THE PRODUCTION OF FRESHWATER FISH FOR FOOD
by
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(Freshwater Biological Association)

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by

and E. B. Worthington, M.A., Ph.D.

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It has been estimated that in England and Wales fresh water covers some 340 square miles of which about one quarter is inhabited mainly by salmon and trout; in Scotland the lakes cover an area of 340 square miles. The total acreage of fresh water is thus small and it cannot make a large contribution to the nation's food supply, but, since war-time policy is to make use of every available piece of the country for food production, inland waters should not be neglected, especially as they can be made to yield crops with little labour.

The principal object of this publication is to make available in handy form some of the methods, especially those involving the use of manures, by which crops of fish from water can be increased. The cultivation of water which this implies may be compared directly to the cultivation of farm land: the conditions for growth are made as favourable as possible, the seed is sown in the form of young fish, and after one or perhaps two growing seasons the crop is harvested. There are however many waters about the country where marketable fish are already available and can be removed without prejudice to, and indeed to the advantage of, sporting fisheries. In such cases it is necessary only to remove the fish and to rely on the natural processes of reproduction of those which are left to repopulate the water. Farming waters in the true sense is the concern of the greater part of this publication; the removal of crops of otherwise unwanted fish is considered in the last two sections on perch trapping and eel fisheries.

Cultivation of fish, notably carp, for food is widely practised on the continent, and in Germany it has been the subject of intensive research during the last few decades. The following pages have been written after a comprehensive study of the literature up to 1939. Of 426 original papers and other works consulted no less than 296 were German; the United States of America with 22 papers is third on the list and Great Britain with 9 is seventh. In spite of all this work a great deal about successful fish cultivation remains to be found out. On the continent the erection of special fish farms at some considerable initial cost is found to be a profitable investment. It is doubtful whether this would pay in Britain, so the present paper is written more with a view to exploiting existing lakes, ponds, disused quarries, old brick workings and other bodies of fresh water.

There are two important principles which are essential for the production of a good crop of fish, though both of them are usually neglected in this country. The first is that a pond, like agricultural land, cannot be expected to yield a large crop unless it is periodically treated with appropriate fertilisers. The second is that careful attention must be paid to cropping if fish of a good size are to be obtained. If the population is allowed to become excessive few if any fish have a chance of growing large. It is, for example, roughly true to say that a pond capable of supporting 100 lb. of fish may either contain 100 fish weighing 1 lb. each or 400 fish weighing ¼ lb. each.

Really large cropping rates can only be expected from ponds which can be drained. Such ponds can be stocked with whatever species of fish is desired and the numbers of fish of different age can be arranged so that the greatest advantage is taken of the natural food resources. At the end of the season all the fish are removed; those which are large and have reached the end of the period when growth is rapid are sent to market and the smaller specimens are kept for another season. In ponds which cannot be drained and from which fish can only be taken by netting, it is far more difficult to control the numbers and ages of the different species of fish present and it is not possible to gather the crop so efficiently. Consequently the yield is bound to be smaller. It is in general more difficult to crop a large lake efficiently by netting than it is to crop a small one, but, if no stocking is undertaken, the larger reserves of a large lake will enable it to recuperate more rapidly if over-fished during the war years.
Angling is an inefficient method of cropping since only a proportion of the larger fish, which have reached a size where growth is slow, are removed. Nevertheless angling has to be considered most carefully when planning food fisheries because freshwater fish in Great Britain often have a higher value to the nation for angling than merely as food. Thus a rod caught salmon which would sell on the fishmonger's slab for £1 or £2 has an economic value on average of £5 or £10, made up by land values, rentals, wages, hotel industry, and tackle making. Similarly a trout which would sell for a shilling or two is worth ten or twenty times as much, androach which in peace time would not sell for a penny a piece have a national value difficult to assess in providing recreation for the hundreds of thousands of working men anglers. It is significant that in England and Wales considerably more than a quarter of a million people take out angling licenses from fishery boards each year.

Mortimer made the study of literature on which much of this publication is based. Macan is responsible for the arrangement and for most of the drafting. Worthington has added the two final sections and has edited the whole. We are indebted to a number of people for reading and commenting on the M.S. and especially to Dr. A. Parker, Director of Water Pollution Research in the Department of Scientific and Industrial Research, for re-writing part of the section on sewage fish-ponds.

USEFUL FISH.

The following three species are the most suitable for stocking ponds:

Carp (Cyprinus carpio) is the most extensively cultivated fish on the continent for it grows fast and is a good table fish. It grows best in warm waters and for this reason it is not likely to do as well in this country as on the continent, but it was well known in the days when every large house had its own fishpond to supply the table. In Britain commercial stocks of this fish are low but it is found in many ornamental waters.

Tench (Tinca tinca) is a slow grower but, being hardy, is recommended for ponds where adverse conditions are likely to be encountered.

RAINBOW TROUT (Salmo irideus) is also a slow growing fish compared with the carp but on account of its qualities on the table it is widely cultivated.

Table I. Growth rates of fish according to Schäperclaus (1933).

<table>
<thead>
<tr>
<th>Species</th>
<th>Age</th>
<th>Weight at beginning of growing season</th>
<th>Weight put on during growing season</th>
<th>Percentage likely to die during growing season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carp ...</td>
<td>1 yr.</td>
<td>2 ozs.</td>
<td>12 ozs.</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>2 ,,</td>
<td>14 ,,</td>
<td>32 ,,</td>
<td>2—5%</td>
</tr>
<tr>
<td>Tench</td>
<td>1 ,,</td>
<td>½ ,,</td>
<td>2 ,,</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>2 ,,</td>
<td>2 ,,</td>
<td>6 ,,</td>
<td>2—5%</td>
</tr>
<tr>
<td>Trout</td>
<td>1 ,,</td>
<td>2 ,,</td>
<td>5 ,,</td>
<td>2—5%</td>
</tr>
</tbody>
</table>

Provided there is an adequate supply of food and no overcrowding the growth rates of these three species of fish are not likely to depart very far from the figures given in Table I. Variations may come from (1) differences in temperature and other climatic conditions from place to place and from year to year (2) differences in chemical constitution of the water; “hard” water is generally more favourable than “soft” water, (3) differences in the race or strain of fish: little is known about this subject, but there is no doubt that, with rainbow trout, some races may add weight considerably more quickly than others, when kept under similar conditions.

