FAO Fisheries Biology Technical Paper No. 14
(Distribution restricted)

FB/T14
Fish Culture - Indo-Pacific

HANDBOOK ON FISH CULTURE in the INDO-PACIFIC REGION

Based on a manuscript by S. L. HORA and T. V. R. PILLAY
prepared in co-operation with
the Fisheries Division of FAO

FISHERIES DIVISION, BIOLOGY BRANCH
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1962

The fish culturist regularly examines the water in nursery ponds for the presence of adequate quantities of food, and as soon as a shortage is observed the fry are let into the rearing pond. They are usually kept in the nursery for a period of about 30 days in which time they reach a length of 5 to 7 cm and a weight of 1.4 to 3.7 g. The rearing ponds, about 0.4 to 0.8 ha in size, are also sections of the stocking ponds with level bottoms and devoid of perennial vegetation. High salinity in shore ponds, due to evaporation during long periods of low tides, and decay of organic matter in inland ponds, are the two common causes of mortality during nursing and rearing, which should be detected and remedied in proper time if the survival rate is to be maintained at a fairly high level. Ordinarily, only a 30% survival is expected by the fish farmer in Indonesia but some Chinese fish culturists in the country, who specialise in the nursing and rearing of milkfish fry for supplying pond owners, obtain a survival of 60% to 80% by special feeding methods and proper care. An adequate supply of fingerlings permits the raising of three crops of milkfish a year in the ponds (tambaks) of Java.

Practices in Formosa (Taiwan). Milkfish nurseries in Taiwan consist of small rectangular ponds, 100 18 200 square meters in area, and holding about 30 cm of water. The preliminary treatment of ponds before the introduction of fry is almost the same in nurseries as in stocking ponds. By about November the pond bottom is levelled and all necessary repairs or improvements to the embankments, sluices, etc., effected. The pond bed is allowed to dry in the sun for a period of about two weeks until cracks appear on the top layer. Water is then left into the pond to a depth of 7.6 cm to 12.7 cm and allowed to evaporate until the bottom becomes dry. In February the pond bed is manured with rice bran. Bags of rice bran, each containing 22 to 27 kg are stacked at approximately equidistant spots, then a depth of 7 to 13 cm of sea water is admitted. After one or two days the bran from the bags is spread out as evenly as possible on the bottom. Sometimes straw, grass and sugar cane leaves are also used as manure. The water is then allowed to dry off completely and the pond remains in this condition until March when more rice bran is added to the pond bottom. Sometimes night soil is used instead of rice bran or is mixed with it before application. The same volume of water is let in again. After five to seven days more sea water is let into the pond, raising the level to about 12 to 18 cm. Camellia seed cakes broken into small pieces are then cast into the water at various spots, to kill any extraneous fishes that may have gained access. About ten days, to allow the water to become innocuous, should elapse before the fry are planted. The ponds are now filled to a depth of 18 cm to 20 cm. All these preliminary preparations are completed by the end of March when a profuse growth of algae will have developed. About 800 kg of rice bran is required to fertilize each hectare of pond. Soya bean cake, or night soil is applied at the rate of about 400 kg per hectare. The fry from the nursery ponds are let into the stocking ponds when they reach the fingerling stage. Care is taken to maintain the correct salinity in the ponds.

It is the usual practice in Taiwan to raise two crops of milkfish and for this purpose fry are planted first in March, then in April/May and again in June. While for the last two plantings, new fry, captured during the same season, are used, stocking in March is done with fry reared in special wintering ponds. In Taiwan, the temperature may drop as low as 2 to 4°C, and the milkfish are sensitive to such low temperatures. Unless protected from cold, large-scale mortality may occur. It is essential to preserve the fry during winter because the late fry, planted in June, do not reach marketable size by October, when harvesting is done. These fry are used for the first planting in the following March before supplies of new fry become available. The special wintering ponds consist of ditches 0.9 to 1.2 m in depth, protected by windbreaks constructed of bamboo frames thatched with straw or reeds, slanting at an angle of about 30° towards the pond on the north-eastern side. As the winter is the dry season in South Taiwan, the salinity of the water may often increase due to evaporation, necessitating the addition of fresh water. The fish are introduced in October and kept there until March, feeding them with rice bran on warmer days. On very cold days the fish do not appear to feed. By March the fingerlings will measure 6 to 12 cm in length.

Transport of Fish Fry

When fry have to be transported to far-off places the equipment and methods used for short journeys may not be satisfactory. While the eyed ova of cold water fishes, such as the trouts, can be transported in ice over long distances, warm water fishes are generally transported in the fry stage.

Theoretical Considerations

The basic physiological requirements of the spawn and fry have to be fully considered. In spite of its importance, detailed studies of this aspect have not yet been undertaken. Preliminary work conducted in India and Indonesia has yielded some interesting data and indicated the lines for future investigations. The main requirement in transporting fry is adequate quantities of oxygen. The dissolved oxygen in the water is used up and carbon dioxide is given out. Recent studies indicate that the fry may die in large numbers not only when the oxygen content is low, but also when the carbon dioxide content increases. Even when the oxygen level is much above the minimum requirement, the fry may die if the carbon dioxide concentration is high. Experimental work done in Canada on goldfish has demonstrated a reduced ability to extract oxygen at lower temperature in the presence of carbon dioxide. The oxygen and carbon dioxide thresholds of some of the cultivated fishes under certain conditions have been determined in India and Indonesia. Studies conducted on the respiratory and digestive waste products of trout in the United States of America have shown that respiration is affected both by low oxygen and high ammonia contents and that high ammonia contents result in distress from lack of oxygen. The conclusion drawn is that trout can be held for indefinite periods at low water temperatures if the water is saturated with oxygen and the metabolic products removed, and that these ammonia products are much more noxious than carbon dioxide. A winter concentration of 0.1 ppm of ammonia has been found to be harmless to trout fry, 0.25 ppm is toxic and 1 ppm indicates serious pollution. There is an increased rate of excretion at high temperatures which saturates the water rather quickly with ammonia products. Similar work on the common cultivated fishes of the Indo-Pacific Region has not yet been undertaken. Experiments conducted in India indicate that larvae and fry of the major carps of India and Pakistan cannot live in oxygen concentrations below 0.5 ppm; in concentrations of 0.5 to 1 ppm they can survive for over 24 hours. Fry 4 to 8 cm in length stand concentrations of oxygen up to 25 ppm for 24 hours or more without any significant mortality. The lethal effect of carbon dioxide varies with the oxygen concentration of the water. While it may be lethal at concentrations as low as 2.5 ppm for larvae and 10 to 15 ppm for fry when the oxygen concentration is at a low level of 0.5 to 1 ppm, it becomes lethal only at 100 ppm to larvae and 250 ppm to fry at concentrations of 2 ppm or above of oxygen. The haemoglobin affinities of various gases affect the respiration of fishes. But unfortunately our knowledge of the haemoglobin picture of the cultivated fishes in the region is too meager to be useful in standardizing fry transport techniques. The oxygen consumption of a fish is proportional to its weight and increases considerably with rises of temperature. The results of work done so far on Indian carps indicate that the oxygen consumption of larvae and fry can be considerably reduced and maintained at a temperature of about 20°C. As regards pH, it was found that the larvae and fry consume the maximum amount of oxygen when this is between 6.0 and 7.9. Other factors for consideration are the accumulation of ammonia, as mentioned above, the increase in biochemical oxygen demand due to the decay of dead fry or larvae and the increase in the bacterial load of the water. Experimental work has not so far indicated any means of disinfecting the water, as the addition of adequate doses of disinfectants proved lethal to the fry and larvae.

On the analogy of results of investigations on some European fishes, such as the common carp, tench and pike, it has been assumed that the intensity of respiration of a fish is in proportion to to the second power of the cube root of its weight, as in warm blooded animals. Constants have been worked out in Indonesia in respect of different species from which can be estimated the period in which a given number of fry of a particular size can be transported in a closed container holding 5 liters of oxygen and 20 liters of pond water. The relationship of the intensity of respiration to the weight, on the basis of the above assumption, can be expressed by the formula $C = N \times W \times 2/3T$, where C is a constant, N = the number of fish, W = average weight of a fish in grams and T = time in hours. If the value of the constant is known, the respiratory requirements of the particular species can be estimated with reference to its weight and time of transport. The values established are as follows:

Tilapia mossambica	: 11355.5±325.09
Cyprinus carpio	: 14343.3±771.43
Puntius javanicus	: 9294.4±403.9

Preliminary experiments have given the following range of results for:

Trichogaster pectoralis	: 10000 - 11630
Osteochilus hasselti	: 8837 - 14570
Helostoma temmincki	: 5358 - 7703

Further experiments are necessary to establish the exact values.

The death of fry due to the accumulation of carbon dioxide in the containers has been referred to. It is believed that mortality can be checked if the drop in pH, due to carbon dioxide accumulation, can be counteracted by buffers such as boric acid and secondary sodium phosphate, and experiments conducted in Indonesia have shown that even slight buffering results in an increased survival of fry.

Experimental studies have proved that the metabolic activities of larvae and young fry are much greater than those of advanced fry, fingerlings or adults, the oxygen consumption rate of which is very high on account of greater body weight. Further, the delicate larvae and fry are vulnerable to mechanical injuries. However, in fish culture enterprises the farmer's aim is to obtain the maximum number of fish for rearing in ponds, and so the latest stages at which they can afford to transport may be the fry and fingerlings, except in the case of fishes that breed in ponds, when the transportation of the brood fish themselves may be justified.

The formula expressing the relationship of respiratorial intensity and the weight of fish fry indicates that it will be economical to transport very small fish, as under given conditions a larger number can be transported at a smaller cost. For example, a container of the type used in Indonesia (about 25-liter capacity), which can successfully transport 50 fingerlings each weighing 64 g, can with equal success transport 800 fry weighing 1 g each, over the same period of time.

As mentioned previously, it is generally considered beneficial to condition the fry before transport, to avoid the use of part of the oxygen by the faeces passed into the water and increase in the bacterial load of the water. This might also help in reducing the metabolic rate and the excretion of ammonia products. Some workers are, however, of the opinion that it is not desirable to starve the fry to the point where they may be weakened, because some may die at the beginning of the journey and so foul the water, thus causing mortality among the others.

Transport in Open Containers

Scientific results on the physiological requirements of the cultivated species are of recent origin in the region and much work has yet to be done before a fully satisfactory system of fry transportation can be evolved. However, the available information can be utilized profitably in the improvement of the existing methods and the equipment used. Containers for fry transport in the region are of the open or closed types. The common open containers are the earthen haundies used in India and Pakistan, the unglazed earthenware jars of the Philippines and Indonesia, the different types of bamboo baskets or wooden tubs used in China and Malaya and the flat coal-tarred baskets of Indonesia. Even though earthen vessels are comparatively inexpensive and help in keeping the water cool during transport, there is the great disadvantage that they break easily; also when large numbers of fry are to be transported over long distances, earthenware vessels are very inconvenient to handle. Wooden and bamboo containers are better because of the lesser chances of breakage.

To prevent breakage on the way and to provide arrangements for the easy changing of water, fish transport cans similar to those common in Germany have been developed and are in use in the Philippines, Indonesia, Ceylon and India. There are two types of such cans made of stout tinned iron plate. The larger measures about 50 cm in diameter at the lower half and is about 38 cm in height.* The mouth is about 20 cm in diameter and has a pressed-in perforated lid to admit air and at the same time prevent the water splashing or the fish from jumping out. The can is fixed on a wooden base to lessen heating through contact with warm surfaces during transport. A close-fitting cloth jacket, which is kept moist, helps to maintain a uniform cool temperature during transport, even when the container is exposed to the sun.

The cans used in the Philippines have a separate drain pipe attached to the side on the upper half near the mouth; but in India, draining and replenishing is done through the perforated lid. Cans are about three-quarters filled with clear, cool, natural, decanted or filtered water. During the journey the disturbance caused by jolting keeps the water aerated. Where halts are made the can is examined and all dead fish removed. Over long distances the addition of fresh water may be necessary every hundred miles or every four hours. Chlorinated drinking water is not suitable for the purpose, but water from railway hose pipes, taps and the like can be used after allowing it to cool and settle for about an hour and a half. The can is first partially drained by tilting it with the lid on and allowing the water to run out; the fresh water is immediately poured in from a moderate height through the perforated lid. If the water to be added is considerably warmer or of markedly different properties it should be added in small quantities so that the change is not sudden. In the absence of good water, aeration is effected with a garden syringe or by agitation with a hand dipper. The Department of Fisheries in the State of Orissa (India) fits ordinary semi-rotary pumps (1.27 to 2.54 cm sizes) to the containers for the aeration of the water. The delivery pipe has two rows each being at such an angle to the other that in action two batteries of water jets are produced, one on the near side and the other on the far side, spraying the entire surface. Fry will travel in such containers to distances of over 480 kilometers with a mortality of only about 5%.

Other types of transport containers exist but are not in common use.

On train journeys it is best to put the cans in the van nearest to the engine, so as to avoid violent jolting which may affect the fish. Fifty to a hundred fingerlings are generally carried in the larger type of can in Madras State, whereas no more than ten are carried in the smaller. The Indonesian tin plate cans are roughly similar to those used in India.

---

* Smaller and shallower cans are also available.

A can has been developed specifically adapted to tropical conditions, in that the lid is designed to hold about 1 kg of ice. The bottom is oval and so balanced that two of them can be carried by hand or on a bamboo pole.

The flat, shallow, basket-like containers of tightly plaited bamboo are very useful. Treated with coal-tar they are completely water-tight, almost unbreakable, light, inexpensive and easy to store. Equipped with a lid of coarse wickerwork they can be immersed during transport in a canal or pond with a full load of fish. A 60 cm diameter basket can hold 180 carp weighing 60 g each; one of 80 cm diameter, 250 fishes of the same weight, and one of 100 cm will carry as many as 500 if the water is changed from time to time. Special 15-liter baskets can accommodate 10,000 fry 3 cm long or 2,000 of 5 cm. Adult carps need about 1 liter of water for every 250 g of fish during transport. Oval wooden 150-liter casks are used in Indonesia to ship brood fish all over the archipelago. They hold up to 36 kg of live fish.

The Chinese fishermen consider that fry smaller than 40 mm in length are unsuited for long-distance transport. Baskets and tubs of various sizes are used, the largest measuring as much as 2 m in height and 1.9 m in bottom diameter which carry about 50,000 fry. The water in the container is kept agitated throughout the day and night with wooden paddles. If the agitation stops, even for a few minutes, serious mortality can result. The foul water is continuously baled out in small quantities and renewed. For every three to four containers four to six experienced attendants are necessary and, if the weather is favorable and the attendants work regularly, the survival rate is about 60% on journeys taking less than six or seven days. On long journeys over-night halts are made wherever possible at selected spots. The fry are then liberated into a net trough fixed in a pond on bamboo poles and fed with yolk of egg and flour spread on a small rectangular piece of wood. On very long journeys the fry are fed with cooked yolk of eggs or soya bean ground into a fine paste. Great care is taken to see that the food is all consumed and that nothing is left behind to foul the water.

Two types of boats with live holds having holes to allow water to enter are used for river transport. One type, about 8 meters long, has four compartments with several holes which can be closed when desired. The walls of the hold are lined with fine ramie cloth to prevent the escape of fry. In such a boat 1,000,000 to 1,500,000 fry can be transported at a time. In the second type, with a capacity of 10,000,000 fry, there may be six or seven compartments with arrangements for inter-communications through screened openings in the walls. Each hold has three holes at the bottom, each fitted with a piece of short perforated bamboo pipe. The outer end of the pipe projects into the river to produce sufficient pressure to drive water through the perforations, the force of flow being adjusted by manipulating the level of the pipe. The middle compartment of the boat receives the water from the other compartments and a water wheel pumps it out; thus a constant circulation is maintained.

Special types of live fish boats, known as pamandawan or hatiran in the Philippines, are used to transport milkfish fingerlings over long distances. Made of wood, dug-out or flat-bottomed, they have two or more well-screened holes to allow the free entrance of water. Similar boats are used in Indonesia. The holes are often provided with short bamboo tubes, screened at the inner ends. The outer ends are cut in such a manner that the rate of flow of water into the boat can be controlled; adjusted to face the direction in which the boat is moving, more water enters the boat, while if it is turned backwards the inflow is reduced. Dug-outs measure from 10 to 20 meters in length and are propelled by outboard motors. Larger flat-bottomed barge-like boats can transport 15,000 to 50,000 fingerlings, depending on the size. Trains of these boats are often towed by tugs.

The boats are thoroughly cleaned, the inlet arrangements checked and partly filled with water before the fingerlings are introduced. The holes are then opened to admit water and simultaneously one or two men start baling water out from a special enclosure of close-meshed bamboo screen, thus maintaining a continuous flow of well-aerated water. Transport during inclement weather and through very shallow or turbid waters is avoided as far as possible.

Special fry transport trucks provided with pumping and cooling arrangements to maintain a circulation of cooled oxygenated water are very efficient in western countries, but in the Indo-Pacific Region there appears to be very little prospect, at present, of using them on a large scale, due to the unsatisfactory condition of roads near fry-collection and nursery centers and the economic status of the fish culture operatives.

Transport in Closed Containers

Some of the defects of transport in open containers can be obviated by carrying fry in hermetically sealed containers with an excess of oxygen. Cans of the type used for kerosene and petrol, and galvanised iron drums have been used for the purpose. These containers must have a sufficiently wide opening with an airtight lid and fitted with two metal pipes, preferably reaching the bottom, one with a narrow bore for oxygen. If the pipes reach the bottom the possibility of the sharp ends injuring fry will be minimised. However, very often the water displacement pipe reaches to only one-third of the container's depth, facilitating the addition of the required amount of oxygen. For very small fry or larvae the lower ends of the tubes should be covered with fine meshed netting to prevent their escape.

To use, the container receives more than two-thirds of clean, filtered pond water, the fry are put in through the wide mouth, and then the container is filled with water to exclude all air. The lid is tightly closed and oxygen is then introduced through a regulator and the narrow pipe from an oxygen cylinder. Since the can is full of water, a volume of water equal to the volume of oxygen introduced will be displaced through the second pipe. When sufficient oxygen has entered, both the pipes are hermetically sealed.

Although the number or weight of different species of fry or larvae that can be carried in a closed vessel under a given set of conditions has not yet been determined accurately, some available data enable such estimates to be made. At the Inland Fisheries Research Station, Barrackpore, India, 18-liter cans are used to transport fry of the major carps of India in the presence of about 6 liters of free oxygen. Such cans will hold 900 to 1,000 fry 1 to 2 cm long (about 285 g) and can be safely transported by plane for over 20 hours. The fry should be conditioned for about six hours in water that has been left to settle for some time. Transport of fry above 5 cm in length is uneconomical. The experience gained at the Hong Kong Fisheries Research Station indicates that the following data can be used as a guide for the transport of Chinese carps (grass carp, big head, silver carp and common carp):

Number of Chinese carp fry that can be transported in a container of 18.5 liter capacity containing 8.5 liters of free oxygen

Size of fry in mm	Wt. per 1000 fry in g	No. of fry	Amount of free oxygen per g of fry in ml
10-20	50-200	4000-5000	42.5
30	450	1500-2000	12.9
40	800	800-1200	10.6
50	1500	500- 800	5.7
60	2500	400- 500	3.4
70	3000	350- 400	2.8
80	3500	250- 300	2.4
90	4500	200	1.9
100	6000	150	1.4
110	8000	100	0.85
120	12000	80	0.70

From the studies on the physiological requirements of fish larvae and fry, conducted in India, it is inferred that the closed container will be suitable for fish fry transport only if the duration of the journey does not exceed 20 to 24 hours, otherwise the accumulating carbon dioxide and other metabolic products may prove lethal to the fry and cause serious mortality. However, the Indonesian experiments show that the addition of suitable buffers may be effective in counteracting this.

FRESHWATER POND FISH CULTURE

Indigenous Ponds

Freshwater ponds are a distinct feature in many villages in the Indo-Pacific Region. A large number of them are not drainable, but even so they have a potential value for fish culture. The need is to make use of these ponds, rather than to construct new ones.

A classification of ponds can only be very loose since they exist in many forms and originate in various ways.

Village ponds are water reservoirs used for such purposes as bathing, washing and watering stock. They are often communally owned. Homestead ponds are found in low-lying areas, such as deltaic regions and coastal tracts where they were dug to obtain earth for house construction and reclamation of low-lying land. In regions with intensive agriculture, ponds of various sizes are dug in fields and gardens for watering crops and cattle. Irrigation ponds are larger in size to collect water from catchment areas for storage. Spill ponds (the bheels or bhils of India and Pakistan) are constructed in spill areas of rivers formed by the changing course of rivers. Moats around forts, villages and small towns are not common, but do occur in China, India and Ceylon. Open mine pits and quarries are numerous in some places, but are seldom suitable for cultural purpose.

Proper care is seldom bestowed on the upkeep of ponds. They may be overgrown with vegetation and form breeding places for mosquitoes. Dense growths of hardy aquatic plants on the pond surfaces usually prevent the penetration of light to deeper water layers, and they kill submerged vegetation. Plants die off and rot, and deposits of debris are formed at the bottom. Such ponds are often perennial and rather deep, with a dense population of predatory and weed fishes. For want of proper embankments, drainage from surrounding areas may flow into them. Smaller ponds may dry up during certain periods of the year. Homestead, farm and garden ponds are generally less than one hectare in size and are better maintained than the larger village ponds.

Irrigation ponds are called bunds in India and waduks in Indonesia. They have strong embankments on one, two or three sides. Some are perennial and other dry out seasonally. Spill ponds are sometimes as large as 250 ha, two or more meters deep and many have dense growths of water weeds.

Improvement of Indigenous Ponds

The three main types of ponds needed for a self-supporting fish-culture enterprise are nursery, rearing and stocking ponds. Small seasonal ponds can be used as nurseries and for rearing, and large seasonal and perennial ponds for stocking, but most of them have to be improved before they are suitable for cultural purposes.

If rank vegetation exists, it is essential to eradicate the growth in such a way that there will be little chance of quick reinfestation.

