully for fertilization. According to the data of S. Dorokhov, 1 ton of freshly cut sedge, rushes and reeds contains roughly the following quantity of substances: 32 kg of nitrogenous substances, 126 kg of non-nitrogenous extractive substances, 109 kg of cellular tissue, 2.16 kg of calcium, and 0.86 kg of phosphorus.

V.M. Il'in (1955) recommends securing cut plants, rolled into cylinders or loosely bound in sheaves, under water with poles or stakes so that the cylinders or sheaves are 20-30 cm short of the bottom and the layer of water above is no deeper than 10-15 cm. It is inadvisable to deposit freshly cut /162/ macrophytes in large heaps of compost straight in the ponds since under anaerobic conditons they undergo lactic fermentation and the lactic acid preserves them for a long time. Il'in considers that cut plants should under no circumstances be allowed to float free on the surface of the pond, since they block out the light and may impair the oxygen regime. It was noted earlier that other methods of securing the plants in the pond are also possible. Il'in, A.N. Lipin, V.I. Bakhtina et alia (1956), on the strength of experiments in the fertilization of experimental carp ponds with plants at the Savvin fish nursery near Moscow, calculated that the addition of aquatic plants in quantities of 3-6 tons per hectare ensures a rise in the fish yield of 200-300 kg/ha. But these figures raise doubts. It is improbable that, according to these calculations, every 15-20 kg of aquatic plants should increase the yield by 1 kg. The authors could only have arrived at this figure as the result of a clearly understimated yield from the control pond. If we compare not the computed figure but the actual figure for the fish yield of the control pond, we find that the fertilization factor (the expenditure of fertilizer per kg of increase in the fish yield) of the aquatic plants was 37.5 (Il'in, Bakhtina et alia, 1956; Il'in, Lipin et alia, 1956). The authors recommend adding aquatic plants in small amounts 10-12 times in the course of the summer, making sure to submerge them to a depth of 10-15 cm, or, tying them up in bundles, to secure them to the bottom with stakes.

The workers of the State Lake and River Fisheries Research Institute, aiming to determine the effect of various organic fetilizers on the devolopment of the forms making up the food supply of the fish, staged a series of experiments in tanks and in the commercial ponds of the Sokolov fish farm (Valdai hill), at the Pelchi fish factory in Latvia and Salmi in the Karelian ASSR (Ioffe, 1950, 1954, 1957; Ioffe, Yandovskaya, Galkin, Mosevich et alia, 1955). In the experiments of these authors the addition of manure led to intensive development of Daphnia and Diaphanosoma; fertilization with birch branches stimulated the development of Bosmina; fertilization with sedge produced abundant development of Diaptomus . In these experiments manure and birch branches induced abundant development of oligochaetes, whereas fertilization with sedge intensified the devolpment of chironomids. The repeated addition of small portions of fertilizer to the ponds made possible a substantial increase in the fish yield. In individual cases the yield was increased to 170 kg/ha and was 6-7 times greater than in the control pond (young salmon being bred).

M.M. Isakova-Keo (1947, 1950) suggested the so-called /163/ zonal method of fertilization, which is based entirely on the use of green fertilizer. In this method the sun-dried or fresh green vegetation, obtained either from the same body of water or from elsewhere (weeds, branches of deciduous trees, hay, and so), is placed in layers along the bank, 1-4 metres wide and 20-30 cm thick, so that water is above and below the layer. The authors recommends that each deposit of fertilizer should occupy one third of the length of the bank of the pond, and that the fertilizer should be added three times a season, being placed in a new place every time. Thus, by the end of the summer the entire periphery of the pond will be covered by zonal fertilization (Isakova-Keo, 1950). Since loose layers of vegetation near open banks may be broken up by the pounding of waves, Isakova-Keo recommends making the ponds a special shape, with narrow extended inlets, branches, and so forth. It is suggested that the time for the addition of the next batch of fertilizer can be estimated from the degree of oxidizability of the water, determined at a distance of one metre from the zone of fertilization. If the level is lower than 12 mg O/1 this means that it is time to fertilize again. Isakova-Keo tested her method on the ponds of the "Ropsha" experimental farm near Leningrad and on the ponds of the Prozersk fish breeding establishment on the Karelian isthmus, in which trout, carp, salmon, sturgeon and other fishes were being bred (Isakova-Keo, 1950, 1954, 1957). The dimensions of the ponds were 0.012-0.4 hectares, and only in one case was a larger pond (1.5 ha)fertilized by the zonal method, and this one the outhor considered large. In small ponds the method proved fairly effective. The fish in the fertilized ponds grew better and the fish yield was larger than in the same ponds prior to fertilization. However, on really large ponds with an area of several tens of hectares or more than 100 ha it is much more difficult to use the zonal method, and its effectiveness in such cases is probably weak. In the first place pounding by waves is inevitable in large ponds, and

this destroys the "zone of fertilization", and in the second place when the banks are hundreds and thousands of metres apart the narrow strip of fertilizer along the bank is hardly likely to have a serious effect on the yield of the pond as a whole.

As one of the elements in integrated fertilization, aquatic plants were used with success in the experiments conducted by the Zoological Institute of the Academy of Sciences of the Soviet Union, under the supervision of V.I. Zhadin, in different conditions of soil and climate on commercial fish farms throughout the Soviet Union. These experiments were pursued with the aim of devising an integrated method of effective fertilization and determining in the process the mechanism of the action of the individuals elements used (Zhadin, 1955, 1957, 1958). From the published results of this research it is difficult to determine to /164/ what degree the changes noted in the biological regime and fish yield of the ponds were due to the plant fertilizers, for the simple reason that they were used in combination with other forms of organic and mineral fertilizers.

Summarizing what has been said concerning green fertilization, we can note that both techniques - the sowing of the bottom of the pond with plants and the skilful application of cut plants - yield good results. In particular it should be emphasized that preliminary composting of the plants and even sundrying are now regarded as unnecessary, and this considerably reduces the expenditure of labour and materials on the preparation and application of vegetable fertilizer. At the same time it has been shown that even hard plants which decompose slowly give good results if they are added repeatedly every 15-20 days, or at least once a month.

4. Mixed Carp and Duck Culture

An unusual source of organic fertilizer for ponds is water-fowl. The most commonly used technique is mixed carp and duck culture. The first studies of the piscicultural effectiveness of tending ducks on carp finishing ponds were conducted at the Willenbach station in Germany (Probst, 1934) and on the ponds of the Timiryazevsk Agricultural Academy near Moscow (Cherfas, Orlova, 1935). After the second world war carp and duck culture received a big boost in the Soviet Union, East Germany and Czechslovakia. Probst estimated that under the optimum conditions one duck feeding on a pond for six months can cause an increase in the fish yield of 1 kg. Secondary nursery ponds (breeding of yearling with a three-year cultural cycle) in Probst's experiments proved 274% more productive than control ponds when accommodating 330 ducks per hectare during the season.

D.E. Semenyuk (1956), working with the ponds of Kiev oblast, showed that ducks can also be accommodated on nursery ponds stocked with carp fry. In his experiments the number of ducks was 400 per hectare, and the fish yield rose by a factor of 2-3 compared with the control ponds, and the losses of underyearlings were no greater than in the ponds without ducks.

F.G. Martyshev (1954) notes that on the "Gzhelka" fish farm in Moscow oblast there is an increase of up to 1.5 kg in the weight of the carp for each duck on the pond during the growing season. According to the date of F.M. Sukhoverkhova (1953), 250 ducks per hectare have the same effect as the addition of 6 tons of manure to the same area. /165/ It is estimated that one duck stationed on the pond for 45 days excretes into the pond about 10 kg of droppings, which are a most valuable fertilizer. B.I. Cherfas and G.A. Zernyshko (1946) and other authors recommend 150-200 ducks per hectare of pond area.

Dyk, Podubsky and Štedronský (1956) prefer a figure of 100 ducks per hectare when the ducks are stationed all over the flooded area of the pond, or 220-250 per hectare if they are confined to an area with a depth of no more than one metre. The same densities are favoured by A.K. Shcherbina (1952) on epizootic and sanitary grounds, provided the level of oxidization of the water is suitable for carp ponds.

Extremely instructive data on the effectiveness of keeping ducks on carp ponds in Czechoslovakia are contained in the paper of M. Frček (1957). The author traced a steady rise in the fish yield of a number of commercial ponds over a period of seven years (1950-1956), and sole cause of this rise was ducks. It was found that the greatest increases in productivity were observed in the first two to three years the ducks were kept on the ponds, and the lower the initial fish yield of the ponds the greater the relative increase in the yield. Thus, the yield of the pond prior to the advent of the ducks (1953) was 76 kg/ha, but during the first year when ducks and carp were bred together it rose to 356 kg/ha, i.e. the yield increased by a factor of nearly 4.7. In the next two years of mixed culture the yield rose to 450 kg/ha, or 592% of the original figure, but was only 1.26 times as large as during the first year of joint culture. In 1956 the survey embraced 94 duck ponds. In 86 of these the yield rose on average by 98%. Only those ponds which were overloaded with organic matter of another origin failed to exhibit an increase in yield. The author stresses that experience of joint carp and duck culture in the Soviet Union has been favourable, and he recommends breeding ducklings and younger animals on fry and nursery ponds in Czechoslovakia, and fattening the ducks for the market on carp finishing ponds.

In the experiments of Wolny (1956c) in Poland the keeping of 200 ducks per hectare on a finishing pond for 2½ months led to an increase in the fish yield from 100 to 188.7 kg/ha. When 220 ducks per hectare were kept for three months the yield rose from 103 to 242.5 kg/ha. Three hundred and twenty ducks per hectare for 3½ months helped to increase the yield from 100 to 307 kg/ha, i.e. more than trebled it. This experiment also gives a very full picture of the nature of the effect of ducks on the regime of the ponds. The author found that an oxygen deficiency occurs in the shallow parts of the pond (down to 60 cm) at night. In the deeper parts, which as a rule are rarely visited by the ducks, the oxygen regime was so favourable that vendace placed in the ponds as

an indicator of suffocation phenomena ~~freely~~ easily survived. At the same time, in the ponds in which ducks were being bred the oxygen content in the deeper parts was even higher than in the control ponds. Hence it follows that the keeping of 200 ducks and over per hectare of pond surface is permissible only in those ponds in which parts with depths of more than 60 cm occupy a large percentage of the area. In shallower ponds the density of stocking must be limited to 100 per hectare.

According to Wolny's observations (Wolny, 1956c), a flock of ducks with a density of stocking of 200-320 per hectare retarded the development of hard plants in the pond, but when they were thinned out the development of plants with floating leaves became slightly more intensified. Down to a depth of 60 centimetres the bottoms of the ponds were freed from moss and benthic fauna developed very plentifully in the area thus liberated. The quantity of bacteria in the pond with ducks was much higher than in the control pond.

In the experiments of V. Janeček and V. Janeček (1958) on fish ponds in Czechoslovakia it was shown that three batches of ducks can be reared one after the other during the growing season without harm to carp. The authors found by experimenting that the most suitable density of ducks on carp ponds will be the number per hectare adequate to maintain the oxidizability of the water at a level of 26.5 mg O_2/litre. In that case the fish yield is 500 kg/ha, and when there is a mixed stock of fish of various ages the figure is as high as 785 kg/ha. Oxidizability above the level indicated is regarded as undesirable, although in the experiments it was sometimes as much as 52 mg O_2/l, and the oxygen content in the morning hours fell to 0.1 mg/l. Nevertheless, cases of suffocation were not observed.

In recent times the practice of allowing free ranging of ducks on fish ponds has become widespread in the German Democratic Republic (Thumann, 1955a, 1955b, 1956; Blume, 1958, 1960; Wundsch, 1960; Eppel, 1961). With this method the fish yield is increased by 100%. The fish are not fed, but the feed boxes for the ducks, which are placed straight in the pond at different points, are designed so that the remains of the ducks' food are easily washed into the water and pounced on by the carp. It has been noted that the losses of carp in ponds with ducks are 12% lower than in the control pond.

/167/

Thus, ~~ranging~~ grazing of the ducks on fish ponds in quantities of 250-300 per hectare has a fertilizing and amelioratory effect. Hard plants are eliminated from the pond not only because the ducks feed on them and trample them down, but because where they feed the water becomes turbid from the abundance of organic substances and plankton, and this suppresses the higher aquatic plants. In addition, in seeking food on the bottom ducks stir up the bottom sediments and this helps to aerate them, accelerates decomposition and intensifies the transfer of the nutritive elements from the bottom sediments to the water.

When practising combined carp and duck culture it is as well to bear in mind that excessive concentration of ducks within a confined area may lead to hyperaccumulation of easily

decomposing organic matter, and this may have an adverse effect on the oxygen regime of the pond or certain parts of it. In such conditions there may be outbreaks of branchiomycosis. Therefore the recommended densities of stocking should be strictly adhered to, and the oxygen regime in the water of the ponds should be examined periodically.

5. Fertilization With Waste Waters

The waste waters from the municipal sewerage system (household drain-water) and from certain branches of the food industry contain many substances which are necessary for the growth and development of living organisms. As industry grows and the sewerage system develops the quantity of waste water increases and more money has to be spent on purification to prevent pollution of natural waters. Of the existing methods of purifying waste water the most suitable for the fish industry is purification in ponds and utilization of these ponds for fish breeding.

According to estimates which have been made, for one inhabitant using the sewerage system 7-8 grams of ammonium nitrogen, 1.5-1.8 grams of phosphates and up to 3 grams of potassium find their way into various receptacles in the course of 24 hours. The amount of water used by each inhabitant ranges from 50-250 litres (Botuk, 1949). Assuming that the mean quantity of water consumed by one inhabitant in 24 hours is 200 litres it is easy to calculate that a pond with an area of 1 hectare and a mean depth of 1 metre filled once with undiluted waste water will hold 24 hours of drainage from 50,000 inhabitants. Together with the waste water the pond will receive over 350 kg of ammonium nitrogen and nearly 80 kg of phosphates. The load of organic matter will be more than 2.5 tons/ha. Such large quantities of fertilizing substances are not used in pond pisciculture. Overloading with easily oxidizable organic matter in ponds filled with undiluted waste water results in /168/ the creation of anaerobic conditions in which not only the fish but also most forms of zooplankton and benthos cannot survive.

In the course of time, as the result of self-purification processes taking places in the waste water, aerobic conditions are established, phytoplankton develops and give a strong boost to aeration owing to photosynthetic evolution of oxygen, and then there is a sudden flourishing of heterotrophic organisms of plankton and benthos. Conditions are created which are favourable for the life of fish. But the waste water continues to flow in and the purified areas must be evacuated as soon as possible. To combine purification of waste water with fish breeding we must either dilute the waste water with a quantity of fresh water as it enters the pond, or have a series of ponds so that the undiluted self-purifying waste water can pass from one to another, thereby creating favourable conditions for the culture of fish.

The first experiments in the use of household waste water diluted with fresh water were conducted in 1887 in Berlin, where purified drainage water from irrigated fields was directed into experimental trout pools. Gradually the Germans evolved the practice of utilizing domestic waste water in carp breeding ponds, and this practice later became very widespread (Walter, Demoll, 1937). The largest biological installation

for the purification of household waste water by means of fish ponds was the pond carp farm in Munich, which started operations in 1929. This thoroughly organized farm, with a total area of 223 ha, was designed for a three year cycle. The finishing ponds, into which most of the waste water flowed, were rectangular in shape and measured 300 X 200 m. The waste water from the municipal drains was first clarified in settling tanks and then passed along a pipeline to the ponds, before entering which it was mixed with fresh water in a ratio of 1:3. On this farm one hectare of pond area processed waste water from 3.000 inhabitants. In the wintertime the waste water was accumulated in a 600 hectare lake situated higher up. It was not allowed to enter the hibernating ponds and store ponds. The fish yield of the ponds in Munich after fertilization with waste water averaged 450 kg/ha, and individual ponds gave a much higher yield (Kisshalt, Ilzhoefer, 1937; Scheuring, 1939; Kaufmann, 1958). The annual production of the farm was more than 250 tons of fish./i.e. metric tons - translator/. Conditions in summer ponds were such that a large number of ducks could also be reared on them.

The spread of this method has been held back by the necessity for complex equipment and sources of large quantities /169/ of clean water for the dilution of the effluent. Three times more pure water is required than is consumed by the municipal water supply system, and in large towns this poses quite a problem.

In the Soviet Union another method has been tried for the utilization of household waste water for fish breeding without the consumption of large quantities of fresh water. Experiments in the use of undiluted waste water from Moscow were begun in Lublin in 1913. A series of ponds was used in which the fluid passed in succession from the first to the second, from the second to the third, and so on. By the time it reached the last pond (usually the fourth) ~~the fourth)~~ the waste water had been processed so thoroughly by self-purification processes that conditions favourable for the existence of carp had been achieved. By 1928 the ponds covered an area of 220 hectares.

Between 1927 and 1931, V. A. Meien, (1928, 1932), working with the same type of purifying ponds in Lyubertsy, bred carp experimentally. Undiluted waste water from Moscow flowed into the ponds at a rate of 178 m^3/ha per day. According to the observations of Meien, in the fourth pond of each series the oxygen content was 10 mg/litre, organisms of the zooplankton and benthos devoured by fish developed in vast quantities, and the carp grew well. The fish yield was 376 kg/ha. However, the oxygen regime in Meien's experimental ponds was unstable owing to the constant flow, i.e. the constant inflow of waste water more or less purified in the upper ponds of the series.

At the present time a method of purifying household waste water in biological ponds not intended for fish breeding has been developed intensively and is becoming more and more widespread (Vinberg, 1955). Ten years of research into the self-purification processes in shallow stagnant biological ponds established in the Minsk filtration fields have shown the great efficieny of this method of purification and revealed the basic principles underlying the processes which take place (Vinberg,

1955). Ten years of research into the self-purification processes which take place (Vinberg, 1955, 1957; Vinberg, Sivko, 1952, 1956, 1959, 1960; Vinberg, Ostapenya, Sivko, 1957; Vinberg, Ostapenya, 1961; Sivko, 1961). The main advantage of the stagnant biological ponds is that they can handle a load twice as big as that handled by the flowing ponds in series which were previously used near Moscow. This conclusion arrived at by the authors working at Minsk was later confirmed by A. A. Kukharenko and N. S. Podlesnyuk (1962), who did their research on the purification ponds at Lyubersty. Waste water which has undergone purification in autotrophic ponds contains a greater quantity /17c/ of organic matter in the composition of the bodies of the live cells of planktonic algae (usually small Protococcaceae or flagellates). Organic matter in this form not only cannot increase the biological oxygen requirement of the receiving pond, but, owing to photosynthesis of the algae, promotes aeration and increases the pond's capacity for purification. In this connection the drainage of water purified in biological ponds into summer fish ponds is quite harmless. According to the observations of T. N. Sivko (1961), the biomass of algae in the biological ponds in Minsk is 1250-1500 kg/ha. The increase in the phytoplankton over twenty-four hours during mass development is roughly 900 kg of wet weight per hectare. If, for calculation of the mean, we take take half this figure, even then the increase in the organic matter of the algae during the 100 days of the growing season will be 45 tons per hectare. This vast mass of ready planktonic material could ensure a marked increase in the yield of fish ponds.

But until recently waste water purified in biological pools has been discharged into open drains and not been used rationally. It seems quite evident to us that household waste water previously purified in biological pools should be used to raise the yield of ponds.

A great piscicultural effect may also be achieved by using for the same purpose waste water purified in other ways. As we know, activated sludge is being widely used to purify waste water from the municipal sewerage system. After purification the water cannot pollute natural bodies of water, and it is discharged into lakes and rivers. Meanwhile, the purified water normally contains a large quantity of nitrogen and phosphorous, i.e. those nutritive elements which are the main active principles of the artificial fertilizers employed in pond pisciculture. For example, in the waste water of Kielce (Poland) (Wolny, 1962) was found, after purification with activated sludge, 44.3 mg of NO_3/ litre and 2.5 mg of PO_4/litre. Three years of observations of the breeding of carp of different ages in five experimental ponds filled with undiluted purified waste water from Kielce revealed that it was entirely possible to use such water not only in summer ponds but also in winter ponds. Wolny's experiments embraced two types of ponds - flowing and stagnant. In the flowing ponds the entire volume of purified waste water was completely replaced in two to three days. The best breeding results were obtained in the stagnant ponds. In one of them, in ~~which two-year-old~~ carp and crucians were being reared the fish yield was 1317.7 kg/ha and was eight times higher than the natural yield of unfertilized ponds in that region. Wolny emphasizes that "such a high yield has never before been noted /171/

in our literature. Moreover, it was achieved on natural food alone...". In the other stagnant ponds filled with purified water the yield was 2.8-6.8 times higher than that of unfertilized ponds. In fast-running ponds the yield was lower than in the control pond (163 kg/ha). This example shows convincingly the great pisciculturd effect achieved by using purified water in pond pisciculture.

Some industrial effluents can also be used successfully to raise the fish yield of ponds.

Experiments performed before the war in Germany showed the possibility of using waste waters from cellulose factories in ponds, provided this water was diluted with ten times its volume of clean water. After the second world war work began in Czechoslovakia and other countries on the purification in fish ponds of waste water from various food manufacturing plants.

Pytlik and Švec (1954) suggested a method for purifying and utilizing in fish ponds waste water from dairy factories. Chemical and biological studies conducted by these authors on seven ponds in different parts of Czechoslovakia revealed that drainage of effluent from dairy factories into biological pools is the best method of purifying them and raising the fish yield of ponds. The authors came to the conclusion that this waste water can be used in the ponds all year round provided there are no fish in the ponds during the winter. It was estimated that waste water together with whey from the processing of 10,000 litres of milk a day can be used in a carp pond with an area of 6 hectares and a mean depth of 1 metre. At the same the ponds must be limed every year with a concentration of 20 centners of CaO per hectare.

In the same year Pytlik, Votava and Beneš (1954) devised a method of using waste water from sugar refineries. The authors demonstrated that in a storage pond of such size that with a depth of 1 metre, it could accommodate all the waste water from a plant during its period of operation with liming at the rate of 50 centners of CaO per hectare, the waste water would be completely purified during the winter, the organic matter contained in it would be mineralized, and in spring the pond could be normally stocked for the fattening of carp. During the summer the fish are fattened, in autumn the pond is drained and the fish harvested, and then the pond is filled with effluent, limed and restocked the next spring. The fish yield of such ponds reaches 500 kg/ha. An experiment showed that a pond with /172/ an area of 4.5 hectares is sufficient to receive pulp effluent from the processing of 3,000,000 centners of beet. The six years of study by the authors in Kelčany showed the great effectiveness of this method of utilizing the waste water of sugar refineries.

From 1950 to 1953 Pytlik and Dušek (Pytlik, Dušek, 1956; Pytlik, 1957) made a study of a fish pond into which effluent from an abattoir was discharged. The authors came to the conclusion that a pond area of 1.4 hectares is sufficient for every ten head of cattle slaughtered a day, and that when the same number of cattle are processed at mean combines 2 hectares of area (mean depth 1 metre) are enough. In this event all the effluent can be assimilated without preliminary purification.

To avoid intensive local pollution it is advisable to discharge the effluent into fish ponds not at one point only but evenly over the entire area of the pond. This ensures optimum conditions for the processing and utilization of the effluent. The oxygen regime of the ponds receiving the effluent must be strictly controlled, and the inflow of effluent adjusted accordingly.

Thus, when suitably processed, domestic waste water and the effluent of certain food manufacturing factories not only help to increase the fish yield but also to enrich the ponds with a quantity of nutritive substances which cannot be matched by any other methods of fertilization. There is no doubt that in future this method of "fertilizing" ponds will find wide application.

CHAPTER V.

THE EFFECT OF FERTILIZATION ON THE FOOD SUPPLY OF THE FISH.