Other freshwater fish of importance as food include the following:

Brown Trout (Salmo trutta). This species, widely cultivated for sporting purposes, is first rate on the table except occasionally when taken from muddy waters. Its growth rate during the first two years is definitely less than that of rainbow trout, so brown trout are at a disadvantage for rearing in ponds for food.
SALMON (*Salmo salar*) and SEA TROUT (*Salmo trutta*) are in the sea during the years when they are growing most rapidly and they do not come within the scope of the present work.

CHAR (*Squalius cephalus* and related species) is perhaps the most delicate flavoured of all freshwater fish. Char live only in a few deep lakes in the Lake District, Scotland and Ireland where they are taken by angling and were formerly netted for the luxury market. They cannot be cultivated in ponds.

FRESHWATER HERRING or whitefish (species of *Coregonus*) inhabit some deep lakes. The Pollan of Lough Neagh in Ireland is the subject of an extensive net-fishery, and a similar fishery is now established for the Powan of Loch Lomond. Another species, the Skelly which inhabits some of the Lake District lakes is sometimes netted for market. All these species require open water conditions and therefore are unsuitable for cultivation in ponds.

PIKE (*Esox lucius*) and PERCH (*Perca fluviatilis*) are both recommended for eating purposes but since they feed on fish their introduction to ponds where other species are being reared is generally held to be undesirable. Some authors, however, suggest that these two fish should be introduced into ponds which cannot be drained so that they may prevent the population of small fish from becoming excessive, but this is likely to involve a nice adjustment of the balance of nature which may prove difficult to maintain.

In many natural waters in Britain there exist abundant supplies, especially of perch. Their utilisation as food supplies is discussed on page 21.

FISH (*Anguilla anguilla*) is a food fish of first rate importance and is treated separately on page 25.

Coarse fish, other than those mentioned above, are not usually esteemed highly as food though the committee appointed in 1917 to enquire into the position of our freshwater fisheries report:

"Members of the Committee have at intervals during the period of its existence been experimenting with various kinds of fish as food, and have satisfied themselves that there is none of our freshwater fish which cannot be made palatable by some device of cookery, and that nearly all of them are of surprising excellence." Fish taken from muddy localities often have a muddy flavour. This may be removed by keeping the fish alive in running water, or in clean water occasionally changed, for two or three days, by soaking the dead cleaned fish in strong salt solution for some hours or by cooking the fish in vinegar. Recipes for cooking all kinds of freshwater fish are given in a book called "From Creel to Kitchen" by Ambrose Heath, price 2/6.

THE FOOD CHAIN IN NATURAL WATERS.

The vegetation of ponds and lakes consists of rooted vegetation such as the pond weeds and water-lilies and minute floating single-celled organisms which collectively receive the name phytoplankton (fig. I, A). Many of these minute floating plants are too small to be discerned by the naked eye but when present in great numbers they give the surface layers of the water a distinct greenish yellow tint.

The animals of ponds may be grouped into (i) those floating in the water (zooplankton, fig. I, B), (ii) those lurking in the weeds or under stones (fig. I, C) and (iii) those living buried in the mud (fig. I, D). The zooplankton animals are all small, though most...
can be made out with the naked eye, and comprise the water flea (*Daphnia*) and related forms. The inhabitants of weeds and stones are the larval stages of caddis-flies, stone-flies, dragon-flies and Ephemeroptera, all of which are aerial in the adult stage, and the snails, shrimps, haglice, mites, etc. which spend their whole lives in the water. In the mud are found the midge larvae or blood-worms, pea-mussels and the alder-fly larve.

Plants are able to build up water and carbon dioxide into sugar and starch using the sun as a source of energy. They also need to build up proteins for which they require certain elements such as nitrogen and phosphorus in compound form as nitrate, phosphate, etc. Water is present in unlimited quantity and it is seldom that there is insufficient carbon dioxide to fulfil the requirements of the plants, but the amount of nitrate, phosphate and similar substances is often extremely small, and it is the supply of these salts which limits the amount of life produced in any body of water. Algae, living either free in the water (phytoplankton) or attached to the bottom and submerged objects, provide the main source of food for the zooplankton and other very small animals. These are eaten direct by the young of most fish and by some fish throughout life; they are also eaten by the larvae of insects which themselves, directly or indirectly, provide food for fish. Thus fish depend ultimately on the plants for food; these plants depend on the amount of certain salts available. Making good deficiencies in the natural supply of salts is often the most satisfactory way of increasing the productivity of a lake or pond.

Most of the coarse fish feed to some extent on vegetable matter, but it seems to be essential that a good supply of animal food should be available if they are to show satisfactory growth. The salmonid fishes (trout, etc.) feed almost exclusively on animals. Different species of fish have different feeding habits; carp for instance, feed mainly on or near the bottom while tench take snails more readily than anything else if these are available. Further the same species of fish feeds on different organisms at different stages in its life, in general eating larger organisms as its own size increases. On the whole, however, the data on this subject are rather inadequate and the significance of the various invertebrate organisms in the food chain also requires much further investigation. It is clear that some animals are of little value because they are unpalatable or because they live in situations where they are not available to the fish. Others, such as water-beetles, are undesirable because, being carnivorous, they compete with the fish for food and may even prey on the fish fry. All insects which are aerial as adults (caddis-flies, dragon-flies, Ephemeroptera, etc.), build up their bodies from substances available in the water, and when they emerge and fly away they remove these substances from circulation. Theoretically, therefore, animals which are aquatic throughout life are preferable to those which are aquatic only in the immature stages, but, until more is known, the invertebrate fauna of a fishpond must of necessity be left largely to providence. It would in any case be difficult to control since most forms invade new habitats with the greatest of ease. Snails and shrimps, however, may profitably be introduced though attention must be paid to the ecological requirements of the different species. For instance the Wandering Snail (*Limnaea peregra*) will thrive in almost any water but the larger species such as the Great Pond Snail (*Limnaea stagnalis*) or the Ramshorn (*Planorbas corneus*) will not survive in waters where there is a deficiency of lime. Similarly the shrimp (*Gammarus pulex*) will not thrive in very soft waters though in Ireland the related species, *Gammarus duebeni*, is abundant in peaty loughs.