It is most desirable to drain and desilt the ponds before they are used for fish culture. Draining is not difficult when the ponds are situated immediately above low-lying areas. When they are not, the expenses involved will be high, but the removal of excessive organic debris from the bottom of old, perennial ponds will often be worth the labor involved. Mechanical water-lifters and motor-driven pumps are now fairly common in the region. The excavated silt can be used for repairing embankments or as a fertilizer for agricultural crops. Even when it is not possible to drain the pond, due to restricted water supply for refilling or because it is very deep, it may be possible to remove some of the excessive organic deposits from the bottom with machines. This is done in China with flat bamboo shovels fitted with long handles to reach the bottom of the pond. The mud is collected in boats or thrown on the banks. The banks should be raised and strengthened wherever necessary.

Wherever possible each pond should be provided with an inlet and an outlet, preferably fitted with pipes of concrete, galvanised iron or wood, and protected with fine-meshed sieves to prevent the entry of extraneous animals and the escape of fish.

Large spill ponds should be divided into smaller units by the erection of suitable cross dikes the better to control pond conditions.

Specially Constructed Ponds

For really efficient fish culture ponds specially constructed for the purpose are most desirable. Pond construction is essentially an engineering matter and most fish culturists have little training in this field. This often leads to selection of unsuitable sites and faulty construction resulting in considerable loss of money and effort. Constructional details have to be worked out with due reference to the topography of the area, nature of soil, water supply, etc., and it is therefore always advisable to seek the help of technicians familiar with this kind of work. Pond construction is mostly done in the Indo-Pacific Region by human labor, and mechanical devices such as bulldozers, carry-all scoops and rippers are not yet common, mainly because the farmer cannot afford the heavy expenditure involved.

Selection of Site

In general terms it can be said that the most suitable sites for pond construction are those with fertile soil and an adequate water supply throughout the year. Low-lying deltaic areas and coastal districts are generally well suited and so are hilly areas with good irrigation facilities. In coastal regions ponds depend mainly on rain water; in hilly areas an additional supply of water should be available from canals or rivers. Easy access is an important factor in selecting sites for ponds. In the absence of roads it will be expensive and difficult to bring equipment and stocking material to the pond farm and to send the produce to the markets. In deltaic districts and those adjoining rivers, canals and lakes, water transport should be feasible and inexpensive.

If rainfall runoff has to be used as the only source of water supply, a ratio of 10 hectares of catchment area to one hectare of pond is required if pasture land is involved, a slightly higher ratio for wood-land, and smaller for land under cultivation. The most suitable soil for pond construction is clay. Loamy soil, marl and peat are also satisfactory. If the soil is slightly porous it can be improved by puddling with clay. Sandy soils, or limestone outcrops are not suitable because their waterholding properties are very low. Unless the site has a high water table it will be very difficult to keep a sufficient depth of water in the pond. If the soil is rocky, excavation will be expensive and the excavated soil may not be suitable for the embankments.

Saline deposits will render a pond unsuited for purely freshwater fishes. If such fishes are to be cultured, the soil must first be improved by flooding with fresh water to wash out the salt. On the other hand, brackishwater fish can be reared.

General Layout

A fish farm should preferably be self-sufficient, so that all operations from breeding to final cropping can be conveniently done. Breeding and segregation, nursery, rearing and stocking ponds, and wintering ponds in cold climates, are the main divisions necessary. An essential requirement is that the various ponds can be supplied with water and drained independently. The ponds should be arranged in series, with the water inlet at one end and the drainage at the other. The size of various types of ponds has necessarily to be determined with reference to the type of fish cultivated. The following proportions of pond are recommended for the cultivation of the common carp in association with Tilapia.

	Area in m^2	Approx. percentage
2 segregation ponds	500	0.4
2 or 4 carp spawning ponds	400	0.3
4 nursery ponds	5,000	4.0
4 rearing ponds	10,000	8.0
10 or 20 stocking ponds	100,000	80.0
2 Tilapia spawning ponds	5,000	4.0
Dikes	4,100	3.3
	125,000 m^2	100.0

Similarly, for the cultivation of gourami the following proportions have been suggested:

	Area in m^2	Percentage
One head pond (a reservoir where water from a supply channel can settle and produce plankton).	100	1.0
Two or more breeding ponds.	1,000	10.0
Three rearing and stocking ponds, house site and dikes	8,900	89.0
	10,000 m^2	100.0

Stocking ponds can be of any size, but they are generally not larger than 5 ha as there may be difficulty in harvesting the crop if they are larger.

The whole fish farm should be provided with good fencing to prevent the entry of unwanted intruders. Shade trees protect the fish from the intense heat of the sun and also add to the beauty of the place. Marginal or central ditches are often dug in shallow ponds as retreats for the fish on hot days. These ditches are also useful for draining the ponds.

Building the Pond

In the Indo-Pacific Region, expenses of pond construction can generally be kept low by using cheap manual labor; expensive power machinery is not as a rule justified so will not be discussed.

Ponds can be of almost any shape. A rectangular pond about 50 m wide is probably the most convenient shape for netting operations. The depth and the height of the embankments will depend on the climatic conditions and the use to which the pond is to be put. In most of the countries of the region the winter is not so cold as to freeze the water, so the ponds can be comparatively shallow. Depths of 0.5 to 1.0 m for nursery ponds, 0.6 to 2 m for rearing, and 1 to 2.5 m for stocking ponds are generally considered adequate. But in a few areas, with cold winters, stocking ponds have a depth of 3 to 8 m. Where there is excessive evaporation or temperature variations, deep ponds are recommended. Since costs of construction increase in proportion to the depth, excavation should be restricted to the minimum. When a fish farm is built as a self-sufficient unit, with nursery and stocking ponds, it will be advantageous to have it so arranged that water from a stream can be let into the various sections by a system of channels, pipes and sluices.

The site should first be cleared of all trees, brush and similar growth. The surface organic deposits should be kept aside and later put into the pond as fertilizer. The surface should also be kept for use later in facing the embankments, on which grass and other vegetation should be planted. The shape of the embankment must depend on the type of soil, but generally a slope of 1 in 3 is adequate. Sandy or other porous soils should have a less steep slope, say of 1 in 5. For small ponds up to 1.5 m deep, a slope of 1 in 2 will be satisfactory if the embankment is made of heavy material. When the banks are higher than 3 m and are to be used as roadways, the width should be about 2.5 m. The crest of the embankment should be about 0.5 to 1 m above the mean level of the pond water, and in areas with flash run-off, additional free board may be necessary. With these requirements in mind, it will be possible to determine the width of the embankment base. If this is not done in advance, the provision of the correct slope may be difficult.

The embankment foundation should go down to firm. impervious soil. If the foundation soil is porous, a trench 30 cm wide should be dug along the center line of the dam wall down to the impervious layer and filled with damp clay, each layer being rammed as tightly as possible. This procedure may be advantageous even with other soils, as the junction between the fill and the surface ground is often a weak point and may give rise to seepage. If there is a rock outcrop it will be necessary to build a concrete wall in the rock and extend it up into the fill. The advice of an engineer should be sought when such circumstances arise. The fill from the embankments is generally obtained by the spoil from the pond. It should be placed in layers over the full length and width as the wall rises, and not in sections, as otherwise leaks may develop due to the variations in the material and differences in compactness. Allowance should be made for settling, which may be, on average, one meter for every five meters of height, when completed. The corners of the pond should be protected against erosion. The top and slopes should be faced with soil in which planted grass will grow. This will bind the soil and prevent erosion. Small nursery pond banks in China and Indonesia are reinforced with planking or bamboo gratings held in place by wooden piles driven deep into the earth at regular intervals.

Water Control

All water supplies to a pond should pass through an inlet pipe or sluice, and provision for this should be made when the embankment foundation is being built. The inlet is usually located at the highest portion of the pond site, adjacent to the source of water supply. From this point the pond bed should gradually slope to the deepest portion where the drain is located. It is a general practice to provide fine-meshed screens for the inlets, to prevent the entry of undesirable animals. .The materials for the pipe or sluice will depend on the quantity of water it has to carry. Concrete and steel pipes and sluices are usual in western countries, but bamboo pipes, hollow palm stems and wooden sluice structures are more common in the Indo-Pacific Region.

A simple way of making a wooden sluice is to nail together four planks, 30 cm to 60 cm wide and long enough to pass through the embankment base, rectangular in section, open at both ends. A sliding wooden gate at one end will control the flow. For ponds over 1 ha in extent a concrete sluice may be necessary, the dimensions of which will vary with the size of the embankment and that of the pond. Arrangements for complete drainage are necessary. The drain pipe or sluice can have arrangements for controlling the water level. A 10 to 15 cm pipe is sufficient for average sized ponds, and should be built into a concrete or a similar wall inside the embankment to hold it in position.

In hilly areas ample spillways are often necessary to prevent damage by floods. Very few fish are likely to be lost during floods over a wide spillway in which water flows in a shallow stream. Shallow spillways may also avoid the necessity for screens which have the disadvantage that they are likely to get clogged. A 15 cm wide spillway, properly protected to prevent erosion, is recommended for every 0.4 ha of catchment area.

When the pond is used for watering stock, the animals should not be allowed direct access, but the water should be pumped or bailed.

Prevention of Seepage

It is a common experience in many localities that ponds, when filled, do not hold water satisfactorily until sufficient silt has precipitated at the bottom. This is especially so on gravelly or sandy soil. The bottom of such ponds should be levelled and well consolidated by rolling or ramming and a layer of mud clay then spread to a thickness of over 20 cm on the bed. The inside of the embankments should also be lined with clay. Water should be admitted into the pond and allowed to remain for a long time. The trampling of livestock or laborers in the pond while filling, will help. A layer of loam should be spread over the clay to encourage the growth of fish food.

Some Chinese fish culturists in Singapore prevent seepage in sandy soil by covering the bottom with cement and planking the sides. Since no natural food is produced in such ponds, artificial food has to be supplied in adequate quantities.

PHYSICO-CHEMICAL PROPERTIES OF WATER AND SOIL

Water is the basic element in fish culture and its specific properties as a cultural medium are naturally of great significance in the productivity of a pond. Pure water is unable to support living organisms but its content of nitrogen, phosphorus, potassium and calcium salts, dissolved organic matter and gases like oxygen, nitrogen and carbon dioxide determine to a large extent the productivity. The physical features, such as the depth of water, shore conditions, water movement, light penetration and temperature, also influence the biota and the growth of fish. Similarly, the physico-chemical properties of the pond soil are of greater significance than is generally realised. When the soil conditions are not favorable, the production will be limited. Very few scientific investigations on the physico-chemical properties of soil and water of fish ponds have been conducted in the region and accurate information on the optimum properties for the culture of different species of fish have yet to be obtained. A classification of the types of water, based on their capacity to produce fish food, and the level of natural or artificial replenishments in terms of nutrients needed to maintain them in a state of optimum productivity, will be of immense help in standardising fish culture techniques and expanding the industry on a scientific basis. In the absence of the necessary scientific knowledge even the advice of hydrobiologists must be based on empirical experience. The fish farmer often recognises the suitability of water by its color and taste. In India the crystal clear water from hill streams, artesian wells and the like is considered barren, and the slightly brackish water from canals near the coast, samples of which at first are slightly turbid and change a little later to a brownish color, are also unproductive. Conditions are sometimes improved by applying suitable quantities of manure and by the addition of lime to keep the water slightly alkaline. These measures promote the growth of a bloom of phyto- and zooplankton; when the water becomes green, the pond is suitable for the culture of fish.

Physical Properties of Pond Water

The depth of water in a fish pond is most important since the penetration of light to the bottom contributes in a large measure to the pond's productivity. The layers of water below 3 to 4 meters in temperate regions and below 1.5 to 2 meters in tropical regions have little significance in biological productivity. Shallow waters get warm rapidly and provide optimum conditions for life and reproduction. The assimilative functions of submerged water plants mainly take place at a depth of 0.01 to 1 m. However, fish ponds should not be too shallow, as extremely high temperatures may adversely affect productivity and may lead to a loss of fish. In Indonesian carp ponds a minimum depth of 0.3 meters is considered suitable for healthy pond life.

The sun's heat in tropical countries keeps the surface temperature constantly high, thereby creating a stratification in the pond. Three distinct water layers are recognised, namely (1) the epilimnion or the warmer waters of the surface zone, (2) the thermocline, a thin middle layer, where the temperature drops abruptly, and (3) the hypolimnion or the cooler water at the bottom. This thermal stratification may not be prominent in shallow ponds. It was generally believed that the surface layer of water in tropical climates does not mix completely with the layer below three meters except in ponds exposed to strong wind action. However, observations conducted in Indonesia have shown that instead of an annual turn-over, as found in temperate climates, a daily turn-over takes place in tropical ponds. During the nights, circulation takes place, bringing about a mixing of the water. This turn-over is of extreme importance in the circulation of oxygen and nutrients in pond water.

Within limits, all life processes in a water area are enhanced by an increase in temperature. A rise in temperature induces the migration of surface biota to deeper waters. High temperatures indirectly influence the dissolved oxygen content of the water, the oxygen consumption of the biota and the mineralization of organic substances. The oxygen content of the water decreases proportionally with a rise in temperature but super-saturation helps to bridge-over periods of extremely high temperatures. Even though, generally speaking, warm water is better for fish production, it is emphasised that different species of fish have different levels of temperature tolerance. Unfortunately, information on these aspects of most of the cultivated fishes of the region is very limited. In practice, when the water temperature is suspected to be reaching the lethal limit, fish culturists provide suitable shade or shelters in ponds to protect the fish. Deep trenches are often dug on the pond-bed, where the fish can remain during the hot hours of the day, but because such trenches often become the haunt of predatory fishes, some fish culturists prefer shade, in the form of thatched platforms, over a part of the pond surface.

The turbidity of the water in a fish pond may be due to suspended clay, silt and finely divided organic matter. It may be only temporary, due to rains, floods, drainage inflow and mechanical disturbances, or permanent on account of the nature of the soil and constant wind and wave action. Turbidity is an important limiting factor in the productivity of a pond. Light can penetrate deeper into clear water and influence the migration of food organisms and also induce the growth of plants in deeper waters.

The photosynthetic activity of plants in turbid water will be reduced and the fish fauna needing clear oxygen-rich water will be replaced by a predominently labyrinthiform fauna. The turbidity tolerance of various species of cultivated fishes is not yet known, but a few of them have been found to be extremely tolerant of turbidity fluctuations. The carp, Puntius schwanefeldi, which is a clear water fish, has been observed to be tolerant of a turbidity ranging from that of clear hill streams to as low as 4 cm, in terms of Secchi's disc, sharing this property with other Puntius species. The cat fish, Pangasius pangasius, is able to live in water with a visibility as low as 2 to 5 cm in terms of Secchi's disc. Profuse growth of plankton, which may reduce the visibility of water, is a sign of fertility, but turbidity due to silt or mud may be harmful to both fish and their food organisms. The production of fish food will decrease with the reduction of sunlight, and sand and mud may smother the food organisms. It is therefore essential to prevent the water from becoming too turbid with silt or mud.

Water movement or a current of water is necessary for the survival of certain fishes and especially for their breeding. Most of the cultivated fishes of the region can thrive in stagnant water, but species like Rohu, Catla, Mrigal and Nilem require flowing water to spawn, even though they grow and fatten well in lentic environments.

Chemical Properties of Pond Water

Dissolved Oxygen. Of the various chemical factors governing fish life in a pond, the dissolved oxygen is of primary importance, as all fishes, as well as their food organisms, depend on dissolved oxygen for their respiration. The aerobic bacteria are also major consumers of dissolved oxygen. Besides the atmospheric oxygen that dissolves in the water, plants release oxygen during the process of photosynthesis. The rapid water circulation in tropical ponds helps the process of aeration considerably. Accurate estimates of the aeration constants of different tropical waters remain to be made. The oxygen-carrying capacity of water varies inversely with its temperature, and an increase in temperature results in the decrease of oxygen. The following figures show the normals.

Temp. (°C)	Oxygen (in mg per liter) p.p.m.
0	14.57
5	12.74
10	11.25
15	10.07
20	9.10
25	8.27
30	7.52

While the dissolved oxygen content decreases with increases in temperature, the oxygen consumption of fish increases with a rise in water temperature. It has been found that in cold-blooded animals the rate of oxygen consumption and consequently the release of carbon dioxide generally doubles with a temperature increase of 10°C. This would lead to a consideration of the factors that might contribute to the diminution or depletion of oxygen in fish ponds. For instance, the absence of aquatic plants which contribute to the oxygenation of pond water may be a cause of oxygen diminution. Putrefaction of organic matter uses up considerable quantities of dissolved oxygen and may also lead to oxygen depletion. This often happens in tropical countries during rainy periods, when the sky is overcast for long periods. A sudden rise of temperature during the summer may have a similar effect, as a good quantity of the dissolved oxygen may be driven out of the water.

Very little information exists on the oxygen-consumption rates of different age groups of cultivated fish. An oxygen content of less than 3.5 mg per liter is lethal to common carp in Europe. Similarly, oxygen contents below 5 mg per liter are known to be critical for salmonid fishes in summer. Ordinarily, a concentration of 5 ppm at a temperature of over 20°C, which is equivalent to a saturation of 60% to 70% in a temperature range of 20°C to 30°C, is considered sufficient to maintain freshwater fish in a healthy condition. Supersaturation of oxygen very seldom has any ill effect on fish, even though in certain rare instances it has been found to cause mortality by the formation of gas emboli, which may block the capillaries in the gill filaments.

Biochemical Oxygen Demand

The biochemical oxygen demand (B.O.D.) is the oxygen used up by unstable organic matter for its stabilisation in a water area and is therefore dependent on the quantity of organic substances in it. It is an important indication of the amount of organic matter in a pond. The stabilisation of organic matter is brought about by aerobic bacteria. Since complete stabilisation requires a long period, for the sake of convenience the determination is generally made after five days incubation of the sample at 20°C. A sample of water with no significant organic pollution has a B.O.D. of the order of 2 ppm, 5 days, 20°C. When there are large organic deposits at the pond bottom, or when the water gets polluted by the introduction of effluents, the B.O.D. may rise, resulting in the depletion of oxygen and consequent mortality of pond fish.

Hydrogen-Ion-Concentration. The hydrogen-ion-concentration (pH) is an often used index of the water conditions in a pond. While a pH of 7 indicates a neutral reaction, pH above 7 shows an alkaline reaction, and a pH below 7, an acid reaction. The pH of the water is indicative of its fertility or potential productivity. A slightly alkaline reaction is of great help in the conversion of organic matter into assimilable substances, such as ammonia and nitrates. A pH of 7 to 8, i.e., a feebly alkaline reaction, is a characteristic of good water, suitable for fish life. The presence of dissolved calcium bicarbonate is mainly responsible for the maintenance of such an optimum range of pH. Adequate quantities of calcium bicarbonate will have a buffering action and prevent pronounced variations of pH. Water acidity, besides directly affecting fish, may affect the pond life as a whole by impeding the circulation of nutrients by reducing the rate of decomposition, and inhibit the nitrogen fixation. A satisfactory pond water, having adequate acid-combining capacity, will not have a pH range wider than 6.5 to 8.5.

Many fishes are able to tolerate wide pH variations. The brook trout has a pH range of 4.6 to 9.5, and swamp fishes such as *Trichogaster pectoralis*, *T. trichopterus* and *Ophicephalus punctatus* are known to live well in water ranging in pH from 4 to 9. But there are many others that are rather sensitive to low pH values. Common carp, big head, grass carp, silver carp, black carp and gourami have died when heavy rain water decreased the pH from about 7.2 to 4.6. Trout fry exposed to acid water are adversely affected.

Generally speaking, a pH lower than 5.0 is unsuitable for fish life. It has been observed that a low pH may adversely affect the reproductive activity of fish such as trout. Waters of pH 4.5 to 6.5 can be improved by the application of sufficient quantities of lime to raise the pH to about 8, but below 4.0 little can be done.

Alkaline Reserve. The importance of alkaline reserve, also known as the acid combining capacity and titration alkalinity, in judging the suitability of pond water for fish life has not been fully realised by fish culturists. Even though small amounts of carbonates of magnesium, sodium and potassium may slightly influence the alkaline reserve, for all practical purposes, it can be expressed as the calcium content of the water. The process involved is somewhat as follows:

Suppose, at an alkaline reserve of 2 cc of normal hydrochloric acid per liter, which corresponds to 56 mg of calcium oxide per liter, the water contains 88 mg per liter of calcium bicarbonate and 2.3 mg per liter of free carbon dioxide; if, due to the photosynthetic activity of the aquatic plants, it loses 1 mg of free carbon dioxide, the pH will rise. A part of the calcium bicarbonate dissolved in the water will split up into calcium and free carbon dioxide until a fresh equilibrium and a corresponding pH is brought about. The calcium carbonate is deposited on the plants or in the water and settles at the pond bottom; the alkaline reserve drops. The lime applied to a pond absorbs the carbon dioxide and brings about the same set of conditions. In the reverse manner, when water contains free carbon dioxide higher than 2.3 mg per liter and the pH is consequently low, the excess of carbon dioxide connects the calcium carbonate deposited on the pond bottom into calcium bicarbonate; the alkalinity reserve increases, raising the pH and establishing the necessary equilibrium. This process takes place in a pond almost continuously and accounts for the fluctuations in pH. Based on the alkalinity reserve, waters have been classified by Hey (1941) and Huet (1947) as follows:

(1) 0 - 0.15 cc normal HCl per liter - too acid for fish culture
(2) 0.15 - 2.0 - do - usable
(3) 3.5 - 6.9 - do - optimum
(4) 7.0 - do - and above - too hard with a tendency to deposit alkaline salts

Free Carbon Dioxide. Water contains free carbon dioxide mostly from the decomposition of organic matter, in varying quantities from the atmosphere, or as a result of the respiration of aquatic animals and plants. Plants assimilate carbon dioxide for photosynthesis and release oxygen during the day. Accumulation of free carbon dioxide generally takes place at night.

A high carbon dioxide content of water is lethal to fish life and, besides preventing the oxygenation of water, it might also adversely affect the extraction of dissolved oxygen from the water. Although some information on the lethal carbon dioxide thresholds of the spawn and fry of a few cultivated fishes have been determined, very little work has been done with adult fishes. Based on general observations it may be said that 5 cc per liter is the lethal limit for healthy fish life. A high concentration of carbon dioxide has been observed to increase losses of fry and the number of deformed specimens in trout.