/173/

1. Introduction

The natural food of the ~~so-called docile~~ non-predatory fish reared in ponds is the invertebrates and their larvae populating the mid-water of the pond (zooplankton), the upper layer of the bottom soil (zoobenthos), and the submerged plants (zoophyton). The zooplankton and zoobenthos are regarded as the main natural food supply of a fish pond. As regards the underwater plant population, its role in the food supply of pond fish is determined entirely by the degree of cultivation of the pond. The higher the level of fish culture and hence the higher the fish yield of the ponds, the smaller the population of macrophytes in the ponds and the more insignificant the role of this population in the nutrition of the fish reared in these ponds.

Depending on the species of fishes being bred and on their age, their diet will consist mainly of organisms from this or that community. The fish actively select the most appropriate of their favourite food items. In addition to this ability to select, a large role in the feeding of a fish of a particular species and age is played by the degree of availability of food organisms.

The main fish bred in Europe - the carp - is, like many other species of this family, distinguished by great flexibility of feeding, and they can make equally good use and fatten equally well on both planktonic and benthic food. It is impossible to agree with the opinion propagated by certain fish breeders that carp are distinctly benthophagic in their second year of life.

This view is not borne out by the data of numerous analyses of the content of the intestinesof two-year old carp and does not square with the fact that large increases in the commercial fish yield are obtained from ponds in which plankton is strongly developed and the population of demersal zone is thin.

In pond pisciculture in the U.S.A., where predatory and semi-predatory fishes are chiefly cultivated, the planktonic and bethnic food supply is also of great significance, as species forming part of the diet of predators are reared on it. This merely means that the food chain is lengthened by one additional link.

/174/

The inclusion in pond culture of fishes ~~from the~~ plant eating ~~group~~ (blackcarp, white carp, and silver carp) extends the concept of the food supply for fish culture by adding the vegetable part of the ~~population on~~ community in the ponds. However, since data on the effect of fertilizers on phytoplankton are examined in Chapter III and as the breeding of fish consuming higher aquatic plants is not yet restricted by the food resources, we shall merely confine ourselves here to an examination of zooplankton and zoobenthos as a source of food in fish ponds.

In connection with various experiments to intensity fish culture, including methods of fertilization, numerous studies of the natural food supply of fish in fish ponds have been performed. The papers of German research workers on the fertilization of ponds in Sachsenhausen had described an attempt to ascertain the effect of fertilizers on zooplankton and to find a correlation between zooplankton and the fish yield in experimental ponds.

The detailed paper by Pauly (1919) contains a large number of tables and graphs showing all the fluctuations in the composition of the zooplankton of the ponds he studied. No specific differences were found in the species composition of the zooplankton of fertilized and unfertilized ponds. Nor was there any trace of systematic quantitive differences among the vast amount of material on the number of individuals in the composition of the zooplankton of fertilized and unfertilized ponds. It was impossible to discover any correlation between the plankton and the fish yield of the ponds.

No less typical are the results of three years of painstaking study of the zooplankton performed by Kreutner (1934) on ten small ponds on the Sulau experimental farm in Silesia. After comparing his data on the composition and numbers of zooplankton with the fish yield of the ponds the author found, contrary to what he had expected, that his material failed to reveal a connection between the qualitative and quantitative development of the zooplankton and the fish yield of individual ponds.

Similar data on plankton are contained in the papers of Wiebe (1929, 1930), who examined the species and numerical composition of plankton in several nursery ponds and five cement ponds on an experimental perch farm in connection with various fertilizers. Similar work was done by M. K. Taran (1939a, 1939B) in the Ukraine, who also notes a similarity in the species composition of the plankton in fertilized and unfertilized ponds.

No doubt because of their laboriousness and technical compexity, studies of the zoobenthos have been on a much smaller scale. Here, too, no connection has been revealed between the

composition of the benthos and the measures taken to raise the yield of ponds, and nor has it been possible to find a link between the number of individuals in the benthic population and the magnitude of the yield. In contrast to the data on the zooplankton, the studies of the benthos have from the very beginning been accompanied by determination of the biomass of bottom-dwelling animals, and this has brought the results much closer to the problem posed. But in many cases the authors, in their investigations of the benthos of ponds, have confined themselves and are still confining themselves to a description of the benthos of individual stations or parts of the ponds, without even attempting to determine the stocks of natural fish food in the pond as a whole. Examples of this are the research of M. K. Taran on the ponds of the Ukraine and the studies conducted much later by V. Ya. Pankratova in connection with the fertilization of the ponds of a vimba and shemaia* nursery in the northern Caucasus and carp breeding ponds in Latvia (Pankratova, 1959a, 1959b). /175/

It is easy to understand why no correlation has been discovered between the composition of the food organisms and fish yield of ponds. For pond fish such as the carp it is not essential for specific species to be present among their items of food. There is a wide variety of different forms of food organisms which the fish are capable of feeding on. It is a generally known fact that the species composition of the organisms consumed by the fish differs in different ponds and depends to a large degree on the composition of the fauna of the body of water in question. At the same time it is evident that if the fish are to grow at the necessary rate they should consume a specific quantity of food

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*Chalcalburnus chalcoides

of a relatively fixed chemical composition and other properties enabling it to be included in the metabolism of the fish. These basic conditions are satisfied through the complex system of relations evolved in time with the habitat which determines the behaviour of the fish, selectivity while feeding, regular replacement of favourite items of food in the course of development or at different times of the year, and so on. Hence, in spite of the existence of particular types of diet and their regular abandonment in the course of development, no species of fish has a constant imperative link with specific species of food organisms. The food requirements of each species are determined principally by the type of metabolism peculiar to it and are satisfied by a given quantity of food of suitable chemical composition.

Hence it is clear how important for an understanding of the trophic links are quantitative data permitting an assessment of the food supply in absolute units of matter or energy. For a comparison with the fish yield it is no less important that objective quantitative data reflecting the level of development of the food supply should be related to the unit of area characterizing the pond as a whole, and not to individual parts, zones, stations, etc. Fish bred in ponds may assimilate the food resources of all parts of the pond; therfore it is quite correct for the fish yield to be expressed in units of weight per unit of area. Of course, when making such an estimate it is necessary to take into account all the food stocks which are actually consumed by the fish. Only when we have comparative data can we count on finding a correlation between the phenomena compared. Unfortunately, most of the research on the food supplies of fish in ponds does not satisfy this elementary requirement.

/176/

The existence of a quantitative link between the primary and final production in ponds proves that in the general case the intermediate stages of the reproductive process of the fish are also connected both with the primary and the final production. Earlier we showed that a search for a link between the food supply and the fish yield was for a long time conducted in the wrong direction.

Let us examine what links are possible between the fertilization of ponds on the one hand and the development of food organisms for the fish on the other.

There are insufficient grounds for considering that an increase or reduction in the food supply of the fish, represented in the ponds by heterotrophic organisms of plankton and benthos, may be the consequence of the simple direct effect of fertilization on these organisms. This effect may make itself felt only indirectly, through the intermediate links in the food chain. Under the influence of artificial fertilizers the development of plankton is intensified and the primary production is increased. This creates better food conditions for the filter feeders feeding on phytoplankton and bacteria. This applies to many of the planktonic and benthonic food organisms consumed by the fish.

Organic fertilizers add to the ponds a large quantity of micro-organisms which can be directly consumed by the organisms fed on by the fish. But of much greater importance are those microbes which develop in the pond itself because of the organic fertilizer. However, organic fertilizer, in enriching the pond with mineral nutritive salts, also intensifies the development of phytoplankton. The decaying cells of planktonic algae in their turn provide the substrate for the development of saprophytic bacteria. Therefore the beneficial effect of both artificial and organic fertilizers is reflected in the first place in the feeding conditions of the food organisms consumed by the fish. It is quite clear that if the fertilizer has no initial effect, the development of phytoplankton is not intensified and the number of bacteria is not increased, then there /177/ is no reason to expect that the fertilizer will have a stimulatory effect on the food supply of the fish. The indirect effect of fertilizers on the food supply, mainly through the feeding conditions, cannot be selective and narrowly specific; it cannot affect the development of some of the constituents of the natural food supply of the fish without acting on others. Furthermore, the organisms of the pond zooplankton and benthos are well adapted to a wide range of sudden changes in the conditions. Therefore it can hardly be expected that there will be a substantial change in the species composition of the food organisms consumed by the fish under the non-specific effect of fertilizers.

In numerous studies in which the composition of the planktonic and benthic population of the ponds is analysed in connection with fertilization, no such differences can be detected in the composition which might be attributable to the definite influence of fertilizers (Braginsky, 1954, 1956, 1957; Akatova, 1957, 1959; Dunke, 1958; Lyakhnovich, 1953, 1960, 1963a; Lapinskaite, 1958; Volkova, 1961; Pankratova, 1958, 1959a; Vadze, 1961).

An improvement in the conditions of nutrition of zooplanktonic and benthonic organisms due to fertilizer may help to increase the number of food organisms consumed by the fish, but such an increase cannot always be detected by counting the number of individuals forming the food supply of the species of zooplankton and benthos.

An improvement in the trophic conditions is more helpful in increasing the number of larger species, for example <u>Daphnia</u>. If this leads, as it often does in practice, to a drop in the number of rotifers, <u>Bosmina</u> or <u>Chydorus</u>, then the actual increase in the biomass of the zooplankton will be concealed by a drop in the overall numbers, and so on. The same thing is also possible in relation to the zoobenthos, in the composition of which, as in the composition of the zooplankton, the weight (biomass) of the largest forms differs from the biomass of the small forms by a factor of several hundreds. Hence, to discover a quantitative link between the food supply of the fish and the primary production we must have data reflecting the compared values in absolute units of weight, i.e. we must strive to determine the biomass of the relevant groupings of the animal and plant populations of the ponds. This obvious condition is, unfortunately, not always heeded in piscicultural studies of ponds, and therefore, in spite of many years of research by special piscicultural institues, very few data have been collected for an objective assessment of the food supply of fish in ponds in the various zones of the Soviet Union. This gap is to some extent filled by the research of hydrobiologists working independently of the piscicultural establishments.

Some people feel that the stimulatory effect of intensi- /178/ fication measures on the development of the food supply of fish cannot be detected by the usual method of quantitative estimates because the food organisms are consumed by the fish. As a result, the biomass of food organisms, which has been augmented by fertilizers, soon drops to its original level, and, in spite of the fact that fertilizers really do have a stimulatory effect on the food supply, this effect is not detected during investigation. The effect of the eliminating factor of consumption on the development of the food supply is of fundamental importance, greatly complicates analysis of the connection between the food supply and the primary production, and cannot be ignored. However, the phytoplankton and bacterioplankton of ponds in no way differs in this respect from the zooplankton and other food organisms consumed by fish. For example, the phytoplankton in a pond is also subject to the constant influence of the grazing factor, i.e. its consumption by heterotrophic organisms living on it. Nevertheless, it has been shown more than once that the quantity of phytoplankton greatly increases under the effect of successfully applied fertilizers. It is natural to expect that when fertilization has a beneficial effect the number, or rather the biomass, of the food organisms consumed by the fish must also increase.

In the long evolution of mutual adaption of organisms in ecological systems various species have developed different devices protecting them from complete extermination through consumption by other species. The stability of the systems is governed by their diversity of species, owing to which species with different devices can fulfil similar functions in the system as a whole and substitute for one another. Thus, for example, when some species are devoured intensively by fish and the number of individuals diminishes accordingly, there may be vigorous development of

substitute species which are more resistant to the grazing factor, and the body of water will ultimately be populated as densely as its material and energy resources permit in the light of the nature of the cycle of substances established.

Even in very densely stocked ponds the fish cannot devour all the food items, as may occur in aquariums. Schäperclaus (1961) notes that a fourteen-fold increase in the density of the stocking of fish (from 120 to 1680 per hectare) brought about a drop in the number of chironomid larvae of only 48%, although in the latter case there was hardly any increase in the yield of fish.

Earlier we noted that investigations of the food supply of fish in connection with fertilization of ponds failed to reveal the effect of the fertilizers on the species composition of the organisms used as food by the fish. Nevertheless, it is known that ponds may differ widely in the composition of the invertebrate fauna. /179/ These differences are naturally connected with the character of the ponds and their biological and productive properties. One of the first to direct attention to this was S. N. Duplakov (1922), who studied zooplankton in twelve ponds polluted in varying degrees by man. He discovered that in heavily polluted ponds the plankton contains typically *Daphnia pulex*, *Moina rectirostris*, and of the rotifers *Brachionus urceolaris* and at times *Filina longiseta*. Reduction of the pollution leads to a drop in the quantity of *D. pulex* and *B. urceolaris* and to intensification of the development of *D. longispina*, *Schizocerca diversicornis*, *Polpolyx culcata*. In ponds still less heavily polluted, *D. pulex* disappears from the zooplankton together with *B. urceolaris*, and they are replaced by vigorously developing chydorids.

Later, in Germany, Langhans (1936), on the strength of the results of his own studies of the zooplankton in fish ponds in Bohemia, Galicia, Poland, Rumania and Yugoslavia, accumulated over a period of 25 years, came to the conclusion that mass development of *Daphnia magna*, *D. pulex* and many species of *Moina* is characteristic only of ponds with a high fish yield. Among the rotifers the author also singles out a number of indicator organisms whose abundent development signifies that the pond has good production properties. V. P. Lyakhnovich (1958a) analysed material obtained from a study of the food supply of fish in 100 ponds in Belorussia and confirmed the conclusions of Langhans regarding the indicator organisms of the zooplankton. With reference to the benthos, Lyakhnovich includes among the organisms typical of highly productive ponds chaoborines and chironomid larvae of the genus *Chironomus*. Wunder (1949) also stresses that only in the plankton of very good ponds does *Daphnia* develop abundantly throughout the entire summer, whereas in low-yielding ponds, even when appearing immediately after the filling of the pond, they very quickly disappear from the plankton. Schäperclaus drew attention to the fact that the larger species normally develop abundantly in the more productive ponds and smaller species *of Cladocera*, and sometimes rotifers, but so far no-one has paid any attention to the different species of copepods in this connection.

At first sight it may seem that we are faced with a contradiction: on the one hand the effect of fertilizers on the species composition of food organisms cannot be determined and on the other the composition of the food supply of the fish varies in ponds with different fish yields. But there is no contradiction

here. As was emphasized by V. P. Lyakhovich (1958), the mere presence of an indicator organism cannot be regarded as a biological index of the fish yield. Only its mass development enters into consideration, which is evidence of the flourishing of the indicator species. Thus, the difference amounts to not much more than the ratio of the indicator organisms to the remaining forms of the particular section of the population of the pond. On the other hand, the differences in the species composition of the food organisms consumed by the fish in the ponds are apparently governed by the character of the pond as a whole, the state of its bottom and basin, the degree of cultivation, plant growth, mode of operation over a long period preceding the time of study. In this connection it is quite possible that the prolonged effect of fertilization on the pond in conjunction with other factors will help to change the composition of the food supply. Studies so far made of the composition of the zooplankton and benthos in connection with fertilization have been too short to detect the specific effect of fertilization on the species composition of the invertebrate population.

/180/

Years of study of ponds drained every year for winter and refilled every spring, i.e. ponds which are to a large extent ephemeral, has convinced us that the complexes of living organisms populating these ponds possess great consistency. From year to year in the same pond an ecological system recurs which is surprisingly similar in its species composition to the system which preceded it. This applies equally to the zooplankton and benthos and to the phytoplankton. This is probably the reason why no ways have yet been found of controlling the changes in the species composition of plankton in ponds. Our knowledge of the inner laws governing the relations of the components in the ecological system of plankton is as yet inadequate for such interference, which would enable us to deliberately form a given composition in circumstances similar to the natural conditions of the body of water. The solution of this important problem is in fact far beyond the scope of the problem of pond fertilization.

2. The Effect of Fertilization on the Development of Zooplankton

As we have already observed, the effect of fertilizers on the food supply of fish, including the zooplankton, is only indirect, proceeding through the intermediate links in the chain. First of all there is an increase in the quantity of food organisms, in their biomass. But the fish yield can only increase if the fish consume a certain quantity of food. Therefore we need quantitative data on the biomass of the zooplankton in the pond, which is a highly important part of the natural food supply of fish reared in ponds.

Study of the zooplankton in ponds has recently been linked more and more with computation of its biomass, using the so-called standard weights. Of course, this method is not free from many inaccuracies, if only because the linear dimensions of the zooplankton are not uniformly correlated with their weight under all conditions. Measurement of many individuals of different species under a microscope is extremely laborious, so computations of the biomass are usually based on a small number of measurements. Nevertheless, estimation of the zooplankton in terms of the biomass is much more precise than describing its size according to the number of individuals, a method which was used until quite recently in all piscicultural research on ponds. For example, before scientists began to estimate the biomass it was

/181/

Numbers and biomass of zooplankton in finishing ponds in Belorussia.

1 Группа прудов	2 Число прудов	3 Численность зоопланктона, тыс. экз/м³				8 Биомасса зоопланктона, г/м³			
		4 ветвистоусые	5 веслоногие	6 коловратки	7 всего	4 ветвистоусые	5 веслоногие	6 коловратки	7 всего
9–13 *Прудхозы* 14									
Первая	5	9	61	66	136	0,13	0,36	0,05	0,54
Вторая	23	55	120	373	548	1,08	2,32	0,91	4,31
Третья	19	206	350	1010	1566	5,37	9,55	2,71	17,63
Четвертая	2	3458	505	930	4893	47,72	20,38	2,69	70,79
Пятая	1	4260	1120	2610	8010	56,32	59,52	4,15	119,99
9–13 *Колхозы и совхозы* 15									
Первая	45	1	26	215	245	0.09	0,18	0,13	0.40
Вторая	37	64	73	745	882	2.08	1,01	0.73	3.82
Третья	14	483	415	1750	2648	9,23	9,48	2,73	21,44
Четвертая	2	164	854	2434	3452	37,00	30,97	1,11	69,50
Пятая	2	4920	1688	2240	8848	58,85	57,48	10,85	127,18

KEY:

1. Group of ponds.
2. Number of ponds.
3. Numbers of zooplankton in thousands of specimens per cubic metre.
4. Cladocera.
5. Copepoda.
6. Rotifers.
7. Total.
8. Biomass of zooplankton, grams per cubic metre.

9.-13. First - Fifth.

14. Pond fisheries.
15. Collective and state farms.

widely thought that rotifers occupied a very important position among the pond zooplankton. Only when the biomass was estimated was it found that, in spite of the num~~b~~erical preponderance of rotifers over other groups of zooplankton, they do not normally constitute more than 10% of the biomass, and often far less.

Ponds may differ widely in the quantity of zooplankton even when the species composition of the latter is similar or identical. For example, according to the data of V. P. Lyakhnovich (1964b), the finishing ponds in Belorussia differ by a factor of more than 200 in the numbers and biomass of the zooplankton. After analysing the results of his own studies extending from 1952 to 1962 and embracing 150 finishing ponds (more than 2,500 quantitative samples), Lyakhnovich discovered certain characteristic features in the relationships of the groups of zooplankton, depending on the quantitative development. The quantitative data from ~~the~~ Lyakhnovich's studies are included in Table 8. All the ponds examined by the author have been subdivided into five groups /182/ according to the size of the total biomass of zooplankton. The first groups contain finishing ponds with a very small total biomass of zooplankton - less than 1 g/m^3 ; the second group contains ponds with a total biomass ranging from 1 to 10 g/m^3, which is regarded as low; the third group is made up of ponds with a total biomass of 10-50 g/m^3 (mean); the fourth, of ponds with a total biomass of 50-100 g/m^3 (high); the fith of ponds with a total biomass in excess of 100 g/m^3 (very high). The grouping of the ponds of specialized pond fish farms and for the ponds of collective and state farms.

The first point which strikes one is the number of ponds in each group. On pond culture farms only 10% of the ponds have a very small biomass of zooplankton, 46% of the finishing ponds are characterized by a low total biomass, the biomass for this group being 4.31 g/m^3, and 38% have a mean total biomass of zooplankton of 17.63 g/m^3. Only in one finishing pond was the total biomass of zooplankton greater than 100 g/m^3. The nature of the group distribution of the ponds of the collective and state farms is different. Here 45% of all the farms examined have a total biomass of less than 1g/m^3, with a mean for the whole group of 0.40 g/m^3, whereas 37% of the ponds are characterized by a low biomass of zooplankton ranging from 1 to 10 g/m^3. On pond fish farms almost half the finishing ponds (44%) have a biomasssof zooplankton which is average or above-average, whereas on the collective and state farms the figure is only 18%. Thus, the finishing ponds of pond-fish farms as a whole are characterized by higher indices of quantitative development of zooplankton than are the ponds of collective and state farms. This is evidently due to the more correct system of exploiting the pond resources on the specialized farms. It is striking that the fish yield of the ponds of fish farms is much higher than the yield of collective farm ponds.

It is a matter of interest to determine the correlation of the main groups of zooplankton in relation to their general level of development. First of all it must be noted that increase in the number of zooplankton is not proportional to the growth of its total biomass. Thus, for a 220-fold increase in the mean biomass of the third to fifth groups of ponds on the fish farms, and a more than 300-fold increase for the ponds of collective and state farms, the total population increases by factors of 59 and 36 respectively. This means that a greater biomass of zooplankton is ensured not only by a greater density of the mid-water population, but also by larger forms of zooplankton eaters. As the total numbers and biomass of zooplankton increase the proportion of rotifers diminishes and the role of Cladocera grows. Thus, in the first group of ponds of the fish farms the rotifers constitute 48% of the total /183/ number of zooplankton, whereas in the fifth group they amount to only 33%. This pattern is even more distinct in the groups of collective farm ponds, where the proportion of rotifers drops from 88% in the first group to 25% in the fifth. As the total numbers of zooplankton grow, the proportion of Cladocera increases accordingly from 2-7 to 53-56%. It appears that in those ponds where conditions exist for abundant development of zooplankton cladoceran crustaceans increase more vigorously than rotifers. Suffice it to say that when the total number of zooplankton increases by a factor 36-59 the numbers of Cladocera increase by a factor of 480-1200, whereas the rotifers increase only by a factorof 10-40. Such a tendency in the nature of the relationship between these two groups of zooplankton can also be detected in the weight indices, although the proportion of rotifers in the total biomass of zooplankton does not exceed 32%, and frequently drops to 5-10%.

This tendency for the correlation of the main groups of zooplankton to vary in the direction of the predominance of larger forms over smaller forms as the total numbers and biomass increase is of great piscicultural importance to fish ponds in general, and for finishing carp ponds in particular, since two-year old carp prefer to feed on the larger forms of crustaceans, while carp of 400 grams and over are apparently quite unable to filter out the small planktonic rotifers.

An important role in the composition of the zooplankton is also played by the copepods, which are avidly consumed by carp of any size in the adult state. In numbers this group constitutes on average 8-25% of all the zooplankton in finishing ponds. Only in the first group of ponds on the fish farms, with very small indices of quantitative development of zooplankton, was the proportion of copepods 45% of the total population. In the biomass of zooplankton as a whole however, copepods generally represent 45-55%. The material examined revealed no trace of a correlation between the proportion of copepods in the zooplankton and the general indices of its quantitative development.

In another of his papers V. P. Lyakhnovich (1960) notes that the nursery ponds of Belorussian fish farms are characterized by a mean biomass of zooplankton equal to 8.92 g/m^3, with wide fluctuations ranging from 0.13 to 169.9 g/m^3. A higher biomass of zooplankton was discovered in ponds which had been cultivated, cleared of plant growth and fertilized. The lowest biomasses of zooplankton were found in marshy nursery ponds containing an excessive amount of hard vegetation. The researches of A. D. Reinsone-Yurane, M. N. Matisone, Dz. R. Wadze and /184/ A. P. Volkova (1961), conducted on 33 ponds in Latvia, revealed that 21% of the ponds in Latvia have a biomass of zooplankton of less than 1 g/m^3, 55% between 1 and 10 g/m^3, and the remainder between 10 and 31 g/m^3. In the ponds of one of the Latvian farms which had been fertilized with artifical nitrogen and phosphorous fertilizers, A. P. Volkova and R. V. Vun'kis (1962) observed a mean seasonal biomass of zooplankton of between 12 and 30 g/m^3, whereas in an unfertilized pond it was only 4 g/m^3.