The provision of places in which these animals are protected from attack by fish and birds and which will act as reservoirs from which the rest of the pond may be colonised is often recommended. Such places are shallow bays protected from water and air by wire-netting, or broad flat areas in the inflow stream planted with water-cress and similar vegetation.

The pond bottom. The nature of the bottom is extremely important in the biology of a body of water. Large numbers of the plankton organisms and some of the insect larvae and fish die and fall to the bottom of the pond. Here their bodies decompose into the simple salts from which they were originally built up and these salts are available once more to the plants. On a good bottom decay is rapid, while on a poor bottom decay is slow. The good bottom has the further advantage that the products of decomposition are absorbed and held by the mud and are given off slowly over a long
period. This property is of the first importance when fertilisers are
applied; the effect of fertiliser spread on a good bottom may last
for more than a year, but fertiliser spread on a poor bottom is not
held and the greater part of it may be washed out of the pond before
any use has been made of it.

Though they grade into one another, three types of bottom
may be distinguished:—

1. Inorganic bottoms of gravel, sand or clay. This type is
poor; it may be improved by the application of stable manure
or sewage sludge.

2. Mud bottoms. A mixture of organic matter from the dead
bodies of animals and plants and inorganic matter in a fine state of
division (silt) forming a soft black mud is the most productive
type of bottom.

3. Peaty bottoms. These, formed by the accumulation of
vegetable débris which has not decomposed, are barren. The
application of large doses of lime (see table III) may bring about
decomposition and result in a great increase in fertility.

**PRODUCTIVITY OF NATURAL WATERS.**

Soil conditions, nature of the dissolved substances in the water,
and temperature, all factors important in the cultivation of fish,
vary greatly in different parts of the country, so it is difficult to lay
down any rules by which the productivity of a pond may be assessed.
Table II will, however, serve as a rough guide to the crops to be
expected from different types of untreated natural waters. The
figures are based on German experience of ponds stocked with one
year old carp (Schäperclaus, 1933). They are likely to be appreciably
lower in this country, on account of the lower average summer
temperature. For trout the figures should be reduced to less than
one-half (see Table I). It is estimated that pasture will produce
between 5 and 300 lb. of meat per acre per annum according to the
quality of the grassland, so it will be seen that fish culture in ponds
may compare favourably with stock rearing.

<table>
<thead>
<tr>
<th>Class</th>
<th>Nature of water supply</th>
<th>Nature of pond bottom</th>
<th>Annual yield of fish in lb. per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>hard</td>
<td>good</td>
<td>200—400</td>
</tr>
<tr>
<td>2</td>
<td>hard</td>
<td>inorganic</td>
<td>100—200</td>
</tr>
<tr>
<td>3</td>
<td>soft</td>
<td>good</td>
<td>50—100</td>
</tr>
<tr>
<td>4</td>
<td>soft</td>
<td>peaty</td>
<td>25—50</td>
</tr>
</tbody>
</table>

The lowest concentration of calcium for really good production
appears to be about 65 parts per million of calcium carbonate or its
equivalent in other calcium salts; waters with less than this may
be regarded as soft, and waters with more as hard. This does
not coincide with the waterworks engineer's classification, in which
all waters with less than 100 parts per million of calcium carbonate
are considered to be soft.

**METHODS OF INCREASING PRODUCTIVITY.**

The crop of fish which can be produced from a pond may be
increased either by artificial feeding or by increasing the natural
food supply; in war-time the latter alternative is the more important.

*Artificial feeding.* Lupins and soya bean meal are recommended
as the best food for carp and tench; rye, barley and maize are also
satisfactory. Trout should be given chopped fish, offal or horse
flesh with a proportion of biscuit meal.

*Increasing the natural food supply.* The application of chemical
fertilisers is the most feasible way of bringing this about and with
proper treatment an increase of 100% or more should be obtained.
Although intensive research, chiefly in Germany, has been carried
out during the last 20 years, it must be emphasized that the results
have not yet reached a stage where it is possible to lay down rules
for all conditions and the discovery of the most profitable dose must
still be to some extent a matter of trial and error.
The most important point that has come to light is that if a soil is deficient in lime it is useless to apply fertilisers until the lime requirements have been satisfied. When this has been done the pond may be given a dressing of either inorganic or organic manure. The best inorganic manure is phosphate and the addition of potassium has usually been found to be profitable.

The manures should be spread from a boat, if the pond is not dry, as evenly as possible over the surface of the water and particular care must be taken to avoid high local concentrations if there are fish in the water. If it is possible to check the flow of water through the pond, this should be done during manuring and for two or three days afterwards. If it is not possible it may be advisable not to spread the manure on those parts of the pond where the flow is greatest. The fertiliser should not be spread in places where there is emergent vegetation (rushes, reeds and sedges).

**Lime.** Lime may be applied in the form of ground chalk (calcium carbonate), ground limestone (calcium carbonate), slaked lime (calcium hydroxide) or quick-lime (calcium oxide). Calcium carbonate is commonly used, quicklime and slaked lime being reserved for localities where it is desired to kill fish parasites, though in Germany quicklime has been found to have a beneficial effect on peaty ponds which did not respond to treatment with calcium carbonate. Quicklime and slaked lime may be applied to a drained or to a full pond, but in the latter case no stock should be introduced for at least a fortnight as both substances are toxic to fish.