Nitrogen. Nitrogen forms one of the basic elements of fertility in ponds. Certain quantities of nitrogen may be taken into soil or water from the atmosphere by rain or lightning. There are also soil bacteria that can fix atmospheric nitrogen and thus make it available to the phytobiota. In addition, certain types of blue-green algae, living on the muddy bottom of ponds, probably are capable of aerobic nitrogen fixation. However, ponds derive the major supply of nitrogen from the putrefaction cycle. Anaerobic, aerobic and facultative bacteria bring about the decomposition of vegetable and animal matter. The nitrogenous compounds in waste matter are first broken down by the anaerobic bacteria into ammonia, and their sulphur compounds are converted into hydrogen sulphide and certain other compounds. If the supply of oxygen is slow, this phase will be prolonged, resulting in the formation of gaseous substances. However, when free oxygen becomes available, the aerobic bacteria take up the work of oxidation and the ammonia is converted into nitrites and nitrates. Nitrates are the end products of this cycle and form the main source of nitrogen for various forms of life. The nitrates can be broken down by the action of certain micro-organisms into nitrites, then into oxides of nitrogen and finally into free nitrogen, a process known as denitrification.

This putrefaction cycle is of extreme importance in the maintenance of a balanced pond life. Adequate quantities of nitrogen compounds, especially nitrates, are essential for the productivity of the pond. The quantities obtained by the natural processes may not always be sufficient for a high production of fish. The best production of plankton is obtained when the water contains 4 ppm of nitrogen with 1 ppm of phosphorus and 1 ppm of potassium. The relation between nitrogen and carbon concentrations is also of great significance. Nitrogen fixation by bacteria takes place on a pond bed rich in carbohydrate materials which are essential both as a source of energy to anaerobic forms and a constituent of bacterial protoplasm.

The ammoniacal nitrogen content of water is an index of the degree of its pollution. Its concentration in unpolluted water is never more than 0.5 ppm. Healthy growth of fishes can be expected in waters containing less than 2 ppm of dissolved ammonia. The toxic effect of ammonia compounds is at a maximum in pH ranges of 7.4 to 8.5. Concentrations of ammoniacal nitrogen up to 4 ppm at pH 7.3 to 7.5 have no ill-effects on tilapia, common carp, big head, grass carp, silver carp and black carp.

Hydrogen sulphide. Hydrogen sulphide can be a severe limiting factor in fish ponds. It is formed by anaerobic bacteria, and sometimes accumulates in ponds having a thick layer of organic deposits at the bottom. In muck soil the gas may be formed by fire. Due to the high organic content, dry muck may burn and, combustion often being incomplete, sulphides are formed instead of sulphates. When the alkaline sulphides are carried into slightly acid wet muck, hydrogen sulphide is formed and is carried off in solution. This may ultimately be carried into ponds and an accumulation of it may cause severe fish mortality. A concentration of 6 ppm of hydrogen sulphide will kill common carp in a few hours. Aeration of the pond by mechanical agitation helps to a large extent to free the pond of hydrogen sulphide.

Phosphorus. Unlike nitrogen and carbon dioxide, phosphorus is not derived in a pond from the atmosphere. Even though present only in very small quantities in natural waters, phosphates, together with silica, are intimately associated with the life cycle of phytoplankton. The nitrogen supplied by the nitrogen-fixing bacteria and phosphorus released from dead organisms give rise to the growth of phyto- and zoo-biota in the water. A concentration of 1 ppm of phosphorus is the optimum for good growth of plankton.

Potassium. Potassium is another important chemical constituent that determines the fertility of a pond. The nature of the pond bed is an indicator of its potassium reserve. Sandy soil is often poor in potassium and a clayey soil generally rich in it. It is readily absorbed by plants and is specially effective in stimulating the growth of aquatic flora. Potassium stored in the plant tissue is released back into the water directly, or from the pond bottom as a result of the decomposition of the plant bodies that die and settle there. A concentration of 1 ppm of potassium in combination with 1 ppm of phosphorus and 4 ppm of nitrogen is believed to be most favorable for plankton production. It has been observed that potassium is able to improve the growth of young common carp more quickly than of older fish. It is thought that the effect of potassium may possibly be indirect and that it facilitates the phosphate cycle by releasing dilute acid.

The Role of Pond Soil

The role of the chemical constitution of the soil in the productive potential of a pond is generally not fully understood. There are often significant differences in the productive capacity of ponds situated in similar surroundings. The productivity of an unfertilized pond may sometimes be the same or more than that of fertilized ones, which can often be traced to the chemical and physical properties of the soil. The soil fertility is of special importance in the growth of benthic vegetation. While water fertility will contribute largely to the production of plankton, soil fertility will under favorable physical conditions induce a good growth of benthic flora.

This is the reason for the special care taken by the milkfish culturists of South East Asia in selecting sites with alluvial soil for their brackishwater ponds. The quality of the soil underlying the pond bed and the organic deposits over it should be given full consideration in an appraisal of its productive capacity. The pond bed releases nutrient material into the water and helps in the fixation or chemical combination of such substances released in the pond itself or introduced from outside. Benthic biota grow and derive nutriment and shelter from the pond bed.

Production in ponds with a bottom rich in fertilizing elements is much greater than in those with poor soil. When the soil contains excessive quantities of alumina and ferric compounds, the water may be rendered acid by the slight colloidal solution produced. In tropical countries, the soil may often be poor in calcium and rich in iron oxide and alumina. This accounts for the soils of such low pH as 4.7 to 5.5 in countries like Malaya. Certain coastal soils become more acid due to the oxidation of sulphur compounds in decaying plant material. Peaty areas, particularly swamps, may have a pH as low as 3.6. Acid pond bottoms not only do not contribute to the fertility of the water but also deprive it of calcium and other substances. The colloidal content of a soil, especially of the muddy layer on the top, is of importance in its capacity to fix or chemically bind nutrients. The productive capacity of the pond bottom has to be preserved by alternate periods of mud formation and mineralisation. This is the scientific basis of the general practice of regularly draining fish ponds.

POND BIOTA AND THEIR CONTROL

The two main aspects of biotic control practised to increase fish production are the encouragement of the growth of food organisms and the control of biota that are directly or indirectly harmful to the fish crop. It therefore follows that the systems of management will depend largely on the type and size of fish cultivated and their feeding habits. For example, in a pond where plankton-feeding fish are reared, the food chain is modified in such a way that the greatest possible quantity of plankton is produced and converted into fish flesh. For the successful cultivation of herbivorous fish, the growth of algae and other suitable vegetation is encouraged. In the culture of omnivorous and carnivorous fishes the food cycle is used to support artificial feeding by the production of natural food.

Phyto-biota

The phyto-biota of a pond consist of bacteria, planktonic and attached microscopic and macroscopic algae and submerged, floating or emergent macrovegetation. The bacterial flora is of special importance, as it is essential for the mineralisation of organic substances. The conditions in ponds in tropical climates are favorable for the growth of bacteria if the water is alkaline, and so they are often found in abundance in such environments. They grow floating freely in the water or attached to higher organisms on the pond bed. The mud layer at the pond bottom is also rich in bacteria. The planktonic phyto-biota form the food of the zooplanktonic organisms as well as that of fish and contribute, when decayed, to the formation of the fine colloidal slime or mud on the pond bed. Algal forms like *Oedogonium*, *Spirogyra*, *Aphanothece*, *Aphanocapsa*, *Oscillatoria* and *Lyngbya* may be seen in large or small quantities throughout the year as constant forms in ponds. Other forms are seen for short periods but are not really constant. Even though algae are highly adaptable to environmental conditions, hydrological and climatological changes do affect them to a great extent. Correlated with seasonal changes, fluctuations in the density and the composition of planktonic growths occur. Investigations conducted in India have shown that ordinarily there are two periods of rapid growth in a year, a lesser one in the hot weather and a greater one during the cold weather. The cold season is favorable for the growth and reproduction of a majority of green filamentous forms such as *Zygnema*, *Spirogyra*, *Bulbochaete* and *Oedogonium*.

Desmids, Chlorococcales and certain Myxophyceae, like *Anabaena,* occur in abundance during this season. During the hot season most of the desmids disappear and members of Myxophyceae predominate along with numerous Eugleneae. During the period of heavy rains the growth of algae is at a minimum, resulting in a scarcity of phytoplankton in the ponds. The disturbance of water due to wind and rain seems to be inimical to the development of floating vegetable organisms.

The lack of sufficient light for photosynthetic activity and the sudden changes in the concentration of dissolved matter are also limiting factors in phytoplankton production. But during periods of bright sunshine, even in the rainy season, swarms of algae such as *Pandorina* may occur in ponds.

The macrovegetation of ponds may consist of emergent, submerged and floating plants. Most of the aquatic weeds are large plants, either submerged or floating. Some of the common submerged vegetation of ponds are *Nitella, Utricularia, Vallisneria, Potamogeton, Elodea, Myriophyllum, Ranunculus, Chara, Ceratophyllum* and *Hydrilla.* *Lotus* and *Nelumbium* are rooted but have floating leaves. *Eichhornia* may be rooted or floating. *Lemna, Wolffia, Azolla, Pistia* and *Salvinia* are common floating plants not attached to the pond bottom. Plants like the reed mace, *typha,* the burr reed and *Sphagnum* grow on the margin of ponds or in shallow water. There are also plants like *Jussiaea, Enhydra,* and *Ipomaea* which spread to the surface of ponds from the banks.

Submerged vegetation in ponds is normally beneficial to the growth of fish and helps in the maintenance of healthy pond life. Plants are directly eaten by fish or they give shelter to food organisms. They extract inorganic nutrient materials from the soil, from the water or the atmosphere and bring them into the life cycle of the pond. Although plants consume oxygen they also release considerable quantities of it during the day, when carbon dioxide is absorbed and oxygen is given out. Even though accurate determinations of the quantity of oxygen donated by plants by photosynthetic activity have not been made in the region, it is believed that the capacity of tropical freshwater algae in this respect is remarkably high. An adequate growth of plants helps the fish directly by providing the necessary shade during long periods of sunshine. A marginal growth of plants may be beneficial in checking erosion in a pond exposed to wind and wave action. Plants have also a favorable effect on the biological purification of the water in newly fertilized ponds, and many fishes need aquatic weeds on which to deposit their eggs. Thus, controlled growth of vegetation is beneficial, but excessive growths may have harmful effects. oxygen depletion. Green and blue-green algae may grow in such profusion that the pond becomes practically filled with green scum and slime and the pond bed may become carpeted with thick layers of filamentous algae, such as *Cladophora, Vaucheria,* and *Spirogyra.* Besides interfering with fishing, such over-abundant growths of algae may result in the creation of abnormal ecological conditions in the pond. For instance, quick utilization of oxygen resources may bring down the oxygen content to a lethal minimum for fish life. In other cases, excessive growths of submerged plants may become noxious as it may lead to biogenic decalcification and an increase in pH. This may be injurious to fish and result in diseases such as fin rot. Thick growths of floating plants cut off light and prevent the growth of valuable phyto- and zooplankton and also hamper aeration. In ponds overgrown with rank submerged vegetation the fish have difficulties in finding their food. Marginal growth of weeds sometimes encourages mosquito breeding and so does floating and emergent vegetation. Predatory fish will hide among the weeds and so the survival rate of cultivated fishes might decrease. Decaying water weeds also often accumulate in such large quantities in the ponds that their mineralisation becomes impossible. These facts show the need for controlling pond vegetation either by biological or by technological means.

Control of Algae

The three common methods of controlling aquatic vegetation are mechanical, biological and chemical. Mechanical removal of algal growths is not always successful, although areas can be cleared with nets or screens. The Chinese fish culturists in Malaya prevent over-development of algae by seine-netting the ponds once or twice a week. The algae removed are mashed and fed to ducks and pigs raised close to the ponds. There are few animals that can be confidently recommended for controlling algae in fish ponds. Some snails are algivorous but their efficiency in this respect is very limited. However, plant-feeding fish can be used for the purpose and experiments in Indonesia have demonstrated and experience has proved that Puntius and Tilapia can keep down growths of filamentous algae.

Algae mostly derive their food directly from the water and can, therefore, be controlled by soluble chemicals in the water. Copper sulphate has been widely used in western countries but its effect is only temporary. A weak solution may kill some algae, but stronger dozes are necessary for others. Doses higher than 1 to 2 ppm may be necessary to clear a pond completely but this may be toxic to fish. Copper sulphate has little effect on Cladophora and related species, so to minimize the chances of reinfection, it is advisable to drain off as much of the water as possible before the chemical is applied. A great defect of the method is that the dead algae will decay in the pond and the resulting oxygen depletion might become dangerous to the fish life. It is therefore advisable to give the treatment about a month before the bloom is expected. It is desirable to remove organic debris from the pond bottom and to prevent the entry of other such rubbish.

Control of Macrovegetation

A common cause of rank vegetation is the shallowness of the pond, and a thick layer of mud can also give rise to dense growths of weeds; so by removing the excess of mud from the pond bed, the weed growth can be considerably decreased.

Ducks feed on some kinds of water weeds and a few of them on a pond may help to control their growth, but they can eat the weeds only to a limited depth. Herbivorous fish are very useful and should be used more generally.

Another biological method of controlling the growth of submerged vegetation is to encourage an algal bloom or dense growth of algae by the application of fertilizers. Although efficient, this might deplete the oxygen. Another method is the temporary introduction of a thick layer of floating vegetation, such as water hyacinths, which will completely shade out and thereby kill submerged plants. The method needs very little labor, but there is the possibility of decayed submerged vegetation disturbing the physico-chemical balance of the pond water.

Mechanical removal of weeds and manual cleaning of the pond are the most common control methods in the Indo-Pacific Region. The most efficient mechanical method is to drag them out with grapnels and similar devices. Mowing the pond bed regularly and closely two or three times a year is satisfactory, using a drag scythe, sufficiently heavy to lie on the bottom while cutting. For large bodies of water, a power weed-cutting machine or a power dredge may be necessary. Various other machines, some operated from the bank and others in boats, are used for removal of weeds. Floating vegetation can be mechanically removed either by wading in the water or from boats.

As far as possible, weeds should be removed before they have borne seeds or spores, so that the chances of re-infestation are minimized. Cut weeds should not be left on the pond bed but should be carried right away from the bank so that spores or seeds are not washed back into the water. In some fish ponds, in Malaya, the weeds are composted with molluscs, worms and insects removed from the pond, and the compost is used as manure for the ponds. Weeds can also be dug into the pond bottom as green compost before refilling.

Chemical Control

It must be remembered that weed-killing substances are often poisonous to fish, to livestock and to human beings. Further, the composition of the water and the properties of the mud must be taken into consideration as they can have an effect on the chemical. In water containing large quantities of dissolved salts, chemical weed killers are less effective and doses lethal to fish may have to be used.

Before treating a pond with weed killers care should be taken to prevent the escape of water to areas in the vicinity which might be adversely affected.

Of the several chemicals that can be used, sodium arsenite appears to be the best. In concentrations of 1 to 2 ppm it kills weeds like Ceratophyllium, Potamogeton and Elodea. Sodium chlorate is satisfactory for killing reeds and other emergent vegetation that grow in shallow pond areas. A 2½% solution, sprayed or sprinkled evenly on a sunny day, may kill them completely. The treatment should be repeated after about two weeks, if there is a secondary growth. In ponds where the distribution is made from a boat, the chemical, such as copper sulphate, can be put in a sack and towed around until it is completely dissolved; or a solution of the correct strength can be applied with a spraying machine.

Recent researches have shown that certain plant growth-regulating substances can kill weeds in concentrations which are not lethal to fish life. These are known as herbicides.

this is DIOXIN + Deadly!

The chemical known as 2,4-D is one of these, among others, and is available in several forms under various trade names. An 0.2% solution, applied as a very fine spray at the rate of 1 liter per 3 to 4 square meters will destroy floating weeds in about a month without harming fish. Old dense vegetation, rooted in the soil may, however, need higher concentrations. Herbicides can be diluted by rain or dew, so it is not advisable to spray on rainy or very cloudy days. From experiments conducted in India it was found that 2,4-D can also kill submerged vegetation like Hydrilla and Najas. Even rooted plants like Vallisneria and Nympheae can be killed in about 20 days by spraying the pond surface.

Herbicides must come into contact with the plant leaves to be effective and so it may be necessary to lower the level of water in the pond before spraying. A marked rise of the plankton production has often been noticed after applying herbicides.

The concentrations and rates of application for particular weeds and conditions should be ascertained before ponds are treated with these substances.

Zoo-biota

Zoo-biota in a pond also consist of floating, attached, and bottom-dwelling organisms. Copepods, cladocerans, rotifers and flagellates constitute the main portion of the micro-fauna in ponds. The zooplankton exhibit a seasonal periodicity in their abundance similar to that of the phytoplankton. In ponds with thick deposits of organic matter, and abundance of cladocerans, fewer copepods and a paucity of rotifers is often noticed. On the other hand, eutrophic ponds may contain large numbers of rotifers during hot periods. The zooplanktonic organisms are of great importance in the productivity of fish ponds, as they form the main food of young fish.

Among the macro-fauna of ponds, worms, molluscs, crustaceans and insects are of importance. Oligochaetes, such as Nais, Chaetogaster, Dero and Aulophorus, are found among vegetation or in the bottom mud. Among the crustaceans, prawns and shrimps are common and crabs, like Paratelphusa, are also found. Both the adults and larval forms of insects are frequent in ponds. Mayflies (Ephemeroptera), caddis flies (Trichoptera) and midges (Diptera) are very common forms and they constitute the food of certain fishes. Mosquito larvae are found in most stagnant waters and adult fish and the young of some cultivated species feed on them avidly. Larvae of various species of Chironomids are consumed in quantities by common carp.

Extraneous fish in ponds can be divided into weed fishes and predators. Water bugs, such as Notonecta, Nepa, Ranatra, and beetles, such as Cybister, may become harmful in nursery ponds. Their control is difficult as it is not easy to keep them out or to remove them. A satisfactory method of controlling insects is to spread a layer of linseed or mustard oil on the pond surface. It is practised by a few fish culturists in Bengal and the method was found to be effective in experiments recently conducted in India. The insects are suffocated.

Some of the weed fishes may be useful for checking mosquito larvae, but they also compete with the cultivated fishes for food and their number should, therefore, be kept down to the minimum. To control mosquito larvae in fish ponds, it is better to introduce strongly larvivorous species like Gambusia, Lebistes and Aplocheilus, rather than species that only take larvae in the absence of other food material. Most of the common food fishes fall under the latter category. By stocking a few larvivorous fish and by keeping the pond surface free of aquatic weeds, mosquito breeding can be minimized.

The predaceous fishes are notably inimical to the cultivated fishes in ponds. The murrels (Ophicephalus spp.), the freshwater shark (Wallago), the climbing perch (Anabas) and the cat fishes (Clarias) are probably the most destructive predaceous species in the region. Periodic draining and cleaning enable the fish culturist to remove most of the predaceous fishes, but in ponds that cannot be drained or desilted the chances of their survival are great. The murrels are extremely hardy and, because of their breathing habits, can survive in almost all types of waters. Even in times of drought they are able to survive by burrowing deep down in the wet mud.

To exclude predaceous fishes from a pond, it should be completely drained and desilted before stocking. Great care should be taken while filling the pond to exclude spawn or fry of predaceous fishes. In ponds which cannot be completely drained and cleaned, repeated fishing is the only method of controlling predators. Besides fishing with drag nets and cast nets, longlines can be used, because they can be used regularly even after a pond has been stocked. Similarly, murrel nooses can keep that species under control.

Certain birds, such as cormorants, fish eagles, herons, and kingfishers, feed mainly on fishes. Cormorants in flocks of 20 or more swim in a row on a pond and by flapping their wings, drive the fish into a shallow area where they are eaten. A cormorant is said to eat double its weight of fish daily. Fish eagles, herons and kingfishers also take a heavy toll of fish from ponds, especially when the water level is low. Thin lines stretched across the pond are the most efficient means of preventing their entry.

Otters are extremely destructive of fish and are found both in hills and plains. They bite and kill a great number of fish, but eat only a few. Otter traps can be used to catch them, but proper fencing is the best preventive. Trained otter-hounds on a pond farm eliminate the nuisance.

Snakes, which can cause great losses of young fish, can be caught in baited fish-traps.

PREPARATION OF PONDS FOR STOCKING

Preliminary

The first step in the preparation of a pond for stocking is to check the inlet and outlet arrangements and the embankments. Repairs or improvements are effected if necessary. Undesirable aquatic biota and the correction of the physico-chemical properties of water and soil should also be undertaken if needed. Stocking ponds should, as far as possible, be drained regularly and large accumulations of organic deposits at the bottom removed. Where draining is not possible, excess of organic matter can be collected with long scoops from the banks or boats. If a pond is drained before stocking, predatory fish and other animals can be controlled to a large extent. Where this is not possible, repeated fishing should be done. But for a more efficient control of predators, fish poisons may be used with advantage before stocking. The ponds should be stocked only after the water has become free of all traces of the poison.

Liming

Another important matter in pond preparation is liming. Liming serves a double purpose: it helps in maintaining the sanitation of the pond and also acts as an agent which increases the productivity of the water. Ponds in which there has been a fish disease, or which have acid water or a low alkaline reserve, should be limed before restocking them. Lime, by its toxic and caustic action, will kill bacteria as well as fish parasites and their intermediate stages. The alkaline reserve will be increased and marked fluctuations in the pH will be effectively stopped. Furthermore, undesirable iron compounds in the water will be neutralized and, in acid waters, the pH will be brought to alkaline level. The condition of the soil is greatly improved by liming as it will enhance the process of mineralization. A reduction of organic matter will also diminish the chances of survival of fish parasites. Liming will reduce the hazards of oxygen depletion and may precipitate the excess of dissolved organic matter and thus lessen the chances for diseases like gill rot. Lime is generally applied in the form of ground limestone, (calcium carbonate), slaked lime (calcium hydroxide) or quicklime (calcium oxide). The calcium carbonate slowly dissolves in the water and is converted into calcium hydrocarbonate. It is of special value in liming light pond bottoms for the purpose of fertilization. Quicklime has the property of binding acids and influencing the pH rapidly, but the process of calcium enrichment and increase of alkaline reserve proceeds more slowly than with calcium carbonate. However, quicklime has the advantage that the same results can be obtained in a pond by the application of only half the quantity.