The fish ponds of the more northerly regions of the country, for example Novgorod and Leningrad, the Karelian ASSR and others, are apparently characterized by smaller indices of quantitative development of zooplankton than the ponds of Belorussia and Latvia. This is brought out particularly well by the data of Ts. I. Ioffe and his colleagues (1955), who studied the zooplakton of the ponds of "Sokolovo" fish farm in Novgorod oblast and the "Sal'mi" fish factory in the Karelian ASSR in connection with fertilization of these ponds with plants . For the twelve ponds of the "Sal'mi" fish farm the mean seasonal biomasses of zooplankton are cited, i.e. 1.5-6.3 g/m^3, while eleven out of the twelve were intensively fertilized with manure, alder twigs and various grasses. The regular observations of L. P. Maksimova (1961) on the development of zooplankton in four ponds of the "Popsha" fish farm in the Leningrad biomass of zooplankton noted in these ponds was 21.2 g/m^3. The mean seasonal biomass ranged from 1-8 g/m^3, and only in one pond with an area of 3 hectares was it 13.2 g/m^3.

In spite of many years of research by the All-Russian Pond Fisheries Research Institute there are no data available on the quantitative development of zooplankton in the commercial fish ponds of the central zone of the European part of the USSR. The numerous publications put out by this Institute, describing the zooplankton of small experimental ponds (with an area of 300-1000 m^2) in connection with fertilization, only contain data on the number of specimens of cladocerans and copepods and rotifers. It

is quite impossible to make an objective assessment of the quantitative development of the zooplankton from these data.[1] Only in one paper is it reported that the mean seasonal biomasses of planktonic crustaceans in experimental finishing ponds ranged from 2.7-23.6 g/m^3 (Il'in, Sheina, Bakhtina, Batenko et alia, 1956).

For one of the commercial finishing ponds (area 83 hectares) on the "Para" fish farm in Ryazan oblast I. V. Komarova calculated the biomass of crustaceans and found that the figures were relatively high, ranging from 3 to 40 g/m^3. The mean biomass per season of observations was 20 g/m^3 in 1953 and 26 g/m^3 in 1954 (Il'in, Brudastova, Sheina et alia, 1958).

In 1949 N. N. Kharin, V. N. Shutenko and V. G. Mushenko (1954) investigated 107 ponds in the Rostov district and discovered biomasses of zooplankton in them ranging from 4.7 to 43.5 g/m^3. After carefully analysing the copious data from systematic processing of samples of zooplankton the authors arrived at the conclusion that the "composition of the zooplankton of most of the ponds does not reveal groupings differing in quality..." Later the authors note that "in spite of a certain similarity in the composition of the pond zooplankton the quantitative development of the organisms displays an extraordinary mixed picture depending on the differences in the dynamics of the environmental factors." The quantitative data of the authors reveal the high level of development of the zooplankton in the ponds of Rostov district. /185/

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[1] Trudy VNIIPRKh. Vol. VIII, 1956, Vol. IX, 1958.

High biomasses of zooplankton characterize the ponds of the steppe part of the Ukraine, for which G. I. Shpet gives a mean value of 19.1 g/m^3. In the ponds of the Ukrainian forest-steppe the biomass of zooplankton is far smaller, averaging 5.72 g/m^3, while in the forest areas of the Ukraine it is only 2-3 g/m^3 (Spbet, 1962). However, for a number of fertilized ponds in the forest-steppe of the Ukraine L. P. Braginsky (1957) gives figures for the biomass of zooplankton greatly in excess of 10 g/m^3, and sometimes as high as 50-60 g/m^3. M. F. Yaroshenko (1952) reports still higher figures for the quantitative development of zooplankton in the fish ponds of Moldavia. The mean biomass of zooplankton in commercial ponds is normally greater than 20 g/m^3, but at peak periods it may rise as high as 286.6 g/m^3 for a mean pond depth of 1 metre this represents 2866 kg/ha.

Unfortunately, insufficient data have been accumulated so far for us to be able to give a quantitative description of the food zooplankton consumed by the fish in ponds in relation to the various soil and climate zones of the USSR, but the material which has been given already leaves no doubt that in this connection the northern ponds differ substantially from those in the south. Owing to the research of the Ukrainian Fisheries Research Institute, the Hydrobiological Institute of the Academy of Sciences of the Ukrainian SSR, the Dnepropetrovsk Institute of Hydrobiology and other establishments in the Ukraine we do have sufficient data on the fish ponds of the Ukraine to give separate descriptions of the development of the zooplankton of the ponds of the forest, forest-steppe and steppe zones (Shpet, 1962). Judging by the results of the research of the Belorussian Fisheries Research Institute set out above, the fish ponds of Belorussia exhibit no substantial differences in the development of zooplankton due to the geographical situation of the ponds, and this made it possible to examine the material on the republic as a whole.

Generally speaking, as we move from the north to the south of the European part of our country we find that the fish ponds /182/ are characterized by larger and larger indices for the quantitative development of zooplankton. It is important to note that the natural fish yield of the ponds is also normally higher when the pond is situated further south. On the strength of the results of research by German authors Schäperclaus cites a mean biomass of zooplankton between 10 and 20 g/m^3 for the fish ponds of East and West Germany. The author classes the ponds according to fish yield as bad, good and very good and notes that the better the fish yield of the pond the more profuse the development of zooplankton in it. Later Schäperclaus emphasizes that "in general the more productive the pond the larger the zooplankton eaters that populate it". This agrees with the data of V. P. Lyakhnovich cited above for the fish ponds of Belorussia.

Data on the mean biomass of the food zooplankton are very important for the fish yield of a pond, but we also need to know the distribution of this biomass in the course of the growing season. The quantity of zooplankton, their numbers and biomass in ponds may vary within very wide limits within a short space of time. The variation in the quantity of zooplankton in the course of the growing season has been determined in numerous ponds of various types and different yields, and this has helped to establish some of the features of the dynamics of the quantity of zooplankton in relation to the production properties of the ponds.

This rise is followed by a more or less rapid decline in the quantity of zooplankton, which in turn is succeeded by a new rise in the numbers and biomass. The peaks in the development of the zooplankton are normally due to a comparatively small number of species which boost the population to a far greater extent than other species normally do, and this ensures a larger biomass of zooplankton. As a rule, the higher the peak in the development of the zooplankton the smaller the number of species involved in this development. In summer ponds used for the breeding of fish from April to November (nursery ponds), there is normally either one spring-summer peak or two, i.e. spring-summer and summer-autumn, with a minimum in the middle of the farming season. In rare case the summer peak does not occur. Typical curves for the quantitative development of zooplankton for ponds with various production properties are shown in Fig. 15.

It has been observed (Dunke, 1958) that each type of curve reflecting the variation in the quantity of zooplankton during the growing season is characterized by specific values of the mean biomass of zooplankton during this period. The higher biomass /187/ corresponds to large values at times of peak population and biomass. Different types of dynamics of quantitative development may be ensured by a very similar species composition of the zooplankton. The characteristic decline in the middle of the summer, which is clearly marked in curves II, III and IV, cannot be explained as yet.

The interests of the fish industry are met most closely by the fifth type of zooplankton development. This is due not only to the higher figures for the mean and maximum biomasses, but also to the maximum correspondence between the distribution of the biomass in time and the food requirements of the stock of fish. Unfortunately, this type of development is still rarely found in practice on the fish farms of Belorussia.

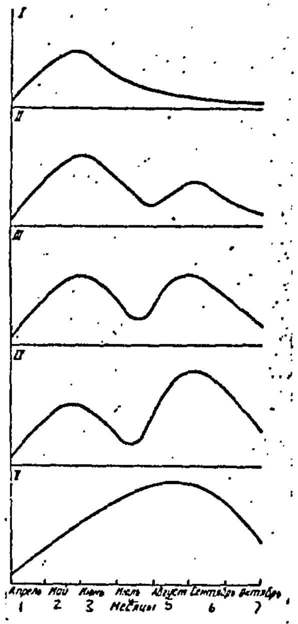

Fig. 15 - Types of dynamics of biomasses of zooplankton in fish ponds with different fish yields (after Dunke, 1958).

Key: 1-7 - April to October.

In most cases types I, II or III prevail, or others similar to them. We still have no data to judge ~~to judge~~ to what extent these types of dynamics recorded for ponds in Belorussia are valid for ponds in other soil and climate zones, nor do we know which of them prevail where. We can only suppose on the basis of the tendencies established for a limited regions that the more productive ponds of the southern region of the country will be characterized by dynamics closer to types IV and V than to 1 and II.

The quantitative development of the zooplankton in ponds is governed by their properties and their material and energy resources. /188/ Extremely important among the factors controlling the life of the zooplankton in the pond is its food supply – the trophic factor. In this connection the question of the effect of fertilization of ponds on the quantity of zooplankton is of great interest.

The effect of artificial fertilizers on the biomass of zooplankton is illustrated by the figures in Table 9.

The table summarizes the results of studies by various authors on the development of zooplankton in fertilized and control experimental ponds in Belorussia and Latvia only, since we have so far been unable to discover parallel data for other regions. For convenience of comparison superphosphate and the various types of nitrogen artificial fertilizers have been expressed in terms of the quantities of the active principle - nitrogen (N) and P_2O_5. The mean biomass of zooplankton, based on 9-13 measurements during the entire growing season, is expressed in kg/ha. There is a clear-cut connection between the quantity of fertilizer and the mean biomass of zooplankton. Nitrogen and phosphorus /189/ fertilizers applied separately have far less effect on the mean biomass of zooplankton than the two used in combination. It is characteristic that within the range studied, i.e. up to 265 kg/ha of nitrogen and up to 80 kg/ha of P_2O_5, the biomass of zooplankton was higher when more fertilizer was added to the experimental pond.

Table 9

The quantity of fertilizer in relation to the biomass of zooplankton.

Quantity of fertilizer (active principle) in kg/ha		Zooplankton kg/ha	Authors
N	P_2O_5		
-	-	14	G.G. Vinberg, N.A. Dunke and Yu.N. Dorozhkin, 1958
70	-	22	
80	-	33	
80	86	79	
95	90	52	
-	-	12	G.G. Vinberg and N.A. Dunke, 1958
17.5	10	21	
35	20	49	
70	40	83	
-	-	47	V.P. Lyakhnovich, I.T. Astapovich et alia, 1964
-	40	71	
68	40	162	
136	40	258	
-	-	49	
102	40	65	
210	72	166	
210	72	216	
265	80	366	
-	-	40	A.P. Volkova & R.V. Bun'kis, 1962
-	40	120	
43	45	213	
150	53	300	

In the most intensively fertilized ponds the mean biomass was more than nine times as large as the biomass of zooplankton in the control ponds. It is important to note that in all cases a greater fish yield was obtained from the fertilized ponds than from the unfertilized ones, while many of the fertilized ponds were also stocked several times more densely than the control ponds.

In different experiments and even in different versions of artificial fertilizers were expended per unit of increase in the biomass of zooplankton. Thus, in the experiments with nitrogen fertilizer alone, 4.2 - 8.8 kg of the fertilizer were expended in producing a 1 kg increase in the mean biomass of zooplankton during the period of investigation. With different forms of nitrogen-phosphorus fertilizer from 0.25 to 2.5 kg of nitrogen and from 0.25 to 2.5 kg of P_2O_5 were expended to produce a 1 kg increase in the mean biomass (compared with the control). The data available at present are inadequate for us to determine under what conditions nitrogen-phosphorus fertilizers have more effect on the quantitative development of the zooplankton. However, the material examined shows convincingly that there is a definite link between the quantity of fertilizer added to the pond and the mean seasonal biomass of zooplankton.

In all of the experiments performed the artificial fertilizers were added to the water repeatedly in small doses.

An increase in the quantity of zooplankton under the effect of artificial fertilizers was also observed by L. P. Braginsky (1956, 1957), N. A. Akatova (1957), Wirzhubski and Sarig (1953) and many other authors, but the data of their studes are cited in a form which is unsuitable for comparison of the observed effect and the quantity of fertilizer expended.

Organic fertilizers also help to bring about intensified development of zooplankton in fish ponds. Thus, for example, in the experiments of Havlena (1956) in Czechoslovakia, fertilization of ponds with pig's manure was accompanied by abundant development of large Daphnia. When the manure was added to fry ponds in quantities of 5 -7 metric tons per hectare the biomass

of zooplankton rose to 600 h/m^3 (Havlena, 1958).

In the fish ponds of India inadequate development of the zooplankton was the main reason for heavy losses of young Indian carp resettled for breeding purposes after harvesting from /190/ rivers. The losses of larvae were frequently as high as 90% and more (Ali-Kunhi, Chauduri, Ramachandran, 1955). Regular fertilization of the ponds with 15 tons of manure per hectare and 150 kg of lime per hectare, added in fractional doses, promoted the development of the zooplankton, and as a result the losses of young carp were sharply reduced.

An increase in the quantity of zooplankton as the result of the addition of manure to ponds was also observed by M.M. Isakova-Keo (1950, 1954) in ponds on the "Ropsha" fish farm near Leningrad and the Priozersk fish products factory on the Karelian peninsula, by Ts. I. Ioffe (1950,1954,1957) in the ponds of the "Sokolovo" fish farm in Novogorod region and the "Pelchi" fish products factory in Latvia, and by many other authors. An objective assessment of the effectiveness of manure and other similar organic fertilizers influencing the development of zooplankton is greatly hampered by the fact that these fertilizers are not spread evenly over the pond but concentrated within small areas. The authors working with organic fertilizers note accumulations of zooplankton in the zone of fertilization or a short distance away from it. In some cases such accumulations may be the result of the migration of zooplankton to fertilized parts of the pond from unfertilized parts, as was observed by L. P. Braginsky (1956) in ponds in the Ukraine. But in the majority of cases organic substances really stimulate the development of the organisms of zooplankton in the immediate zone of application.

Even then, however, it is unclear what is the proportion of these zones of intensified development in the total mass of the population of the midwater of the pond, since ~~noone~~ no-one has made any attempt to give a quantitative assessment of these facts. Normally authors of such papers content themselves with stating that there is more plankton in the zone of fertilization than further away from it, and then regard the question as closed (Chaplin, 1953, Isakova-Keo, 1954; Akatova, 1957; Bombovna, Krzeczkowska, Klimczyk, 1962). In actual fact such an accumulation at the fringe of the organic fertilizer may mean nothing to the pond as a whole if the proportion of it in the total mass of the pond population is very small.

In the paper of G. S. Karzinkin and S. I. Kuznetsov (1956), in which experiments with rigid vegetation in the spawning and nursery ponds of the "Yamat" fish farm are described, it is noted that after three years of systematic cutting of plants and their use for fertilization the number of Cladocera increased by a factor of 44, and the number of Copepoda by a factor of 45. True, the initial numbers were very low, there being 1024 specimens of Cladocera per cubic metre and 792 specimens of Copepoda.

The papers of S. I. Kuznetsov, G. S. Karzinkin and colleagues contain no indication of the amount of vegetation placed in the heaps of compost. A substantial contribution to this research effort is the paper by V. V. Mil'shtein (1957), who set out to determine what doses of vegetation help most to increase the /191/ zooplankton. In experimental ponds in the Volga delta, measuring 0.5 hectares, the author placed 2.4 and 6 tons per hectare of

rigid vegetation. The averaged data computed from Mil'shtein's table are shown in Table 10.

Table 10

Effect of vegetable fertilizers on zooplankton (based on data of V.V. Mil'shtein, 1957)

No. of pond	Quantity of fertilizer	quantity of zooplankton, g/m³	
		in centre of pond	on fringe of fertilization point
1	-	2.9	-
2	2	6.7	15.6
3	4	15.0	26.2
5	6	4.4	7.8

On the basis of the results achieved the author came to the conclusion that 2-4 tons per hectare of cut vegetation should be left in the pond for fertilization, and as the biomass of plants in spawning and nursery ponds amounts to 30-40 tons per hectare the excess vegetation should be removed after cutting. This clearly shows that when the amount of vegetation used is increased the biomass of zooplankton grows not only on the fringe of the fertilizer but also in the middle of the ponds, which may be the result not only of fertilization but also of the removal of the excess vegetation.

The rearing of ducks on fish ponds also has the effect of sharply intensifying the development of zooplankton. Thus, for example, D. E. Semenyuk (1956), studying ponds in the Ukraine, found that the biomass of zooplankton increased by a factor of 8-12 purely as the result of duck ~~breeding~~ rearing. The biomass rose to 75-150 g/m^3. Similar results were obtained by Wolny (1956c) in Poland and by Thumann (1956) in East Germany.

Thus, the zooplankton reacts to fertilization in the first place with intensified quantitative development and augmentation of its biomass. This occurs as a consequence of an increase in fertility and acceleration of the rate of development and maturation of the zooplankton eaters in fertilized as against unfertilized ponds (Karzinkin, Kuznetsov, 1956; Ioffe, Yandovskaya, Galkin et alis, 1955).

Unfortunately there are no data by which we can determine the quantitative link between the biomasses of phytoplankton and zooplankton, because parallel studies of the development of the biomasses of these associations have so far been a rarity in research on fish ponds. Meanwhile we can make the very general comment that the biomasses of phytoplankton and zooplankton in ponds are normally of the same order of magnitude. Often the /192/ total biomass of phytoplankton is on average several times greater than the biomass of zooplankton. Thus, for example, for various groups of fish ponds in Belorussia V. P. LYakhnovich and L. N Prosyanik (1964) cite average biomasses of phytoplankton ranging from 9.5 to 207 g/m^3. In another research project on the same ponds Lyakhnovich (1964) discovered biomasses of zooplankton ranging from 0.54 to 120 g/m^3. It is also known that abundant development of phytoplankton (bloom) is noted far more often in the ponds of the more southerly regions of the country than in those of the north. It was shown above that the biomass of zooplankton in fish ponds increases from north to south. It seems that systematic parallel studies would reveal a direct quantitative link between the biomasses of phyto- and zooplankton. Of course, we could not expect to discover such a link on the basis of a single study of a small number of specimens. It would probably require a large quantity of statistical material, but there is no doubt that a quantitative link between the biomasses of phyto- and zooplankton will be found at least within certain limits of the quantitative development of the phytoplankton.

It is often stated that exceedingly vigorous "excessive" water bloom, particularly of blue-green algae, suppresses the development of zooplankton (Mel'nikov, 1953, Ulomsky, 1962; Tseeb, Litvinova and Gusinskaya, 1962, and others). This conclusion is in most cases based merely on the fact that a drop in the quantity of zooplankton in bodies of water is accompanied by more intensive development of algae. However, from the same data we could draw an opposite and no less probable conclusion. If we assume that the quantity of zooplankton diminishes not because of the suppressive effect of the algae but for some other reason, for example as the result of more intensive grazing on the zooplankton, we can arrive at the conclusion that "excessive" bloom develops because the phytoplankton is consumed in small quantities by the zooplankton. We can be sure of at least one thing in such an interpretation, i.e. that very many forms of filter-feeding ~~eating~~ zooplanktonop~~hages~~ are actually feeding on phytoplankton. Meanwhile we know so little about the other forms of interaction and reciprocal influence of the various species of organisms in the plankton that any attempts to explain the mechanism of the observed correlations from these standpoints must inevitably be based on more or less probably suppositions. In view of this we do not insist on the assumptions made above.

It is also important to note that many studies of the fish ponds of Moldavia (Shalar' and Naberezhny, 1962), Belorussia (Lyakhnovich and Prosyanik, 1962), and the European countries (Novák, 1961; Havlena, 1956; Wunder, 1949) fail to confirm the /193/ conclusion concerning the suppressive effect of water bloom on the development of zooplankton and the fish yield of ponds. As has already been observed more than once, water bloom, particularlythe intensive development of the blue-green algae _Aphanizomenon flos-aquae_, is regarded in the theory and practice of pond-fish culture in Germany [1] and several other countries as an indication of the high productivity of the ponds.

The relationship between the primary production of the plankton and the biomass of the zooplankton is illustrated in Fig. 16. The figure contains the results of systematic studies of the pri- /194/ mary production and biomass of zooplankton in nine finishing ponds on "Izobelino" fish farm which were fertilized with various doses of nitrogen-phosphorous fertilizers.

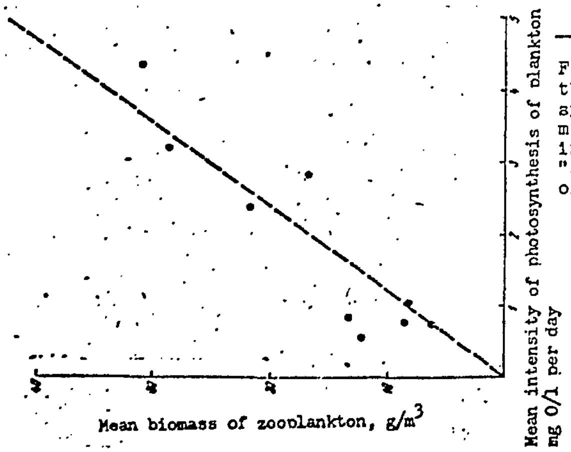

Fig. 16–Relationship between the mean intensity of photosynthesis of plankton and mean biomass of zooplankton in experimental ponds on "Izobelino" farm (from data of V. P. Lyakhnovich).

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[1] the data refer to pre-war Germany

(Lyakhnovich, Astapovich et alia, 1964). For the same ponds it was found that both the primary production and the fish yield were directly dependent on the doses of fertilizer.

From the data for the nine ponds the method of least squares was used to calculate the equation of the straight line lying closest to the empirical points reflecting the link between the primary production and the biomass of zooplankton. It was found that $y = 0.4 + 8.4\ x$, where y is the mean biomass of zooplankton in g/m^3 for the period of observations, and x is the mean seasonal value of the gross primary production expressed in grams of O/m^3 per day (24 hours).

The fact that the computed curve diverges only slightly from the origin of the coordinates shows that under the given conditions the biomass of zooplankton was formed mainly at the expense of the primary production. When the primary production was zero the biomass of zooplankton was a mere 0.4 g/m^3. Such a quantity of zooplankton could exist at the expense of other energy sources, such as bacterioplankton, higher aquatic plants, and organic substances flowing into the pond together with water from the source.

Of course, the data just examined are inadequate for us to judge to what extent the empirical formula given for the relationship between the biomass of zooplankton and the primary production is typical of fish ponds. It may be that under other conditions the quantitative expression of this relationship will be different, but within certain limits there is no doubt surrounding the direct link between the gross primary production and the biomass of zooplankton.

Thus far we have not touched on the problem of the effect of grazing fish on zooplankton ~~on the quantitative~~ development ~~of~~

~~the latter~~ in connection with the fertilization of ponds. Nevertheless this problem is of great interest, because intensively fertilized ponds are normally more densely stocked in order to obtain a higher fish yield. Hence, the influence of the grazing factor is greater in ponds receiving larger quantities of fertilizer. In this connection we might note that in the post-war fish breeding literature the ill-defined concept of "residual biomass" has been widely used, and this has confused and unnecessarily complicated investigation of the natural food supply of the fish. When, after fertilization, no increase in the quantity of zooplankton is detected, this is ascribed to the fact that it has been duly consumed by the fish and that only the"residual biomass" has been taken into account, i.e. what remained in the pond after the fish had left off eating. Such arguments /195/ are seductive in their simplicity, but they appear to have very little in common with the actual facts. The concept of the "residual biomass" is used only in connection with the food supply of the fish. But the biomass of the food organisms consumed by the fish is no exception. The biomasses of phytoplankton, bacterioplankton, phytobenthos and other associations of living organisms occupying an intermediate position in the food chain are also affected by the grazing of other organisms. Hence, if the concept of the "residual biomass" is well-founded it should be used in connection with all the links in the trophic chain in the body of water, except for the very last link.