It is important that the amount of lime added should meet the requirements of the pond as nearly as possible; too much as well as too little will mean that maximum production will not be obtained. In general sufficient lime should be added to make the mud and the water just alkaline. The acidity is conveniently expressed in terms of pH; pH 7 is neutral, if the pH is below 7 the water is acid and decreasing pH indicates increasing acidity, while a pH exceeding 7 indicates alkaline conditions. Natural waters are seldom more acid than pH 4 or more alkaline than pH 9. pH can easily be measured by means of a universal indicator, obtainable through any chemist, but the fact that it can be measured so easily has led to an undue amount of significance being attached to it. Table III indicates the dose of lime required by muds of different pH, but where it is possible to have an analysis made, it is better to base the treatment on this rather than on the pH alone.

<table>
<thead>
<tr>
<th>pH of mud</th>
<th>Calcium carbonate required in cwt. per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 4</td>
<td>30—60</td>
</tr>
<tr>
<td>4—4.5</td>
<td>24—48</td>
</tr>
<tr>
<td>4.5—5.0</td>
<td>18—36</td>
</tr>
<tr>
<td>5.0—5.5</td>
<td>15—24</td>
</tr>
<tr>
<td>5.5—6.0</td>
<td>8—15</td>
</tr>
<tr>
<td>6.0—6.5</td>
<td>7—8</td>
</tr>
</tbody>
</table>

If quicklime or slaked lime be used the amounts in Table III should be halved.

**Phosphorus.** The application of phosphate manures has yielded better results than any other treatment and increases in production of the order of 100% have been obtained with it. There are four main phosphate manures on the market:—1, superphosphate, 2, basic slag, 3, bone meal and 4, di-calcium phosphate. Superphosphate is the most and basic slag the least soluble. Basic slag contains up to 50% of calcium oxide and allowance for this must be made when basic slag is being used in conjunction with lime treatment. Superphosphate and basic slag have given the most consistent results.

The dose is 1—1½ cwt. per acre; a heavier dose will result in a further small rise in production but the results will not be commensurate with the initial cost. The manure is usually applied in two doses, the first in May or June, about a fortnight after liming, where this has been necessary, and the second in July or August. Frequent small doses may be necessary where the bottom of the pond is poor and unlikely to retain the salt.
Potassium. The addition of potassium manure to phosphate manure has a favourable effect, particularly on peaty bottoms. Potassium is usually sold as “40% salt,” a mixture of potassium chloride with other salts including sodium chloride, or “kainit,” a Stassfurt natural mineral containing potassium chloride, sodium chloride, magnesium sulphate and other salts. The dose is about ½ cwt. to the acre, the potassium and phosphate manures being mixed for the purpose of application.

Nitrogen. Results of manuring with nitrates and ammonium salts have been very variable, and, as the price is high, the use of these manures is not recommended until more is known of their effects.

Organic manures. Liquid manure, farmyard manure, sewage sludge (see page 20), etc., may all be applied to fishponds with good results, and the last two are particularly recommended for new ponds or ponds with an inorganic bottom (see page 10). The disadvantage of manures of this kind is that they must be applied frequently in small doses because the decomposition of organic matter requires much oxygen, and the addition of a large quantity might result in an oxygen deficit serious enough to prove fatal to fish.

The practice of “green manuring” may be considered here. Ponds are left dry and sown with some crop, usually a leguminous crop, which is ploughed into the soil before the pond is refilled. The merits of this practice are discussed below. Some workers have obtained good results by making compost heaps of water weeds and other vegetation on the bottom of dried ponds.

POND MANAGEMENT AND CONSTRUCTION.

Draining of ponds. In the carp farming industry the ponds are drained in the autumn, so that the crop may be gathered, and are usually left dry all winter. There seems to be general agreement that drying is beneficial; even sewage fishponds, which are required to be in as constant use as possible for the purpose of purifying sewage, are left dry for at least three weeks every other winter. There is less agreement about the advantages of the practice, strongly advocated by some workers, of leaving the pond dry for a whole year and planting lupins, potatoes or clover on the bottom. The advantages are the increased decomposition of organic matter in contact with the atmosphere and the destruction of fish parasites, but whether they outweigh the disadvantages of the destruction of the bottom fauna and the breaking up of the colloidal mud surface layer remains a disputed point.

Control of vegetation. Reeds, rushes and sedges should be removed from a fishpond, but a good development of submerged vegetation is desirable as it oxygenates the water and provides cover for invertebrate life and a spawning ground for some species of fish. Where the growth of vegetation is poor, the provision of shelters of brushwood or heaps of stones for the invertebrate life is advantageous, and this practice is advisable under all circumstances where there is danger from poachers with seine nets. On the other hand an excessive development of vegetation should be controlled as it restricts the “Lebensraum” of the fish, provides such dense cover that fish have difficulty in finding a good supply of food, and may cause serious lack of oxygen when it dies down and starts to rot. The weeds may be cut with a scythe attached to the back of a boat or dragged out with a chain or wire hawser, the latter technique being preferable as it will pull some of the plants up by the roots. Poisoning with a concentration not exceeding 10 parts per million of sodium arsenite may also be resorted to, but only by those experienced in the use of this very poisonous substance. Vegetation removed from an overgrown pond may be dumped in a pond where there is little plant growth, but the same precautions must be observed as with other forms of organic manuring, for if too much is put in, decay, especially in hot still weather, may result in an oxygen deficit fatal to fish. The lowest concentration of oxygen which carp and trout can tolerate is stated by Demoll (1925) to be as follows:

| Table IV. Concentration of dissolved oxygen at which fish are likely to die. |
|--------------------------------|-------------|--------------|
|                              | Long period | Short period |
| Carp  ...  ...  ...          | 2           | 0.5 c.c. O₂ per litre. |
| Trout ...  ...  ...          | 3–4         | 1.5          |
Ice. In severe weather, when gaseous exchange between water and air is prevented by ice, the oxygen concentration in the water may drop below the lethal point and products of decay, especially ammonia and carbon dioxide, accumulate and may become toxic. The process starts at the mud surface and works upwards through the stagnant water. In countries with severe winter climates fish are often lost in large numbers by this so called “winter kill.” In Britain this rarely occurs, but if ice on a shallow fish pond lasts for say a fortnight precautions should be taken by breaking air holes and even by pumping air under the ice. If the ice is clear and there is rooted vegetation below, the water will be oxygenated sufficiently by the plants. The likelihood of winter kill is greatest when snow on top of the ice prevents the penetration of light and when there is dead vegetation decaying in the water.