Lime can be applied on the pond bottom, added to the water at the inlet, or spread on the water surface. Slaked lime and quicklime should as far as possible be applied in ponds after draining. It is desirable to leave the pond dry for at least two weeks after application to take full benefit from the treatment. When lime is applied for controlling the growth of parasites or for the improvement of the pond bottom, the pond bed and not the water should be treated. Only when control of gill rot disease or the precipitation of organic substances is intended, should the water itself be limed. A dosage of about 200 kg of quicklime per hectare is recommended for the purpose, but the quantity applied should be so regulated as to maintain the pH below 10. For a thorough disinfection of a pond, a dose of about 10,000 kg per ha is necessary, but if the liming is regularly done every year for fertilizing purposes, 100 to 200 kg per hectare are sufficient for soils which are not very acid or poor in carbonates. A dressing of 1,000 to 1,500 kg per hectare will be required for ponds with acid soil and water.

The quantity of lime to be applied should be determined with regard to the alkaline reserve as well as to the nature of the pond soil. While about 200 kg per hectare are usually sufficient to bring the alkaline reserve of water to the desirable level of 1 cc of hydrochloric acid per liter, much larger quantities may be necessary to neutralize the acids present at the bottom. It is necessary to bring the pH of the soil to about 6.5 to prevent a sudden fall of the pH of the pond water.

The calcium requirements of the soil can be roughly determined on the basis of its pH. Schäeperclaus (1933) quoted the following table from Trenel, which can be used for estimating the lime requirements of a pond soil when its pH is known.

pH of the soil	Lime requirements in hundreds of kg of calcium oxide per ha		
	Heavy clay or loam	Loamy sand	Sand
more acid than 4	40	20	12.5
4 - 4.5	30	15	12.5
4.5 - 5	25	12.5	10.0
5 - 5.5	15	10	5
5.5 - 6	10	5	2.5
6 - 6.5	5	5	0

Macan, Mortimer and Worthington (1942) recommend the following applications of calcium carbonate to muds of different pH:

pH of mud	Calcium carbonate required in hundreds of kg per ha
Less than 4	60 - 120
4.0 - 4.5	48 - 96
4.5 - 5.0	36 - 72
5.0 - 5.5	30 - 48
5.5 - 6.0	16 - 30
6.0 - 6.5	14 - 16

Another method is by shutting off the pond and applying lime in small quantities until the alkaline reserve reaches 1 to 2 cc of hydrochloric acid per liter.

Fertilizing

There is a continuous consumption of nutrients in a pond to operate the metabolic cycle and, unless the nutrients are regularly replenished, the biological productivity of the pond is necessary for the maximum production of fish. Periodic draining mobilizes the nutrients in the pond soil by exposure to the atmosphere. But in intensive fish culture it is often necessary to apply fertilizing agents to enhance the natural productivity.

As in agriculture, organic and inorganic fertilizers increase production. Cow-dung, pig and poultry manure, spoiled oil cakes, spoiled cotton seed and soya bean meal, compost, sewage, and green grass are commonly used as organic manure in fish ponds to get higher yields. Nitrate of sodium, ammonium sulphate, ammonium superphosphate, muriate of potash and standard mixtures of these materials are used as inorganic manures. Although it is well known that fertilizers can increase fish production, very little is known about the actual mixtures and quantities best suited for particular conditions. Earlier investigations in Germany and experiments conducted in Alabama (USA) by Swingle and Smith (1938, 1939, 1941 and 1942) yielded considerable information on the effect of fertilizers, especially inorganic, under temperate climatic conditions. The fish-carrying capacity of ponds in Alabama was increased by 300 to 400% as a result of fertilizing.

Very few critical investigations on pond fertilizing have so far been undertaken in the Indo-Pacific Region, but there are traditional practices of fertilizing fish ponds with organic manures. The Chinese and the Indonesians build latrines above their fish ponds, or buy night soil to put into them. Letting sewage into fish ponds, as practised near Calcutta and now experimented with in other areas, is a system of organic manuring that has proved to be profitable. Organic manures have the obvious disadvantage that (i) their nutrient values are highly variable, (ii) unless applied under strict control they may give rise to organic pollution and oxygen depletion, and (iii) they induce heavy growths of filamentous algae which might harbor mosquito larvae and pupae.

Preference is usually given to organic manures under tropical conditions because import restrictions limit the supplies of inorganic manures and when available they are relatively expensive, whereas manures, like grass, dung, etc., are usually readily available. Further, organic manures improve the physical structure of the soil, their nutrients are held by the soil for longer periods and so their activity lasts longer. Smith and Swingle (1942) inferred that the effectiveness of manures like cotton-seed meal and soya-bean meal can be increased by the addition of an inorganic fertilizer like superphosphate.

The effectiveness of fertilizers in a pond is greatly influenced by the nature of the pond bottom. If it is satisfactory, in which mineralisation of organic matter takes place rapidly, nutrients are absorbed, held and released slowly over a long period. On such a bottom the effect of fertilizing would last over a year, whereas on a poor one the fertilizers applied are leached out in a short time. Macan et al (1942) classified pond bottoms into the following main types:

(1) Inorganic bottoms of gravel, sand or clay, which are very poor, but can be improved by the application of stable manure or sewage sludge. (2) Peaty bottoms, formed by the accumulation of vegetable debris which has not decomposed, and are therefore barren. The application of large doses of lime may bring about decomposition, resulting in increased fertility. (3) Mud bottoms, composed of a mixture of organic matter of decomposing animals and plants and fine inorganic matter, forming a soft black mud. This is the most productive type.

In view of the importance of the pond bottom in fertilizing practices, a proper study of its composition and defects should be made before adopting a suitable fertilizing technique.

In applying organic manures proper care has to be taken to balance the oxygen budget, and the oxygen concentration should not be allowed to fall to the lethal level, which for most fishes is below 3 ppm. As at present practised, this is done by trial and error. If the techniques are to be standardised, it is necessary to study the constants of different types of water areas and the biochemical oxygen consumption of different types of organic manures. Phelps (1948) mentions that the aeration constant of small ponds in temperate climates is 0.05 to 0.1 per day, but this value will be different in tropical countries, mainly on account of the prevailing temperature conditions.

Ordinarily, a dose of over 1,000 kg of cattle or horse manure per hectare is recommended; when poultry manure is used, about 560 to 1.21 kg per ha is sufficient. These quantities have, of course, to be varied to suit the condition of the soil and water. Where organic manures derived from livestock are not available, compost can be used as a substitute. Any available plant matter, such as leaves, grass cuttings and aquatic vegetation, can be composted in layers of about 30 cm high with 7.5 cm layers of manure between, dusted liberally with superphosphate of lime. Roughly a proportion of 1 : 10 of nitrogen to carbon is necessary for rapid decomposition of vegetable matter. For this purpose 25 kg of nitrate of soda for about 1,000 kg of compost have to be applied and, to maintain the necessary humidity of the compost heap, some 4,000 liters of water will be necessary. The compost should be turned after five weeks and again at eight weeks, and it should be ready for use in about three months. About 5,000 kg per ha may be needed to give rise to a sufficiently abundant growth of fish food in ponds.

The practice of composting green grass with cow-dung and oil-cake in nursery ponds has been referred to, and this is also done in stocking ponds. It is best to apply organic manure after the pond is drained, when it can be raked into the pond bottom. If this is not possible, manure can be heaped at selected spots within the pond in suitable enclosures from where it will slowly diffuse into the water. The chances of water pollution are greatly avoided by this practice.

The important fertilizing elements can be supplied to a pond by applying standard fertilizers such as sodium nitrate, superphosphates and muriate of potash. Fertilizer mixtures are used when there is a deficiency of more than one element. Inorganic fertilizers are generally expressed as percentages of available nitrogen (N), phosphoric acid (P_2O_5) and potash (K_2O). Thus 6 - 8 - 4 (N-P-K) would contain 6% N, 8% P_2O_5 and 4% K_2O. A number of formulae for inorganic fertilizers for fish pond manuring have been evolved; and two of them which have given good results in the USA are given below:

I.
100 kg of 6-8-4 (N-P-K)
10 kg of nitrate of soda

II.
100 kg of sulphate of ammonia
150 kg of superphosphate (16%)
12.5 kg of muriate of potash
37.5 kg of finely ground limestone.

While the ingredients of the first formula can be applied separately or as a mixture, in the latter they are invariably mixed before application. A mixture of organic and inorganic manures, consisting of three parts of animal manure and one part of superphosphate, applied at the rate of about 500 kg per ha per annum, is also quite effective.

It is most desirable to apply and rake the inorganic fertilizers into the pond bed after the pond is drained. Where this is not possible, inorganic manures can be applied from boats or, in small ponds, strewn on the pond surface from the banks. The first application can be made after the rainly season, and in a new pond it should be repeated two or three times at weekly intervals. Later, it will be necessary to apply fertilizers only at intervals of a month or so, or when the water becomes clear. The application of fertilizers causes a bloom to develop and, if the turbidity is such as to make a Secchi disc disappear at a depth of about 45 cm, the pond is considered to be properly fertilized. A rough test is to extend the forearm into the water up to the elbow, and if the fist is not visible, it can be inferred that the pond has been satisfactorily fertilized.

STOCKING PONDS

General Principles of Pond Stocking

The foremost objective in commercial fish culture is the production of a maximum quantity of fish through the most economic management measures. All cultural operations have to be planned with this in view. Even though there are many biological principles that govern stocking procedures, economic factors are so important that stocking methods vary greatly from country to country. For example, some of the Japanese fish culturists feed an almost exclusively artificial diet in quantities that make it possible to stock an incredibly large number of fingerlings per unit of surface. In India artificial foods are very seldom used. The foods that could be given in India are relatively expensive and so stocking methods are devised to utilize to the maximum extent the fish food produced in the ponds naturally or by fertilizing.

To evolve sound stocking techniques the basic information necessary is the food requirement (quantity of food consumed in unit time) of different age or size groups of fish and the quantity of fish food that is or could be produced in the pond. This sort of information is unfortunately not available in the region at present. Until it has been ascertained, stocking systems have to be based on common sense and empirical experience. Based on the expected growth increment of the fish, the total production and the expected mortality figures, the number of fish to be stocked can be computed by the formula:

$$\text{Number of fish to be stocked} = \frac{\text{Total expected increase in weight}}{\text{Expected increase of weight of individual fish}} + \text{Mortality}$$

For example if in a one-hectare pond, a total production of 1,000 kg of carp can be obtained and the pond is to be stocked with 30 g fingerlings, to be harvested when they have attained a weight of 330 g, the expected mortality being 10%, the number of fingerlings to be stocked will be:

$$\frac{1000}{0.3} + 100 = 3433$$

It should be understood that the growth rate of a fish and the total production obtainable are dependent on the environmental conditions. They vary, therefore, from place to place. However, by using the available information, stocking rates can be calculated, which might have to be modified for other areas on the basis of local experience. According to popular belief in India, a mature fish would need about 5 cubic meters or 4.5 square meters of water in a stocking pond for its health growth. Although critical experiments have not so far been conducted to determine the correct quantity of water needed for fish of various species to thrive, the experience of fish culturists in China and Japan has shown that they can do well in much less space, provided respiratory and nutritional requirements are fully met. The following table shows the space allowed per fish in a stocking pond in some of the countries in the region, where intensive fish culture is carried out:

Country	Surface area of pond in m^2 per fish	Volume of water in m^3 per fish
Malaya	9 - 15.5	13.30 - 20.10
Hong Kong	0.30 - 0.38	0.51 - 0.65
South China	0.94 - 2.00	1.90 - 2.80
Yang Tze Region	1.30 - 1.60	3.30 - 4.10
Japan:		
Stagnant common carp ponds	2	3
Ponds with flowing water	0.03	0.05
Eel ponds	0.02	0.05

The Hong Kong fish farmers provide only 0.30 square meters of water area per fingerling at the time of stocking but after three or four months they start thinning the stocks and remove all fish weighing over 150 g. A space of 1.3 to 3.3 cubic meters or 0.94 to 2.8 square meters only is allowed in many stocking ponds in South China. The density of stock in some of the Japanese ponds is probably the highest that has so far been attained. Since the oxygen requirements of common carp are not high, Japanese fish farmers stock as many as 85 fingerlings per square meter of pond area but provide flowing water to replenish the oxygen consumed.

An important factor in productivity is the association of compatible species in ponds. Many of the cultivated fishes are extremely selective in feeding habits and so if any one species alone is stocked it would make use of only a part of the food resources. This is obviously not economical. If fish culture is based on an association of species which together utilize all the food produced, a higher yield can be obtained. Species tolerant of each other are generally the most productive associates; but in the USA carnivorous species are added to maintain the population at an optimum level. This is seldom done in the Indo-Pacific area.

Species that have complementary feeding habits or feed in different zones in the habitat form very suitable associates. The difference in the feeding habits of the young and adults of certain species of cultivated fishes can also be exploited. For this purpose the ponds are stocked with a suitable number of fish of different age groups. As a natural extension of this practice, initally a combination of size groups is stocked in a pond at a high level of population density, and then periodically thinned as the fish grow. Based on these practices, fish associations have been evolved in many countries of the Indo-Pacific Region.

In China, various species of carp with complementary feeding habits are stocked together. The fish culturists of Hong Kong have added the bream and the grey mullet to this association. The fish culturists of Malaya follow the same system, but have often added the tilapia to it. In Indonesian freshwater fish ponds, carps and tilapia are now cultured together. In India and Pakistan, catla, rohu, mrigal and calbasu, sometimes with bata, form a common combination. In the State of Madras, pearl spot, gourami and acclimatised milk fish are also cultivated with carps. These are all herbivorous species, but in Vietnam and Japan certain carnivorous fishes are added to the combination. In Cambodia, for example, siluroid and cyprinid fishes are cultivated together.

The omnivorous common carp and the carnivorous eel are stocked together in Japan. The provision of artificial food in sufficient quantities appears to check the predaceous instincts of the eel.

As already pointed out, although the principles underlying stocking operations are essentially the same in the various countries, the details of the techniques vary greatly with the culturable species available and the environmental and other conditions existing in the area. In view of this, the stocking operations followed in the various countries of the region are now described separately.

Pond Stocking in China. An outstanding feature of the Chinese fish farming technique, which has influenced the selection of compatible species, is that artificial feeding is almost a universal practice. Therefore associations have been evolved not only to utilize the fish foods that are produced in the pond but also to use the artificial foods that can be provided.

The fishes usually cultivated together in China are (1) the grass carp which feeds on coarse vegetable matter either present in the pond or supplied; (2) the black carp which feeds on snails and other molluscs either present in the pond or artificially introduced; (3) the big head, which consumes the macroplankton produced in the pond; (4) the silver carp feeding on all planktonic organisms; (5) the mud carp feeding at the bottom on worms and organic matter; and (6) the common carp which is omnivorous and acts as a scavenger.

The fish farmers in Hong Kong have slightly enlarged this association. On account of the scarcity of available carp fry in the colony and the difficulty in procuring fry from the mainland of China, the farmers had to look for locally available species to add to the restricted supplies. The grey mullet, *Mugil cephalus*, and the bream, *Parabramis pekinensis*, proved to be quite satisfactory. The grey mullet feeds on organic debris and algae, including diatoms, and also takes rice bran and ground cereals. The bream is described as "mildly omnivorous". This combination of species has proved very profitable and it has now gained in popularity to a considerable extent in the slightly brackish coastal ponds of the New Territories of Hong Kong.

The fish culturists in Taiwan include in their carp ponds the milkfish, which feeds on algal matter, either decayed or growing in the benthic zones. This combination has proved to be satisfactory and gives good yields.

Lin (1954) collated the available information on the different stocking procedures followed in China and his information is summarised below. But it is emphasized that these systems are only those at present practised and found to be profitable and are not necessarily the most efficient. The Chinese systems can be broadly classified into three: (1) the Kiangsu and Chekiang, (2) the West River Regions, and (3) the Hong Kong system.

Stocking in Kiangsu and Chekiang evolved with due reference to the nature of local ponds and the availability of stocking material. Ponds in this region vary in depth from 2 to 7 meters. Black carp, (*Mylopharyngodon piceus*), is preferred to grass carp because of its greater market value and the fact that pond snails, which form their favorite food, are easily available. The cold climate of the area precludes the culture of mud carp, and common carp is considered an essential fish because of its scavenging habits. In ponds having average depths of 2.5 m the following three systems are generally practised:

Stocking Rate of Ponds in Kiangsu

Species	Length of fish stocked, in mm	Number of fry per ha System I	System II	System III
Black carp	250 - 350	1000	2000	2400
Black carp	150 - 180	2000	200	-
Grass carp	200 - 300	-	2000	-
Silver carp	150 - 200	3000	3000	2400
Big head	150 - 200	600	1600	-
Common carp	150 - 200	200	200	1200
Bream	120 - 150	500	500	-
	Total	7300	9500	6000

The following three systems of stocking are adopted for cultivation of yearlings in deeper ponds, the depth varying from 3 to 7 meters.

Stocking Rate of Deep Ponds in Kiangsu

Species	Wt. of yearlings in g	Number of yearlings per ha System I	System II	System III
Big head and silver carp	500	4500	4500	9000
Grass carp	500	600	-	3000 (*)
Black carp	500	-	450	-
Common carp	200	200	200	200

In Tinghai and Shaoshing in Chekiang, the number of associates is considerably reduced and the proportion of black carp increased. The fishes are usually cultivated for three years. The system of stocking is shown in the following table. During the first year they are reared in ponds 1.3 to 1.5 m deep; in the second year in ponds about 2 m deep, and during the third year ponds of 2½ to 3 m deep are used.

(*) The grass carp is often substituted by an equal number of black carp.

Stocking Rate of Ponds in Chekiang

Species	First year: Initial wt. in g	First year: No. of fingerlings per ha (age 3 to 9 mths)	Second year: Initial wt. in g	Second year: No. per ha (age 15 to 21 mths)	Third year: Initial wt. in g	Third year: No. per ha
Black carp	35	6000	500	1300	2750	240
Silver carp	40	400	600	1000	600	400
Big head	40	400	600	80	600	300
Common carp	30	400	350	50	350	200
Total		7200		1530		1140

By the end of the third year the black carp attain a weight of 5,000 g and the 15- to 21-months-old silver carp, big head and common carp weigh 1,500 g, 2,000 g and 750 g respectively. Mortality during the first two years is about 10% and in the third year the mortality is negligible.

Stocking in the West River Region

In certain regions of South China and in the Tonkin province of Vietnam, belonging to the West River system, the stocking methods are modified to suit local conditions. The climate here is warmer than in Kiangsu and Chekiang and so it is likely that the rate of mortality will be higher. The black carp is therefore given less importance, but mud carp grow very well in the subtropical climate of the region and there is an abundant supply of grass, silkworm wastes and mulberry leaves to feed the grass carp.

Stocking Rate of Ponds in the West River Region

Species	Length of fish in cm	Number of fish stocked per ha: Ponds with average depth of 1½ m: I	II	III	Ponds with average depth of 2 m: IV	V	VI
Grass carp	60 - 15.0	1200	1200	600	480	1200	2400
Silver carp	10.0	300	240	600	1200	1800	400
Big head	10.0	300	240	1200	510	1800	400
Mud carp	7.5	1800	4800	-	2400	3600	7200
Common carp	5.0	1200	360	3600	-	1200	300
Black carp	5.0 - 10.0	100	24	120	60	-	150
Bream	7.5	-	-	-	600	-	-
Total		4900	6864	6120	5250	9600	10850

Systems I and II are suitable for very fertile ponds in which a good supply of artificial foods can be provided. Systems III and IV are suited to fairly deep ponds when it is not possible to obtain sufficient quantities of fodder for grass carp. In deeper ponds with a good water supply, stocking system V and VI will be the most suitable.

Shallow ponds are also utilized for raising big fish, though they are not so productive as the deeper ones. Fewer fish (about 3,000 to 3,600) can be stocked per hectare in such ponds. The two stocking systems commonly practised for ponds with an average depth of 60 cm are indicated below:

Stocking Rate of Shallow Ponds in the West River Region

Species	Initial wt. of each fish in g	Number of yearlings per ha	
		I	II
Grass carp	50	240	480
Silver carp	20 - 40	1200	972
Big head	100 - 150	120	240
Common carp	0.4 - 0.5	1680	972
		3240	2664

As the water temperature in shallow ponds may become too high for mud carp and black carp in summer, they are not kept in these ponds during the hot period, and even the other carps are stocked only in February/March and removed in the summer. Fish of marketable size (above 500 g in weight) are sold and the smaller ones are transferred to deeper ponds for further growth.

Hong Kong System of Stocking. The distinctive feature of pond stocking in Hong Kong is the use of grey mullet which are abundant in that region. In the coastal ponds with slightly brackish water it is possible to culture various species of carp. Stocking systems that have been found to be profitable for ponds, 1 to 2.5 m in depth, are given below.

Stocking Rate of Ponds in Hong Kong

	Length of fry in cm	Number of fingerlings per ha		
		I	II	III
Grey mullet	2.5 - 4.5	12,000	27,360	15,000
Grass carp	5.0 -10.0	1,524	300	700
Silver carp	7.5	2,208	2,568	600
Big head	7.5	1,536	524	600
Mud carp	5.0	9,600	3,120	9,000
Common carp	5.0	-	-	4,800
Bream	5.0	-	-	-

These systems are modified to a large extent on the basis of personal experience and availability of stocking material. When the mullets have attained a size of about 12 cm the stock is thinned by regular fishing.

Stocking System in Malaya and Thailand. The stocking systems in Malaya and Thailand are to a large extent based on the Chinese systems, but several modifications have been effected to suit local conditions. In both these countries fry other than of common carp have to be obtained from China and the import is restricted due to high prices and transport difficulties. Further, the returns from the culture of mud carp are found to be not commensurate with the expenses and effort involved in bringing the fry from China. On the other hand, plants suitable as food for grass carp are freely available in the area; so the fish culturists in Malaya stock their ponds with proportionately larger numbers of grass carp in association with silver carp, big head and common carp. The ponds are often relatively understocked but, by intensive feeding and fattening, the farmers obtain a satisfactory yield. Utilising the large quantities of food available, the fishes grow rapidly and reach marketable size in a short time so it is possible to raise two crops of fish a year. This ensures satisfactory returns to the farmer. Four typical systems of stocking ponds, 1.2 to 1.5 m deep, are shown below, but, depending on the availability of stocking material and the food resources of the pond, modifications are effected.