Since any biomass of the intermediate links is utilized in the production process in some way or another, there are no grounds for singling out the biomass of the food organisms and calling it the "residual biomass". To indicate the increment to the biomass, including that part of the increase at the expense of which the food requirements of the organisms of the adjacent links in the food chain are satisfied, hydrobiologists use the term "production", which embraces the possible concept of the "residual" or "unconsumable" biomass. Reckoned by normal methods, the biomass of any link in the food chain is the sum not only of the processes of consumption of this link by another but also of its increment as the result of multiplication, increase in the weight of its component organisms, immigration of organisms from other places, and so on. All these generally sufficiently well-known facts do not fit in with the concept of the "residual biomass". The determination of the production in all links in the process of reproduction by the fish is a highly important problem in the theory and practice of pond pisciculture, but its solution is attended by many difficulties. The normally used methods of quantitative investigation of the food supply are inadequate for estimating the production of the heterotrophic links. Not only have ways of computing the production of aquatic invertebrates not been devised - piscicultural specialists show little interest in the problem! There is always a certain amount of zooplankton in fish ponds and other bodies of water in spite of grazing by fish. A. P. Shcherbakov (1956) notes that under certain conditions less zooplankton is expended on the nutrition of the fish than on its consumption by other types of invertebrates which are also among the organisms preyed on by the fish.

On the basis of spawning ponds in Belorussia V. P. Lyakhnovich (1958b) showed that even with very high stocking densities the decline in the biomass of zooplankton in spawning ponds cannot be attributed merely to grazing by the fry.

Calculations showed that only 2.1 - 7.2% of the available biomass was expended on the nutrition of the fry in the spawning ponds, and in spite of this it diminished by a factor of several tens in the course of a few days. The author admits that in the pond conditions observed by him the consumption of zooplankton by other forms of invertebrates (including the plankton eaters themselves) had a greater effect on the nature of the quantitative development of the food biomass than did feeding by the carp fry. Hence, grazing on the zooplankton and on other representatives of the populations of bodies of water always occurs, and there is no need to use the term "residual biomass" solely in relation to the quantity of zooplankton food organisms devoured by the fish. ~~Research workers who studied the effect on the quantity of zooplankton produced by fish grazing on it arrived at completely unexpected conclusions. In order to discover the effect of the grazing factor on zooplankton and on other representatives of the populations of bodies of water always occurs, and there is no need to use the term "residual biomass" solely in relation to the quantity of zooplankton food organisms devoured by the fish.~~ Research workers who studied the effect on the quantity of zooplankton produced by fish grazing on it arrived at completely unexpected conclusions. In order to discover the effect of the grazing factor on zooplankton Grygierek, Gil'brikht and Spodnevskaya (1962), Gurzeda (1960) and Grygierek (1962) examined the nature of the quantitative development of zooplankton in experimental ponds of very similar quality, specially stocked with young carp in widely differing densities. Beyond expectation, it was found that in many cases, in the more densely stocked ponds, the number of most species of planktonic crustaceans ~~were~~ was greater than in the ponds with lower

/196/

density of stocking. Such abundant forms of pond zooplankton as Bosmina longirostris, Daphnia longispina and many species of Ceriodaphnia either maintained their numbers in the face of the intensified pressure of grazing, or actually increased them. In his very detailed paper Grygierek (1962), after a comprehensive examination of the possible mechanism of the observed phenomena, suggests the following explanation. Firstly, intensified grazing tends to eliminate the larger forms of zooplankton eaters, which have ~~inferior~~ lower reproductive capacities. As a result, conditions are created for intensive development of smaller forms of relatively great reproductive capacity. It is also noted that representatives of the same species - Daphnia longispina - in more densely stocked ponds are more fertile, i.e. a relatively greater percentage of the populations of these ponds is made up of egg-bearing females (15-30%), whereas in thinly stocked ponds the figure is only 5 - 15%. Secondly, it is assumed that a denser population of fish improves the living conditions of the zooplankton, the water being fertilized with excretions which accelerate the processes of mineralization and intensify the mixing of the water with the top layers of the bottom sediments.

In 1961 V. P. Lyakhnovich also made a special study of effect of the grazing factor on the development of zooplankton. By contrast with the circumstances described above in these experiments the ponds were used for culture of commercial fish. The ponds were divided into identical pairs, one of which was densely stocked and the other remained without fish. Under these conditions regular observations of the development of the ~~zooplankton failed to reveal observations of the development of the~~

/197/

~~the~~ zooplankton failed to reveal the eliminating effect of grazing by the fish on the numbers and biomass of the zooplankton. The biomass of the zooplankton proved to be surprisingly similar in the stocked and unstocked ponds as revealed by both observations every day and by the seasonal mean, and in some cases it was even somewhat lower in the unstocked ponds. Nevertheless, in one case a fish yield of 470 kg/ha was obtained from the experimental ponds, and in another 532 kg/ha - without feeding. According to calculations, the expenditure of food organisms on increasing the fish yield in the stocked ponds was almost 30 times as high as their mean biomass for the period under study.

It is interesting to note that even in the experiments in so-called ultra-high density plantings the latter did not appear to have any effect on the quantity of zooplankton. Thus, for example, in the experiments of L. V. Erokhina (1961) with fivefold planting the normal density of the mean seasonal biomass of zooplankton in the experimental ponds was 1.9 g/m^3, whereas with fifteenfold planting it was 1.8 g/m^3. In intermediate experiments with tenfold planting the biomass of zooplankton was between 2.5 and 3.2 g/m^3, i.e. much higher than with fivefold planting. In the experiments of V. S. Prosyany and Z. O. Makina (1960) to study the effectiveness of breeding commercial carp with high-density plantings 2.5, 7.5, 10 and 12.5-fold plantings were tried. It should be noted that as the density of stocking rose from 2.5-fold to 12.5-fold the mean seasonal biomass of the zooplankton in the experimental ponds increased. For example, in the pond in which the density was increased 2½ times the mean biomass of the zooplankton was 16.5 g/m^3, while in the pond in which the density was increased by a factor of 12.5 it was 38 g/m^3.

In the multiple planting experiments the fish were, of course,

fed with cake and mixed foods, and the increase in the fish yield was due mainly to the feeding. Yet it is considered that natural food must constitute a certain percentage of the ration of the fish, and hence the greater the density of stocking the greater the quantity of natural foods necessary to ensure this percentage.

Thus, it may be regarded as proved that in many cases the grazing of fish on zooplankton has only a slight effect on the quantitative development of the food supply of the fish in the mid-water. Naturally this doesn't mean that cases of a decline in the biomass of zooplankton under the influence of grazing by fish will not generally occur in ponds. There are grounds for thinking that in conditions of uncontrolled ultra-high density stocking, for instance in the event of reproduction in non-draining goldfish ponds, the grazing factor will affect the quantitative development of the zooplankton. But with controlled stocking, when the aim /198/ is to obtain the optimum (i.e. the greatest as to total yield and weighed batches of fish) increase in fish production per unit of area, the grazing factor has no substantial effect on the magnitude of the biomass of zooplankton. This circumstance increases the value of the indices of quantitative development of the zooplankton for assessment of the fish producing properties of ponds.

3. Quantitative Development of Zoobenthos in Ponds in Connection with Fertilization.

The population of the bottom and bottom sediments (zoobenthos) in ponds is the second highly important component of the natural food supply of fish. The pond zoobenthos normally consists of larvae of ~~mosquitoes~~ midges of the family Chironomidae and other insects, and also of oligochaete worms, mollusks, crustaceans and other invertebrates leading a demersal form of life. The diversity of species of the zoobenthos is due to the nature of the bottom sediments in ponds, the degree of overgrowth, the method of exploitation and other features of the ponds. So far it has proved impossible to detect the influence of fertilizers on the species composition of the ponds benthos, so we shall for the most part examine data on the quantitative development of the food fauna consumed by the fish in the bottom region of the pond.

Data on the numbers of benth~~on~~ic organisms, like those on the numbers of zooplankton, are unsuitable for an objective assessment of the food resources of fish, because the weight of the representatives of different stages of development differs by a factor of several tens and even hundreds. Therefore the only important data are those on the biomass of benthos expressed in units of weight. Different ponds differ greatly ~~according~~ in ~~to~~ the biomass of benthos. For example, the finishing carp ponds of Belorussia differ by a factor of over 200 in this respect.

After examining 155 finishing ponds in Belorussia V.P. Lykahnovich (1964a) subdivided them into five groups according to the quantitative development of the zoobenthos (Table 11).

Of the ponds investigated, 8% had a very low biomass of benthos - less than 1 g/m^2. The overwhelming majority of the ponds were characterized by a biomass of benthos ranging from 1-10 g/m^2 (60%). Only 12% of the ponds had a biomass of 100 g/m^2. On making a separate examination of ponds of specialized pond fisheries and ponds of collective and state farms, the author found that the latter had higher indices of quantitative development of zoobenthos (see Table 11). Analysis of a large number of samples (1120) revealed that, when the density of the bottom population of the ponds rose from 135 to 8640 specimens/m^2 and the biomass from 0.41 to 106 g/m^2, the proportion of chironomid larvae in the benthos rose from 71 to 95% in abundance and from 66 to 99.5% in biomass. In another paper by the same author (Lyakhnovich, 1960) it is noted that the zoobenthos of fifty nursery ponds in Belorussia is characterized by biomasses ranging from 0.1 to 24.8 g/m^2.

TABLE 11

The numbers and biomass of benthos in finishing ponds in Belorussia

1 Группа прудов	4 Число прудов	5 Численность бентоса, экз/м²				10 Биомасса бентоса, г/м²			
		6 личинки хирономид	7 олигохеты	8 прочие	9 всего	6 личинки хирономид	7 олигохеты	8 прочие	9 всего
11 Прудхозы									
2 Первая	3	520	—	—	520	0.62	—	—	0,62
Вторая	52	707	96	54	857	3,47	0.26	0,35	4,08
Третья	12	1591	117	42	1750	19.60	0.43	0,71	20,74
12 Колхозы и совхозы									
3 Первая	10	96	22	17	135	0.27	0,07	0,07	0.41
Вторая	40	906	187	54	1147	3,70	0.53	0.53	4,76
Третья	30	2399	388	206	2993	16.96	2,78	1,47	21.21
Четвертая	7	6518	1463	93	8074	57,72	12,57	1,37	71,66
Пятая	1	8240	400	—	8640	106.44	0.24	—	106,68

Key: 1. Group of ponds. 2. First-Third. 3. First-Fifth. 4. Number of ponds. 5. Abundance of benthos, number per square metre. 6. Larvae of chironomids. 7. Oligochaetes. 8. Others. 9. Total. 10. Biomass of benthos, grams per square metre. 11. Pond fisheries. 12. Collective and state farms.

/199/

A vast amount of material (over 2000 specimens) from the benthos of fish ponds in the Ukraine was analysed by G. I. Shpet (1958, 1962). In the ponds of the forest-steppe and steppe part of the Ukraine the mean biomass of the benthos is 5-6 g/m^2 (with a range of 0.18 to 13.83 g/m^2). V. S. Prosyany (1958), who used fairly limited material, came to the conclusion that the mean biomass of benthos in the ponds of the Polesye region of the Ukraine was 3.5 g/m^2. However, A. D. Konenko, M. L. Pidgaiko and D. A. Radzimovsky (1961) cite different figures for the benthos of this part of the Ukraine which are just as high as those given by Shpet for the forest-steppe. The fish ponds of Moldavia have a biomass of benthos ranging from 2.4 to 20.1 g/m^2(Yaroshenko, 1952).

Judging by the data of L. P. Maksimova (1961) and other authors, the fish ponds of the northern regions of our country are no different in the biomass of their benthos from ponds situated in the southern regions. In a number of experimental ponds on the "Ropsha" fish farm the mean seasonal biomasses of the benthos range from 8.9 to 23.5 g/m^2 (Maksimova, 1961). Similar ponds of the Rostov (Kharin, Shutenko and Mushenko, 1954), Volgograd (Nikol'sky and Sokolova, 1950) and Saratov regions (Konstantinov, 1953), /200/ the Tatar ASSR (Aristovskaya et alia, 1951) and Latvia (Lapinskaite, 1958; Ioffe, Yandovskaya, Galkin et alia, 1955). In general, from the data available at present on the benthos of the ponds of the different zones of the Soviet Union it is impossible to detect regional differences in this connection.

The very productive fish ponds of Israel are also characterized by comparatively low magnitudes of the biomass of zoobenthos. According to the data of Wirzhubski and Sarig (1953), the mean annual biomass of the zoobenthos in experimental ponds in Zde-Nahum ranged from 3.7 - 10.9 g/m^2.

Variations in the abundance and biomass of benthos in ponds during the growing season are governed mainly by the cycles of development of the forms of living organisms making up the bottom fauna. Mass pupation and departure of chironomids is usually

accompanied by sharp drops in the biomass of benthos. The minimum values of the biomass are normally observed in the middle of the growing season. When there is a large preponderance of elements of anamniote fauna (oligochaetes, mollusks and others) in the benthonic population the fluctuations in the amount of benthos are less sharp than when chironomids predominate. In draining fish ponds, on the other hand, chironomid larvae are the main component in the benthonic food supply of the fish, dominating all other groups.

Fertilizers have less effect on the development of zoobenthos than on the development of zooplankton. In many experiments in the fertilization of ponds the stocks of benthonic food for the fish failed to show any increase, while in other experiments insufficiently clear-cut results were obtained. Judging by the data available, organic fertilizers have a greater effect on the development of the benthonic fauna than do artifical fertilizers.

Fertilization of experimental ponds at the vimba-shemaia nursery in the North Caucasus in 1951-1952 (Pankratova, 1959a) revealed that in spite of a very similar species composition the mean seasonal biomass of the benthos was 4.98 g/m^2 in an unfertilized ponds and 6.28 - 7.48 g/m^2 in ponds fertilized with plants. The benthos consisted mainly of chironomid larvae. The larger biomass was found in the pond to which more vegetable fertilizer had been added. Such data were obtained from experimental ponds stocked with equal quantities of vimba and shemaia eggs. (200,000 per hectare).

The studies of V. Ya. Pankratova (1959a) of the development of the benthos in three commercial ponds of the same nursery yielded the following results: for an unfertilized pond, a mean for the period of study of 0.6 g/m^2, for ponds fertilized with plants, 0.8 and 1.6 g/m^2. Here we see low figures, but the stimulatory effect of the vegetable fertilizer on the size of the /201/ biomass is still clearly manifested. In these experiments the vegetable fertilizer was added by the zonal method recommended by M. M. Isakova-Keo (1950). V. Ya. Pankratova emphasizes that the greatest number of benth~~on~~ic organisms were observed in the immediate vicinity of the decomposing vegetation. It is also noted that the fertilizers have a greater effect on the development of the benthos in ponds of average ~~filtration~~ seepage and less in ponds of strong ~~filtration~~ seepage. It appears that as the result of strong ~~filtration~~ seepage in the ponds of the vimba-shemaia nursery artificial fertilizers had no effect on the development of the benthonic fauna. It is curious to note that in the ponds fertilized with vegetation Pankratova found a higher percentage of non-predatory chironomid larvae, whereas predatory larvae were discovered far from the zone of fertilization and in the unfertilized ponds.

In the carp fish ponds of the Latvian collective farm (Pirmrindnieks" Pankratova (1958) found a higher biomass of benthos in a pond fertilized with vegetation than in an unfertilized pond. But in this case, as distinct from the ponds of the vimba-shemaia nursery, predatory larvae of invertebrates developed vigorously on the vegetable fertilizer, and in the opinion of the author this greatly reduced the quantitative development of the food fauna of the fish. In these experiments too artificial fertilizers appeared to have no effect on the development of the benth~~on~~ic fauna.

The author explains this by the fact that the artifical fertilizers were added at a late juncture. Unfortunately, in the papers of Pankratova (1958, 1959a, 1959b) the data on the development of the benthos in fertilized and unfertilized ponds is presented in such a form that it is very difficult, and at times simply impossible, to compare the ponds on the basis of them.

In experiments in the fertilization of nursery ponds on the Latvian fish farm "Rita Ausma" in 1955 Ya. S. Lapinskaite (1958) failed to detect any positive effect which the organic and artificial fertilizers might have had on the development of the benthos. Out of five fertilized ponds only in one was the mean biomass somewhat higher than in the unfertilized pond, while in the remaining fertilized ponds it was 2-3 times lower than in the control pond. Nevertheless, a large quantity of superphosphate (480 kg/ha), ammonium sulphate (320 kg/ha), potassium chloride (40 kg/ha), lime (420 kg/ha) and vegetation (1700 kg/ha) was added to the fertilized ponds. Ya.S. Lapinskaite (1958) notes that only in the immediate vicinity of the decomposing vegetation did the larvae of chironomids and other benthonic organisms develop abundantly, but this did not affect the development of the benthos on the bottom of the fertilized ponds. Thus, on the vegetation the biomass of animals was 13-53 g/m^2, whereas it was no more than 7 g/m^2 outside the zone of fertilization.

A. P. Volkova and R. B. Bun'kis (1962), on investigating the development of the food supply of fish in fertilized finishing ponds on the Tukumsk fish farm in Latvia, failed to find /202/ signs that superphosphate and ammonium sulphate had a positive effect on the development of benthos. They share the view of Ya. S. Lapinskaite that artificial fertilizer may affect the development of the benthos not the year it is applied but in subsequent years. So far, however, this has not been borne out by convincing data.

In experiments in the fertilization of finishing carp ponds at the Savvin fish nursery (Moscow region) V. M. Il'in, V. I. Bakhtina et alia (1956) found higher indices of the biomass of benthos in fertilized ponds than in unfertilized ones. The ponds were fertilized with superphosphate (200 kg/ha), lime (200 kg/ha), manure (up to 20 centners per hectare) and aquatic vegetation (up to 60 centners/ha). In four of the five fertilized ponds the mean biomass of benthos was between 2.5 and 3.6 g/m^2, whereas in the unfertilized pond it was only 1 g/m^2. In one pond, to which, in addition to superphosphate and lime, was added 4 metric tons of peat per hectare, the biomass of benthos almost twice as low as in the control ponds. In experiments in nursery ponds at the same establishment, Il'in, Bakhtina, A. N. Lipin et alia (1956) also observed a higher biomass of benthos in the fertilized ponds than in the unfertilized ones, although no direct link was found between the quantity of fertilizer applied and the magnitude of the biomass. Whereas in the control ponds the mean biomass of benthos was 2.38 g/m^2, in the twelve fertilized ponds it was as much as 7.8 g/m^2. The fertilizers used in these ponds were lime and superphosphate (150 kg/ha each), and aquatic plants and vegetable meal (3 tons per hectare each).

As shown by K. Arbuzova (1956), in a spawning and nursery pond on the "Yamat" fish farm in the Volga delta the cutting of rigid plans and their use for fertilization failed to promote the development of the benthos as regards either the composition or the quantity or organisms. The picture was different on the

vegetation itself used as fertilizer. At peak periods the number of chironomid larvae per kg of rigid plants reached 200. Similar results were obtained by Ts. I. Ioffe (1950, 1954) and M. M. Isakova-Keo (1950, 1954) when fertilizing ponds with vegetation in the northwest region of the Soviet Union. The authors note abundant accumulation of larvae of chironomids and other benth~~on~~ic organisms on and in the immediate vicinity of decaying land plants (alder, birch, will herb and others) and aquatic plants ~~submerged in the water~~. According to the data of Ioffe, the biomass of the benthos on the decomposing macrophytes was as much as 800 g/m^2. Unfortunately, the author does not indicate how much vegetation was used per square metre. From these papers it is not clear either to what extent this zonal fertilization affected the strict- /203/
ly benthonic population of the ponds. In fish ponds in Belorussia we also observed a large quantity of larvae of chironomids and other insects on vegetation submerged in the water and at the edges of compost heaps installed in filled ponds. It is curious to note that already two or three days after the immersion of twigs of alder or birch in the water of the pond a large number of chironomid larvae in the III-IV stages of development can be found on the leaves (Lyakhnovich, 1960). This is evidence of the active migration of animals to the vegetation from other parts of the ponds. As noted by V. Ya. Pankratova (1959a), the larvae leave the vegetation when it becomes strongly putrefied.

M. Dimitrov (1959, 1961) in Bulgaria staged special experiments to estimate the number of organisms developing on plants bound in sheaves and submerged in water. His results did not conflict with those obtained by Soviet authors.

Many research workers (Khomchuk, 1948; Wlodek, 1956; Jasinski, Klimczyk, Rosol, 1957) who have studied the sowing of the bottom for fertilization note that chironomid larvae develop abundantly on the inundated crop. S. Wlodek (1962) also found that manure had a strong effect on the development of chironomid larvae in experimental vessels.

As long ago as 1927 V. A. Meien demonstrated the scope of the development of benthonic organisms in ponds fed by domestic waste water. In the four stages of a series of purifying ponds containing 2400 yearling carp per hectare the mean biomass of the chironomids was 64 g/m^2 and the abundance 27,000 per square metre. In some lakes in the USA polluted with domestic waste water the development of chironomids is so intense that the question arises of finding special methods of controlling the phenomenon. (Provost, 1958).

In the literature it is noted that the ~~breeding~~ rearing of ducks in ponds also helps to increase the quantity of benthos. Thus, for example, in the experiments of Thumann (1955a), when ducks were kept on a fish pond the number of chironomids rose by a factor of 22.6, while the ~~quantity~~ number of oligochaetes increased by a factor of 16.6.

Thus, it may be regarded as an established fact that organic fertilizers have a definite effect on the development of the benthos. The measure of this effect depends to a large extent on the quantity of fertilizer and the nature of its distribution in the pond. Organic fertilizers such as manure, compost or decomposing vegetation contain a large ~~quantity~~ numbers of bacteria which

are used directly as food by many benthonic animals, and in the first place by non-predatory chironomid larvae. Hence it is /204/ possible to speak to some extent of the direct effect of organic fertilizers on the zoobenthos.

Artificial fertilizers always act on the benthonic fauna consumed by the fish through one or more intermediate links in the food chain, e.g. through phytoplankton and bacteria, and it is therefore more difficult to detect this effect. Unless the artificial fertilizer causes an increase in the primary production of the pond there is no reason to expect it to influence the benthos. But even when the mineral salts have a positive effect on the development of the phytoplankton the latter may be utilized in the midwater through the zooplankton and the bacterial link, or to a lesser degree reach the bottom and serve as food for the benthonic organisms. The experiments of O. N. Rusi[illegible] (1956) showed that, for the chironomid larvae, which often form the basis of the pond benthos, small Protococcaceae cannot serve as full-value food, whereas the large blue-green algae apparently vegetate for a long time in the midwater before descending to the bottom and becoming available to the animals dwelling there. It is no accident that it is very difficult to establish a direct quantitative link between the development of the plankton and benthos in a body of water. There appears to be not a simple relationship but a series of complex relationships caused by many factors which have not yet been studied.

As was shown by Wirzhubski (Wirzhubski and Sarig, 1953), in Israeli ponds which were intensively fertilized with superphosphate and ammonium sulphate the biomass of chironomids was 2.5-3 times higher than in unfertilized ponds. In these experiments the important point is that the ponds were only fertilized with mineral nitrogen and phosphorous salts, and the fish were not even fed. The author notes the complex nature of the relationship between the development of the plankton and the benthos. However, he emphasizes that the mean biomass of chironomids is generally higher where there is more microplankton. In one of the experiments in pond fertilization in the USA (Michigan state) the artificial fertilizers used also exhibited a positive effect on the development of the benthos and particularly on the chironomid larvae, the quantity of which as the result of repeated additions of fertilizer to the water increased by 144%, whereas the total quantity of all benthonic populations rose only by 56% (Patriarch, Ball, 1959). Repeated applications of nitrogen-phosphorous fertilizers to a small sea cove, spread over a period of two years, brought about an increase in the density of the benthonic population by a factor of 7.5 (Raymont, 1947).

Hence, artificial fertilizer too may in some cases have a positive effect on the development of benthonic organisms.