Raising the water level. Extensive shallows are desirable features of lakes where fish are being cultivated, as they are highly productive and rapidly warmed by the sun, a factor of some importance in carp culture. A lake surrounded by extensive areas of marsh or low-lying ground may, therefore, be greatly improved by a slight increase in the water level. Arrangements should always be made so that the water can be dropped easily to the former level in order to expose the flooded land for treatment.

Control of silting. Some ponds are fed by streams which, when in flood, bring in quantities of silt and débris sufficient to fill up the pond in a comparatively short time. This may be prevented by the construction near the mouth of the stream of a sedimentation tank, through which the stream can be diverted when in flood and which can be cleaned of deposit when conditions have returned to normal.

Pond construction. Land which is too water-logged or too poor for agricultural purposes may profitably be flooded and, with suitable treatment, made to produce a good crop of fish. The most economical site for a pond is a valley of which a considerable area can be flooded by the construction of a dam across the mouth. Watertight dams can be made from most types of soil and it is often practicable to deepen the pond and obtain material for the dam in the same operation. The width of the crown of the dam should be equal to the height and the slope should be 1 in 2 on the inside and 1 in 1 on the outside, though, of course, a dam made of concrete, stone or brickwork can safely be much taller and more upright. The erection of dams above a certain size is subject to certain legal restrictions. The pond should be provided with a screened sluice or cock whereby the water can be drawn off completely, and with water boards at the point of outflow arranged so that the level can be dropped a foot or two without using the draining cock. Cropping is greatly facilitated if it can be arranged that when drained, the last of the water, and the fish with it, collects in a pool just in front of the dam. A device, which is perhaps unnecessarily elaborate, is a square concrete pool with a box of perforated zinc or galvanised iron fitting into it exactly. When draining is finished the entire catch can be removed by the simple operation of hoisting out the box.

STOCKING AND CROPPING.

Table II gives a rough indication of the total weight of fish which a pond of given type is likely to produce in a growing season. Table I gives the annual increase in weight of different kinds of fish at different ages and also the percentage mortality which is to be expected. From a consideration of the two, allowance being made for any increase in productivity due to artificial feeding or treatment with manures, it is possible to calculate the number of fish with which the pond should be stocked. This may be expressed by the following formula:

$$\text{No. fish to be put in} = \frac{\text{Total expected weight of crop (table II)}}{\text{Annual increase in weight of individual fish (table I)}} + \text{Loss (table I)}$$

As different species and different age groups feed on different types of food, the greatest advantage of the natural food supply will be taken if the pond is stocked with a mixture of species and age groups. The following figures for stocking a pond of which the yield is estimated at 100 lb. per acre per annum are suggested as a rough guide.
For the culture of rainbow trout for food supplies the layout of ponds is similar. The chief difference is that instead of the spawning ponds there is a hatchery where the eggs, obtained and fertilised by stripping adult fish, are hatched in troughs of running water. The first year ponds should be smaller and more numerous, and the fry are not transferred to them from the hatchery until the spring or early summer when they have started feeding.

**Table VI. Details of types of pond in a simple carp farm covering 100 acres.**

<table>
<thead>
<tr>
<th>Type of pond</th>
<th>Total area in acres</th>
<th>Approximate area of individual ponds in acres</th>
<th>Depth in feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spawning</td>
<td>1</td>
<td>1/2</td>
<td>1—2</td>
</tr>
<tr>
<td>First year</td>
<td>5</td>
<td>1/3</td>
<td>2—3</td>
</tr>
<tr>
<td>Main</td>
<td>90</td>
<td>3</td>
<td>1½—7</td>
</tr>
<tr>
<td>Winter</td>
<td>5</td>
<td>1/3</td>
<td>6—8</td>
</tr>
</tbody>
</table>

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**SEWAGE FISHPONDS.**

Most people are revolted by the idea of eating fish reared in sewage ponds. Nevertheless the subject is worthy of consideration. The fish do not feed directly on the sewage; the nutrient substances in which it is so rich come to them at second, third or fourth hand through the intermediation of plants and small animals. The
food relation between the fish and sewage is, in fact, less intimate than that between a manure heap and a man when the latter is eating a vegetable marrow grown on the former.

At several places on the Continent, mainly in Germany, town sewage from which solid matter has been removed by passage through screens, grit chambers, and sedimentation tanks, is used to fertilise ponds in which carp are grown. It is claimed that crops of 300 lb. to 500 lb. of carp per acre per annum have been obtained. It has been stated that in the fishponds attached to the sewage disposal works of Munich rainbow trout in addition to carp and tench have been grown successfully.

In addition to the settled sewage liquor supplied to the ponds there must be provided a sufficient quantity of suitable fresh water to bring about the necessary dilution if the concentration of dissolved oxygen is not to fall below that required to support fish life. The quantity of fresh water employed varies but is generally from four times to ten times the volume of the settled sewage liquor. It is important that the sewage liquor should be in a fairly fresh and not a septic condition and that it should not have been in contact with septic sewage sludge, otherwise it will contain sulphuretted hydrogen, which may be present in sufficient concentration to render the liquid toxic to fish. In some towns the sewage contains appreciable quantities of toxic substances carried by trade effluents discharged into the sewers. The quantity of fresh water added to the ponds must be sufficient to ensure that the concentration of these toxic substances is not so great as to harm the fish.