Stocking Rate of Ponds in Malaya

Species	Initial weight of each fish in g	No. of fish stocked per ha			
		I	II	III	IV
Grass carp	350 - 600	300	320	375	500
Big head	"	100	120	75	175
Silver carp	"	100	125	75	200
Common carp	30 - 60	145	150	120	250
	Total	645	715	645	1125

Gopinath (1950) reported that the combination of species that gave the best results is grass carp, big head, silver carp and common carp in the proportion of 2:1:1:3.

An improved system of stocking has been developed in Singapore. In this the period of fry rearing (except that of common carp) is extended to about eight months instead of the usual three months, and from the nurseries the fish are transferred to fattening ponds where they are allowed to grow for about six months. The stocking rates commonly followed are shown in the table below.

Stocking Rate of Ponds in Singapore

Species	Wt. in g of fry put into the nursery	No. stocked per ha	Wt. in g of fish stocked in fattening pond	No. stocked per ha
Grass carp	30	1250	1500	450
Big head	40	250	2000	150
Silver carp	40	250	1800	175
Common carp	30	-	-	225
	Total	1750		1000

Stocking Ponds in Japan. The Japanese system of pond stocking is probably the most intensive in the world and the production obtained from some of the ponds is phenomenal. The distinctive feature of the Japanese system is the dense populations of fish reared by intensive artificial feeding. The hazards of oxygen deficiency are overcome by maintaining a constant flow of water and, as the fish increase in size, the populations are thinned out by regular fishing. Common carp and eel are either cultivated in association or separately in freshwater ponds.

Common carp are stocked either in stagnant ponds or ponds having a constant flow of water. In stagnant ponds with a depth of about 1.5 m, one carp of 20 to 50 g weight is stocked for every square meter of water, and in such ponds a yield of 2,500 to 4,500 kg per ha is usually obtained. With adequate water supply and feeding it is possible to increase the yield to 5,500 kg per ha per annum.

The flowing water ponds are constructed as diversions from streams. They are seldom more than 100 m^2 in extent and 1.5 m in depth, a size most suitable for the maintenance of a proper current of water and for efficient feeding. In such ponds carp weighing 56 to 150 g are stocked at the rate of 280,000 to 850,000 per ha. Allowing for a mortality of 10 to 20%, these ponds will yield up to 700,000 per ha per annum.

Eel ponds carry 20 to 44 elvers, 10 to 20 g in weight, per square meter of water. Twenty elvers, about 15 g in weight, per m^2 is a suitable stocking rate for stagnant water ponds. When artificially fed, eels often leave a good portion of the food uneaten. To utilize this food and to act as scavengers, common carp fingerlings, about 7 cm long, are introduced at the rate of one per square meter. When properly fed, about 30% of the elvers will attain a weight of about 120 g in one year and are then harvested. The remaining eels may not have attained that size and a fresh lot (the same number as those harvested) of elvers, about 10 g in weight, are then stocked and allowed to grow for a year. The whole crop is harvested at the end of the second year. A yield of 16,000 kg per ha can thus be obtained with a survival rate of 60 to 90%.

Stocking of Ponds in India and Pakistan. The most important pond fishes of India and Pakistan, catla, rohu, mrigal and calbasu are often cultured in association. Catla feed at the surface zones, mrigal at the bottom and rohu is generally a column feeder. Calbasu is added to this association in certain areas, as it feeds on molluscs. Even though pond culture has been in existence in these countries from very early times it has never been seriously investigated, and it is not yet known what are the most suitable stocking rates. The difficulty experienced in distinguishing the fry of different species of carps is also a great handicap to proper stocking. It is generally believed that in a stocking pond each carp fingerling should be provided with about 0.1 m^3 of water in the first year, 0.23 m^3 in the second year and 0.45 m^3 in the third year. This is achieved by thinning the populations at the end of each year. Rearing fish after the third year is not profitable as large fish are not relished and do not fetch a good price. Allowances should be made in the stocking system for an annual mortality which may be more than 30%, also for losses by reduction in the volume of water in the ponds as a result of evaporation during summer, which can be computed as about 10%. A proportion of 30% catla, 60% rohu and 10% mrigal is recommended. About 1,875 catla, 3,750 rohu and 625 mrigal, all 8 to 13 cm in size can be stocked in a one-hectare pond. If calbasu is included, the percentage of rohu may be decreased to 50% and the difference made up with calbasu. The mortality rates under present conditions in the ponds are rather high and the actual production is often much lower than should be obtained in view of the high growth rates of these species. As regards the other fishes cultured in India, a stock density similar to that adopted for catla, rohu and mrigal is recommended, even though the optimum rates have not so far been determined. Personal experience has to a large extent influenced the local practices in this respect.

Stocking of Ponds in Indonesia. One of the distinctive features of fish cultivation in Indonesia is that fishes are reared in ponds only for short periods and so several crops are obtained from a pond every year. The preference of local consumers for small fish enables the fish farmers to profit from this. Seldom are fish allowed to grow to more than 200 g in weight. The consumers in rural areas often buy fingerlings of gourami or tilapia and keep them in small ponds or tanks near homesteads, where they are fattened on kitchen waste.

Association of species for the full utilization of food resources is not so highly developed in Indonesia as in China, but the following combination has been tried and found to be suitable:

Common carp	30%
Tilapia	35%
Nilem	20%
Gourami	15%

The methods previously described of stocking common carp in nilem ponds for raising marketable fish have been found to be very satisfactory in Indonesia.

FISH FEEDING AND GROWTH

Foods and Feeding

One of the main factors governing the growth rate of pond fish, and thereby the productivity of a pond, is the availability of suitable foods. The food elements that are produced in the course of the annual biological cycle, and the natural or artificial foods that are supplied, are the two main types of food available to the fish.

Mention must be made of the organic debris, composed of decayed or decaying vegetable or animal matter. Many bottom-feeding fishes depend largely on this and the benthic flora and fauna that grow on them. Organic debris, besides directly forming nutritive food material, gives rise to a good planktonic growth as a result of mineralisation. However, the amount of organic debris accumulating in a pond should be kept under control and regulated in accordance with the requirements of the fish cultivated.

The fish food produced in a body of water is influenced by a variety of factors and so the natural fish production per annum varies from less than 10 kg per hectare to 2,000 kg and more. If artificial feeding is done regularly it is possible to stock ponds with larger populations of fish than they can normally sustain. Three types of fishes are recognised in pond culture: they are (1) those that thrive on artificial foods; (2) those that thrive best on a diet composed of both artificial and natural foods; (3) those that take only natural food and do not relish artificial foods. Grass carp, black carp and eel are examples of the first group; common carp, mud carp, catla, rohu and mrigal belong to the second group; and big head and silver carp to the third group. In selecting food for fish, the dietetic values as well as the economic practicability of using them have to be taken into consideration.

The ratio of food consumed to the fish flesh produced is known as the forage ratio. The term food quotient, expressing the unit weight of fish food required to produce unit weight of fish flesh, indicates the relative value of fish foods. The food quotient is determined by dividing the weight of the food consumed by the fish's total weight increment. The food quotient of a species of fish is not constant and may vary considerably, depending on such factors as temperature, oxygen content of the water, size of the fish, feeding habits, and general condition. It has been found that the consumption of food increases directly with the increase in temperature of the water in which the fish lives. It has also been observed that the food quotient falls with an increase in the oxygen content of the water. Because the amount of food required for the maintenance of normal life is relatively more in a larger than in a smaller fish, it is possible that the food quotient of the different size groups of fish varies, although this does not appear to have been conclusively proved. Climatic factors and the health condition of fish greatly affect their feeding activity. However, the food quotients often cited are useful for judging the food requirements for normal weight increment. While the food quotients of some of the artificial foods have been determined, the exact dietetic requirements of the pond fishes of the region are not at all well known. Even though an artificial food may be eagerly eaten, the quantity of flesh that will be ultimately produced, and the net profit, has to be considered. It is therefore necessary that artificial foods should be relatively cheap in price. For example, the fish farmers of Japan feed carp, eel, trout, etc., with small fish or fish meal, and in spite of the fact that the forage ratio is high, the industry is profitable because of the high price of cultivated fish and the easy availability and low price of the foodstuffs. But this practice is hardly feasible in other areas of the region where the food material may cost as much as, if not more than, the fish flesh they would contribute to produce.

The food requirements of a fish are often judged by what is known as the sustenance ratio, which is the ratio of the crude protein and the nitrogen-free components, such as fat and carbo hydrates, required for the catabolic activity of the fish. The sustenance ratio of fishes varies greatly with age. For example, for common carp in the first year of its life the ratio is 1:0.4 to 0.5, in the second year 1:0.7 to 0.8, and in the third year 1:1.00 to 1.25. Younger carp need a larger percentage of proteins and the older ones a larger percentage of nitrogen-free carbohydrates, (Fujida, 1933). According to Schäperclaus (1933), cultivated fish can be broadly divided into three categories: (1) those with a low sustenance ratio of the order of 1:2 to 1:4; (2) those with a medium ratio of about 1:5 to 1:6; and (3) those with high ratios of 1:8 to 1:12. Trout, as a cold water fish, comes under the category of fish with a low sustenance ratio, common carp comes under the medium ratio, and the grass carp has a high ratio.

A satisfactory means of judging the efficiency of foods is by comparing the food quotients. The selection of artificial foods should be based on this information.

The food quotients of some of the artificial foods are listed below (Shih, 1937; Chen, 1935):

	Food Quotients
Fresh silkworm pupae	5.5
Dried silkworm pupae	1.66
Pressed dry silkworm pupae	1.40
Soyabean cake	2.22
Barley	2.60
Rice bran	5.05
Wheat bran	4.22
Peanut cake	2.13
Spirodela polyrhiza	27.77
Panicum crusgallii	13.33
Cynodon dactylon	11.90

From the above it will be seen that pressed dry silkworm pupae is a highly efficient food, but the economic aspects of its use have to be taken into consideration. The method suggested by Fujida (1933), which consists of expressing the nutritive value of a food in terms of carbohydrates by multiplying the protein and fat values by two and thus arriving at the total carbohydrate values, is useful to some extent in determining this. The total carbohydrate values of foods can be easily compared and equated against their market values to ascertain the economics of using them.

The foods that can be directly provided by the fish farmer consist of the natural foods he collects from other waters and the artificially prepared foodstuffs. Fish show a preference for natural foods and pond fish generally thrive best when natural foods are included in their diet.

Aquatic plants are often used when they are readily available in the vicinity and grass is commonly fed. The composition of common varieties of land grasses and aquatic weeds fed to pond fish is given below (Chen, 1935, Birtwistle, 1931 and Wu 1940):

Composition of Fresh Vegetable Fish Foods

	Water	N %	Crude protein (n x 6.25) %	Crude fat %	Carbohydrate %	Fiber %	Ash %	Sustenance ratio *
Land grasses								
Cynodon dactylon								
fresh	77.6	-	4.89	0.78	10.40	4.17	2.00	1:2.5
dried	-	-	21.99	3.51	46.76	18.75	8.99	
Panicum crusgallii								
fresh	84.28	-	3.65	0.76	6.43	3.43	1.55	1:2.2
dried	-	-	23.22	4.83	40.26	21.82	9.87	
Aquatic weeds								
Duck weed (*Spirodela polyrhiza*)	94.37	-	1.62	0.02	2.85	0.35	0.79	1:1.8
Wolffia arrhiza	93.46	0.39	2.44	-	1.78	0.73	1.59	1:0.7
Plankton								
Microcystis	93.36	0.53	3.31	0.27	1.81	0.23	1.02	1:0.8
Pond debris	92.07	0.63	-	0.12	-	-	23.16	-

* The sustenance ratio is derived by the formula: $\frac{\text{crude fat x 2.2 carbohydrate}}{\text{crude protein}}$ (Kellner, 1929; Schäperclaus , 1933)

Other aquatic plants like, *Cyperus*, *Ceratophyllum* and *Elodea*, are also suitable for grass carp ponds.

Grass carp, *Puntius javanicus*, *Tilapia mossambica* and a few other pond fishes will eat some of the higher plants. About 10 to 15 kg of grass will produce one kg of grass carp flesh. On this basis, the total quantity of grass required to achieve a certain production in a given period of time can be estimated, and this quantity should be given in suitable amounts during the period of rearing. Generally speaking, the grass carp should receive fresh grass at the rate of 10% to 15% of its total estimated weight when grass is the only food provided, usually in the morning and evening when the water is cool. The grass is fed as soon as it is cut, before it wilts. Tender grass grown on fertile land is the best. It is not advisable to throw the grass, or for that matter any food material, indiscriminately into a pond. The usual practice is to construct a special feeding enclosure into which the food is put. In a pond of about 0.5 hectares one enclosure, about 4 m^2 should be sufficient; more in larger ponds.

In the absence of sufficient quantities of natural foods it will be necessary to provide the fish with artificial foods, so as to achieve the maximum rate of growth. Artificial foods are of vegetable or animal origin and the choice depends on the feeding habits and the possibility of training the fish to take the particular food. Fish such as the common carp, grass carp and gourami can be fed on a variety of artificial foods, whereas fish like black carp require a special diet. The composition of some of the artificial foods available in the region is shown in the following table.

Composition of Artificial Fish Foods

	Water	N %	Crude protein %	Crude fat %	Carbohydrate %	Fiber %	Ash %	Sustenance ratio
Peanut cake	12.77		31.82	9.01	27.99		16.89	1:1.5
Soyabean cake	15.86		37.03	9.43	28.03	4.81	4.84	1:1.3
Soyabean milk	91.80		4.40	1.80	1.50	-	0.49	1:2.0
Bean meal	13.62	7.0	43.75	7.56	26.91	4.15	4.01	1:1.0
Barley	13.03	-	10.29	2.17	66.34	5.81	2.36	1:7.0
Flour	14.85	2.40	15.00	0.64	69.05	-	0.46	1:4.7
Wheat	13.59	-	13.07	1.96	63.61	3.91	3.85	1:5.2
White wheat flour	12.80	-	10.80	1.10	74.60	0.20	0.50	1:7.1
Wheat bran	10.50	-	13.90	4.20	55.60	10.50	5.30	1:4.6
Rice bran	9.15 - 11.20	-	13.24 - 15.80	4.30 - 16.05	42.65 - 47.40	6.50 - 6.63	13.28 - 14.80	1:3.6 - 1:5.9

Rice bran or a mixture of rice bran and fine particles of broken rice are very popular fish foods, relished by grey mullet. The different kinds of oil cakes (the residue left after the oil has been pressed out from peanuts, mustard seeds, soyabean, linseed, coconut and the like) are good foods. These cakes should either be powdered or soaked in water before being fed to fish. Starchy foods, such as tubers, should be cooked, not fed in the raw state. Rice bran can either be scattered over the entire pond surface or spread in a feeding frame of the type described above. In mullet ponds it is better to put the bran in bags or baskets submerged in the water at different spots. Oil cakes and similar foodstuffs can be fed in a similar manner. This enables the farmer to assess correctly the quantity of food the fish are actually consuming and to remove all the food left over, which might decay and pollute the pond water.

Artificial foods of animal origin are particularly suitable for omnivorous and carnivorous fish. The commonly used ingredients are fresh and dried silkworm pupae, fish meal, snails and other shell fish, weed fish, shrimp wastes, slaughterhouse refuse, cow dung, pig and poultry manure, silkworm wastes and night soil. The composition and sustenance ratios of some of these foods are given as follows:

Composition of Fish Foods of Animal Origin

	Water %	Crude protein %	Crude fat %	Carbohydrate %	Fiber %	Ash %	Sustenance ratio
Fresh silkworm pupae	64.63	19.12	12.75	2.33	-	1.16	1:1.6
Dried silkworm pupae	10.03	55.91	24.50	5.58	-	2.98	1:1.1
Defatted silkworm pupae	8.90	75.36	1.75	8.40	-	5.59	1:0.2
Flesh of other snails	75.76	19.10	0.55	-	-	4.59	1:0.07
River snail (whole)	36.80	5.70	0.70	2.00	-	1.70	-
River snail flesh	78.40	12.20	1.40	4.30	-	3.70	-
Mussels	79.60	18.40	0.80	-	-	1.20	1:0.09
Small clams	84.04	13.20	0.77	-	-	1.96	1:0.1
Small shrimps	17.20	55.45	5.52	4.37	-	17.65	1:0.3

Fresh or dried silkworm pupae, rich in proteins and fat, are an important fish food in China and Japan, where they are available in considerable quantities. In Japan, common carp and eel are fed on silkworm pupae, and in China they are given to the grass carp and common carp. A daily diet of three pupae is considered sufficient for a grass carp weighing about 600 g. Since the pupae contain a high percentage of fat, it is necessary to reduce the daily ration or even stop feeding altogether during hot periods. The pupae should be as fresh as possible, because tainted pupae can cause serious diseases and also impart a bad taste to the fish flesh. The pupae are generally thrown into the pond. To balance the diet, grass or other vegetable matter should be included.

To store the pupae for later use, they can be cooked and dried. The keeping quality can be considerably improved by extracting the fat. Dried pupae can be thrown to the fish but they are usually mixed with wheat flour and powdered soyabean cake.

Fish of inferior quality can be used as food for common carp, grass carp and catfish, chopped into small pieces and mixed with silkworm pupae and vegetable foods. Sardines and certain species of mackerels, which are available in large quantities in certain periods of the year, are used in Japan as food for eels, either fresh or dried. Fish meal being relatively expensive in the region, few fish culturists use it, except in Japan, where it is sometimes cooked with such materials as wheat flour and rice meal. In some of the fishing centers where large quantities of shrimps are dried and shelled, shrimp wastes in the form of shells and small broken pieces of shrimp meat are available; these, when mixed with wheat flour, corn meal or other vegetable matter, make a very good food for pond carps.

Freshwater snails and mussels are relished by black carp, common carp and grass carp. While black carp can be fed on whole live snails and mussels, the meat alone should be used for the other carps. Since snails and mussels might have parasites, it is essential that only cooked meat be given. All food not eaten should be removed without delay.

Slaughterhouse refuse of different types is given, either fresh, dried or powdered, to trout, eels and carps. It is advisable to mix it with cereals and vegetables for carp.

Farmyard manure, when applied to a pond, is to some extent eaten directly by the fish and the rest helps to increase the fertility of the pond, thereby giving rise to a bloom of planktonic or benthic growth. Since night soil might spread infectious diseases it should not be used in ponds stocked with marketable fish.

Climatic, seasonal and environmental adjustments in feeding

The climatic conditions prevailing in an area have to be considered in arranging feeding procedures. As already mentioned, water temperature has a great influence on the feeding activity of fish. In subtropical climates, when the temperature drops below 15°C in winter, the feeding activity is lowered or entirely stopped, and, until the temperature rises again in the spring, the fish do not resume feeding. The feeding should therefore be scheduled accordingly. Similarly, it has been observed in some cases that when the water temperature rises above 25°C, the feeding activity decreases.

Besides marked alterations in feeding activity there is a less conspicuous seasonal fluctuation in the nutritional and physiological rhythm of fish. The growth rate also varies according to this and so naturally do the food requirements.

In the Kwangtung delta of China, a thickly populated area, grass is scarce but silkworm pupae can be had in good quantities. The ponds being well fertilized, silver carp, big head, mud carp and black carp get sufficient food from the pond itself and only the grass carp need intensive feeding. A schedule followed in the area for feeding grass carp and to some extent common carp and mud carp is given below.

Feeding Schedule for Grass Carp in Kwangtung. China

Months	Approx. mean temp. °C	Percentage of fish growth and food consumption %	Estimate wt. of fish in pond		Quantity of food required per month in kg			
			Wt. increment per month in kg	Total Wt. in kg	Grass	Silk-worm waste	Fresh silk-worm pupae	Rice bran
February	15			70.00				
March	16	6	127.80	197.80	1534	1022	639	639
April	20	7	149.10	346.90	1739	1193	745	745
May	24	9	191.70	538.60	2301	1534	959	959
June	28	12	255.60	794.20	3067	2054	1278	1278
July	30	15	319.50	1113.70	3834	2556	1598	1598
Quantity harvested at the end of July				800.00				
New stocking material added				200.00				
Stock				513.70				
August	31	20	426.00	939.70	5112	3408	2130	2130
September	28	15	319.50	1259.20	3834	2556	1597	1597
October	27	7	149.10	1408.30	1789	1193	745	745
November	23	5	106.50	1514.80	1278	852	533	533
December	16	4	85.20	1600.00	1022	682	426	426

In the absence of foods shown in the table, others can be substituted, but grass should always be included in the diet. Assuming that the food consumption is directly proportional to the rate of growth, the food requirement for each month is calculated by multiplying the monthly weight increment by the food quotient of the particular food. A feeding schedule can thus be drawn up for any locality and for any species of fish, if the temperature and the growth rate of fish during each month are known. As an example, a general schedule for black carp is given below. It should be stressed that it will be necessary to alter the feeding procedure if the fish do not consume the whole of the daily ration, or if there is any abnormality in their behavior.

Feeding Schedule for Black Carp

Month	Wt. increment kg	Total wt. kg	Wt. of food to be given in kg			
			Mussels	Barley	Bean cake	Total
April	-	450	small quantities	small quantities	-	-
May	155	605	800	-	140	940
June	344	949	1000	634	-	1634
July	937	1886	5000	1000	-	6000
August	937	2823	5000	1000	-	6000
September	376	3199	1880	-	376	2256
October	376	3575	1880	-	376	2256

Small quantities of artificial foods can be given to black carp by the middle of April, but intensive feeding is done from May to October, when the water temperature is around 20°C. In May and June, when it is relatively cold, they can be fed with mussels and snails alone, which are foods of low sustenance ratio. In later months the fish need to be given a diet consisting of half vegetable and half animal foods.