Grazing on the benthos by fish appears to have a greater effect on the quantity of benthos in ponds than on the quantity of zooplankton. This applies especially to the larger forms, which are characterized by relatively longer development and a comparatively lower rate of multiplication. /205/ For example, in the paper by Grygierkek and Wolny (1962) it is shown that the young carp in small ponds consume all the progeny of the mollusks in a given season, thereby greatly reducing the total quantity of animals in that group. According to the observations of V. P. Lyakhnovich, there were 200 times more *Limnaea stagnalis* in an unstocked pond

than in a neighbouring pond densely stocked with two-year old carp.

The grazing factor affects the chironomid larvae and oligochaetes to a lesser extent. Studies conducted by Lyakhnovich (1953) on finishing ponds at "Volma" fish farm in control areas from which fish were barred, and in neighbouring parts of the pond where the benthos was being consumed, revealed that the quantity and biomass of the benthos diminishes under the influence of grazing. According to ~~the~~ unpublished data of Lyakhnovich, a decline in the quantity of benthos under the influence of grazing by young fish also occurs in nursery ponds. At the same time it is observed that the nature of the dynamics of the population and biomass of the benthos does not vary under the influence of ~~the~~ grazing ~~factor~~ during the growing season. When the stocks of benthonic food within the area accessible to the fish diminish there is a simultaneous drop in the stocks in the control areas. There is also a parallel increase in the abundance and biomass of the benthos in the bottom areas of the pond accessible and inaccessible to the fish. Only where there is no grazing are the figures for the benthos slightly higher than in the area accessible to the fish.

The results of the experiments described above, in which Lyakhnovich and his colleagues worked with stocked and unstocked ponds on the "Izobelino" fish farm in Belorussia, fully confirm these conclusions.

As the result of research on the fish ponds of Moldavia, M. F. Yaroshenko (1956) also came to the conclusion that grazing by fish has no effect on the nature of the dynamics of the quantity of benthos in the course of the growing season. He stresses that there is an increase in the quantity of organisms and biomass of of the benthonic fauna in the first half of summer even in densely stocked ponds, whereas from July or August there is a drop in these indices even when the pond contains no fish. The effect of fish on the benthos is probably not confined to grazing. Some authors, Volny (1962) among them, consider that the disturbance of the bottom by fish searching for food is of great benefit to the development of the benthonic fauna. In 1959, when investigating ponds filled with purified waste water from the town of Kielce, Wolny estimated that the area of the bottom in a pond stocked with two-year-old carp was 30% greater than in an unstocked /206/ pond owing to the micro-relief created by the fish seeking for food in the bottom sediments.

Many aspects of the complex relationship between the benthos and the fish consuming it, like the complicated relationship between the plankton and benthos, require further study.

4. The Relationship between the Fish Yield and the Biomass of Food

As the result of the use of the food organisms of the plankton and benthos by fish there is a greater or lesser increase in the fish yield, which in turn determines the economic value of the ponds. The more natural food consumed, the more likely it is that there will be a large increase. But a high level of consumption is ensured by large available stocks of food organisms. Hence there should be a quantitative correlation between the biomass of food organisms and the magnitude of the increase in the fish yield. Of course, the growth of the fish may also be limited by many other factors, such as disease, their age, the climatic conditions, and so forth. But when the density of stocking is controlled and there is a deliberate selection of fast-growing

species of the right age, the food supply appears to be the chief factor limiting the increase in the fish yield. Searches for a correlation between the quantity of natural food and the growth of fish production have been undertaken by many authors but have remained fruitless for a long time. Earlier it was noted that there had been no success in establishing a link between the compostion of the populations of ponds and their fish yield.

In his time Alm (1923, 1924) tried to find a quantitative link between the biomass of benthos (B) and the fish yield (F) of lakes. To express this relationship he suggested the F/B (Fisch-Boden, i.e. fish-bottom) coefficient used in hydrobiology. Subsequently, Lundbeck (1927) calculated the possibil~~ity~~e productivity of the pond benthos, taking an F/B coefficient of 3 and a food coefficient of the benthonic food for carp equal to 3. On the basis of these and other assumptions Lundbek arrived at a figure which was thirty times higher than the estimated biomass of zoobenthos. Consequently the ratio of the computed production to the biomass (P/B coefficient), according to the calculations of Lundbek, proved to be equal to 30. The main defect of these calculations was the fact that they were based solely on data on the biomass of /207/ the pond benthos, which were later compared with the entire fish yield from these ponds. However, we know that in carp ponds not all the yield is obtained as the result of the use of benthonic food, since carp of all ages consume zooplankton also. This explains the unjustifiably high value of the P/B coefficient for the pond benthos obtained by Lundbek in his calculations.

If we are to compare the food supply with the fish yield it seems to us more correct to use data on the biomass of all the food organisms which may be used by the fish of the body of water in question. Apart from this, the first task is to discover the dependence of the fish yield on the food supply and not the reverse.

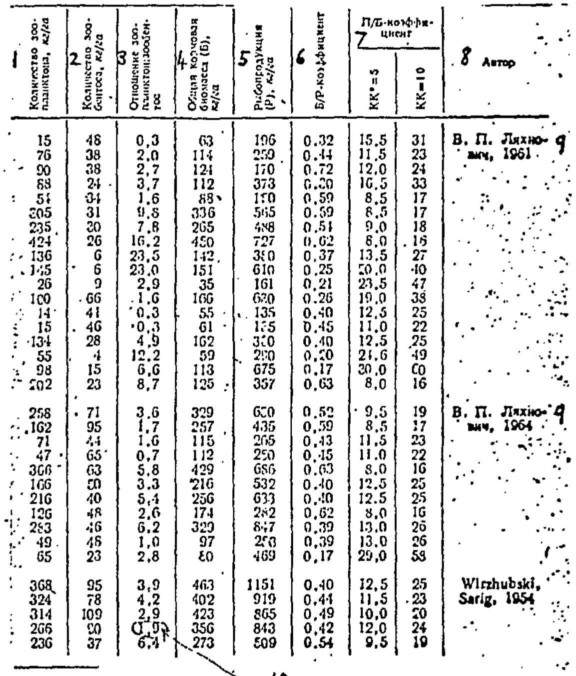
We possess data on 34 carp ponds in which the biomasses of zooplankton and zoobenthos were systematically estimated throughout the entire period of culture of the fish, at the end of which an exact estimate was made of the fish yield. Of the 34 ponds 29 are in Belorussia and the remainder in Israel (Table 12).

From the figures in Table 12 it can be seen that the proportion of the zooplankton and zoobenthos in the total biomass of food organisms in the ponds is not the same. As a rule, the biomass of zooplankton is much higher than that of the benthos. Only in four ponds was the ratio of the biomass of zooplankton to the biomass of zoobenthos less than 1. All these figures relate to ponds with a relatively low fish yield. In the more productive ponds the biomass of zooplankton is usually 3-4 times (and sometimes even 16-23 times) greater than the biomass of zoobenthos.

The preponderance of zooplankton over zoobenthos in the total biomass of food organisms consumed by the fish in highly productive ponds is apparently widespread. In the survey of data on the quantitative development of zooplankton and zoobenthos we noted that the ponds of the southern regions of the U.S.S.R. were characterized by higher biomasses of zooplankton than those of the northern regions, whereas the difference between north and south is not so marked in respect of the biomass of zoobenthos. It was also noted that zooplankton develops more vigorously than benthos under the influence of fertilizers. All this gives us grounds for thinking zooplankton plays an important role in the fish yield of carp ponds.

Table 12

Relationship of zooplankton & zoobenthos in the food biomass and the fish yield of carp ponds.



1 Количество зоопланктона, кг/га	2 Количество зообентоса, кг/га	3 Отношение зоопланктон:зообентос	4 Общая кормовая биомасса (Б), кг/га	5 Рыбопродукция (Р), кг/га	6 Б/Р-коэффициент	7 П/Б-коэффициент КК*=5	П/Б-коэффициент КК=10	8 Автор
15	48	0,3	63	196	0.32	15,5	31	В. П. Ляхнович, 1961 9
76	38	2.0	114	250	0.44	11,5	23	
90	38	2,7	124	170	0.72	12,0	24	
68	24	3,7	112	373	0.30	16,5	33	
54	34	1,6	88	150	0,59	8,5	17	
205	31	9,8	336	565	0.59	8,5	17	
235	30	7,8	265	488	0,54	9,0	18	
424	26	16,2	450	727	0.62	8,0	16	
136	6	23,5	142	380	0,37	13,5	27	
145	6	23,0	151	610	0,25	20,0	40	
26	9	2,9	35	161	0,21	23,5	47	
100	66	1,6	166	630	0.26	19,0	38	
14	41	0,3	55	135	0,40	12,5	25	
15	46	0,3	61	135	0.45	11,0	22	
134	28	4,9	162	330	0.40	12,5	25	
55	4	12,2	59	290	0,20	24,6	49	
98	15	6,6	113	675	0,17	30,0	60	
202	23	8,7	125	357	0,63	8,0	16	
258	71	3,6	329	630	0,52	9,5	19	В. П. Ляхнович, 1964 9
162	95	1,7	257	435	0,59	8,5	17	
71	44	1,6	115	265	0,43	11,5	23	
47	65	0,7	112	250	0,45	11.0	22	
366	63	5,8	429	686	0.63	8.0	16	
166	50	3.3	216	532	0.40	12,5	25	
216	40	5,4	256	633	0,40	12.5	25	
126	48	2,6	174	282	0,62	8,0	16	
283	46	6,2	329	847	0,39	13,0	26	
49	48	1,0	97	250	0,39	13,0	26	
65	23	2,8	80	469	0,17	29,0	58	
368	95	3,9	463	1151	0,40	12,5	25	Wirzhubski, Sarig, 1954
324	78	4,2	402	919	0,44	11,5	23	
314	109	2,9	423	865	0,49	10,0	20	
266	90	0,9	356	843	0,42	12,0	24	
236	37	6,4	273	509	0.54	9,5	19	

* КК — кормовой коэффициент. 10

should be 2.9

Key:
1. Quantity of zooplankton kg/ha.
2. Quantity of zoobenthos, kg/ha.
3. Ratio of zooplankton to zoobenthos.
4. Total food biomass (B), kg/ha.
5. Fish yield. (R), kg/ha.
6. B/R coefficient.
7. P/B coefficient.
8. Author.
9. V. P. Lyakhnovich.
10. KK - food coefficient.

The material examined failed to reveal a quantitative connection between the biomasses of zooplankton and zoobenthos. In ponds with a very high biomass of zooplankton the biomass of zoobenthos may be either low or high. Comparing the fish ponds of the collective and state farms of Belorussia with the carp ponds of specialized fish farms in the republic, V. P. Lyakhnovich and E. P. Leonenko (1962) sifted through a large amount of factual /208/ material and found that the former are characterized by higher biomasses of zoobenthos and comparatively weakly developed zooplankton, while the latter are distinguished by more vigorous development of the zooplankton and comparatively low biomasses of zoobenthos. These data are important by virtue of the fact that /209/ they relate to ponds in the same locality, situated close together, and differ only in the degree of cultivation and forms of exploitation. They show that there is apparently no close link between the quantitative development of animal associations in the mid-water and on the bottom of fish ponds, if these associations are viewed as a whole and not subdivided into small systematic groups.

It is probable that this also served as the basis for the conclusion drawn by Schäperclaus on the strength of an analysis of the development of the zooplankton and zoobenthos in the fish ponds of pre-war Germany. The author states that while the development of the zooplankton can be judged to some extent from the fish yield of the pond the data on the benthos are quite unsuitable for this purpose, since the benthos may equally well be poorly or well developed in both high-producing and low-producing ponds. Such a categorical denial of the value of the benthos to

piscicultural description of the pond is hardly convincing, particularly since a direct link was discovered the biomass of benthos in ponds and their productivity in a series of investigations oonducted on fish ponds in the Soviet Union (Ioffe et alia, 1955; Il'in, Bakhtina et alia, 1956). It would be more correct to estimate all the component parts of the food biomass and strive to make an objective assessment of the importance of each of them in the formation of the yield of the ponds.

After totalling up the mean seasonal biomasses of zooplankton and zoobenthos expressed in kg/ha, we obtained an overall biomass of food organisms consumed by fish (B) and compared it with the fish yield (R), thereby computing the values of the B/R coefficient for each pond, as was done by V. P. Lyakhnovich (1961) on a smaller number of samples. In all cases the ratio of the biomass of food organisms to the fish yield proved to be less than 1 and lay between 0.17 and 0.72 (see Table 12). The mean B/R coefficient was equal to 0.43. This means that, on average, 0.43 units of food biomass go into each unit of increase in the fish yield in carp ponds.

It is quite obvious that less than 0.5 kg of food organisms cannot ensure an increase of 1 kg in fish production. It is well known that several units of live food must be expended to produce one unit of weight increase. As a rule the caloricity of food animals is nearly half that of fish. Moreover the fish assimilates at most slightly more than 80% of the energy contained in the food. Of this assimilated energy only part is used for growth and the remainder is expended on energy exchange. G. G. Vinberg considers that the energy contained in the body of the fish constitutes /210/ 1/3-¼ of the food energy consumed. In view of the differences in the caloricity according to the crude weight it may be assumed that at least 5-6 weight units of natural food will have to be expended on each unit of increase in the fish yield. V. P. Lyakhnovich (1961), in his calculations of the quantity of food consumed by carp, took the minimum possible value of the food coefficient, equal to 4.5. M. F. Yaroshenko and A. I. Naberezhny (1955) feel that in the conditions of the fish ponds of Moldavia the food coefficient of natural food for carp is 10.

If we calculate the quantity of natural food expended on the growth of the fish from some food coefficient close to the real coefficient for the conditions in question and then compare the values obtained with the estimated food biomass we obtain some idea of the productivity of the fish food supply of a given pond. After using this method of calculating the productivity V. P. Lyakhnovich (1961) rightly stressed that it is possible to estimate in this way not the entire production of the food biomass but only that part of it which goes to satisfy the food requirements of the fish. This part of the production may be termed the ~~culturally~~ economically effective production of the food supply, and the P/B coefficient thus computed (ratio of production to biomass) will be the lowest possible. It is easy to show that not all the production of the food biomass consumed by the fish is used for increasing the fish yield, even in comparatively densely stocked ponds. In all cases the zooplankton and zoobenthos contain predators living by consumption of the same forms as serve as food for the fish. Demonstrations under experimental conditions were given to illustrate the tremendous capacity of predatory larvae of chironomids, dragonflies, water beetles, Chaeoborinae and others for destroying small animals. If the devastation of the food supply caused by predatory invertebrates under experimental conditions should occur in nature, little more than 10-20% of the production of the food supply would remain for the fish. To this should be added losses of production of food organisms as the result of their natural mortality, the departure of adult forms of secondary aquatic insects and so forth.

In actual fact the matter appears to be different, and in correctly used ponds most of the production of the food supply goes to increase the fish yield. This is shown in particular by the high values of the P/B coefficient of the food base set out in Table 12.

Since determination of the food coefficient of the organisms of the zooplankton and benthos consumed by fish is beset with insuperable difficulties under natural conditions in the ponds it /211/ becomes necessary to make more or less probable assumptions. Earlier we demonstrated that the food coefficient under ideal conditions cannot be lower than 4-5. On the other hand, since rapidly growing young forms (age 1-3 years) are normally reared in ponds, we can hardly assume that the food coefficient in these circumstances will be greater than 10. Therefore we calculated the possible quantities of food consumed by fish for two values of the food coefficient (KK=5 and KK=10), presuming that the actual level of consumption will lie somewhere between these two values. A comparison between the estimated quantities of food consumed by the fish and the existing food biomass yielded two extreme values of the effective P/B coefficient for each pond. At KK=5 the P/B coefficients range in individual ponds from 8 to 30, while at KK=10 they vary between 16 and 60 (see Table 12).

The mean P/B coefficent was 13.3 for KK=5 and, of course, twice as great for KK=10.

The results obtained show the effectiveness with which the fish use the food supply in carp ponds, since the quantity of food consumed is on average 13.3-26.6 times greater than the mean biomass of food organisms for the same period. On the other hand, the high productivity of the natural food supply in fish ponds stands revealed.

The dependence of the fish yield of ponds on the magnitude of the food biomass is illustrated in Fig. 17. The graph is based on data for the mean seasonal biomass of food organisms (in kg/ha) and the fish yield for five essentially different groups of ponds. The data on the commercial nursery and finishing ponds were obtained under breeding conditions in which the fish were given artificial foods. For these ponds the portion of the fish yield resulting from the utilization of the natural food supply was computed from the quantity of artificial foods expended and their food coefficient (Lyakhnovich, 1961). In some of the commercial finishing ponds a considerable part of the fish yield resulted from the culture of goldfish, which were regarded as additional to the carp.

All the rest of the data relate to small experimental nursery and finishing ponds in which carp were bred alone and exclusively on the natural food supply. The experimental ponds were fertilized with various doses of nitrogen-phosphorous fertilizers.

In spite of the scattering of the empirical points, the graph clearly shows a direct linear relationship between the

/212/

values compared. It is important to note that the fish ponds of Israel, which are marked by very high natural fish yields (three harvests of carp per year) and are exploited quite differently than in the Soviet Union, are characterized by a quantitative link between the food biomass and fish yield such as is found in the fish ponds of Belorussia.

The straight line lying closest to the points (see Fig. 17) was calculated by the method of least squares and is expressed by the following equation: $y=18 + 2.1x$, where y is the fish yield in kg/ha and x is the mean seasonal food biomass in kg/ha.

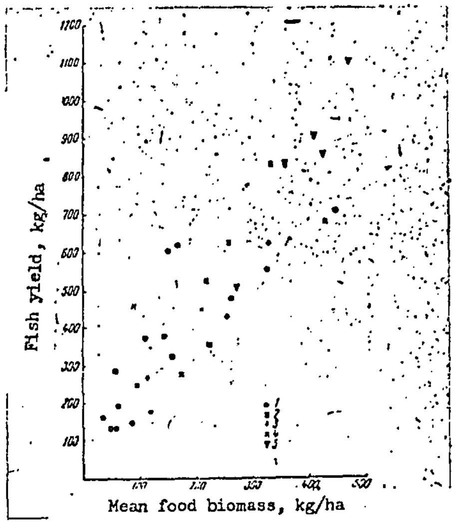


Fig. 17: Relationship between mean food biomass and fish yield of carp ponds:
1-commercial nursery ponds in BSSR, 2-commercial finishing ponds in BSSR, 3-experimental nursery ponds in BSSR, 4-experimental finishing ponds in BSSR, 5-experimental finishing ponds in Israel.

The fact that the zero value for the food biomass corresponds to 18 kg of fish production appears to mean that not all the food supply actually used for increasing the yield was taken into consideration. In particular, neither in the Belorussian nor in the Israeli ponds was the fauna of the plant growth near the banks allowed for. In addition, of some importance in the diet of the carp are elements of plant food from among the phytoplankton, phytobenthos and underwater macrophyte growth, as well as flying insects alighting on the surfaces of the ponds. /213/

The data examined enable us to a certain degree to determine the possible fish yield of carp ponds from the development of the natural food supply in them. This is important when planning the extension of fish culture to new bodies of water. In intensive pond fish farming practice, where the fish are bred with additional food, it may also be necessary to estimate the part of the increase obtained at the expense of the natural food supply of the fish. Hitherto this has been achieved in pond culture through an indirect method based on estimating the quantity of artificial foods expended and their food coefficient. As shown by V. S. Kirpichnikov (1960), this method suffers from many serious deficiencies. Our data enable us to assess the fish yield of ponds directly from the food supply.

Depending on the quantitative development of the natural food supply [f2] fish in fish ponds, we can distinguish five classes , as shown in Table 13. Each class is characterized by a specific magnitude of the fish yield, which increases on average from 225 kg/ha in ponds of class I to 880 kg/ha in ponds of class V. It is worth noting that as the biomass increases from 68 to 435 kg/ha the amount of the biomass per kilogram of increase in the fish yield also rises on average from 0.34 to 0.52 kg (see Table 13).

Like any classification of this type, based on quantitative differences, the suggested grouping of the ponds according to the food biomass of the fish is conditional in that there are no clear-cut boundaries between the classes. But it may prove useful when determining the piscicultural value of the ponds. /214/

So far in all our comparisons of the fish yield and computations of the possible values of the P/B coefficient we have used the total biomass of food organisms, uniting the zooplankton and zoobenthos. Such an approach is completely justified by the results obtained. However, there is no doubt that the functional role of the zooplankton in the formation of the increase in fish production differs substantially from the analogous role of the benthos. This difference is due not only to the different habitats of the orgamisms of the zooplankton and benthos and the corresponding difference in their availability to the fish, not merely to the different dimensions, caloricity and so on, but chiefly to the different ~~yields~~ turn over rates of the zooplankton and zoobenthos.

All other things being equal, the productivity of freshwater zooplankton appears to be somewhat higher than the productivity of the benthos. Unfortunately, there are not yet enough data for a reliable estimate of either the zooplankton or the benthos of fish ponds. Some hydrobiologists consider that the annual production of the freshwater zoobenthos is 1-3 times greater than its mean biomass. M. F. Yaroshenko and A. I. Naberezhny(1955) considered it possible to take a P/B coefficient of 8 for the chironomid benthos of the fish ponds of Moldavia. At the same time, for the zooplankton of the fish ponds the authors computed a P/B coefficient of 180 for the 180 days of the growing period, but then they reduced it to 45, calling the latter figure the "working biological productivity". The authors think that in summer 60% of the zooplankton in fish ponds dies from natural causes, 25% is consumed by different animals, and only 25% is used by the fish. Thus, according to the data of Yaroshenko and Naberezhny the productivity of the zooplankton is 22 (or 67) times greater than the productivity of the zoobenthos.

P. G. Petrovich, E. A. Shushkina and G. A. Pechen' (1961), on the basis of experimental data, computed the P/B coefficient for the zooplankton in some lakes in Belorussia. These coefficients are 20-30 times greater than the analogous coefficients for the benthos of the same lakes calculated by M. M. Drako. (1953).

Table 13

Classification of ponds according to fish food supply

1 Классы	2 Число прудов	3 Кормовая биомасса (Б), кг/га		6 Рыбопродукция (Р), кг/га		7 Б/Р-коэффициент	
		4 минимальная — максимальная	5 средняя	4 минимальная—максимальная	5 средняя	4 минимальный—максимальный	5 средний
I	8	<100	68	135—469	225	0,17—0,59	0,34
II	12	101—200	134	170—675	385	0,17—0,79	0,42
III	5	201—300	255	435—633	520	0,40—0,59	0,49
IV	4	301—400	335	565—847	720	0,39—0,59	0,46
V	6	>400	435	686—1161	880	0,40—0,63	0,52

Key: 1. Classes. 2. Number of ponds. 3. Food biomass(B), kg/ha 4. Minimum-maximum. 5. Mean. 6. Fish production (P) in kg/ha. 7. B/P coefficient.

On the strength of data of ecological physiology and his own investigations of the intensity of exchange among animals of different taxonomic groups, G. G. Vinberg (1962), when computing the /215/ productivity of the ecological system of a body of water, used a mean annual P/B coefficient of 30 for zooplankton and 3 for zoobenthos. On the whole, the productivity of the zooplankton is quite clearly higher than that of the benthos. It should also be remembered that in highly productive ponds the biomass of zooplankton is also 2-3 times greater than the biomass of benthos. If we assume that the P/B coefficient of the zooplantkon is roughly 3 times greater than the P/B coefficient of the zoobenthos, even then we shall find that the production of the benthos forms only slightly more than 15-20% of the total yield of the food organisms in highly productive ponds.

Further work must be done to determine the P/B coefficients for narrow systematic groups of fish food organisms in ponds. This will enable us to discover what forms of zooplankton and zoobenthos are of most piscicultural value in fish ponds. This problem acquires particular importance in connection with the controlled development of the biological regime of the ponds.

CHAPTER VI

PISCICULTURAL EFFECTIVENESS OF POND FERTILIZATION /216/

1. Introduction

Many experiments and much practice in the commercial utilization of different fertilizers have shown that their addition to a pond generally leads to a rise in fish yield. Many examples of the effectiveness of the use of fertilizers have been given in the preceding chapters. Often, however, pond fertilization has failed to yield any piscicultural dividends.