According to the literature one acre of fishpond with a depth of several feet, can receive the settled liquor from average domestic sewage from a population of about 1,000 people. From published data for the operation of the fishponds at Munich it seems that with a flow equivalent to a period of retention of the diluted sewage liquor of about 40 hours in the ponds during the summer months, the purification of the diluted sewage liquor in the ponds is 40 to 50 per cent., as measured by the test for oxygen absorbed from potassium permanganate. This is one of the tests usually employed for assessing the quality of sewage and sewage effluents.

In England a standard of sewage purification considerably higher than 40 to 50 per cent. is generally required. Therefore, considered solely as a method of purifying sewage liquor, it is unlikely that it would be economical to utilise fishponds in most circumstances. It may be desirable, however, to carry out experiments under some of the more favourable conditions in this country with the object of assessing the possibilities of utilising ponds for the double purpose of growing fish and of treating the sewage liquor. Such experiments should include bacteriological tests to determine to what extent there is a risk of the fish becoming contaminated with harmful pathogenic organisms. The fish grown in ponds fertilised with sewage liquor on the Continent are transferred to clean water for a week or two before being supplied to the market. There seems to be insufficient information at the present time, however, on how far this procedure is a safeguard against the transmission of pathogenic organisms; tests are also required to determine whether any pathogenic organisms that might remain are destroyed when the fish are cooked.

We conclude that the possibility of purifying sewage in fishponds in this country is worth serious consideration as it would make use of a valuable resource not exploited at all by other methods of treatment, except sewage farming which is tending to fall into disuse. The practice has the disadvantage that initial costs are heavy and it is not applicable unless the following three conditions are fulfilled: first, the sewage must be free of poisonous trade wastes; second, there must be a reliable supply of diluting water; and third, an area of suitable waste land must be available at a low price. Where such waste land is available sewage fishponds might be a good way of making use of it.

PERCH TRAPPING.

There are many permanent sheets of water about the country which are not adequately cropped by angling or netting, and today contain great numbers of small unwanted fish. Their removal, wherever it can be effected at small cost of money and labour, would make a valuable addition to home produced food supplies and at the same time would improve the waters. Perch in particular, when living in favourable conditions, breed very quickly and are apt to become too numerous. Often perch exist in great numbers side by
Perch trapping is a method devised by the Freshwater Biological Association for the removal of these unwanted fish, and has been tried out on a commercial scale on Windermere in 1941. It has proved highly effective as a means of catching perch, together with some pike and eels, with the expenditure of very little labour, and thus offers considerable opportunities for expansion to many other waters during future years. Perch traps catch the fish in the spring months, when the breeding stock is specially vulnerable. Thus perch trapping, if carried out intensively involves over-fishing, and consequently big crops are not likely to be maintained for more than two or three years running. It is a method which is applicable especially to those waters where the reduction in the numbers of perch in favour of other species is desired.

The perch trapping season is short, starting towards the end of April and finishing early in July. During that time the traps are set on the bottom at a depth of 10 to 20 feet, their positions being marked by the floats at the surface. They are not baited in any way and serve not only to catch the fish but to store them alive until the moment comes, about three times a week, to land the catch from a large number of traps. The job is simplicity itself provided the weather is calm, as it usually is during the early summer when this fishery is in progress. Each boat manned by a fisherman and his mate goes to its allotted beat of shore line, lifts and empties the traps which are set about 50 yards apart and replaces each trap at the right depth which is marked on the rope. One boat can lift 100 traps in a day without difficulty, or 20 traps during a couple of hours’ work after tea. Three hundred and eighty of these traps were fished in Windermere in 1941, the correct depth for the fleet being determined from time to time by a pilot series of traps fished on one part of the shore at different depths. The catch during the two months season was more than a million perch, about 550 eels and 200 pike. For the area of water less than 65 feet deep, which is inhabited by these fish,
regarded as typical: the fish present in the lake are pike, eels, perch, minnows, brown trout, char, occasional sea trout and salmon, and bullheads, perch being by far the most numerous. After removing several millions of perch, we expect the following things to happen:

1. The perch themselves, fewer in number, will grow to a size more worth taking with rod and line.
2. Reduced competition for food supplies will allow more of the shrimps, snails and insect larvae to reach maturity, and hence more fish food and more fly.
3. Part of the space and food supply vacated by the perch will be available for trout and char.
4. Minnows, which are at present eaten extensively by the perch, may become more numerous.
5. Pike will show up more and might turn greater attention to trout, char and minnows.

Thus the only bad effects likely from the removal of perch is an increase in the numbers of minnows and an apparent increase in the predatory activities of pike. These fish could hardly be more of a nuisance than are the perch to-day, and if they should develop into a real pest, it is not impossible that some means can be devised for dealing with them as we can now deal with the perch.

EEL FISHERIES.

The fish so far considered breed in the waters where they live as adults or in the streams feeding those waters. The freshwater eel, on the other hand, travels across the Atlantic Ocean to the Sargasso Sea in order to spawn, after which it dies. The eel larvae drift back to the west coast of Europe and North Africa in the surface currents of the ocean, the journey taking from two to three years, and at the end of it the larvae are known as elvers. When they reach the coast the elvers enter estuaries and rivers in the spring months, and many of them swim upstream until they reach some lake, pond, river or ditch, which is suitable for permanent quarters; sometimes on the way they have to make short passages over land. Then, known as yellow or brown eels, they settle down to grow for a period which may be as short as 5 years or as long as 15 years. At the end of it they undergo certain changes; they become fatter, their eyes enlarge, their snouts change shape, their generative organs start to develop, and their colour changes to black above and silvery below. During dark and stormy autumn nights, these silver eels as they are now
called, leave the waters where they have lived quietly for many years, and swim down stream in shoals, on the first stage of their final journey back to the Sargasso Sea.