The climatic conditions in Japan necessitate a different system of feeding. Even though light artificial feeding can be done and some results in the way of noticeable increases in the weight of fish can be attained during cold months, the most suitable temperature for feeding carp in Japan is around 24° to 25°C. At temperatures below 7°C, the fish become quiescent and remain at the bottom of the pond in a state of hibernation. Under these conditions feeding starts by about the middle of April and intensive feeding is done from July to early September, after which it is slowly decreased and completely stopped by the middle of November. The following is a schedule for feeding the common carp in such a climate, as adopted by Lin (MS) from Shih (1937).

Feeding Schedule for Common Carp in Japan

Month	Monthly feeding rate in % of total annual quantity	Essential foods	Daily feeding frequency	Time required to finish food at each feeding
January	Nil			
February	Nil			
March	Nil			
April	1	wheat, snail, pupae, soya-sauce waste, earthworm, rice bran	Once a day	Within 1 hour
May	4	mixed foods	Once increasing to 3 times	30 minutes
June	15	pupae as staple foods; and also mixed foods	3 to 6 times	15 to 30 mins.
July	20	silkworm pupae	3 to 7 times	ditto
August	30	ditto	5 to 9 times	ditto
September	20	ditto	5 to 7 times	ditto
October	9	pupae, wheat, bean meal, vegetable and fish meal	2 to 5 times	
November	1	ditto	Once daily, to once every 2 days	30 minutes
December	Nil			
	100%			

This schedule is modified according to the daily weather conditions. On stormy days with heavy showers and strong wind when the temperature falls very low, either the feeding should be stopped or only a little food given. On a sunny warm day the ration can be somewhat increased.

The feeding should be much more intensive in ponds with running water and large stocks of fish. From May to June they are fed once every hour or two, or six times during the day. From July to September the feeding is increased to 12 times a day. In October and November they are fed only six times a day at intervals of two hours. During summer, which is the period of rapid growth, feeding should be done more often in the morning or evening, even up to as late as 9 to 10 p.m.

The feeding schedule for eels in Japan is similar to that of carp. Feeding is done from about March to November and a quantity of food weighing from 5 per cent to 10 per cent of the weight of the fish may have to be given. However, much depends on the behavior of the fish and the experience of the farmer.

Fish Growth in Ponds

The growth of fish is influenced by a variety of factors. The genetic characteristics of the stock themselves are of importance, and this has been well recognised in the cultivation of the common carp. Chinese and Indonesian fish culturists therefore select the quickest growing, fat and healthy specimens for breeding purposes since experience has shown that the offspring of such stock grow more rapidly and yield better.

The rate of growth is directly affected by temperature and other physical conditions of the water. The lowering of feeding intensity or the non-availability of certain types of food affect growth considerably. While a fish will be able to survive in a stunted form when fed on an austerity diet, that is just sufficient for the maintenance of its life, a richer diet is necessary for its rapid growth. The density of the fish population in a pond is therefore a very important factor which influences the growth rate, because it determines the degree of competition in feeding and consequently the amount of food available per fish. The growth of fish is much quicker in understocked than in overstocked ponds. In view of the fact that several environmental and other factors affect the growth rate, it is rather difficult to judge with accuracy the normal or even the maximum growth that can be expected for a species. Data regarding the weights attained by some of the important cultivated fishes are given in the table below. While this should help to form some idea of the comparative growth rates of the species, it is emphasized that these figures are based only on observations; they are not the results of controlled experiments.

Growth Rate of Fishes in Ponds in the Indo-Pacific Region

Species	Weight increment in g during			
	1st year	2nd year	3rd year	4th year
China				
Grass carp	225-680	1200-2300	2700	4800
Black carp	600	2750	4500-5000	9000
Big head	150	900	1800	4200
Silver carp	150	900	1800	3600
Mud carp	75	3300	600	-
Common carp	300	900	1500	2100
Bream	75	450	900	-
Grey mullet	300	1200	2000	
Malaya and Thailand				
Grass carp	1500	3000		
Big head	2000	4500		
Silver carp	1800	4500		
Common carp	400	800		
Philippines and Indonesia				
Tilapia	450-850			
Gourami	120-450	450-680	2400	3800
Belinka	675			
Lampai		2000		
Nilem	350			
India and Pakistan				
Catla	1125-4100	4000-5000	6750	
Rohu	900	3600	5400	
Mrigal	650-1800	2600	4000	
Calbasu	450			
White carp	330			
Cauvery carp	300			
Nagendram fish	700			
Sandkhol carp	900-1400			
Copper mahseer	112			
Carnatic carp	113			
Tench	113			
Cock up	1500-3000	5000		
Indo-China				
Cat fish (*Pangasius larnaudi*)	-	1000		
Cat fish (*Pangasius sutchi*)	-	4000		
Japan				
Common carp (stagnant ponds)	375	927	1980	2300
Common carp (ponds with running water)	350-2400			
Eel	10-120	110-120		

POND MANAGEMENT

Pond Sanitation

It is well known to aquatic biologists that ponds or other bodies of water are able to maintain themselves in a sanitary state under natural conditions. The biological processes that operate under normal conditions rapidly mineralize all dead organic matter, restoring the nutrient cycle which sustains the pond flora and fauna. The oxygen utilized by the fauna and flora is replenished from the atmosphere and the oxygen released by the carbon dioxide assimilation of plants. The free carbon dioxide produced escapes into the atmosphere. But when the pond is used for intensive fish culture, which involves manuring, heavy stocking, etc., the normal biological processes are interfered with and abnormal hydrological conditions may develop. It therefore becomes essential for the fish culturist to keep a vigilant watch on the pond sanitation so that the fish he cultivates will not be affected by the artificial environment created.

One of the main factors to be watched is the gaseous content of the water, especially of oxygen and carbon dioxide. When a pond is heavily stocked with fish there is a rapid consumption of oxygen and, unless there are special means of replenishment, conditions may become unfavorable for fish life. This is the reason why Japanese fish farmers maintain a constant flow of water in heavily stocked ponds. Letting in fresh, oxygenated water at suitable intervals is essential in such ponds to prevent mortality due to asphyxiation. By cascading the water into the pond, its oxygen content can be increased. Regular netting of the pond is often recommended as a means of aerating pond water, but this has to be done cautiously because the organic matter at the pond bottom is otherwise likely to be stirred up; instead of improving the oxygen content, the disturbed organic matter would use up large quantities of oxygen. Under certain meteorological conditions the putrefaction cycle might assume abnormal proportions and affect the pond sanitation. This happens where there is an accumulation of decaying organic matter. In cloudy, sultry and humid weather, absence of rain and wind, the putrefaction of organic matter is accelerated and due to the absence of sunlight the photosynthetic activity of plants is arrested. The putrefaction processes make a heavy demand on the oxygen and the oxygen budget becomes unbalanced. When there is a thick bloom of algal growth in a pond, similar conditions may result. In such circumstances treatment with an algicide, such as copper sulphate, will reduce the algal growth and bring back the pond life to a normal condition. When the oxygen content of the pond becomes low, the fish often come to the surface gasping for breath. The hunger for oxygen also drives other animals to the surface and bottom-dwellers like molluscs to the sides of the pond. Injudicious manuring of ponds would also give rise to the same condition. Mortality due to asphyxiation often takes place under such conditions. The fish culturist has to prevent the development of the above-mentioned conditions, which do not occur in regularly desilted and drained ponds.

Since very dense growths of aquatic flora give rise to abnormal hydrological conditions it is necessary to check them adequately. But once insanitary conditions have developed, suitable eradicatory measures should be undertaken immediately, otherwise the whole fish population will die in a short time. A chemical examination of the pond water is of great help in diagnosing the immediate cause of abnormal fish behavior. Oxygen deficiency is usually the cause of mortality and the best method of rectifying this is to add well-aerated fresh water from any nearby source. Besides increasing the oxygen content of the water this will have the immediate effect of diluting the noxious substances produced in the pond by putrefaction. If the water in the pond can be agitated without stirring up the organic deposits the water can be considerably oxygenated. A portable pump should be kept ready at every pond farm to spray the water and thereby agitate it, in case of emergency.

If the water becomes acid due to putrefaction it can be treated with lime in concentrations of not more than 10 ppm. Should the water become very foul, potassium permanganate can be used in doses not exceeding 1.5 ppm. Besides adjusting the pH of the water this chemical will kill fish parasites and also control excessive bacterial growth. Ordinary washing soda, crude potassium carbonate and wood ash are also useful in reducing acidity; but the optimum concentrations of these materials have not yet been ascertained. Fish farmers in Bengal often cut up banana plants and float them in the water, or extract the juices beforehand and mix them in the pond. Although banana stem juice is acid in reaction (pH 5.2 to 5.7) it contains a considerable alkaline reserve and its buffering action might control fish mortality.

When the generation of noxious gases in pond bottoms becomes excessive, they can be smelt and will ignite and produce high flames on the whole pond surface. Indian fish farmers prevent accumulation of such gases by raking the pond bottom.

High water turbidity due to suspended silt can cause serious fish mortality. The silt chokes the gills and also depletes the dissolved oxygen in the water. Protecting the ponds against dust is helpful in preventing this. Very small doses of alum might help to settle the suspended matter.

Exposure to very low temperatures might cause mortality but this is comparatively rare in the Indo-Pacific Region, except in the subtropical areas of Japan, Taiwan and Central China. In Japan the farmers transfer fish, especially common carp, to wintering ponds, when the temperature of the water drops to zero. A wintering pond of 1 m^2 in area and 3 m deep will sustain 20 to 25 kg of carp during the winter months.

Besides directly killing fish, deterioration of water conditions in a pond may render the fish highly susceptible to parasitic attacks and other diseases. The vigilant farmer can easily detect abnormalities in the water and quickly take remedial action.

FISH DISEASES AND THEIR CONTROL

Fish are prone to hundreds of parasitic and nonparasitic diseases, especially when grown under artificial conditions. Adverse hydrological conditions often precede parasitic attacks, as the resistance of the fish is thereby lowered. Mechanical injuries sustained by a fish when handled carelessly during fishing or transport may also facilitate parasitic infection.

The prevalence of fish diseases is very much dependent on the intensity of stocking. Diseases are more common in China than in India, Pakistan, and other countries where the density of stocking is relatively low. So, when a farmer decides to raise the stocking rate, he has not only to provide extra food, but also to take special care to prevent and cure outbreaks of diseases. Diseases are more common in freshwater environments, and it has been found that susceptible freshwater fish are significantly free from disease when grown in slightly brackish water.

Well-kept and properly managed ponds usually remain free of disease. Carelessness in stocking and feeding may result in serious parasitism and mortality. Prevention is better than cure. Care should be taken to prevent parasites gaining access from a nearby infected source. Even though several curative methods are available, treatment is difficult and often impracticable in ponds containing a large number of fish. Preventing the spread of the disease by quick removal and destruction of infected fish is probably the most effective method of control. Disease-resisting fish should, as far as possible, be selected for stocking.

Some of the common diseases of fishes are described below.

Dysentery. One of the most common non-parasitic diseases is dysentery. Feeding with tainted or indigestible food containing too much fat or protein may lead to this disease. Intensive reddening of the rectum and profuse quantities of yellowish mucus in the gut are noticeable symptoms. The only remedy is to stop feeding, especially with animal food, for a suitable period. Draining the pond and letting in fresh water will help the fish to recover quicker.

Gill Rot. Among the fungal parasitic diseases, gill rot is fairly common among cultivated fishes in the Indo-Pacific Region. It generally occurs in ponds where there is an abundance of decaying organic matter and is caused by the fungus, Branchiomyces. It is often common in summer, especially after a period of hot days. Some of the gill filaments, particularly the upper ones, become blackish red in color and the rest whitish as a result of the penetration of fungus which obstructs the blood vessels. The disease becomes epidemic and causes rapid mortality especially in the early stages of the outbreak. Within about eight days the attack subsides. Some fishes may survive and their affected gill filaments may slough off and then heal gradually. When there is an attack of gill rot in a pond the following measures are recommended: (i) introduce cool water, (ii) prevent undue turbidity of the water and organic pollution, (iii) discontinue feeding, and (iv) add lime to the water. In serious epidemics, if possible, the fish should be netted out and the pond water completely changed before putting the fish back.

Saprolegnia Infection. The fungus Saprolegnia attacks fishes that have sustained mechanical or other injuries. For example, they attack the gill filaments affected by gill rot. Tender parts of the body are more susceptible and so the gills are more commonly affected than the skin, fins, mouth and eyes. When it settles on the body, the fungus sends mycelial branches through the epidermis into the inner layers of the skin causing general disturbance of the system and ultimate death. Saprolegnia often attacks eggs and hatchlings and this may cause serious mortality in hatching ponds. Over-abundance of algal growth, mechanical injuries, over-crowding and fouling of water are considered to be the factors that encourage the attacks of this fungus.

While it is possible to treat individual fish by gently rubbing the affected portions with cotton wool soaked in a 1:100 solution of iodine or potassium permanganate, the most practicable way of treating a large number of fish is by giving them a bath in a 3 per cent solution of common salt, or in a 1:2000 solution of copper sulphate, or in a 1:1000 solution of potassium permanganate, for 5 to 10 minutes or until they show distress. All the affected fish from a pond can be removed in small lots in a hand net and dipped into the solution. Where facilities exist, it is advisable to transfer the fish into a separate small 'hospital pond' where they can be properly treated with chemicals. As with other parasitic fish diseases, it is always desirable to drain the pond and treat the bottom with lime or other sterilizing chemicals.

Fin Rot. Fin rot, or tail rot as it is sometimes called, is caused by a rod-shaped bacterium which grows on the fins. The fins lose their rays and become reduced to a stump. The first sign of this disease is the appearance of a white line along the outer margin of the fin which slowly spreads towards its base until the whole fin is destroyed. This disease is often fatal to younger fish.

The best treatment for fin rot is a bath for one or two minutes in a 1:2000 solution of copper sulphate, which should be done by a skilled person who adjusts the period of treatment according to the behavior of the fish. The treatment should be stopped as soon as the fish shows signs of distress.

Ichthyophthirius Infection. A common protozoan parasite that attacks pond fishes. The infected fish develop small white pimple-like growths on the gills, body and fins. The parasites are about 1 mm in diameter and ovoid or spherical in shape. When they reach maturity they drop off the fish and each divides into about a thousand and are seen as swarms in the pond. They then attach themselves to new hosts, especially young fish. Disinfection of the pond with salt or quick lime is the most effective method of controlling the epidemic. The fish can also be treated with a 3 to 5 per cent solution of common salt for 30 minutes, or a 5 per cent solution of aluminum sulphate for about 1 minute, or a 1:2500 solution of formalin for 15 minutes. If the fish are kept in a live cage and a current of water is passed through it, the parasites will fall off and be carried away by the flow of water. The fish will then recover within two or three weeks. This treatment is not practicable in all ponds.

Cyclochaeta. This attacks the body, gills and fins. It has a flattened ventral side, by means of which it attaches itself to the surface of the fish. In the early stages of the disease, a bath in a 1 per cent solution of salt for 5 to 10 minutes will be sufficient to kill the parasites. In serious attacks, treatment with a 3 per cent solution of salt or a 1:500 solution of glacial acetic acid may be necessary. The best treatment is a bath for 10 minutes in a 1:2500 solution of formalin.

Costia Necatrix. This parasite is microscopic but can be detected by the appearance of a light bluish or greyish film over the body and the fins. The fish stop feeding and become very weak and die in a short time. A bath for about 10 minutes in a 1:2500 formalin solution will kill most of the parasites. A 1:500 solution of glacial acetic acid will also be effective.

Carp Lice. The attack of the carp louse (*Argulus foliaceus*), a parasitic copepod, is a very common cause of fish mortality in ponds. The louse is oval in shape with a flattened body and small bilobed abdomen. It attached itself by means of a pair of disc-like suckers, on the ventral side of its body, to the skin at the base of the scales. The scales subsequently fall off, exposing the body. The males attain a length of about 6 mm while the females reach a size of about 8 mm. At the time of breeding the louse leaves its host and lays eggs on stones and twigs. The nauplii that hatch out resemble the adults and immediately swim out in search of hosts on which they attach themselves. If a suitable host is not found within three weeks they die.

In about six weeks it attains maturity and is able to reproduce. It sucks the blood of the fish, the infected fish becomes restless and the exposed skin is subject to fungal and bacterial attack. Young fishes succumb to the attack more easily than the adults. The lice leave the host as soon as it dies.

The most practicable way of treating a pond infected with the lice is to remove the fish as quickly as possible, drain the pond and expose the bottom to the sun for at least 24 hours. This kills eggs as well as adults. Where draining and drying are not possible, lime applied at the rate of 0.1 to 0.2 g per liter is often effective. As the parasites die within three weeks in the absence of a host, it is not advisable to restock the pond until that period has elapsed.

Schäperclaus (1953) recommends a lysol bath as a treatment. The fish, caught in a basket or dip net, should be immersed in an 0.2 per cent solution of lysol for a period of 5 to 15 seconds, depending on the size of the fish. After the treatment the net along with the fish should be rinsed in clean fresh water.

Worms. Among the worm parasites of pond fishes, the trematodes of the genera Dactylogyrus and Gyrodactylus are the most important.

The adult Dactylogyrus measures 0.2 to 0.5 mm and attaches itself to the gills by means of rows of spines (14 in the outer and 8 smaller ones in the inner row) at the tail end of the body. It is also generally parasitic on the gills. The infected fish rapidly lose weight and due to the continued disturbance of the respiratory mechanism will ultimately die.

In many cases combined infections of Dactylogyrus and Gyrodactylus and Ciliate protozoans have been found.

Infection takes place mostly as a result of poor nutrition and unfavorable environmental conditions. The improvement of these conditions is an effective treatment. If noticed in the early stages of an epidemic, the infected fish should be removed from the pond and destroyed. Slight infections can, however, be treated by the application of a 1:100,000 solution of potasium permanganate or a 1:2500 solution of formalin for about half an hour.

Gyrodactylus is very similar to Dactylogyrus but is morphologically distinguishable by the absence of eyes and the presence of only a single row of 16 spines on the attachment organ as against the two rows found in Dactylogyrus. The parasite is viviparous. It has a definite preference for the skin of the hosts. The preventive and curative measures are the same as for Dactylogyrus.

CAPTURE AND MARKETING

The capture and marketing of the fish crop raised in a pond are as important as the cultural techniques. Capture operations may start a few months after stocking, to thin out the stock. Before using any fishing nets it is necessary to remove all weeds or other obstructions that may be lying in the pond.

Fishing Gear

Drag nets and cast nets made of cotton are the most common fishing gear used. A drag net is a rectangular piece of netting with a foot rope and a head rope. The head rope may be provided with floats and the foot rope with weight so as to keep the net fully stretched when dragged.

The length and breadth of the net are determined by the extent and depth of the area in which it has to be operated. The net is dragged from one end of the pond to the other and the catch is then hauled up.

Cast nets are conical in shape with lead weights at the periphery and may be stringed or stringless. In the stringed type, the hauling rope may have a radiating system of strings attached to the periphery. When the fully spread net is thrown over the fish the rim of the net sinks, thus trapping the fish below. When the net is hauled the rim is drawn together forming a bag or pouch in which the fish are caught. In the stringless type the rim forms the entry to a shallow bag.

Both cast nets and drag nets should be regularly treated with suitable preserving materials and dried in the shade. The best way of storing them is by hanging on beams or poles.

When a pond is fished to thin out the population, a drag net of a suitable mesh is preferred as it is easy to sort the catch in it than in a cast net. For large-scale fishing the drag net is used, but because several men are needed to handle it, the cast net is more economical for catching small quantities of fish. Small boats may be required to operate the nets in very large ponds.

Partial fishing can often be easily done by letting a good supply of fresh water flow into a pond from a nearby source. When a current of fresh water flows into a pond there is a tendency for the fish to swim towards it and collect near the inlet. Grey mullet and many other fishes have the habit of swimming against currents when many of them can be easily caught with cast nets. In some ponds a "fish race" is built for this purpose.

The most efficient means of capturing all the fish from a pond is to drain it completely. While draining, the outlet is covered with a suitable net or sieve to prevent any fish from escaping with the out-flowing water. There is generally a deep portion near the outlet where all the fish will collect when the pond is drained. If this portion is made into a regular catching tank and an open box with a small-meshed grill is fitted into it, all the fish can be easily collected.

Marketing

The demand for pond fish is to a large extent due to the fact that they can readily be had in a live state. The price that can be obtained for live fish is higher than for dead fresh fish. The cultivated fish being generally hardy and sometimes even capable of living out of water for appreciable periods, it is not very difficult to transport or maintain them in a living state. Fish that have accessory respiratory organs, such as the climbing perch, the murrels, the catfish and gourami can be transported or kept alive for quite long periods in any type of container with a little water to keep body and gills moist. These live fish often travel long distances in the holds of boats. Sometimes a separate enclosure is made in the pond with strong netting or bamboo gratings fixed in position by poles stuck into the pond bottom. The catches from the pond are immediately transferred to this enclosure and removed and sold when there is a demand. Or separate small subsidiary ponds can be dug near the main ponds for the same purpose.

Cages made of bamboo or wood are useful for keeping fish alive in a pond and also for transporting them through water. A live cage for the transport of fish should be streamlined to facilitate easy towing by a boat. This method is possible only when the market can be reached along an inland water route. For transport by road, wooden or metal tanks containing water are often used. Canvas tanks in motor vehicles are very suitable for carrying fish to market.

Over very long distances it may be necessary to aerate the water with a pump or from an oxygen cylinder.

The fish can be kept alive at the market in cement cisterns. If running water can be supplied they will live for several days. They should, however, be properly fed to maintain their weight and condition. Storing fish in clean water in this way will remove any muddy flavor they may have acquired in the pond. A concrete tank, 3 m by 2 m by 1 m will keep 100 to 300 kg of fish alive for several days if running water is provided.

For small quantities of fish, steel or wooden tubs can be used and a supply of flowing water can be arranged by placing a large bucket or drum with a hole at the bottom, at a higher level in such a way that there will be a steady flow of water from it into the tub. Excess water from the tub can be run out through an opening in the bottom. Where it is not possible to keep fish alive on the farm or in the market, the catches should be sold as soon as possible. If the market is far away, ice will have to be used. If there is a demand, the fish can be cured in salt and sun-dried.