The complex series of transformations from the time of addition of the fertilizer to the pond to the emergence of the final product - the fish - obscures the piscicultural value of pond fertilization. Although fish breeders use fertilizers to improve the conditions of nutrition of the fish being reared, the introduction of fertilizers also affects other aspects of their lives. For example it improves or impairs the oxygen regime, alters the pH of the water, and so forth, whereas some important factors of the fish production either change slightly under the effect of fertilization or else change not at all. Depending on the specific conditions in which they are used, the same fertilizers may display different degrees of effectiveness. Therefore, up till now the fish breeder has found it difficult to determine what sort of an increase in the fish yield he can expect when adding a particular quantity of fertilizer to a pond.

To estimate the piscicultural economic effectiveness of different fertilizers we must compare the quantity of fertilizer expended with the increase in fish yield achieved. When doing this it should be remembered that the two things are not directly related, but that there are many intervening factors. Right up to the present time, the experimental work of practical fish breeders and many workers of piscicultural institutes has been confined to estimating the fish yield as the sole criterion of the effectiveness of fertilization. The necessity for such an estimate has never been in doubt. However, it was quickly found that an approach of this sort is inadequate for an understanding of the mechanism of the action of fertilizers in ponds and for determination of the conditions under which, and reasons for which, fertilization has a piscicultural effect. In other words, one became aware of the need to formulate a theory of fertilization of bodies /217/ of water. At the same time many researchers, concentrating their attention on different aspects of the complex mechanism of the action of fertilizers, were unable to take in problems of practical importance such as the determination of the piscicultural effectiveness of fertilization. As a result some of the important experiments and investigations of the past decade suffer from the great defect that they do not show what quantity of fertilizer the increase in fish yield attained in the experiments corresponds to. This is particularly true of papers on organic fertilizers. In a number of cases the authors do not give either the quantity of fertilizer added or the resultant increase in fish yield (Karzinkin, 1952).

In the study of the rates of artificial fertilization of ponds there has been a marked tendency in the last decade to find and take as the basis for recommendations specific concentrations of active principles of fertilizers which are recognized as being optimal. Some researchers recommend maintaining a given concentration of nutritive elements in the water of ponds by very frequent application of fertilizers (L.N. Mamontova), while others advise bringing the concentration of active principles to a given level each time the artificial fertilizers are added (M.B. Fel'dman, V.S. Prosyany and A.V. Sukhovii). In both cases the criterion for the desired quantity of fertilizer is the result of chemical analyses of samples of water from the fertilized ponds, which indicates the presence of the nutritive elements of concern to the researcher. It was noted earlier that it was very difficult to judge the fertilization requirements of a pond from chemical analysis of the water.

For a piscicultural assessment of the effectiveness of fertilization it would seem that the most correct procedure would be not only to investigate the mechanism of the effect of fertilizers but also to find the most economical combinations of fertilizers expended per additional unit of increase in fish yield. By analogy with the food coefficient, which defines the quantity of artificial foods expended per kg of additional increase in fish yield, we can use the concept of the "fertilization coefficient", which was first suggested by V.M. Il'in and his colleagues (Il'in, Lipin, Bakhtina et alia, 1956).

In intensive pond culture practice it is normal to distinguish between two ways of estimating the fish yield of the ponds when feeding the fish: that part of the fish yield which is obtained through utilization of the natural food supply ("the natural fish yield"), and that increase which results from the use of foods added to the ponds from outside. Strictly speaking, the yield of the pond includes only that /218/ part of the increase in yield which is provided by the material and energy resources of the pond.

The increase in fish yield following the application of fertilizers is due to intensification of the cycle of substances in the pond or to an increase in the mass of material participating in the cycle. The increase in fish yield with this form of intensification of culture is the result of the same sort of processes as take place in the pond without the addition of fertilizers, only on a smaller scale. Therefore there is no necessity in principle for making a sharp distinction between a "natural" or "initial" fish yield and the part of the yield obtained as the result of fertilization. It is more correct to speak of the increase in the natural yield due to the use of fertilizers.

On economic grounds we should determine what part of the fish yield is the result of the adoption of a particular measure designed to raise the natural fish yield of a pond. Only in this way can we assess the piscicultural effectiveness of the measure and judge the advisability of proceeding thus in future.

The quantity of fertilizer expended per kg of additional increase in fish yield depends on the conditions of application and on the combination of the fertilizing substances themselves in the mixutre used, so naturally it cannot be constant. Hence, the ratio of the quantity of fertilizer used to the size of the additional increase in the fish yield can be employed as a criterion for assessing the effectiveness of fertilization under the actual conditions of application. Since we have already described in previous chapters present-day ideas on the effect of fertilizers on various aspects of the life of ponds and given numerous examples of the effective use of fertilizers in different countries, in this chapter we shall examine only the piscicultural effectiveness of fertilization from the standpoint of the expenditure of fertilizing substances per unit of additional increase in fish yield.

2. The Piscicultural Effectiveness of ~~Artificial~~ Mineral Fertilization

Let us first examine the piscicultural effectiveness of phosphorus fertilization alone. One of the best-known examples of the successful use of phosphorus fertilizer is the experimental pond farm at the Willenbach piscicultural station (now forming part of West Germany), where the ponds have been fertilized with superphosphate over a period of many

years, beginning in 1913. 25-30 kg of P_2O_5/ha were added to the ponds in two doses, the first being applied to the bottom /219/ of the pond before filling and the second added to the water.

From the results published in the papers of Demoll (1925) and Probst (1950) a histogram has been constructed which clearly illustrates the piscicultural effectiveness of the phosphorus fertilization of the Willenbach ponds (Fig. 18). The application of 25-30 kg P_2O_5/ha led to an average increase in the fish yield of 77%. The additional increase due to fertilization was 72 kg/ha. With this method of fertilization an average of 0.4 kg/ha of P_2O_5 was expended per kg of additional increase in fish yield. Converted to superphosphate, this means approximately 2.3 kg of fertilizer per kg of additional increase in fish yield. As will be seen later on, phosphorus fertilization proved very effective here owing to the fact that the fertilizer was applied in limited quantities - not more than 30 kg of P_2O_5/ha or 150-160 kg/ha of superphosphate. An increase in the dose for one application was not accompanied by a commensurate increase in the fish yield. The expenditure of fertilizer per unit of additional increase rises sharply. This is clearly shown in Fig. 19, which we took from the manual of Schäperclaus (1961a).

Using the diagram it is easy to calculate that a twofold increase in the size of the dose of phosphorus fertilizer (from 25 to 50 kg P_2O_5/ha) leads to a rise of only 15% in the

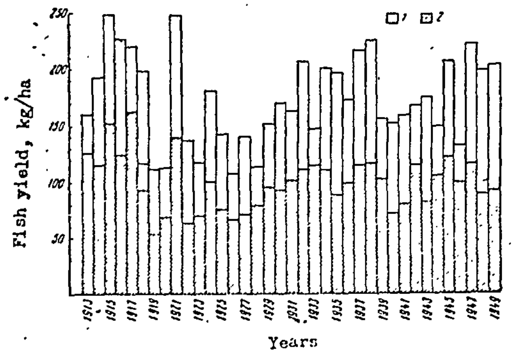


Fig. 18 Fish yield of unfertilized ponds and ponds fertilized with phosphorus at the Willenbach experimental farm (averaged data for 3-4 ponds shown) (from the data of Probst, 1950, and Walter, 1934):
1 - increase in fish yield in fertilized ponds, 2 - fish yield of unfertilized ponds.

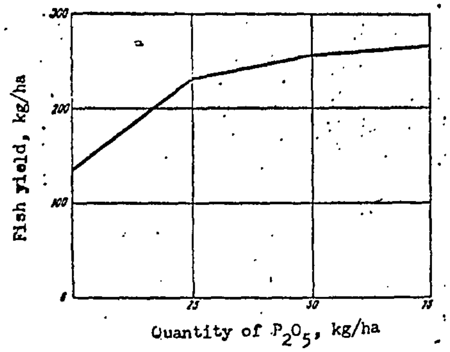


Fig. 19 Relationship between the quantity of phosphorus fertilizer and the fish yield (after Schaperclaus, 1961a).

fish yield, while trebling of the dose raises the increase by no more than 20% compared with the effect of a single dose of phosphorus fertilizer. And so, when adding 75 kg of P_2O_5 per hectare, which corresponds to approximately 500 kg/ha of superphosphate, we shall expend per kg of additional increase in the fish yield not 2-2.5 kg of fertilizer, but 5-6 times more, i.e. 12-15 kg. This is why, in East and West Germany, where phosphorus fertilizer is still regarded as the universal artificial fertilizer, "we take (for ponds) an average dose of 30 (25-35) kg of P_2O_5/ha, which has been hallowed by tradition and legitimized by practice" (Schäperclaus, 1961a). The low effectiveness of large doses of phosphorus fertilizer alone can also be seen from the results of the experiments of M.K. Taran (1939a, 1939b) on the ponds of the Ukraine. From 1933 to 1935 Taran tested doses of superphosphate ranging from 11.3 to 77.8 kg of P_2O_5/ha, using piecemeal, twofold and fourfold application of the fertilizer to the water of filled ponds, and he came to the conclusion that the best effect is achieved when small quantities of fertilizer are used. Therefore for the fertilization of large commercial finishing ponds in 1937 three applications of 16-20 kg of P_2O_5 per hectare were used. However small amounts of phosphorus fertilizer alone had little effect on finishing ponds in the conditions of Vinnitsa oblast. According to the calculations of Taran, 1 kg of P_2O_5 in the finishing ponds brought about an additional /221/ increase in the fish yield of 1.07-2.4 kg. Thus, even before the war the discovery was made that large doses of phosphorus fertilizer alone have little effect.

In the experimental fish ponds of the Moscow region tests were conducted under the supervision of V.M. Il'in of doses of superphosphate not exceeding 150 kg/ha, i.e. not more than 30 kg of P_2O_5 per hectare. In assessing the piscicultural effectiveness of this fertilization Il'in (1955) came to the conclusion that 1 kg of additional growth of the fish yield required 12-15 kg of superphosphate. In other experiments conducted by the same authors the superphosphate proved more effective. In the experiments of V.P. Lyakhnovich (1963a) on Belorussian ponds in 1960, the fertilization of a nursery ponds with superphosphate alone in a dose of 200 kg/ha meant that 13.3 kg of fertilizer were being expended for 1 kg of additional increase in the fish yield, the entire additional increase being 15 kg/ha.

But if large doses of superphosphate have little effect in conditions where small amounts of phosphorus fertilizer alone bring comparatively good results, and if, furthermore, in different conditions even small quantities of superphosphate (150-200 kg/ha) have a weak effect, then it is impossible with the aid of phosphorus fertilizer alone to effect a sharp increase in the fish yield of ponds. Let us recall that the most effective quantity of phosphorus fertilizer in East and West Germany raises the fish yield by an average of 77%. Only by expending very large quantities of fertilizer, i.e. when

its application becomes economically unprofitable, can we obtain twice as much fish from fertilized ponds as from unfertilized ponds.

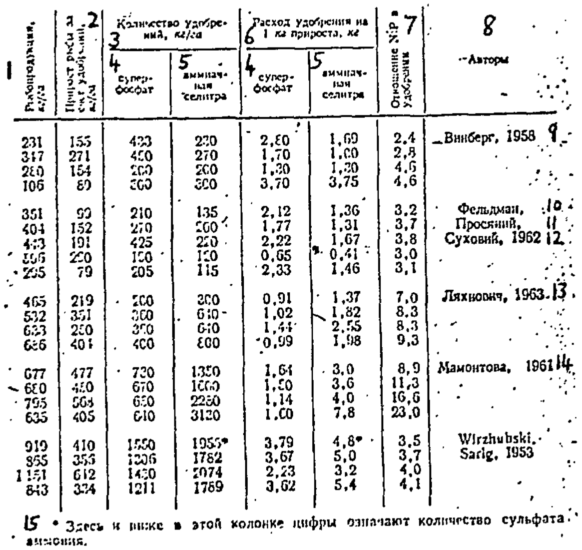
The low effectiveness of large doses of phosphorus fertilizer alone shows that it is not only phosphorus that limits the growth of fish production under these conditions. This confirms once again that phosphorus fertilizer is not universal.

Quite a different picture emerges on analysis of the piscicultural effectiveness of the joint application of nitrogen and phosphorus fertilizer. It is typical that in the USA, where commercial mixes containing nitrogen and phosphorus are used, large doses of fertilizer are applied. In the Soviet Union, after nitrogen and phosphorus fertilizer began to be used in combination, the quantity of artificial compounds of nitrogen and phosphorus added to ponds rose sharply.

Already in the first experiments of G.G. Vinberg (1958) on the ponds of "Shemetovo" fish farm (Belorussian SSR) in 1954 and 1955, in which he applied nitrogen and phosphorus artificial fertilizers together, the amount of superphosphate added was 433 kg/ha, with up to 300 kg/ha of ammonium nitrate being applied simultaneously. In spite of very early harvesting /222/ of the experimental ponds, only 1.3-3.7 kg of superphosphate and 1-3.7 kg of ammonium nitrate were expended for a 1kg additional increase in the yield of young wild carp (*Cyprinus carpio*) (Table 14).

Table 14

The Piscicultural Effectiveness of Nitrogen-Phosphorus Fertilization of Ponds



1 Рыбопродукция, кг/га	2 Прирост рыбы за счет удобрений, кг/га	3 Количество удобрений, кг/га		6 Расход удобрения на 1 кг прироста, кг		7 Отношение N:P в удобрениях	8 Авторы
		4 суперфосфат	5 аммиачная селитра	4 суперфосфат	5 аммиачная селитра		
231	155	433	230	2,80	1,69	2.4	Винберг, 1958 9
347	271	450	270	1,70	1,00	2,8	
280	154	200	200	1,30	1,30	4.6	
106	80	300	300	3,70	3,75	4,6	
351	99	210	135	2,12	1,36	3.2	Фельдман, 10 Просяний, 11 Суховий, 1962 12
404	152	270	200	1,77	1,31	3,7	
443	191	425	220	2,22	1,67	3,8	
506	220	150	120	0,65	0,41	3,0	
295	79	205	115	2,33	1,46	3,1	
465	219	200	300	0,91	1,37	7,0	Ляхнович, 1963. 13
532	351	360	640	1,02	1,82	8.3	
633	250	360	640	1,44	2,55	8,3	
686	404	400	800	0,99	1,98	9,3	
677	477	730	1350	1,64	3,0	8,9	Мамонтова, 1961 14
680	450	670	1600	1,50	3,6	11,3	
795	504	650	2250	1,14	4,0	16,6	
635	405	610	3120	1,00	7,8	23,0	
919	410	1550	1955*	3,79	4,8*	3,5	Wirzhubski, Sarig, 1953
855	353	1206	1782	3,67	5,0	3,7	
1151	612	1430	2074	2,23	3,2	4,0	
843	334	1211	1769	3,62	5,4	4,1	

15 * Здесь и ниже в этой колонке цифры означают количество сульфата аммония.

Key: 1. Fish yield, kg/ha. 2. Increase in yield owing to fertilization, kg/ha. 3. Quantity of fertilizer, kg/ha. 4. Superphosphate. 5. Ammonium Nitrate. 6. Fertilizer expended per kg of increase, kg. 7. Ratio of N:P in fertilizer. 8. Authors. 9. Vinberg, 1958. 10. Fel'dman. 11. Prosyany. 12. Sukhovii, 1962. 13. Lyakhnovich, 1963. Mamontova, 1961. 15. From here onwards in this column the figures denote the quantity of ammonium sulphate.

On average according to the data for two seasons of observations (five different forms of nitrogen-phosphorus fertilizer), in the experiments of Vinberg, for a 1kg additional increase in the fish yield 1.47 kg of ammonium nitrate and 2 kg of superphosphate were expended, which when converted represents 0.51 kg of nitrogen and 0.38 kg of P_2O_5. Hence the combined use of nitrogen and phosphorus fertilizer demonstrated the possibility of making effective use of far greater quantities of superphosphate than when phosphorus fertilizer was used on its own.

When the quantity recognized as optimal in East and West Germany was increased 2½ times there was no diminution of its piscicultural effectiveness owing to the addition of /223/ nitrogen. Particular stress should be laid on the fact that the yield from the experimental ponds fertilized with nitrogen and phosphorus increased by a factor of 3-4 compared with the yield from the unfertilized ponds. Thus, in addition to demonstrating the great effectiveness of using large doses of fertilizer it was shown that it is possible under Belorussian conditions to sharply increase the yield of the ponds through artificial fertilizers.

At the same time, in a pond fertilized with nitrogen alone Vinberg achieved very little by fertilization: for every kg of additional increase in the fish yield he expended 7-12 kg of ammonium nitrate, i.e. almost seven times more than when using nitrogen and phosphorus together in the same ponds. This clearly shows that nitrogen, like phosphorus, cannot be regarded as a universal fertilizer on its own, in spite of the fact that it is a powerful factor in increasing the fish yield of ponds.

On carp finishing ponds in the Minsk region V.P. Lyakhnovich (1963a) tested quantities of up to 400 kg/ha of superphosphate and up to 800 kg/ha of ammonium nitrate, applying the two fertilizers together in fractional doses to the water of filled ponds. In these experiments too the economic effectiveness was high. Per kg of additional increase in the commercial yield of fish 0.91-1.44 kg of superphosphate and 1.4-2.5 kg of ammonium nitrate were expended (see Table 14). On average for four ponds the expenditure of fertilizer per kg of additional increase in yield amounted to 0.67 kg of N and 0.25 kg of P_2O_5. Here the fish yield of the experimental ponds was 2.5-3 times greater than that of the unfertilized ponds, and the absolute increase in yield due to the fertilizer was 400 kg/ha. Lyakhnovich calculated that the average cost of the fertilizer expended in his experiments per kg of increase in the fish yield was 13.6 kopecks /1 kopeck is 1/100 of a rouble-Translator/. This is one third of the cost of the equivalent amount of artificial food needed to achieve an increase of the same order of magnitude. Hence the use of nitrogen-phosphorus fertilizer as opposed to food gives a saving of 0.3 roubles per kilogram of additional increase in the commercial fish yield.

On commercial carp ponds in Latvia N.P. Okhryamkina (1962), T.M. Tsukurs (1962), A.P. Volkova and R.V. Bun'kis (1962) experimented with nitrogen-phosphorus fertilizers in quantities of up to 265 kg/ha of superphosphate and 550 kg/ha of ammonium sulphate. As in the case of the Belorussian ponds they were highly effective.

In the ponds of the Ukraine, in which phosphorus fertilizer alone produced the best effect when applied in quantities of 15-20 kg of P_2O_5/ha (Taran, 1935a), it was found possible through the use of nitrogen and phosphorus together to raise the amount of superphosphate applied with the nitrogen fertilizer to 400 kg/ha, i.e. to 80 kg of P_2O_5/ha, without reducing its effectiveness. Thus, in the /224/ experiments of M.B. Fel'dman, V.S. Prosyany and A.V. Sukhovii (1961), conducted in 1959 and 1960 on the ponds of the "Nivka" fish farm in the Kiev region, when nitrogen and phosphorus were used together 0.65-2.33 kg of superphosphate and 0.41-1.67 kg of ammonium nitrate were expended per kilogram of additional increase in the fish yield (see Table 14).

Still greater quantities of phosphorus fertilizer were used effectively in the experiments of L.N. Mamontova (1961) on ponds in the Moscow district, involving the combined application of nitrogen and phosphorus. In one experiment Mamontova added to the water in fractional doses 730 kg/ha of superphosphate (roughly 140 kg of P_2O_5/ha), and at the same time applied 1350 kg/ha of ammonium nitrate. Here the expenditure per kilogram of additional increase in yield was 1.64 kg of superphosphate and 3 kg of ammonium nitrate. With such a large dose of phosphorus fertilizer, particularly in ponds to which it was previously considered inadvisable to add more than 30 kg of P_2O_5 per hectare, the use of nitrogen fertilizer made it possible to achieve even higher economic effectiveness for phosphorus than when it was used in small doses, but without nitrogen. In the experiments of Mamontova with combined nitrogen and phosphorus artificial fertilizers, the fish yield of carp nursery ponds was raised by a factor of 3-3.5, reaching in some cases 795 kg/ha.

The examples examined show convincingly that in various regions of the Soviet Union the joint application of nitrogen and phosphorus artificial fertilizers has made it possible to increase the dose of phosphorus fertilizer several times over without reducing its piscicultural effectiveness. No less important is the fact that it has been established by experiment that it is possible through the application of nitrogen and phosphorus artificial fertilizers to increase the yield of ponds by a factor of 3-4. These conclusions are of great significance for pond-fish breeding practice in the Soviet Union.

In pond pisciculture in the USA large doses of nitrogen-phosphorus-potassium commercial fertilizer mixes are used with great piscicultural effect. According to the figures available, unfertilized ponds in the USA give a fish yield of 45-168 kg/ha,

whereas fertilized ponds yield 224-560 kg/ha (Reid, 1961). It should be remembered that these figures relate not to carp but to fishes with a semi-predacious or predacious diet, owing to the length of the food chain, which is longer than for the carp. Hence the effectiveness of fertilizers added in quantities of 560-1120 kg/ha must be acknowledged as high.

In the carp culture of Israel combined nitrogen and phosphorus artificial fertilizers also produce a great piscicultural effect. In the experiments of Wirzhubski and /225/ Sarig (1953), from 2.23 to 3.79 kg of superphosphate and up to 5.4 kg of ammonium sulphate were expended per kilogram of additional increase in the commercial fish yield (see Table 14).

Judging from the results of the research of Wrobel (1962a), in the fish ponds of Poland the combined use of nitrogen and phosphorus fertilizers leads to a sharp increase in the piscicultural effectiveness of superphosphate when the quantities are augmented and added to the ponds in fractional doses simultaneously with nitrogen artificial fertilizers. Thus, nitrogen-phosphorus artificial fertilization may be regarded as a universally acceptable and highly profitable device for raising the fish yields of ponds. The joint application of nitrogen and phosphorus fertilizers firstly increases the effectiveness of the use of phosphorus fertilizer, secondly creates the possibility of effective use of far larger quantities of fertilizer than when phosphorus is used alone, and thirdly greatly increases the possibilities of augmenting the fish yields of ponds through artificial fertilizer.

So far we have mainly examined the degree to which the use of nitrogen extends the possibilities of application of phosphorus artificial fertilizers. However, in many European countries with developed pond-fish culture the use of nitrogen artificial fertilizers for raising the fish yields of ponds has been regarded as economically unprofitable and therefore inadvisable. This question merits special study.

We have hardly any examples of nitrogen artificial fertilization without phosphorus. It can, however, be stated with certainty that nitrogen fertilizer alone, like phosphorus fertilizer on its own, cannot produce a great piscicultural effect. In the case of Vinberg's experiment it was stated earlier that when ammonium nitrate was used without phosphorus fertilizer it took 7-12 kg of the former to increase the fish yield by 1 kg. Naturally this is a great deal, and nobody would recommend pond-fish culturists to use such a method of increasing the yield. Nevertheless, it is interesting to compare these data with the normal figures for pond piscicultural practice where the fish are fed with concentrated foods: nine kilograms of ammonium nitrate will cost 0.45 roubles. For this sum it is possible to purchase 5.5 kg of mixed fish food, the food coefficient of which for carp in the pond culture of Belorussia would average 5.5, while in many cases it would be much higher than 6. Nevertheless, no-one doubts the economic advisability of feeding pond fish on concentrated foods.