This astonishing life history of the eel was made known early in the present century, mainly through the researches of the great Danish naturalist Johannes Schmidt. From the practical viewpoint of obtaining food supplies from our fresh waters the important fact stands out that the distribution of eels is controlled by the surface currents of the Atlantic Ocean, coupled with the instinct of the eels to enter estuaries and rivers. It is most improbable that the eels enter only those rivers from which their parents came years before. Therefore we can take as many eels as we possibly can from British waters without making any significant impression on the vast breeding stock which assembles each year in the Sargasso Sea, having journeyed from all parts of Europe and North Africa.

There is a considerable demand for eels in the British fish markets, and this demand has increased during the war when sea fish are so difficult to obtain. The country's consumption of eels is not known, but in peace time two thousand tons of eels are imported to England each year, mostly from Denmark. Our own eel fisheries have been sadly neglected, with the result that we allow most of the adult eels grown in Britain to migrate to sea uninterrupted. This neglect is all the more regrettable when it is considered how favourably Britain is situated to receive the yearly invasion of eels from the Gulf Stream. Our west coast rivers, especially, are well known for their great runs of eels in the spring, and many are scooped out with dip nets for food. There is no doubt that our own British lakes and rivers, if properly fished, could produce all those eels imported in times of peace and many more besides.

An added reason for making use of this home-grown food supply is that eels are among the most nutritious of fish. When they start their migration as silver eels they have laid down food reserves in their flesh sufficient to last them on their journey across the Atlantic. At that time eels have a high percentage of fat and a fuel value as high or even higher than salmon. Some people have a prejudice against eating eels, but this has usually come from lack of experience; there are few who, once they have tested nicely cooked eel, will not return for more.

The Ministry of Agriculture and Fisheries, recognising the need for developing eel fisheries not only as a war-time measure but as an industry of lasting value, published a leaflet on the subject (Fisheries Notice No. 27, of May, 1940) and another on the capture of eels (Fisheries Notice, No. 9). The following paragraphs should be regarded as supplementary to those two leaflets, both of which are available free of charge on application to the Ministry at Hotel Majestic, St. Annes-on-Sea.

**Eel Fishing.** Eel fisheries fall into two categories according to whether the quarry is the full grown silver eel or the growing yellow eel.

**Silver Eels,** as mentioned above, have grown to their full size, have higher nutritive value than yellow eels, and can be captured with the minimum of labour as they migrate in the autumn from lakes, swamps and rivers to the sea. The migration is all downstream so the problem is to stop the eels without impeding the flow of water more than necessary. This is complicated by the fact that the particular times selected by the eels usually coincide with high floods and wild weather when fallen leaves and débris are swept down with the water.

Devices used for catching silver eels are varied. On some large rivers, especially in Ireland, permanent eel weirs are made with gaps or "eel eyes" at intervals in which are set conical nets. Although much of the water in times of flood flows over the weirs many of the eels swimming near the bottom are guided by the weirs into the nets. On some rivers in England eel traps are sited on mill streams where a weir in the main river tends to guide the eels down the side channel. The water is arranged to escape through a grated floor set at a slope, leaving the eels to drop into a box or cage half full of water. In the sluggish rivers of East Anglia where weirs do not exist, special nets called eel-sets are rigged across the stream. By means such as these many silver eels are caught: that many others escape is...
witnessed by the fact that on some rivers several permanent traps are fished at weirs within a few miles of each other. The lower traps have little more to catch than the eels which escape from traps higher upstream, and yet they are fished at a profit.

Thinking of the country as a whole there is no doubt that much more could be made of silver eel fisheries. The object should be to have one really effective trap on every river, but to-day there is no trap at all on some of the most important rivers in England and Wales nor on practically any in Scotland, and other traps once profitable fell into disuse some 25 years ago, and have never been put into operation again. Profitable sites for silver eel traps are to be found not only on large rivers. Even the smallest stream, especially if it drains some pond or lake, may produce a good crop, as witnessed by the remains of old eel traps on small becks in the Lake District and elsewhere.

It is not always necessary to re-erect the complex systems of former days, usually involving a weir to direct the flow of water down a side channel where the eels could be trapped, for in most small streams a much simpler system can be effective. In order to demonstrate this the Freshwater Biological Association erected a simple form of eel trap in 1940 on the Cunsey Beck, a stream some 25 feet across, which drains Esthwaite Water. A lead made of \( \frac{1}{2} \) inch mesh wire netting 2 feet 6 inches high was supported on posts at an angle to the stream to direct the eels through a gap by one bank. A long conical string net of fine mesh, its mouth on a wooden frame, fitted this gap, and the eels caught each night were emptied out by opening the narrow end of the net. The total cost of the trap, including labour for its erection, was only £10, but the trap caught 400 eels during the best 10 days of the season in September, the value of which at current prices was several times the capital cost of the trap. There is little doubt that on many streams about the country it would amply repay the owners or tenants to construct simple traps of a similar pattern. The trouble with apparatus of this sort comes when leaves and debris block up the wire or string netting during an autumn flood. In favourable years, however, when rains in August and September coincide with moonless periods, a large proportion of the eels run during those months before the leaves fall in October.

On rivers, as opposed to small streams, the most favourable sites for silver eel traps are often to be found on mill leads. The weir on the main river acts as a partial barrier to the migrating eels, and many of them will go down the mill lead if a good flow of water is maintained. The trap is best situated on a short cut back to the main river below the weir. A sluice at the top of this cut is shut during daytime to maintain the head of water to the mill, and is opened during the nights when eels are running. The trap itself need consist of no more than a sloping rack, made of metal bars or wooden slats, leading into a box. The rush of water passes between the bars while the eels are swept into the box. Such a trap, in which the sluice, cut and trap are made entirely of wood, is illustrated in figure 3, for which we are indebted to Mr. Roy Beddington.