FISH CULTURE IN LAKES, RESERVOIRS AND CANALS

Besides ponds, there are other natural and artificial waters such as lakes, reservoirs and irrigation canals which are suitable for fish culture, but culture methods in such waters are basically different from those in ponds where a fairly complete control of conditions is possible. In extensive waters fish are reared more as part of a general fishery improvement program than as pure fish culture.

A considerable amount of work has been carried out in the Indo-Pacific Region on the improvement of hill streams in certain areas for the culture of game fishes like trout, following the lines of western countries. But since these practices contribute relatively little to the production of fish for food it is not proposed to describe them here. On the other hand, the rational management of lakes, reservoirs and irrigation systems is of great significance in food production.

The improvement of lakes and reservoirs is a recent development in fish management and is still in its infancy, although several experiments undertaken have proved successful, especially in the United States of America. An integrated system of lake and reservoir improvement as applicable to conditions prevailing in the Indo-Pacific Region has yet to be evolved. Stocking of such waters with economic species of fish and fishing experiments in deep reservoirs have, however, been undertaken, although much work still remains to be done.

Hydrobiological Features of Lakes and Reservoirs

Several definitions have been offered for the term lake, but none of them is considered ideal. The description of a lake as a body of standing water occupying a basin and lacking continuity with the sea has found favor among limnologists. Reservoirs have many of the hydrobiological features of lakes, but differ in certain aspects in that they have been formed by submerging river basins and borderline land or by the construction of dams to collect water from an extensive catchment area. Studies on the limnology of lakes and reservoirs have been made and the book on limnology by Welch (1935) contains a fund of information on the subject. Much about the limnology of lakes and reservoirs in the Indo-Pacific Region was published in a series of supplements to the "Archiv für Hydrobiologie" (1930 to 1950). These publications contain the scientific results of the German Limnological Expedition to the Sunda Islands in 1939.

Lakes and reservoirs differ in size, depth and elevation. Seasonal fluctuations often occur in these waters as evidenced by the formation of increasing areas of exposed beach during the dry months and the submerging of marginal low land during rainy seasons. A wind-swept shore is a characteristic feature of many lakes and reservoirs. Except at rare times of complete calm, the waters of lakes and reservoirs are in constant motion of varying intensity, mainly due to wind. As a result of this the original shore line may be modified by shore cutting and shore building processes.

The most productive area of a lake or reservoir is the marginal shallow zone. An undue decrease in the water level, which would result in exposing considerable portions of this zone, may therefore restrict the productive area. Lake or reservoir bottoms, which in shallow waters are of significance in productivity, differ widely with age, history, etc. The main sources of bottom materials are: (1) bodies of plankton organisms which die and sink; (2) plant and animal remains from the littoral zone; (3) wind-blown materials, both organic and inorganic; (4) silt, clay and similar materials introduced by tributaries or washed in directly by run-off water from adjacent slopes; (5) marl, largely calcium carbonate, produced by plants and animals or precipitated from the water by chemical processes; (6) remains of floating surface vegetation; (7) eroded materials from the shore zones. On the quantity and composition of these deposits, especially in the shallow regions, depends the fertility of the waters.

The influence on organic life in ponds, previously described, also applies to lake fish. Being more exposed to wind action and currents the turbidity may be more intense in lakes than in ponds.

Another important factor that influences the suitability of a lake or reservoir for fish life is temperature. In large lakes and reservoirs the thermal stratification is naturally more pronounced than in ponds, but observations so far conducted seem to show that a true thermocline seldom develops in these lakes. This enables continuous mixing of waters and a more rapid circulation of nutrient elements. Such waters are highly exposed to wind action and this is a factor that helps continuous mixing. The higher biological productivity observed in tropical lakes and reservoirs seems to be largely a result of this mixing. The horizontal currents caused by the wind and the returning currents formed by the excess water piled up on an exposed shore by an on-shore wind, returning underneath along the bottom, influence this mixing. The magnitude of mixing may, however, be dependent on the depth of the lake and may be either partial or complete.

The chemical conditions in a lake or reservoir also follow to a large extent the thermal pattern. The gaseous contents may become homogeneous due to the mixing. But in deep waters there is often stagnation because of incomplete lack of circulation. Observations in some of the reservoirs and lakes in India and Indonesia have shown the complete absence of oxygen in the deep waters during certain seasons and the formation of large quantities of gases like hydrogen sulphide and methane at the bottom due to organic decomposition.

Biota

Lakes and Reservoirs

The biota of lakes and reservoirs are those adapted to life in lentic environments. In reservoirs, formed by the construction of dams across rivers, the biota will be predominantly riverine, except that forms unable to live in lentic habitats will disappear. The planktonic flora and fauna is to a large extent similar to that of ponds, previously described. But the circulation of water as mentioned above will influence their distribution considerably. The greater depth of lakes and reservoirs may also cause a zonation of plankton.

The macrovegetation is of special significance in the suitability of lakes and reservoirs for fish life. In large bodies of water, like lakes and reservoirs, adequate growths of weeds are necessary to afford protection to fish life, as control of predators may not be possible in such environments. Vegetation provides refuge to young and adult fish, and weed beds form the main type of effective natural cover in lakes. Even the benthic vegetation such as "moss" is useful as shelter for the larvae of certain fishes. One of the main items of lake improvement in the United States is the provision of weed beds or brush shelters for the fish.

According to Hubbs and Eschmeyer (1935), major factors that affect weed growths are (1) latitude, (2) altitude, (3) topography of the bottom, (4) fluctuations in water level, (5) exposure to waves (6) turbidity, (7) fertility of water, (8) presence of harmful chemicals in the water, (9) suitability of bottom material, and (10) abundance of algae. The meteorological conditions of a locality, such as the extent of daylight, greatly affect the growth of plants and the type of vegetation that can grow in it.

As regards the region, it is fairly well known that in relatively pure and cool waters of higher altitudes plant growths are more sparse than in the warmer fertile waters of the plains. In some lakes and in most reservoirs the water level fluctuates markedly especially when the water is used for irrigation purposes. This often results in the exposure of fertile shallow marginal areas and may affect weed growth considerably. Exposure to waves adversely affects the growth of marginal weeds. As already mentioned, turbidity caused by agitation of a soft bottom, the erosion of shores, drainage or plankton growth is a great limiting factor in the growth of vegetation. It has been found that by the introduction of vegetation into a lake the turbidity of the water can be greatly reduced. The colloidal clay particles suspended in the water are negatively charged with electricity. Decaying plant material or other organic matter, such as sludge or manure, provide the positive ions which bring about a neutralization of the negative charge on the colloidal soil particles, allowing rapid precipitation. Plant growth on shoals may be greatly diminished by shade, and the shading out of submerged vegetation by broad-leaved surface vegetation has already been referred to.

The nutrient contents of the water is another very important factor affecting the growth of plants. In new reservoirs and lakes the quantity of nutrient substances in the water will often be limited and soft waters are often deficient in the nutrients needed for satisfactory plant growth. Admixture with pollutants, acidity or extensive lime encrustations also limit their growth. The nature of the bottom may influence the growth of plants in lakes and reservoirs by supplying the necessary nutritive material for their growth and by the provision of suitable substrata for the seeds to germinate. The acidity or alkalinity of the bottom also has considerable influence, as well as the shifting of sand or gravel on the bottom due to wave action. Too hard bottoms are unsatisfactory as they do not allow plants to root. The fact that planktonic, attached and filamentous algae are known to compete with higher plants in water areas indicates that the presence of algal blooms in lakes and reservoirs may inhibit the development of suitable weed beds. In lakes with such profuse growths of algae it is necessary to control their growth to establish a healthy macrovegetation.

As in ponds, uncontrolled growths of macrovegetation are inimical to normal life in lakes and reservoirs. While it is not too easy to eradicate weeds from ponds, it is extremely difficult in large lakes and reservoirs. The application of chemical weed killers is expensive and their effectiveness in deep bodies of water rather doubtful. The most practical method would appear to be mechanical removal of excess weeds, supplemented by weed killers wherever feasible.

The animal life in a lake or reservoir is dependent to a large extent on its depth. It is well known that organic life is more plentiful in shallow waters and therefore the fish productivity of such waters will be higher. One point of special significance in the culture of fish in lakes and reservoirs is that, unlike in ponds, it is not possible to restrict the fish fauna to cultivated fishes alone. The fish stocked in these waters have to live in association with the autochthonous predaceous and non-predaceous fishes. In most reservoirs these fishes account for a good part of the fishery. However, it is possible to control the population of predators to some extent by regular selective fishing. For the proper management of a lake or reservoir it is therefore essential to have an adequate knowledge of the habits of the autochthonous fish fauna. Since their migratory patterns may differ widely with topographical and hydrological conditions and the nature of fish fauna, specific investigations should be conducted for each lake or reservoir separately. These studies should give a clear knowledge of the breeding and feeding grounds of the fish populations and it will then be possible to undertake improvement programs, if found necessary.

Crocodiles and turtles often take a heavy toll of the fish in such waters. In some of the reservoirs of India it has been found possible to destroy crocodiles in appreciable numbers by poisoned bait.

Swamps and Irrigation Canals

Swamps, the last stage in the evolution of land from lakes, are extensive shallow water areas often overgrown with rank vegetation. The hydrological conditions in shallow swamps are very similar to those of shallow ponds. The vegetation may be of the mangrove type and there may be very thick deposits of organic matter at the bottom. Others have the same limnological features as rice fields. Very shallow swamps can be converted into fish ponds which can be managed in the manner described in previous chapters. Swamps with large areas of deep water cannot be so converted but can be managed in the same way as lakes. Saline swamps are suited for conversion into brackishwater ponds where euryhaline fishes can be profitably cultivated. A modern method of reclaiming a swamp is to drain it into a selected deep portion within it, known as the sump, which can be deepened and provided with an embankment if necessary. Fish can be cultured in the sump and the drained area will become available for agricultural purposes.

Swamps in the Indo-Pacific Region usually have a fish fauna consisting of hardy air-breathing species, and predaceous fishes may be found in large numbers. But it will be easier to capture them in swamps than in lakes, on account of the shallowness of the water. As a result of thick growths of surface and submerged macrovegetation, and the consequent obstruction of sunlight, there is generally less growth of planktonic organisms in swamps. Control of macrovegetion is therefore a very important aspect of their reclamation for fish culture. The substratum being generally rich in organic nutrients, good growths of plankton should develop when the excess macrovegetation is removed.

Irrigation canals carry water from reservoirs or rivers to irrigate agricultural land. While the biological properties of the water will therefore depend to a large extent upon the properties of the feeder supplies, the hydrological features will be similar to those of small rivers. Since the supplies of water fed into the irrigation canals are determined by the requirements of agricultural crops there is a likelihood of marked variations in the water level.

The flowing water in irrigation and navigation canals contains considerable quantities of oxygen and can therefore sustain large populations of fish if adequate fodder can be supplied, as in the flowing water ponds of Japan. It has been found possible in suitable localities to partition off sections of canals with strong bamboo or metal fencing through which the water can flow freely but which prevent the escape of the fish. Where this is not possible, an entire canal system can be managed as a single unit in which fish which do not migrate to long distances can be cultured. The chances of not being able to capture the fish stocked in the area would thus be minimized.

A system which is gaining popularity in some of the countries of the region is the rearing of fish (chiefly catfish) in bamboo pens in rivers or canals. The culture of the common carp in such pens has been applied with remarkable success in Indonesia and Thailand. The size of the pens varies from that of a large basket to as much as 6 meters square or more. They can, of course, be constructed in any shape but a streamlined form is preferable in a canal with flowing water. In the case of common carp, which feed at the bottom, the variety of benthic fauna, especially chironomids brought by the slow current of water and which accumulate below the pens placed on the canal or river bottom, serve as food to the fish and accelerate growth. By this method it will be possible to utilize the productive capacity of canals and other natural water areas without the risk of losing the fish stock during floods.

Stocking and Management

Stocking Lakes, Reservoirs and Swamps

As already pointed out, the fish fauna of a lake or reservoir under cultivation would not consist entirely of introduced species only. In fact, in most such waters a sizeable portion of the fauna consists of indigenous fish. Among these there is likely to be a large number of predators. In small lakes and swamps it may be possible to use fish poisons, such as rotenone, to kill all fish before stocking operations are undertaken, in which case there will not be any appreciable number of competing or predatory species left. Well controlled culture operations similar to those employed in large ponds would then be possible in such waters. But in large lakes it may not be practicable to use fish poisons effectively, and intensive selective fishing may be the only possible means of controlling the predators or weed fish.

It is often possible in reservoirs to check the predators effectively if proper measures are adopted well before the reservoirs are filled. Except in those built on the lower reaches of rivers, the head waters of most reservoirs consist of small streams which shrink into a chain of shallow pools during the hot dry season. It will be very easy to catch all the fish from these pools and connecting water areas with nets or kill them all with poisons or dynamite. If this is done before the reservoir is filled the risk of predatory or weed fish entering will be greatly diminished, provided proper precautions are taken against their migration into it from below the dam or connected water areas.

For stocking lakes, reservoirs, swamps and irrigation canals, any of the cultivated freshwater fishes listed can be employed, depending on their availability, local demand and profitability. In water containing large quantities of submerged plants it will, however, be advisable to stock macrovegetation-feeding fishes like *Puntius javanicus*, Punten carp or gourami which have proved to be of great use in controlling vegetation.

Ordinarily it will be necessary to rear the fish to a size of about 15 cm before stocking them in such waters. For this purpose there will be a need for nursery and rearing ponds in the vicinity. In the case of reservoirs, the construction of such ponds should not be difficult, as several borrow pits and similar excavations would have been dug to build the dam and auxiliary structures. Water may be readily available from the reservoir itself. For lakes and swamps, suitable natural ponds may have to be found or new ponds have to be made for the purpose. Fingerlings raised in small rice fields can be used for stocking irrigation canals.

Besides the young fish thus obtained, there are other means of increasing the stock in a reservoir. When the sluice gates of a dam are opened large numbers of fish gather below the dam and swim against the current. If a suitable fish-pass is provided they will enter the reservoir but precautions should be taken against the entrance of predators or undesirable species. Even when a fish-pass does not exist, it may be possible to lead a number of fish into the reservoir in the early stages of the dam construction by providing inexpensive devices which break the force of the current when the sluice gates are opened.

In our present state of knowledge it is rather difficult to set out any specific stocking rates for lakes, swamps, reservoirs and irrigation canals. The density of indigenous fish population and the fodder resources of the water have to be considered in working out a suitable stocking rate. The well known methods of population estimation and surveys of biota should be used for the purpose.

In most cases it is not necessary to continue stocking after a few years as the species establish themselves and multiply. Even fishes like catla, rohu and mrigal which do not breed in ordinary confined waters will spawn in suitable breeding grounds on the marginal zones of reservoirs. Improvements, such as providing adequate shallow marginal areas near streams flowing into the reservoirs would appear to facilitate their breeding.

Other helpful measures are shelters and fertilizing with suitable manures. As already pointed out, very little work has been done in this region to justify any firm recommendations in this respect. The results of experiments conducted in Michigan lakes on these lines were described by Hubbs and Eschmeyer (1935) and could form the basis for experimental work in the region. Growing weed beds and setting up brush shelters could be tried in areas where sufficient shelter does not exist. Fertilizing extensive reservoirs, lakes and similar waters would require large quantities of manure and it is doubtful whether any of the countries in the region have any fertilizers to spare for fish culture, especially when their efficiency and profitability have not been established conclusively. However, it is worthwhile conducting experiments to examine its feasibility.

In multipurpose reservoirs there is the risk of fish being drawn into turbines, power intakes, irrigation canals and other erections. Fish screens of different types are used in western countries and also in some Japanese dams. The defect of stationary mechanical screens is that they may get clogged with solid matter unless steps are taken to keep them clean. The removable rotating screen protected by trash racks is considered to be the best of its kind.

Stocking in Pens

Rearing pens of bamboo should have no sharp edges to injure the fish. Generally only fingerlings or more grown-up fish are used; for example, in Cambodia, young Pangasius of about 80 to 150 g are stocked. A floating pen 7 to 10 m long and 2.5 to 4.5 m wide and 1.5 to 2 m deep, will rear seven to eight thousand Pangasius. Hardy species like catfishes, murrels, climbing perch and common carp are suitable for this type of culture. The pens may float or be fully submerged, resting on the bottom. Besides supplies of natural food that flow into the pens, the fish can also be fed with suitable artificial food which is given twice a day through a trap door in the pen. Feeding should be so regulated that all the food is eaten before being washed away. Floating pens should be protected against the sun and it is the usual practice to cover a part of the pen with aquatic plants.

Fishing and Marketing

One of the difficulties of fish culture in deep lakes and reservoirs is the paucity of suitable commercial fishing methods, particularly if the bottom has not been cleared of obstructions. Drag nets cannot be operated in such waters. Cast nets can be used from the banks or from small boats, but they are not suitable for the deeper areas, and in shallow lakes with level bottoms, seine nets may be effective. One type, the Rangoon net, is made of fine yarn, rectangular in shape, the length and breadth varying to a certain extent with the locality. In very large areas several pieces of netting can be joined together to form a long net. The head rope has a number of floats, the thin foot rope has none. Nets made from nylon are more efficient than cotton.

In use, the net is vertical. One end can be tied to a wooden post fixed on the bank and the farther end kept in position by a float, and the net is then hauled from the bank. If operated away from the shore, the net is kept upright with two large floats, one each end, paid out and hauled from small boats. Very cheap but efficient homemade coracles are used.

The net is generally set in the evening and the catches removed the next morning. The size of the fish caught, of course, depends on the mesh. Large-meshed nets (6.4 cm from knot to knot) to prevent the taking of undersized fish, are common in India. The Rangoon net is for surface fish only. A similar type of net known as Udu valai in Madras can be used for bottom fish. This is weighted at the bottom, but it can be used only for fishing the shallower marginal areas. Longlines are very useful for the deeper waters. Another method of fishing, with electricity, might solve the problem of fishing in deep waters.

Large sheets of water may become very rough during certain seasons and the transport of catches to the landing place in fresh condition may become difficult. Small power vessels to tow the fishing boats will help in such circumstances.

The methods of preservation and transport to be employed depend largely on the size of catches. When the source is near a town the catches can be transported and sold fresh or preserved in ice. Fish can be kept alive for short periods in cages or wells of the type previously described. When catches are large it may be necessary to set up small refrigerator and cold storage plants in the vicinity and an organization for marketing. In times of glut a portion of the catch can be preserved by salting or brine-curing, followed by drying. If there is a good demand for fish so treated, it may often be more economical to preserve the catches in this manner. The trash fish caught, if available in sufficient quantities, can be converted into fish meal or manure. In some countries conversion of freshwater fish into fish pastes or sauces is a highly profitable industry.

The economics of fish culture in lakes, reservoirs and the like should be examined, bearing in mind the fact that fish culture is only one of the various means of productive utilization which can be carried out without detriment to other projects. The outlay necessary for fish culture or fish management is relatively small, and will be more so after the first few years, if the fishes stocked in such waters have established themselves and begun to breed. Fishery development in them provides a living to hundreds of fishermen and local inhabitants, besides making available cheap and nutritious food to the people living in the inland agricultural areas or in industrial townships connected with multi-purpose power projects. However, as has already been pointed out, these activities cannot easily be integrated with a rural economy as ordinary pond culture, and have to be organized as state or cooperative endeavors.

Sufficient data are not available to lay down any standards of expected productivity in lakes and reservoirs. It is now fairly well known that the per hectare production of a water area such as a pond or lake decreases sharply as its area increases beyond a few hectares, and that it is the shallow areas that contribute in a large measure to its productivity. Tropical waters are known to give higher yields, and at least double the production obtained in Europe or North America can be expected in the waters of the region. Experience in India has actually shown that a high production can be attained under favorable conditions, as has been demonstrated in the Mettur Reservoir. The Tempe Lakes in Indonesia were stocked with plankton and plant-feeding fish in 1937, and they are now producing 250 to 2,500 kg of fish per hectare per annum. The area which did not produce any fish for export before 1937 has now a marketable surplus of several thousands of tons of dried fish per year.

FISH CULTURE IN PADDY FIELDS

Most of the countries in the Indo-Pacific Region have an agrarian economy and the majority of the population is engaged in agriculture. Rice being the staple food of the people, paddy fields occupy a great share of the arable land. As is well known, it is necessary to keep a certain depth of water in the fields for the cultivation of most strains of paddy, and since many of them are left fallow for varying periods of time after the crop is harvested, such fields offer conditions well suited for the cultivation of fish. When well fertilized and inundated for paddy growing, rich biota develop in the water and these can be utilized for the production of fish. In countries like India, Vietnam, Malaya and Indonesia the farmers have always got crops of fish or prawns from flooded paddy fields which naturally get stocked with fry when being filled with irrigation water. The next stage in evolution was the artificial stocking of the fields and giving proper care and protection to the fish to obtain increased yields. Fisheries agencies in many of the countries have taken an active interest in extending and improving the techniques, and much research has been conducted on this subject in countries like Japan and Indonesia.

Advantages

The culture of fish in paddy fields can be of great significance in the economy of rural areas in this region. It can provide a supply of cheap and wholesome protein food, besides affording an additional income, and the culture of fish in fields flooded after the paddy harvest might serve as an off-season occupation for the farmers. Experience so far gained indicates that in most cases culture of fish along with paddy is beneficial to the latter. The fish feed on many of the noxious insects or their larval stages and thus indirectly contribute to a better production. In China it has been possible to control to a large extent the spread of a serious insect pest, namely the stem borer. The number of rats in paddy fields can also be checked; the greater depth of water maintained in the fields used for fish culture prevents rats from digging holes in the bunds and floods the holes that have already been made.

Another beneficial factor is the increased paddy tillering caused by the movements of the fish, which results in higher yields of paddy. The excreta of fish and the remains of food, if they are artificially fed, also serve as additional fertilizers in the fields. When a strongly herbivorous fish like tilapia is cultured, the growth of weeds is reduced, as it feeds on them and therefore the labor involved in weeding is reduced. Further, the farmer naturally bestows greater care on the field when he grows a double crop and this considerably increases the chances of a good yield of paddy.