Far more interesting is the piscultural effectiveness of artificial nitrogen fertilizers in combined nitrogen and phosphorus fertilization, which has been widely adopted in practice. /226/

Under various conditions, in the experiments of different authors different amounts of artificial nitrogen fertilizers were expended in combined nitrogen and phosphorus fertilization to produce a 1 kg additional increase in the fish yield. Some of the figures are shown in Table 14. The table contains experimental data for different regions of the Soviet Union. We have included only those experiments in which only artificial fertilizers in the form of superphosphate and ammonium nitrate were used, being added to the water in fractional doses, although the details of the method of application varied somewhat from author to author. Only at the very end have we given, for purposes of comparison, data on four experimental ponds in Israel, where ammonium sulphate containing 21% nitrogen was used. This contrasts with the experiments of Soviet authors, who used ammonium nitrate containing 32-35% nitrogen. From the data of Wirzhubski and Sarig (1953) on Israeli ponds we have calculated the total expenditure of fertilizer on the total addition increase in fish yield for three attempts at fish breeding in the course of one year in each pond. It is curious that under these particular conditions the amounts of phosphorus fertilizer expended per unit of increase in the fish yield were similar to those resulting from the combined use of nitrogen and phosphorus under the conditions of Soviet pond-fish culture. The consumption of nitrogen fertilizers appears somewhat high only because Wirzhubski and Sarig used ammonium sulphate in their experiments and not ammonium nitrate. As regards the active principle of the nitrogen fertilizer, the amounts expended on the ponds of Israel hardly differ from most of the data of Soviet authors as shown in the table. It should be noted that these data relate to the first period of experiments in the use of artificial fertilizers on ponds in Israel. Later the doses used were much smaller, when organic fertilizer in the form of bird lime was employed simultaneously and on a large scale together with mineral salts of nitrogen and phosphorus.

As can be seen from the table, when nitrogen and phosphorus were used together the expenditure of ammonium nitrate per kilogram of additional increase in fish yield ranged from 0.41 to 7.8 kg. In eleven cases out of seventeen it did not exceed 2.5 kg. With the exception of the experiments of L.N. Mamontova, which will be discussed later, the expenditure of nitrogen fertilizer per unit of additional increase in the fish yield barely deviated from the analogous consumption of phosphorus fertilizers. Even bearing in mind the fact that nitrogen artificial fertilizers are somewhat more expensive

than phosphorus fertilizers, there are still no grounds for considerable artificial nitrogen fertilizers uneconomical /227/ in pond-fish culture.

Since neither phosphorus nor nitrogen fertilizers used separately can ensure a high increase in fish production, whereas their use in combination is highly effective, the question of the optimum ratio of the active principles in nitrogen-phosphorus artificial fertilization is of particular interest. Evidently we cannot rely on the optimum ratio of nitrogen and phosphorus in nitrogen-phosphorus fertilization being the same under the different conditions of different soil and climate zones. It is more likely that in one and the same region, depending on local conditions, the various ponds, and the way in which they are exploited, the ratio of the main nutritive elements in the fertilizer will differ slightly. In actual fact, in the different experiments performed in Belorussia the piscicultural effect of the use of nitrogen-phosphorus artificial fertilizer with widely diverging ratios of N:P has been very similar. In the experiments of G.G. Vinberg on the nursery ponds of "Shemetovo" fish farm the N:P ratio lay between 2.4 and 4.6, giving an average of 3.6. In this case 1-3.7 kg of ammonium nitrate was expended to produce a 1 kg additional increase (see Table 14). The average of four experiments was 1.51 kg of ammonium nitrate. In the experiments of V.P. Lyakhnovich (1963a) on the finishing ponds of "Izobelino" fish farm the average N:P ration out of four experiments was 8.2, i.e. more than 2.2 times as large as in the experiments of Vinberg. Nevertheless in the case of "Izobelino" 1.93 kg of ammonium nitrate, i.e. only 1.3 times more than used to fertilize the ponds of "Shemetovo" fish farm, was expended per kilogram of additional increase in fish production.

In Ukrainian ponds (Kiev district) M.B. Fel'dman, V.S. Prosyanii and A.V. Sukhovii (1961) tested N:P ratios ranging from 3-3.8. The average value of N:P for five variants in these experiments was 3.4, i.e. very close to the value obtained in the experiments on "Shemetovo" farm. In the Ukrainian ponds 0.97 kg of ammonium nitrate, i.e. 1.5 times less than in the ponds of Belorussia, was expended per kilogram of additional increase in the fish yield.

Meriting particular attention is the N:P ratio in the experiments staged by L.N. Mamontova (1961) in ponds near Moscow, since in these experiments it differed sharply from the values given above. In the various versions of these experiments the N:P ratio ranged from 8.9 to 23 (see Table 14). Typically, as the N:P value rose so did the expenditure of ammonium nitrate per unit of additional increase, i.e. the piscicultural effectiveness of the nitrogen fertilizer /228/ fell while the effectiveness of the phosphorus fertilizer remained approximately the same (1.14-1.64 kg of superphosphate per kilogram of additional increase in the fish yield). The greatest absolute increase (477 kg/ha) was obtained

for the smallest expenditure of ammonium nitrate at the lowest N:P ratio used in the experiments (8.9).

It appears that in the conditions obtaining in the experiments conducted by Mamontova the expenditure of phosphorus fertilizer, which averaged 1.5 kg of superphosphate per kilogram of additional increase in the fish yield, was minimal, and any further increase in the fish yield in the presence of an excess of nitrogen fertilizer was limited by an insufficiency of phosphorus fertilizer. It is possible that with the use of large quantities of superphosphate and the same doses, i.e. using a lower value of the N:P ratio, higher increments could have been achieved in these experiments while improving the piscicultural effectiveness of the nitrogen fertilizer.

Thus, on the strength of the data available we can assume that on the whole the difference in the N:P ratio in artificial fertilizer is not very great, at least for pond fisheries in the central belt of the European part of the Soviet Union, including the Baltic region, Belorussia and the North Ukraine. For these regions, where pond-fish culture is intensively developed, the most effective and economically profitable N:P ratio in artificial fertilizer will apparently lie between 3:1 and 8:1, or thereabouts. Let us remember that in the commercial fertilizer mixes used for the fertilization of ponds in the United States the N:P ratio is close to 2, while in Israel it is 4. The piscicultural effectiveness of the fertilizers can be determined from the actual amounts which have to be added to the ponds per unit is additional increase in the fish yield. Since the active ~~principles~~ factors in nitrogen-phosphorus fertilizer are nitrogen and phosphorus it is interesting to ascertain to what extent these elements are actually transformed into the body of the fish. If, on the basis of the figures in Table 14, we reckon that under optimum conditions 1.5 kg of superphosphate and 1.5 kg of ammonium nitrate are expended per kilogram of additional increase in the fish yield, this will represent 135 g of phosphorus and 525 grams of nitrogen (for 20% P_2O_5 in the superphosphate and 35% N in the ammonium nitrate). Let us assume furthermore that on average the live body of a pond fish, for example carp, contains 0.4% phosphorus and 2.5% nitrogen. Then, approximately 3% of the phosphorus added in the fertilizer and roughly 5% of the nitrogen will be used to produce an additional increase in the fish yield of one kilogram. It is curious that according to these calculations the nitrogen in the fertilizer is used more effectively that the phosphorus. This once again emphasizes the erroneousness of the idea that artificial nitrogen fertilizer is ineffective. /229/

At the same time we discover that the very little use is made of the nutritive elements in fertilizers to increase the fish yield. In theory they could be used much more effectively for this purpose in view of the fact that a substance can be included repeatedly in the biotic cycle through the use in the lower links of the trophic chain of the

metabolic products of organisms at a higher trophic level. More effective utilization of the nutritive elements appears to be hindered by the high absorbence of the bottom sediments, in which up to 80% and more of the fertilizer added settles, as has been shown by many hydrochemical investigations of fish ponds. The finding of methods of raising the effectiveness of the utilization of the nutritive elements in artificial fertilizers is a complicated task, but one of great practical importance for further elaboration of techniques of increasing the fish yield through fertilizers. As shown by the rough calculation made above, these nutritive elements represent large potential reserves for raising the economic effectiveness of fertilizer.

Even now, however, in spite of the poor utilization of the nutritive elements, the use of this method is much more profitable than feeding fish on concentrated foods (Lyakhnovich, 1963a). In particular it should be stressed that, when the N:P ratio is correctly selected and these elements are used properly the increase in the fish yield due to fertilization is directly proportional to the quantity of fertilizer added to the pond, at least up to 700-800 kg/ha, with an initial fish yield of 180-250 kg/ha. It follows[1] that at the present

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[1] The addition of artificial nitrogen-phosphorus fertilizers to finishing ponds in Belorussia in 1964 raised the natural yield to 600-700 kg/ha for an N:P ratio of 6:1 and the expenditure of 1.5-2.0 kg of ammonium nitrate and superphosphate per kilogram of growth in the commercial fish.

level of intensive culture nitrogen and phosphorus are the main nutritive elements normally limiting the fish yield of ponds. However, this does not mean that under different conditions of exploitation of the ponds, at a higher level of intensity of culture, other factors will not emerge to restrict the yield in spite of the optimum supply of nitrogen and phosphorus. It is enough to recall that in intensive cultures of planktonic algae on media with a high concentration of nutritive elements the factors limiting the production process are carbon dioxide gas, the light conditions, and so /230/ on. Something similar is also possible in pond-fish culture, particularly since, as we are speaking of natural fish production, it is based on the photosynthetic activity of planktonci algae.

Undoubtedly there is some upper limit beyond which the effectiveness of artificial fertilizer diminishes. It is probable that the maximum effective doses of fertilizer will prove to be different for different soil and climate zones with disparate temperature conditions, intensity of solar radiation and lengths of the growing season. The doses of nitrogen-phosphorus fertilizer tried so far do not appear to have reached the limit. Even in the experiments of Mamontova, who used up to 32 centners per hectare of ammonium nitrate, the decline in its effectiveness cannot be ascribed to the attainment of an upper limit, since the N:P was clearly inappropriate. In addition a great deal of work remains to be done to determine the optimum N:P ratios in artificial

fertilizers in respect of the different conditions of soil and climate zones in the Soviet Union. This is one of the most important practical problems which must be faced in experimental research on artificial fertilization, since only the optimum N:P ratio for the particular set of conditions will give the greatest increase in the fish yield due to fertilization for the smallest consumption.

3. Piscicultural Effectiveness of Organic and Combined Fertilizers

Organic fertilizers, as already noted in Chapter IV, may be used in two ways in a pond. Firstly, through complete mineralization of the organic matter with subsequent inclusion of the nutritive elements in the biotic cycle via the primary link of autotrophic organisms in the process of photosynthesis. In this case the mechanism of the further transformations of the fertilizers will not differ from the action of artificial fertilizers. Secondly, the organic matter of the fertilizers may be used by animals occupying higher trophic levels - up to and including fish. In this case the path from the fertilizer to the final product - the fish - is much shorter, so that an increase in the effectiveness of the fertilizer can be achieved.

Depending on the type of organic fertilizer and the conditions under which it is used, one of these forms of utilization of the fertilizer will prevail. Therefore the piscicultural effectiveness of organic fertilizers will fluctuate very widely. This greatly hampers calculation of the expenditure of organic fertilizer per kilogram of additional increase in /231/ the fish yield. Furthermore, organic fertilizers are rarely used in a pure form either in pond-fish cultural practice or experimental research on the fertilization of ponds. More often they are combined with phosphorus artificial fertilizers in different ratios or used in conjunction with other measures for raising the fish yield of ponds. Many researchers who have worked with organic fertilizers have failed to pay sufficient attention to calculation of the amount of fertilizer expended and to the resultant increase in fish yield. In a number of cases, for example when plants are cut and left to lie in a pond as fertilizer, when waterfowl are ~~bred~~ fattened on the ponds, or when waste water is allowed to drain into the ponds, the estimate of the amount of fertilizer used will only be a rough approximation, and this further complicates the already difficult task of assessing the piscicultural effect of the particular type of fertilizer being used.

Let us first examine data on the effectiveness of manure in pond pisciculture in the European countries. According to published information, manure, and especially pig's manure, is widely used for fertilizing carp ponds in Czechoslovakia, Hungary and East Germany.

Susta (1953) analysed the results of manuring nineteen ponds in Czechoslovakia. The amount of manure added differed from pond to pond (from 6 to 60 centners per hectare).

According to the author's calculation, from 6 to 133 kg of manure was expended per kilogram of additional increase. Such large discrepancies in the piscicultural effectiveness of manure in the estimates of Susta are due to the fact that for all nineteen ponds he took the same figure for the initial natural fish yield, i.e. 92 kg/ha. Averaging these data we find that 29 kg of manure were expended per kilogram of increase in the fish yield. Similar results were obtained in the experiments with pig's manure conducted by Havlena (1956) on the ponds of the Czech fish farm "Istebnik". Havlena added 50-130 centners of manure per hectare to each experimental pond and obtained an additional increase in the fish yield ranging from 62-278 kg/ha. The same ponds were fertilized simultaneously with superphosphate containing 15-20 kg/ha of P_2O_5. The author does not say what method he used to calculate the additional increase in the fish yield for the various types of fertilizers. According to his calculations 1 centner of pig's manure ensured an average additional increase of 2.9 of underyearlings or 2.63 kg of commercial carp. On the whole we can say from these figures that the fertilization coefficient of the manure is 35. On the strength of the results of his experiments Havlena considers that up to 50 centners/ha of pig's manure may be added to the ponds during the growing season. Hence, with the aid of manure we can obtain an average increase in the fish yield of not more than 150 kg/ha. Large quantities of manure cause suffocation in fertilized ponds with all its consequences.

Havlena, like Susta, gives figures on the economic advisability of manuring carp ponds in Czechoslovakia. Their calculations showed that the cost of 1 centner of manure, including delivery and its addition to the pond, is approximately half the retail price of 1 kg of carp. But as 1 centner of manure ensures an increase of approximately 3 kg in the /232/ fish yield it is quite obvious that the use of manure in Czechoslovak conditions is economically profitable.

Menzel (1956) summed up the results of the application of pig's manure to commercial ponds on four fish farms in East Germany and discovered that when manure was added to ponds in quantities of 2-10 t/ha one ton of manure ensured an additional increase of 30-40 kg in the fish yield. Hence in this case also the fertilization factor is close to 30. On the other hand Schäperclaus (1961) states that in experiments at Willenbach a one kilogram increase in the yield took up to 300 kg of manure.

In Woynarovich's experiments (Woynarovich, 1956) with fish ponds in Hungary the addition of 1 centner of pig's manure to a pond by the so-called carbon fertilization method was accompanied by an additional increase of some 3-5 kg. The author considers that it is possible to add 40-60 centners of pig's manure to ponds without the danger of causing an oxygen deficiency. Thus with Woynarovich's method too it is possible to increase the fish yield by 120-130 kg/ha.

The data cited show that under the optimum conditions of utilization a one kilogram increase in the fish yield takes 30-35 kg of manure. If we take a ratio of manure to fish yield of 35:1 and assume that the content of total nitrogen in the manure averages 0.6% and that of phosphorus 0.12%, then for an increase in yield of 1 kg we will have to apply 0.21 kg of nitrogen and 0.042 kg of phosphorus in the manure. These amounts correspond to 0.6 kg of ammonium nitrate and 0.57 kg of superphosphate. It is extremely interesting that with artificial nitrogen-phosphorus fertilizer, as was shown above, 2-4 times more nitrogen and phosphorus fertilizer are required per unit of additional increase in the fish yield.

The more effective use of the nitrogen and phosphorus in the manure compared with the mineral salts is apparently /233/ due to a number of causes. Firstly, the nutritive elements of the manure are included generally in the cycle, as the manure decomposes, and therefore combine to a lesser degree with the bottom sediments. Secondly, it is possible that the manure promotes the mobilization of the material resources of the fertilized pond and their inclusion in the biological cycle. Thirdly, owing to the enrichment of the water of the pond with free carbon dioxide as the result of fertilization with manure, conditions are created which prevent a sudden shift in the direction of alkalinity, and this is of great importance to high-production ponds. Fourthly and lastly, as a complex fertilizer manure can be used partially, leaving out the first link in the food chain, through the consumption of the organic material of the manure by heterotrophic organisms serving as the direct food of the fishes, and to some extent even by the fish themselves. The manure added to the pond contains a vast quantity of bacteria which are undoubtedly needed as food by planktonic crustacea and other organisms consumed by the fish. This has been demonstrated repeatedly in many experiments and has also been confirmed successfully by the practice of breeding Daphnia semi-commercially on manure.

All this taken together results in the comparatively high piscicultural effectiveness of manure.

The possibilities of increasing the fish yields of ponds by the application of manure alone are limited by the adverse effect of manure on the oxygen regime of the ponds being fertilized. To avoid the danger of causing suffocation of the fish it is usually inadvisable to add more than 5 t/ha during the growing season. As shown earlier, such a quantity will ensure an additional increase in the yield of not more than 150 kg. Large amounts of manure may apparently be added to the pond if they are combined with mineral salts to form an integrated fertilizer, since the artificial fertilizer helps to enrich the water with oxygen.

Green fertilizer in the form of cut higher aquatic and swamp vegetation has become very popular among pond pisciculturists in the Soviet Union and elsewhere. However, there are hardly any data available for assessing the piscicultural effectiveness of this form of fertilizer. Wide-scale experiments in the use of hard aquatic plants for raising the productivity of ponds on spawning and breeding farms /hatcheries/ in the Volga delta were not accompanied by an estimate of the quantity of vegetation cut for fertilizer (Karzinkin, 1952). The experiments of M.M. Isakova-Keo (1954), which were conducted with little ponds on a small scale can give only a very rough idea of the effectiveness of plant fertilizer on its own, as in these experiments /234/ many other organic substances were used as well as the plants. According to the data of Isakova-Keo, an average of 72 kg of green vegetation was used per kilogram of additional increase in the fish yield.

The conclusion arrived at by the research workers at VNIIPRKh /All-Russian Pond Fisheries Research Institute/ that the higher aquatic plants are no less effective than manure as fertilizer seems to us to be insufficiently substantiated. This conclusion was based on a small number of experiments on a few ponds designed to study integrated fertilization and conducted under the supervision of V.M. Il'in.

Judging by the data on the composition of the higher aquatic plants and taking into account the results of several experiments in their use and the cultural effectiveness of manure, we can assume that in the optimum case a 1kg additional increase in the fish yield will result from the addition of 50-80 kg of higher aquatic plants as green fertilizer. But when we turn to the use for fertilization of higher aquatic plants cut from the ponds themselves calculations are less important, since, unless the amount of the plant growth in the ponds is limited, intensive farming is generally impossible. It is a different matter when, without due grounds, it is suggested that twigs of trees and shrubs be provided for raising the yield of commercial ponds (Isakova-Keo, 1947, 1950, 1954). In this case it should be clearly understood that for a 1 kg increase in the yield at least 5 tons of the green fertilizer will have to be prepared and delivered to the pond (and after the leaves have fallen off they will have to be removed from the pond).

From what has been said it can be concluded that even the use of green vegetable fertilizer alone cannot produce an increase of more than 150-170 kg/ha in the yield since large quantities of decaying plants, like manure, will cause an oxygen deficiency.

One of the more complex problems is the estimation of the piscicultural effectiveness of the combined use of artificial and organic fertilizers, firstly because of the diversity of the combinations of different fertilizing substances in the complex fertilizer and secondly because only a few of the published papers can be used for such an estimate (the remainder do not contain the necessary information). Apparently the

simplest and oldest type of combined artificial and organic fertilizer is superphosphate and manure. This gained wide currency in Europe with the development of the carp industry and is still being used.

On the basis of the results of fertilization with /235/ superphosphate and manure of 17 carp ponds in Czechoslovakia, Susta (1953) estimated that an average of 1.84 kg of superphosphate and 12.8 kg of manure was expended for a 1 kg additional increase in the fish yield. In the same paper the author states that when the ponds were fertilized with superphosphate alone in suitable quantities (up to 250 kg/ha) the expenditure of fertilizer per kilogram increase in the yield was 2.22 kg. It should also be remembered that when manure was used on its own in Czechoslovakia nearly 35 kg were expended per kilogram of increase in the yield. From these data it follows that in combined manure and phosphorus fertilizer the superphosphate is used just as effectively as in nitrogen-phosphorus fertilizer. Another Czech research worker - Havlena (1956)-to stage experiments in the fertilization of ponds with manure and superphosphate lays special emphasis on the fact the manure in this combination is a source of nitrogen.

Combined fertilization with superphosphate and manure in Czechoslovakia results in an additional increase in the fish yield of 100-150 kg/ha. Similar results are obtained in pond-fish cultural practice in East Germany and Poland.

A combination of superphosphate and higher aquatic vegetation was tested in the research conducted by VNIIPRKh under the supervision of V.M. Il'in at the Zagorsk experimental station in the Moscow region. 150 kg/ha of superphosphate and up to 6 tons of higheraquatic plants were added to the ponds. In these experiments a 1 kg increase in the fish yield took 1-1.5 kg of superphosphate and 18-35 kg of plant fertilizer. The yield from the ponds fertilized in this way was 243 kg/ha, 15 kg/ha of which was due to the fertilizer. In this case also the vegetation evidently went some way towards satisfying the nitrogen requirement of the ponds. The expenditure of phosphorus fertilizer proved to be close to the figure for combined nitrogen and phosphorus fertilization. In these experiments more complex combinations of organic and artificial fertilizers were also tried, but in all cases without mineral nitrogen. For example, in one instance the ponds were fertilized with manure, aquatic plants, vegetable flour, superphosphate and lime. As a result the yield, according to the calculations of the authors, was increased by 98 kg compared with the unfertilized ponds (Il'in, Lipin et alia, 1956).

A complex combination of fertilizing substances was also tested for the fertilization of carpponds in Latvia. In these projects, which were conducted in 1956 and 1957 under the supervision of V.I. Zhadin, use was made of a combination of aquatic plants and mineral salts of phosphorus, nitrogen, potassium and calcium (Zhadin, 1959; Pankratova, 1958). From

the published results we can estimate that a one kilogram /236/ increase in the fish yield required 8-18 kg of green vegetation, 1.3-3 kg of superphosphate, 2-4.5 kg of ammonium sulphate, 0.5-1.1 kg of lime and 0.16-1 kg of potassium chloride.

Above all it should be mentioned that the amounts of nitrogen and phosphorus artificial fertilizer expended per unit of additional increase in the fish yield are roughly the same as when nitrogen-phosphorus artificial fertilizers are used on their own (Vinberg, 1958; Fel'dman, Prosyanii and Sukhovii, 1961; Lyakhnovich, 1963a). The addition of lime and potassium chloride to the nitrogen-phosphorus fertilizers failed in this particular instance to result in a drop in the expenditure of nitrogen and phosphorus per unit of additional increase, and so did the addition of the vegetation. Therefore it is difficult to understand the advantages of such an elaborate combination as against nitrogen-phosphorus artificial fertilization, particularly as the absolute yields proved to be within the range of 148-300 kg/ha, while the maximum increase in the yield due to the complex fertilizer was 22 kg/ha (including stickleback). The fact that the broad complex of fertilizing substances failed to bring about a drop in the expenditure of the main nutritive elements (nitrogen and phosphorus) per unit of additional increase in the fish yield shows that under the given conditions the potassium fertilizers and lime were not essential elements in the complex and proved ineffectual.

On one of the experimental ponds in Belorussia the following complex of fertilizers was tested: manure, superphosphate and ammonium nitrate (Lyakhnovich, 1963a). The increase in production due to the fertilizers was 565 kg/ha, while the expenditure of artificial fertilizer per unit of additional increase in the yield was half of that obtained in the experiments where artificial fertilizers were used alone. Thus, while on average for four ponds with artificial fertilizers 1.34 kg of superphosphate and 1.93 kg of ammonium nitrate were expended to achieve a 1 kg increase in the yield, in the experiment with the complex of nitrogen-phosphorus artificial fertilizer and manure only 0.49 kg of superphosphate and 0.71 kg of ammonium nitrate and roughly 5.5 kg of manure were required to attain the same result. Naturally, only general conclusions can be drawn from this, but it is possible to suppose that the combination of organic fertilizer and artificial compounds of nitrogen and phosphorus will prove the most effective and economical method of raising the fish yield of ponds.