![Figure 3. A simple form of silver eel trap between a mill lead and a main river. A, Plan. B, Section—side view. C, Section—rear view. Scale: \( \frac{1}{4} \) in. = 1 foot.](image)
In establishing silver eel traps on big rivers it is usually impossible to cause more than a small fraction of the flow of water to pass through the trap. The problem then is to stop as many as possible of the eels from taking an alternative route, usually over a weir by which the trap is situated. A system of gratings is the most obvious method for stopping the eels, but where these are fitted the gaps between bars must be not greater than half an inch, and facilities must exist for removing the debris which will accumulate in profusion. There may be other means of stopping the eels without obstructing the flow of water, and experiments on this subject are progressing.

When traps are originally constructed, the main object should be to get the maximum draw of water to the trap from the deepest part of the river, because it is probable that most of the eels swim near the bottom in the deepest part of the stream.

In developing eel fisheries there are certain other problems which have to be overcome in addition to merely catching the fish. For example, the question of rights may have to be settled in such a way that a trap once established cannot be rendered of less value by the construction of another trap higher up stream on the same river. Again, on some rivers where there is a run of salmon in the autumn months arrangements need making so that the establishment of eel traps does not impede the passage of salmon. The best places for eel traps are usually at weirs and waterfalls which offer obstruction not only to the downward passage of eels but to the upward passage of salmon. It is just at these places where fish passes are required in the interests of salmon fisheries, so that, even in war-time, it may occasionally be possible to install a fish pass and an eel trap at the same obstruction, thereby cropping the eels for food supplies wanted immediately, and laying the foundation for future improvement of salmon fisheries.

Yellow eels can be fished throughout the summer season from April or May when they come out of their winter quarters in the mud, to September or October when they become inactive once again. Methods employed include the use of wing-nets and portable traps of a number of shapes and sizes, long-lines, "bobbing or clotting," spearing, and in a few cases seining and trawling. Since 1939 the Dutch fyke net, usually made of silk (figure 4), has been introduced to this country by the Ministry of Agriculture and Fisheries, and its use has been demonstrated successfully in many parts of the country.

The fyke net consists of an elongated cylindrical net supported on hoops, with several funnels each of which has a smaller orifice than the preceding one, and a wing projecting from the middle of the mouth to lead eels from either side into the net itself. This net is fished without bait staked to the bottom in shallow water; it is highly effective in catching eels in areas of shallow water such as the Norfolk Broads, and in slow flowing rivers and dykes, but is much less useful in deep waters. For the latter the perch traps (figure 2) have proved to catch considerable numbers of eels when set in 15 to 30 feet of water from May to July. The eels go into the traps attracted by perch which have entered before them. In some cases the capital cost of the trap has been seen back several times over in a week in the value of eels taken in it.

An increase of the yellow eel fisheries all over the country would clearly be all to the good, but the yellow eel should nevertheless be regarded as secondary to the silver eel in all drainage basins where the silver eels can be trapped. Even after extensive development of yellow eel fisheries it is probable that the total catch will be assessed only in hundreds of tons, whereas silver eels, which require less effort in their capture, should be capable of assessment in thousands of tons.

* Fyke nets cost from £1 10s. 0d. to £3 each according to size and are being manufactured by Messrs. J. Grundy & Co. Ltd., of Bridport, Dorset, The Gourock Ropework Co., Ltd., 17, Bay Street, Port Glasgow, and Messrs. Beetons Ltd., Sunrise Net Works, Lowestoft.
The marketing of eels is much easier than of many other fish because eels are remarkably hardy and will remain alive out of water for a considerable time if kept damp. They can moreover be kept in good condition in live boxes sunk in the water, provided they have suffered no damage before being confined. Thus eels caught from day to day can be accumulated in live boxes until the appropriate moment for despatch to market. The season for silver eels being restricted to the autumn, suggests that a big increase of the catch all over the country might defeat its own end by causing a glut on the market. One method of getting over this difficulty, already practiced in some eel fisheries, is to store the silver eels in live boxes so that they can be marketed during a long period instead of immediately after capture. It is said, however, that silver eels will keep satisfactorily only in some kinds of water. A trial at Wray Castle in 1940 showed that silver eels concentrated at six per cubic foot of water in a live box in Windermere remained alive in good condition for five months. If supplies of eels should really exceed the demands of the fresh fish market they could be stored indefinitely by canning; already an attractive and highly nutritious form of tinned fish has been made from British eels on a trial basis, so that canning would be another use to which eels could most usefully be put in the event of supplies becoming more than the demands of the fresh fish market.

Distribution of elvers. Britain, as compared with many countries on the Continent, is so favourably situated with reference to the Gulf Stream which brings the annual supply of elvers, that the majority of our rivers and lakes probably receive more than sufficient elvers each spring to keep up the supply of eels. Nevertheless, there are a number of waters to which the access of eels has been limited by man's activities, for example by stretches of polluted water near the mouths of rivers, by turbines where streams are used for purposes of power, and by high dams impounding storage reservoirs. There is no doubt that the numbers of eels in the waters above such barriers could be increased by stocking with elvers. The only organisation in Britain for the collection and supply of live elvers is at Epney near the mouth of the River Severn. Until 1939 this was run by a German firm, which collected up to seven million elvers each spring to stock lakes, rivers and eel farms on the Continent. When stocking elvers it is important to remember that several years are likely to elapse before the eels grown from them reach marketable size, and from 5 to 10 or more before the eels reach maturity and run to sea as silver eels.

Eel farming is practised successfully in Italy and Denmark where eels are kept in lagoons close to the sea. They are stocked each year either by allowing elvers to run into the lagoons by sluices or by artificially introducing elvers from elsewhere, and the crop of adult silver eels is taken each autumn. Eel farming has not yet been attempted in Britain although there are areas of swampy lands near the coast which, if converted into lagoons and manured, might raise heavy crops of eels. Since large eels eat other fish, their introduction to ponds where other species are cultivated is not to be recommended. It must be borne in mind that they may enter such ponds on their own and also that the ordinary method of cropping ponds by draining (page 14) may not catch eels on account of their habit of lying buried in the mud during winter time.

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