In the aforementioned example of combined nitrogen-phosphorus-manure fertilization its great effectiveness can only be ascribed to the stimulating effect of the manure on /237/ the use of mineral compounds of nitrogen and phosphorus. It is absolutely impossible that 5.5 kg of manure could in itself ensure a 1 kg increase in the fish yield. At the same time even this small quantity of manure brought about a sharp reduction

in the expenditure of artificial fertilizer per unit of additional increase. The total cost of the mixture of fertilizers expended per kilogram of additional increase in the fish yield was less than 10 kopecks. This is five times less than the cost of the equivalent amount of artificial foods usually used in pond piscicultural practice as one of the principal means of intensifying the growth of fish production.

In view of the great practical and theoretical importance of the effect achieved through the application of relatively small doses of manure in combination with nitrogen-phosphorus artificial fertilizer it is highly desirable to test these data under different conditions in different soil and climate zones.

Further work on the problems of increasing the fish yields of ponds by fertilization methods must be directed towards a search for the most effective and economically profitable combinations of fertilizing substances and zoning of these combinations according to the areas of our country in which pond-fish culture has developed.

Although with such forms of fertilization as the keeping of waterfowl on ponds or the drainage of waste water into them, it is, strictly speaking, impossible to estimate the expenditure of fertilizing substances per unit of additional increase in the fish yield, it is interesting to determine to what extent these fertilizers raise the yield.

Even the earliest experiments in the breeding of ducks on carp ponds, which were conducted in the twenties in the Soviet Union and Germany, revealed the effectiveness of combined carp and duck culture. Later in different countries appropriate norms were devised for the keeping of ducks on different types of ponds research in the field of combined fish and duck culture continues unabated even today. Particular attention is being devoted in East Germany and Czechoslovakia to improving the biotechnics of keeping ducks on fish ponds.

In the Soviet Union the experiments conducted by B.I. Cherfas and P.I. Orlova (1935), B.I. Cherfas and G.A. Zernyshko (1946), N. Kuznetsov (1940), A.E. Semenyuk (1965) and other authors have shown the possibility of doubling or trebling the fish yield by keeping ducks on ponds. It was found that the breeding of 150-250 ducks per hectare of pond results in an increase in the yield of 100-200 kg/ha or more.

In Czechoslovakia combined carp and duck culture developed only in the post-war years. The experiments of Frcek (1957), Janecek and Janecek (1958) and other research workers yielded wonderful results. They demonstrated that the breeding of ducks produces the greatest piscicultural effect on the worst and most unproductive ponds. Thus, for example, in two ponds which prior to the keeping of ducks had yielded 43 kg/ha each of fish the yield rose to 566 kg/ha, i.e. almost 14 times, when combined carp and duck culture was introduced.

Ponds with a higher initial yield are less responsive to the keeping of ducks, while those which are heavily saturated with substances from other sources fail to show an increase in yield as the result of the keeping of ducks. The best results are obtained on ponds relatively small in area.

On the whole the data of the Czech authors demonstrate the possibility of increasing the fish yield to 450-500 kg/ha through combined carp and duck culture.

In East Germany in the past ten years the accommodation of ducks on large fish ponds has become very common. The ducks are fed directly in the filled pond from specially equipped platforms. Judging from the published data (Thumann, 1955a; Blume, 1958, 1960; Wundsch, 1960; Eppel, 1961), this method of keeping ducks on ponds brings about a striking improvement in the economic performance of the fish-breeding unit in combined carp and duck culture. The authors also note the great piscicultural effectiveness of the method; the fish yield is doubled.

For pond culture practice it is particularly important that combined carp and duck culture should give good results on neglected unproductive ponds, for which other methods of raising the output would probably be less effective.

The density of stocking should not exceed 150-200 per hectare of filled pond area. With this density of stocking it is possible to raise two batches of ducks on finishing ponds during the growing season. Higher densities rapidly lead to congestion of the ponds with organic matter and excessive pollution, which may cause suffocation.

The great piscicultural effectiveness of the utilization of domestic sewage has been demonstrated by the experience of a number of German towns. Particularly widely known is the fish farm in Munich, where the fish yield of the ponds as the result of this form of fertilization was on average 500 kg/ha /239/ (Demoll, 1937; Scheuring, 1939).

The experiments of V.A. Meien (1932) on the purification ponds of Lyublino near Moscow showed the possibility of obtaining up to 500 kg/ha of fish farm from 1 hectare of pond filled with undiluted waster water which had undergone self-purification in the upper sections of the series of ponds.

Splendid results were yielded by the experiments of Wolny (1962) in Poland, where the ponds were supplied with purified waste water from the town of Kielce. In the most successful of this series of experiments 1317.7 kg/ha of commercial carp and crucian carp were obtained, i.e. eight times more than in the unfertilized ponds.

As was shown by the research of Czech authors (Pytlik, Svec, 1954; Pytlik, Dusek, 1956; Pytlik, Votava, Benes, 1954; Pytlik, 1957), the drainage into ponds of waste water from dairy factories and sugar refineries, slaughterhouses and meatworks under adequate safeguards (see Chapter IV) enables a yield of

up to 500 kg/ha to be obtained. The piscicultural effectiveness of the use of domestic waste water in ponds is probably due to the fact that the water is a form of combined fertilizer. Waste water, especially when it has undergone some degree of purification, contains a large quantity of nutrients in a form accessible to the green plants of the plankton and, furthermore, much easily oxidizable organic matter.

Obviously the overloading of fish ponds with waste water is just as impermissible as overloading with any other type of organic fertilizer.

Domestic waste water is a huge and continually growing reserve for raising the fish yield of ponds, and at present it is not being fully exploited in pond cultural practice.

All that we have said above brings us to the conclusion that it is the combined fertilizer which will in time become one of the principal means of increasing the fish yield of ponds. The search for the best combinations of fertilizing substances was begun only quite recently, but already in many cases the results are very encouraging. For the different soil and climate zones and different subjects of culture the most suitable combination of fertilizer must be worked out for the given conditions.

4. Fertilization Requirements of Pond Pisciculture

Owing to the sharp rise in the output of artificial fertilizers planned by the Central Committee of the Soviet Communist Party and government to intensify the production of food products the possibilities for using these fertilizers /240/ to raise the natural fish yield of ponds in the Soviet Union have greatly increased. On the basis of the material set out in the previous parts of this book we can formulate certain general practical recommendations on the application of fertilizers in pond farming and suggest methods of controlling their use.

For a rise in the natural yield fish ponds everywhere require fertilization with nitrogen and phosphorus, and these are most effective when used together.

Experience of the combined use of nitrogen and phosphorus fertilizers in many regions of the Soviet Union and in foreign countries enables us to conclude that the optimum ratio of nitrogen to phosphorus in a mixed artificial fertilizer is between 4:1 and 8:1, i.e. for one part by weight of pure phosphorus there must be 4-8 parts by weight of pure nitrogen. In terms of normal superphosphate and ammonium nitrate, which are the most widely used fertilizers in the Soviet Union, this means 1:1 by weight for a ratio 4:1 for pure elements or 2:1 for a ratio of 8:1 for pure nitrogen and phosphorus.

In pond piscicultural practice nitrogen fertilizers

began to be used only quite recently, and so far insufficient experience has been acquired of their use in conjunction with phosphorus fertilizers for us to be able to specify the optimum ratios of nitrogen and phosphorus in relation to the conditions of the various soil and climate zones in our country. However there are no grounds as yet for thinking that these ratios may diverge substantially from the limits indicated above.

Pointers on this problem can be taken from the analysis made earlier of the mechanism of the phosphorus and nitrogen cycle (see Chapter II). Thus, for example, as was shown, the combination of phosphorus in ponds depends heavily on the degree of mineralization of the water, particularly the active reaction (pH) of the water and the soil. Obviously, in conditions faciliting the combination of phosphorus (high mineralization of the water and an alkaline reaction or, on the contrary, an acid reaction in water with low mineralization) the optimum ratio of nitrogen to phosphorus will vary upward in the first case and downward in the second. Possible sources of nitrogen in artificial fertilization of ponds are ammonium nitrate, ammonium sulphate, ammonia water, ammonia liquor, carbamide (synthetic urea) and others. The most commonly used substances in our country are ammonium nitrate, containing 35% pure nitrogen and ammonium sulphate containing 20.5-21.0% nitrogen. In practice both forms of nitrogen fertilizer are used for the fertilization of ponds. So far no reliable experimental data are available on the comparative effectiveness of the different forms of nitrogen artificial fertilizers. For calculation of the quantities when one is replaced by another we must /241/ take the percentage content of the active principle (nitrogen) in them and work from there. For example, if it is necessary to substitute 1 centner of ammonium nitrate for a quantity of ammonium sulphate containing an equivalent amount of nitrogen we have to make the following calculation: 35:21×100 =166. This means that 166 kg of ammonium sulphate are equivalent to 100 kg of ammonium nitrate.

As may be imagined, a highly effective nitrogen fertilizer in pond-fish culture is ammonium carbonate, which successfully combines in its composition two essential elements in the mineral diet of the phytoplankton, i.e. nitrogen and carbon. The first experiments with ammonium carbonate for the fertilization of carp fry ponds yielded very good results. Of special interest in the future for pond-fish culture will undoubtedly be liquid highly concentrated nitrogen fertilizers, for example ammoniates. The production of liquid nitrogen fertilizers costs nearly half as much as that of solid fertilizers and this may considerably increase the profitability of their use in pond-fish culture. At the same time the~~ir~~re would be a reduction in the outlay on the preparation of fertilizers for addition to the ponds in a liquid form and the problem of the mechanization of the process of adding the fertilizer to the pond would be simplified.

The sources of phosphorus used for the fertilization of ponds are simple superphosphate containing 6.5-8.5% pure phosphorus, double superphosphate (19.8-21.7% P), precipitate* (16.6-17.4% P) and phosphorite flour (8.3-10.0% P). The last two forms of fertilizer contain phosphorus which is not soluble in water but will dissolve in weak acids, therefore their use is recommended in ponds with an acid reaction of the water and bottom.

Unlike agriculture, in which granulated forms of phosphorus artificial fertilizers are being used more and more widely, pond-fish culture requires friable forms of fertilizer which are easily mixed with water and dissolved in it. Therefore it is not a good idea to attempt to add granulated superphosphate to a pond, particularly as it costs more than simple superphosphate and may even be somewhat less effective, since the large grains settle on the bottom of the pond sooner and the phosphorus combines with the bottom sediments (see Chapter II).

In handbooks on phosphorus fertilizers and instruction sheets the content of the active principle is usually expressed not in terms of pure phosphorus but in terms of P_2O_5. This figure can easily be converted to pure phosphorus, remembering that the atomic weight of oxygen is 16 and that of phosphorus 31. As in the case of the nitrogen fertilizers, it would be highly desirable to have phosphorus fertilizers in a liquid form, but so far such a form is not available. With the development of intensification of pond-fish culture through

* a type of phosphate fertilizer

the application of artificial fertilizers local industry will be faced with the problem of producing fertilizer mixes specially for this purpose. The material examined in the preceding chapters of the book allows us to conclude that the best form for such a mix would be a liquid concentrate with an N:P ratio ranging from 4 to 8, a pH reaction close to neutral and easily soluble in water.

So far the potassium fertilizer requirements of ponds have not been demonstrated, and there are no grounds for classing potassium as one of the active principles in artificial fertilization of ponds. At least, at the present level of productivity of ponds potassium does not occur in minimal quantities and does not limit the further growth of production.

The liming of ponds is of trememdous importance as a preparatory measure for effective utilization of artificial fertilizers on ponds with an acid reaction of the water and soil. But in spite of this, there are no grounds for numbering calcium or lime among the active principles of fertilizer proper.

To increase the production of ponds artificial fertilizers should be added to the water of filled ponds in fractional doses in the form of a solution. This recommendation is based on the results of experimental work performed by VNIIPRKh, Ukr NIIPRKh, BNIIPRKh and other piscicultural institutes, and correspond to the instructions issued by these institutes for commercial farms. The experience gained in the application of artificial fertilizers on pond-fish farms in the Soviet Union and foreign countries confirms the correctness of these recommendations.

Fertilization of ponds should begin 15-20 days before stocking and terminated 30-35 days before the ponds are drained for harvesting. Usually it is advisable to add the next dose of fertilizer at the beginning of the season at least every 7-10 days, while in the second half of the season it is possible to reduce the frequency to, say, twice a month. If the fertilizer leads to the development of intensive water bloom, it should be applied less often or even not at all for a certain time, after which applications may be resumed if the water blomm declines or the oxygen regime of the ponds is impaired.

When fertilizing ponds it is inadvisable to aim at holding the concentration of the active principle at some predetermined fixed level, since this results in excessive expenditure of fertilizer. The fertilizer requirements of a particular pond on a fish farm can be determined by the method of biological testing as described in chapter III, while it is possible to judge from the results of measurement of the primary production or from the degree of development of phytoplankton whether it is necessary to add to a pond those nutritive elements to which plankton reacts positively. /243/

When nitrogen-phosphorus artificial fertilizer is correctly applied the fish yield of both nursery and finishing ponds increases at least 3-5 times. When ponds in different zones have different natural (initial) fish yields the absolute increase in the fish production as the result of fertilization when the fish yield increases (by a factor of 3-5) will vary (table 15).

Table 15

Зоны рыбоводства по данным ВНИИПРХа, Гидрорыбпроекта и др. 1	Исходная продуктивность, кг/га 2	Продуктивность при удобрении, кг/га 3	Потребность в удобрениях, кг/га 4	
			суперфосфат 5	аммиачная селитра 6
a Северная европейская	70—80	200—300	300—400	350—450
b Северная сибирская	70—80	200—300	300—400	350—450*
c Северо-западная	80—120	300—400	400—550	450—600
d Центральная нечерноземная и восточная	120—160	400—500	500—600	550—700
e Центральная черноземная и юго-западная	160—220	500—600	550—700	650—800
f Южная европейская	220—250	600—700	600—800	700—1000
g Среднеазиатская	250—300	700—850	700—1000	850—1200*

Key: 1. Fish-breeding zones according to the data of VNIIPRKh, Gidrorybproekt and others: a - North European, b - North Siberian, c - North-West, d - Central non-black earth and eastern, e - Central black-earth and south-western, f - South European, g - Central Asian.
2. Initial productivity, kg/ha.
3. Productivity with fertilization, kg/ha.
4. Fertilizer requirements, kg/ha.
5. Superphosphate.
6. Ammonium nitrate.

* i.e experimental data

In the conditions of experimental ponds a 1 kg additional increase in the fish production (of carp) requires the expenditure on average of roughly 0.5 kg of nitrogen and

some 0.15 kg of phosphorus, corresponding to 1.5 kg of ammonium nitrate and 1.5 kg of superphosphate. The use of fertilizers on a broad scale in large commercial ponds before the work has been adequately mechanized may at first prove less effective than the fertilization of small experimental ponds. Furthermore, the piscicultural effectiveness of fertilization, i.e. the additional increase in fish production resulting from the expenditure of fertilizer in carp culture will evidently depend to some extent on the climatic conditions, and it is likely that in the warmer southern regions its effectiveness will be somewhat greater than in the north. But as already pointed out this problem has not yet been thrashed out in connection with combined nitrogen and phosphorus fertilization. Therefore for all the zones of warm-water pisciculture we can on average assume an expenditure of /244/ approximately 1.5-2.5 kg of ammonium nitrate and 1.5-2 kg of simple superphosphate per kilogram of additional increase in fish production. When calculating the various soil and climate zones where pisciculture is practised in the Soviet Union, we proceed from the maximum values.

There can be no doubt that with systematic fertilization of ponds the piscicultural effectiveness of the fertilizers will be much higher owing to improvement of the methods of application and the use of forms of artificial fertilizers most suited to the needs of the ponds, just as the effectiveness of phosphorus fertilizers was enhanced when they were combined with nitrogen fertilizers.

Of great value in increasing the effectiveness of fertilization will be the combined use of organic and artificial fertilizers and the after effect of systematic fertilization of ponds. When both organic and artificial fertilizers are available on a farm the organic fertilizers must be used on spawning ponds, nursery and finishing ponds right at the beginning of the growing season. The further use of organic fertilizers should be carefully harmonized with the oxygen regime of the ponds (see chapter IV). The use of organic fertilizers should be carefully controlled in ponds where the fish are fed systematically on loose concentrated foods of vegetable origin, creating a heavy load of easily oxidizable organic substances. In such ponds the possibilities of applying organic fertilizers without artificial fertilizers in the middle and second half of the summer will be sharply restricted by the low content of oxygen in the water. In these conditions, as shown in chapter III, the use of artificial fertilizers will help to create a significant improvement in the situation. Consequently, the fertilization of ponds as a method of intensifying fish culture not only does not exlcude the feeding of the fish but, on the contrary, paves the way for a more rational utilization of artificial foods.

5. The Place of Fertilization in the System of Intensification of Pond-Fish Culture

The intensification of pond-fish culture involves a system of measures leading to an increase in the fish yield per unit of area during a given space of time.

An increase in the output of fish production per unit of area of the pond being exploited can be achieved in two different but interconnected ways: firstly, by improving the productive properties of the pond itself through amelioration, agrotechnical preparation of the bed, restriction of the /245/ growth of its higher aquatic vegetation, aestivation and fertilization, and secondly, by more effective use of the material and energy resources of the pond (breeding of more productive varieties of fish making better use of the stocks of food, as reflected in greater growth; the use of stocks of fish of various ages and mixed species (polyculture); improvement of the biotechnics of fish culture).

The two methods of intensification are complementary and in practice are used simultaneously. A special place in the system of intensification is occupied by the feeding of fish on foods introduced from outside.

The fertilization of a pond ranks among the first group of measures which are designed to mobilize the material and energy resources of the pond, intensify the processes of the cycle of substances, and increase the mass of material participating in this cycle.

Amelioration of the ponds is an essential prerequisite for any fertilization in any form. Piscicultural amelioration ensures the optimum hydrological regime in the ponds, prevents excessive silting and overgrowth, creates the necessary water and air conditions in the soil of the bed, and so on. Swampy fish ponds with an acid reaction of the water and bottom require, in addition to other ameliatory measures, liming preparatory to the effective use of fertilizer.

All authors who have worked on the problem of pond fertilization are unanimous in emphasizing that fertilization is ineffectual or useless in poorly ameliorated, overgrown and swampy ponds. Work on intensification of fish culture in such ponds must begin not with fertilization but with amelioration, which radically improves the life of the fish and results in increased fish production. Moreover, it creates favourable conditions for a further rise in the productivity of the ponds through fertilization.

Overgrowth of ponds with higher aquatic vegetation sharply limits the possibilities of effective use of fertilizer. The complete ineffectiveness of artificial and most forms of organic fertilizer in heavily overgrown ponds can be considered finally proved. The fertilization of such ponds with mineral salts, manure, compost etc. is often accompanied not by an increase but by a drop in the level of fish production, since the nutritive substances introduced with the fertilizer are consumed by the higher aquatic plants, and this merely leads to an intensification of plant growth.

In ponds choked with higher aquatic vegetation only those forms of fertilization can be used which are accompanied /246/ at the same time by the necessary ameliorative effect. This

includes the breeding of waterfowl and nutrias, and the application of green fertilizer consisting of plants cut from these ponds. The eating of shoots and trampling of plants by ducks, and the stirring up of bottom sediments by them, and pollution of the water with their excreta, limit the development of clumps of macrophytes, and this in itself has a beneficial effect on the productivity of the pond. The fertilizing effect of the excreta enhances the piscicultural effect of duck husbandry on overgrown ponds. The keeping of nutrias in numbers of up to 20 per hectare on ponds heavily overgrown with higher aquatic vegetation for one or two growing seasons completely frees the pond from overgrowth. Although the fertilizing effect of the excreta from such a number of animals is insignificantly small, as was shown by Wiltowski (1958) in experiments on fish ponds in southern Poland, the fish productivity of the ponds increases by a factor of 2.5-3. Nutrias, in addition to destroying the overgrowth, constantly loosen the bottom sediments, and this helps to mobilize the nutritive substances and include them in the cycle.

The systematic cutting of hard overgrowth also has a beneficial effect on the fish productivity of the ponds. The effectiveness of this measure is enhanced when the plants removed are used as green fertilizer in the same ponds. The pond thereby regains the nutritive substances which were expended on the growth of the higher aquatic vegetation.

Aestivation of the ponds may be an effective way of raising fish productivity, but only when it is accompanied by drying and agrotechnical treatment of the bottom. The mere discharge of water from a pond without adequate drying of the bottom, or further effort to till the bottom, usually brings harm rather than good. The drying and tilling of the bottom of an aestivating pond is, first and foremost, a radical method of suppressing the higher aquatic vegetation, and it also helps to mobilize the nutrients in the bottom sediments by accelerating the process of their mineralization. The piscicultural effect of aestivation is greatly increased by sowing the bottom with plants as green fertilizer.

When the bottom of an aestivation pond is used as farm land to increase the size of the crop, it is also possible to apply both artificial and organic fertilizers. Then the type of fertilizer and doses and times of application will be governed by the requirements of the cultivation of the crops and not by the interests of pisciculture. In such /247/ case the type and dose of fertilizer may be quite different from those required in certain circumstances for raising the fish productivity (for example, potassium fertilizer may be necessary, and so on).

The underlying piscicultural aim of aestivation is to mobilize the rich store of nutritive elements bound up in the bottom sediments, therefore it is evidently inadvisable to add fertilizer to the bottoms of aestivating ponds with the idea of

increasing the fish productivity. Fertilizers may be used much more effectively when they are added to the water in ponds filled for fish culture after aestivation.

In ponds which have been improved, cleared of higher aquatic vegetation and correctly prepared, any form of fertilizer may be used. Of course, the best piscicultural effect will be achieved with those fertilizing substances which contain elements which fulfill the needs of the ponds for a particular fertilizer.

As can be seen from the foregoing, the piscicultural effectiveness of fertilization may be enhanced or lowered when its use is coupled with the adoption of other measures designed to raise the natural fish productivity of ponds. In other words, the piscicultural effect of fertilizers is governed by the conditions under which they are employed.

So far only an approximate assessment can be made of the possibilities of fertilization as a means of increasing the yield of fish per unit of area of a pond.

The results obtained under experimental conditions allow us to state with confidence that the use of fertilizers has made it possible to achieve as much as a four to fivefold increase in the natural fish productivity. As the "initial" productivity of the ponds, which is governed by the natural conditions of the different soil and climate zones, varies, so does the absolute level of fish productivity attained as the result of fertilization vary under different conditions. The improvement of the methods of fertilization and the biotechnics of fish culture will undoubtedly enable us to increase the fish productivity of ponds still further.

We have already noted that the maximum effective doses of artificial fertilizer have not yet been determined, since the quantities tested so far, with a correct ratio of the nutrients in the fertilizer, gave an increase in production proportional to the amount of fertilizer expended. While the doses of organic fertilizing substances are limited by the gas regime of the ponds, on which these fertilizers have an adverse effect, this obstacle can be surmounted to some extent by coupling the organic fertilizers with artificial /248/ fertilizers (see chapter III). Therefore it is quite incorrect to contrast the one type of fertilizer with the other, when they can be complementary when used in combination. The combination of organic and artificial fertilizer into a complex fertilizer undoubtedly makes it possible to increase significantly the effective doses of both. The main efforts of piscicultural research institutes and practising pisciculturists must be directed towards the solution of this problem in relation to the actual conditions of the various soil and climate zones of the Soviet Union.

Another important task is the large-scale application of the results achieved under experimental conditions. This

necessitates the solution of a number of complex technical problems involved in providing farms with the necessary range and quantity of fertilizers, in mechanizing the application of fertilizers to ponds over large areas, and so on.

The collaboration of piscicultural scientists and fish breeders will ensure further successes in increasing the fish productivity of ponds. The first task consists, on the one hand, in developing and perfecting the theory of fertilization, producing complex fertilizers and devising ways of using them under the conditions of the different zones and region, and, on the other, in bringing fish ponds to a state of culture where they will most effectively pay for the fertilizer expended on them in the form of an increased yield from every hectare of pond surface.

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CONTENTS

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