Even though fish culture in paddy fields has great possibilities in the region, it has to be recognized that not all types of fields are suitable for the purpose; adequate irrigation and drainage facilities are essential for success. In areas where there is heavy seepage of water, or where drought occurs frequently, fish culture is extremely difficult. Similarly, facilities for the construction of suitable dams and channels are essential, as all fish may be lost in floods.

All strains of paddy are not suitable for raising such a double crop. It may be necessary to maintain a greater depth of water in the fields for fish culture and only strains that can tolerate deep water and the low temperature prevailing in such waters will thrive. If the water temperature drops below the optimum level, growth and production of paddy may be affected. Paddy varieties with strong roots are necessary for combined cultivation with common carp, as otherwise the fish may uproot the plants and thus damage the main crop.

Types of Fish Culture

Fish culture in paddy fields can be divided into three types, namely:

(a) as a secondary crop after paddy;
(b) along with the paddy during the period of cultivation;
(c) a continuous cultivation, transferring the fish to specially prepared ditches or channels during the paddy harvest or at other times when the fields are drained.

Where there are sufficient irrigation facilities and a continuous supply of water can be maintained in the field, fish can be raised as the only secondary crop, as in certain areas of West Java. The fish may be species introduced from elsewhere or wild fish brought in with the water that is let into the fields. The interval between harvesting and the next planting may be partly used for drying the fields and partly for short-term fish culture. Continuous inundation is not desirable for some soils since they may then become less suitable for cultivating agricultural crops. In such cases an additional secondary crop like groundnut can be raised after draining the fields.

In rearing fish with growing paddy, the duration of culture varies widely. It is often necessary to drain paddy fields for weeding once or twice during a season. Later, the fields have again to be dried for certain periods, to promote proper flowering and ripening of the crop. Fish culture in these fields must therefore be confined to the intervals between successive inundations and drainings. In areas where there is a demand for small fish, quick-growing species can be raised to a marketable size during these intervals, which may range from about 24 to 50 days. When facilities are available for temporarily storing the fish when the field is drained, it is possible to grow them for the whole paddy cultivation period which may be from three to six months, or, as practised by the Japanese fish farmers, from two to three years by transferring the fish to suitable ponds.

The Chinese fish culturists in Taiwan have also evolved a system of continuous fish culture in paddy fields. The fields have channels into which the fish are gathered when the fields are dry.

Water and Soil Conditions

The depth of water and the fertility of the soil and water are the most important factors that determine the production of fish in paddy fields. Wet rice fields in general are suitable, but the most successful fish culture is achieved in areas where controlled irrigation is practised, that is, where the fields are drained and inundated at will. When the fields depend on the rains for water, unfavorable conditions may occur in periods of drought, but when there is a good water supply, the depth of water can be regulated to suit the height of the paddy plants and to maintain optimum temperature for the plants. Where the paddy strains are sufficiently resistant, a depth of about 30 cm of water can be maintained.

If fish are cultured after harvesting the paddy, larger quantities of water can be let in.

The shallow water that has to be maintained in planted fields calls for precautions to prevent fish mortality. The water temperature may rise unduly and unless there are deeper pools or channels in the fields, where the fish can take refuge, the heat may kill them. High temperatures may result in a low oxygen content or, when the field is flooded without removing the paddy stubble, it decays in the water and may use up a large portion of the dissolved oxygen.

However, because of the shallow water and the large surface exposed, re-aeration takes place fairly quickly. In areas such as Malaya, where re-aeration is not rapid, only fishes with accessory respiratory organs are able to thrive.

Most paddy fields are flooded with fresh water, some strains of paddy are resistant to brackish water and in the fields where they are grown, euryhaline fishes like mullets and tilapia and brackishwater prawns can be raised successfully.

Whatever cultural measures are taken, the yield of paddy from a field is largely dependent on the fertility of the soil, and it usually follows that fields that give good yields of paddy also produce good crops of fish. Farmers, generally, fertilize the fields before sowing or planting paddy, and when the field is inundated, some of the nutrients dissolve in the water and give rise to the growth of plankton.

The nitrogen content of the soil in a paddy field used for carp culture, and fertilized in the usual way, is less at the beginning of carp rearing than it is at the end of the period. It appears that in the early stages of cultivation there is a rapid consumption of nitrogen by the phytoplankton and as the paddy crop grows, the nitrogen content of the soil increases due to the deposition of fish excreta. When the fish are artificially fed the soil has a still higher nitrogen content. It has been found experimentally that this variation in nitrogen content does not adversely affect paddy growth.

Besides the nutrient content, the texture of the soil is also of importance in raising fish. In very porous soils it is very difficult to maintain the required depth of water, and the construction of impervious banks is also difficult in such soils.

Biota

The planktonic biota in a paddy field are almost similar to those of shallow ponds. It has been observed in Japan that the ratio of zooplankton to phytoplankton in paddy fields utilized for carp culture is less in the middle and later periods of the rearing than in ordinary fields. This is believed to be caused by the stirring of the water by the carp when searching for food.

Filamentous algae and weeds also grow in paddy fields, and some of this vegetation is used by the fish as food and is kept under control by them.

Paddy fields often harbor various insects, some of which are injurious to the paddy. Mosquitoes may find the conditions suitable for breeding and in some localities mosquito larvae occur in large numbers. Fish, when cultured with paddy, feed on mosquito larvae and also on the adult insects.

The autochthonous fish fauna in fields are mostly weed fishes or those with accessory respiratory organs, such as murrels and catfishes, but being predaceous, it is not desirable to have them present if intensive fish culture is practised. When the fields are drained, fish like the murrels bury themselves in the mud and survive until they are again inundated. Rats usually find suitable conditions to live in the bunds of paddy fields but, as already pointed out, fish culture can considerably reduce this menace.

Fish-eating birds especially night herons may take a heavy toll of the fish stocks. They, as well as otters, weasels, and other predators, can be kept in check with snares, traps, poison and other measures.

Preparation of Paddy Fields

A paddy field to be suitable for fish culture should have an adequate depth of water, and to retain this strong bunds are essential. If the bund is pervious, there will rarely be sufficient water in the fields for the fish to thrive. So, the construction of proper bunds is of great importance.

It is comparatively easy to make new bunds watertight. Old bunds should be ploughed and levelled, then the ground where the new bunds are to be built should be slightly dug up to a width of about 50 cm. The shallow trench, so framed, should be filled with fresh, moist earth, not too hard or too soft and wet, and free of grass, straw or weeds, well consolidated. More and more earth is then heaped over this foundation and rammed until the bund is about 35 cm above the level of the field. Such a bund when it dries will have an approximate height of about 25 cm. A height of about 60 cm is recommended for fields in which tilapia are cultured.

If an old bund has merely to be improved, the lower portion of it on the field side should be removed at an angle and replaced with fresh well-rammed earth. The ground below the bund should be treated in the same way.

Where the necessary preparations cannot be made before the paddy planting, a narrow channel can be dug on the inner side of the existing bund. The earth so obtained should be piled up to form another bund. A system of such channels is very beneficial for fish and essential for a program of continuous culture. The dimensions of the channels will depend on the size of the fish to be reared and whether they are intended only as temporary refuges or are to be used for a prolonged period.

It may be advantageous to erect a low bund along the inner side of the channel (opposite to the main bunds) if the field is to be used for continuous fish culture. When the field contains tender seedlings it is not advisable to allow the fish to graze in them because the seedlings may get damaged. Such low bunds prevent the entry of fish into the main part of the field. Later, when the plants have become strong enough, the bunds can be cut to let the fish spread all over the field. When there are cross channels in the fields these low bunds should be constructed on both sides of the channels. It will also be advantageous to dig a small pond connected to the channels. The channels and pond will give shelter to the fish from the sun's heat and from enemies like fish-eating birds. When draining the field, the fish can be gathered in the channels and ponds, which makes it easier to collect them from the fields.

The extent and number of channels are dependent on the size of the field. Channels can be dug all round in the middle only, or crosswise. In a narrow rectangular field, two or more channels may be dug across it with a single one down the middle. For a pond less than 0.5 hectare a channel around half of the field or along two sides of a square field is sufficient. The usual width of channel is about 50 cm and the depth about 30 cm. Ponds 1 m by 1 m in size can be dug at the points where the channels meet. A depth of 60 to 90 cm and a width of 1.2 to 1.8 m is recommended for rearing tilapia to an average weight of about 70 g.

The best time to excavate the channel is just after harvesting the paddy, but if necessary an all-round channel can be dug at weeding time. Suitable water inlet and outlet arrangements are needed with adequate control devices and screens. A spillway should also be installed at a suitable height, to deal with floodwater during heavy rains.

If fish are to be reared after the rice crop has been harvested, the field should be inundated without removing the stubble. The depth of water will depend on the size of fry or fish introduced.

The decaying vegetation will encourage a good growth of plankton, and some of the stubble may also be consumed directly as food by the fish. In sub-tropical regions an important factor in regulating the depth of water is the degree of flooding that the particular strain of paddy can stand. For tilapia a depth of 7.5 cm is sufficient. Javanese farmers maintain a depth ranging from 4 cm to 20 cm, depending on the size of the fish reared; in India, a depth of 10 to 60 cm is common. It is the general practice to let in fresh supplies of water at intervals of about 10 days to meet the increasing requirements for space, oxygen and nutrients by the growing fish. However, it is generally believed that constant fluctuations in water level are not conducive to a good growth of fish.

Before farmers plant paddy they ordinarily fertilize the fields with chemical or organic manures. Almost all the manures used for paddy are beneficial for fish culture, except a few chemical fertilizers, such as calcium cyanamide, which are poisonous. Organic manures are preferable for common carp because they encourage the growth of phyllopods, such as Daphnia or Moina, which are important items of food. Fish also feed directly on organic manure.

The quantity of manure applied in a paddy field should be increased by 50 to 100 per cent when it is utilized for fish culture. Japanese farmers spread organic composts over the fields that are to be used for common carp at the rate of 1,200 kg per 1,000 m^2 in the early half of April, if it is to yield one crop only in a year, but for two crops, the field is again manured after harvesting. There is no need to manure the channels because part of the manure applied to the field finds its way into them. Experimental work conducted in Japan has shown that the production of natural food for the common carp in paddy fields can be increased by the application of clover or other green fodder extracts.

Stocking

Although most of the cultivated fishes can be cultured in paddy fields, the species most suited are those that can

(1) thrive in very shallow waters;
(2) withstand fairly high turbidity of waters;
(3) tolerate relatively high temperatures and low oxygen content;
(4) grow to a marketable size in a few months.

Very active species and species that can travel over land are not well suited for cultivation in paddy fields, from where they may be able to escape easily. Common carp satisfies all the requirements and is therefore most widely used for the purpose. In Indonesia, an association of common carp, tilapia and tawes (Puntius javanicus) is now grown in paddy fields with success. Tilapia has proved a success in Taiwan and it is being tried with encouraging results in Thailand. In Malaya, where the paddy fields provide a good crop of fish, selective stocking has not been attempted. The fry of sepat siam (Trichogaster) and other fishes gain access to the fields with the water and they grow with the paddy. Before harvesting the water is gradually drained from the field. While many fish are collected in drainage ponds situated in the lower parts of the field, some always find their way into drains and irrigation channels where they breed and produce fry for stocking the fields during the next season. This method is also used to stock paddy fields with young prawns in Travancore-Cochin. The mainstay in Malaya is the sepat siam, but other species such as murrels and catfish (Clarias) also grow in the fields.

The stocking rate largely depends on the productivity of the water, the duration of culture and the size of the fish introduced. The Japanese farmers raise either one-year-old or two-year-old carps in paddy fields. For yearlings, the fields are stocked in spring with fry 5 to 7.5 cm in size.

By the fall, in a period of about 4 to 5 months, they grow to 15 to 18 cm in length and 85 to 115 g in weight. The general practice is to stock at the rate of 200 per ha or 12,500 per ha when additional food is provided. When yearlings are used as stocking material for raising a crop of two-year-olds, 1,200 to 1,600 fish per ha are stocked when no artificial foods are provided, and 4,000 per ha when supplementary food is given. Yearling fish are often kept over in deeper ponds during the winter to serve as stocking material for the next paddy-growing season. Sometimes the farmers stock their fields with a mixture of fry or fingerlings with yearling carp. In the Tonkin area of Indo-China a stocking rate of 1,200 common carp fry per hectare gives satisfactory results.

The main feature of paddy field fish culture in Java is raising several crops of small fish for which there is a ready market locally. Simizu (1944) described the carp stocking schedules followed there, which are summarized in the following table:

Common Carp Stocking in Paddy Fields in Java

Size of fry		No. per hectare	Time of stocking	Duration of culture	Expected mortality %
(1a)	3 to 5 cm	30,000 to 40,000	Between 5th and 7th week after sowing paddy (i.e. between 1st and 2nd weeding)	21 days	60
(1b)	Continued culture of (1a) when fry are about 8 to 11 cm in length		A few days after 2nd weeding, i.e., after the 7th week after sowing	50 days (when rice plants flower)	-
(2)	3 to 5 cm	10,000 to 20,000	A few days after sowing	About 40 days	40-50
(3)	3 to 5 cm	4,000 to 6,000	A few days after sowing	40 days	70
(4)	5 cm	1,000 to 2,000	About 5 days after sowing	40 days	40
(5)	8 to 11 cm	1,000 to 2,000	After the second weeding (about the 7th week after sowing)	50 to 90 days	30-40

In some paddy fields only tilapia are stocked. The stocking rate is so adjusted as to grow them to a weight of 50 to 100 g. When an association of common carp, tilapia and tawes are cultured, 750 to 1,500 fingerlings per hectare are stocked.

In Taiwan, where the temperature may become low in winter, the farmers stock their fields when the water has risen to about 15°C and is not likely to drop again. Stocking is never done until 10 days after the seedlings are planted and then only fry are used. If fingerlings are to be introduced, the farmers wait about three weeks after transplantation. This is done to prevent the fish from damaging the paddy plants. The recommended density of stocking is 7,000 to 8,000 fry or 12 to 180 kg of fingerlings of tilapia per hectare.

The various precautions and procedures described for pond stocking should be followed to ensure the stock gets well acclimatized to the conditions in the paddy field.

Management

Where the water is shallow, great care should be taken to protect the fish from predatory birds. This is why better yields are often obtained in fields near the farmers' homesteads. Excessive growths of filamentous algae can entangle fry, so they should be removed.

In fertile fields, especially when well-manured, fish food organisms grow in sufficient quantities for at least a month. Subsequently, to maintain an abundance of food, fertilizers should be applied as top dressings. About 2,000 kg of compost or 3,500 kg of night soil per ha is used in Taiwan. If chemical fertilizers are used, the field should be drained, the fish being gathered in the channels, before applying them. After two or three days the field is flooded again. Experiments conducted in Japan show that the growth of the favorite food of common carp, namely Daphnia or Moina, is greatly enhanced by the addition of green grass to the manure. Organic manures are more effective than chemical fertilizers for these organisms. The insects living among the plants, many of them harmful to the paddy, are readily eaten by the fish.

All the artificial foods mentioned previously for pond culture will increase fish yields in paddy fields. Some Japanese farmers raise small crustaceans in specially prepared ponds for the purpose, and earthworms, grown on decayed leaves, are also suitable for carp.

Regular inspection of the bunds and the water supply arrangements is essential and, when necessary, repairs should be quickly undertaken. If the field channels get filled up with mud they should be cleaned.

When draining a field for harvesting or weeding, the water should be let out slowly so that the fish can find their way into the channels or a catching pool and not get stranded. The Japanese farmers plough a few shallow furrows in the field, leading from the inlet to the outlet, with a deeper, firm bottom pool about half way between the outlets. The fish are directed into the pool as the water level in the pool goes down and when the whole field has been drained the fish can be scooped out of the pool with small nets.

Economics

The main fact to be remembered is that fish culture is only a subsidiary activity and the cultural operations should be modified to suit the requirements of paddy production. The income from fish culture is an additional one, and it provides a cheap, acceptable and nutritious protein food, in fresh condition. Rice yields are often increased in the presence of fish, sometimes as much as 15 per cent. A slight reduction in paddy yields has been recorded in Taiwan, due mainly to having the fish channels in the field taking up 5 to 7 per cent of the area, but even then, the money value of the fish produced more than compensates for the loss of rice.

The actual yield of fish depends largely on the species stocked, the duration of culture, the fertility of the soil and water, and the food provided. The Javanese paddy fields of cultured carp produce 30 to 50 kg per ha in 40 to 60 days, or a wild crop of about 3 kg of fish per ha in a period of six months between two paddy crops. In Indo-China the yield is about 10 kg to 20 kg per ha over a period of two months. The Japanese farmers get an average production of 145 kg per ha per annum by rearing one-year-old carp without artificial feeding. With artificial feeding the yield can be increased to 2,250 kg per ha or more. In Malayan paddy fields the production ranges from 20 kg to 135 kg per ha per crop.

CULTURE OF FISH IN BRACKISH WATERS

General Considerations

The construction of brackishwater ponds is generally achieved as a step in the reclamation of low-lying coastal or estuarine swamps in the Indo-Pacific Region. Such areas, enclosed by embankments and irrigated with tidal water, gradually get raised by the deposition of silt. The saline content of the soil is washed out by rain and river water, which is allowed to flush the embanked areas and in due course the land becomes suitable for paddy cultivation. Thus, the ultimate aim is agricultural utilization and fish raising is intended to be done only during an interim period of varying duration. However, in recent years there is an increasing realization that sometimes it is technically feasible and profitable to manage such areas purely as fish culture establishments. So ponds are often constructed now for continued fish culture only.

The main factor that governs the selection of sites for the construction of brackishwater ponds is a good supply of tidal water.

Irrigation depends upon the characteristics of the tidal regime, the distance of the site from the sea and the accessibility of tidal water. Ponds situated near the sea or adjacent to the mouth of the estuaries receive salt water at every high tide. Farther up the estuary at distances depending upon the tidal regime of the river, there will be a constant supply of brackish water. Brackish water may be available only during the spring tides for ponds situated further inland. The availability of adequate quantities of salt or brackish water will also be governed by the level of the pond bed. When the pond bed is at a considerably higher level than the river bed, tidal water may not reach the farm at every high tide, and this may lead to a restricted supply of water.

Selection of Pond Site

As was previously stated, pond draining at regular intervals is an established practice in brackishwater fish culture in some of the countries of this region. An adequate tidal range in the feeder river is therefore an important criterion for the selection of sites for brackishwater ponds. Schuster (1951) considers a tidal range of 1.5 m essential for a brackishwater fish farm. Though a lesser tidal range may not be satisfactory for proper draining of the ponds, it will be possible to maintain brackishwater ponds in areas of lesser tidal ranges, if methods such as water pumping and manuring are adopted.

Requirements with regard to the type of soil and the situation of the site in relation to transport, nearness to markets, freedom from floods, etc., that are of importance in the selection of sites for the construction of freshwater fish ponds also hold good here. It will be advantageous to select sites where there is no need for excavation since this will keep down the cost of construction. In such areas a channel has to be dug all round the site to obtain the necessary earth for building the embankments. Clayey soil is the most suitable for pond bottoms and for the embankments. The type of local vegetation is of importance, especially from the point of view of labor and expenses for clearing the site. For instance, swamps overgrown with Nipa palms are more easily cleared than mangrove swamps as it is difficult to clear the mangrove stumps.

Layout of the Ponds

After the site for the fish farm has been selected, the layout of the farm has to be determined with due reference to the topography. Brackishwater farms are generally run as self-sufficient units with nursery or rearing and stocking ponds. Several layouts have been devised in various centers and countries. The simplest type of pond is a sheet of water 0.4 to 2.4 ha in extent and 0.3 to 1.3 m in depth, fed through a wooden or bamboo sluice which controls the ingress and egress of water. When the ponds are made by excavation, large quantities of earth are piled up in the center of the ponds, so they may be irregular in shape.

In Java, the improved *porong* type of brackishwater pond is considered the most satisfactory. On an average, it is 7.5 ha in extent and consists of 3 to 10 irregularly shaped sections connected by secondary sluice gates, the whole being controlled by a main gate which is located in a deep portion having a channel in the middle. This portion is the lowest part of the farm and when it is drained the fish gather in this channel through branching leader channels dug in the pond bed. They also serve as refuges for the fish. Each porong type of farm has a fry pond about 90 to 900 m^2 and a rearing pond 900 to 4,500 m^2 in area. The embankments are 2.4 to 4 m high and 4 to 11 m broad at the base. Such ponds built on high land may have only a depth of 30 to 45 cm of water. During the east monsoon the central parts of the ponds become dry and only the channels and other deeper portions contain water. In very long ponds a deep channel is sometimes dug along one of the long sides. The sluice gates are so arranged that partial draining is possible.

Brackishwater ponds in Taiwan are known as *wun*, and one of their features is that they have a separate water supply channel feeding water into the several ponds through sluice gates. A wun may consist of anything between 3 and 30 sections and generally have nursery, rearing, stocking and wintering ponds. The supply channels are either situated along one side of the wun or between two rows of ponds. The width of these ranges from one to several meters. Water is taken into the supply channels from the sea through a sluice gate and similar gates regulate the flow into the ponds. Wuns situated on high ground have pumps on the embankment to supply water to the ponds. The rearing ponds are 100 to 200 square meters in area and less than 30 cm in depth. The rearing ponds have 90 to 120 cm of water and are rectangular in shape with a width of 3 to 6 m. The wintering ponds are deeper and windbreaks protect them from freezing.

Brackishwater fish farms in the Philippines are run either as self-sufficient units consisting of nursery and stocking ponds or as nursery farms only. A model fry farm consists of nursery ponds, known locally as *pabiayan*, catching ponds, known as *kulungan*, and a few transition or stunting ponds called *impitan*. There is also an elaborate channel system to supply water, known as *sangka*. Water is fed to the farm from a tidal canal or river through sluice gates. The area adjacent to the river or canal contains the deeper transition or stunting ponds and the rest of the land the nursery ponds. Water supply channels are arranged between two rows of nurseries. Every two nursery ponds have a common catching pond, which varies from 20 to 50 m in area. The nursery ponds have a number of small wooden gates and pipes to allow ingress and egress of water without allowing fry to escape. Water is usually taken into catching ponds from the supply channel through pipes. Water is let into nurseries from catching ponds through adjustable gates, but pipes are usually installed near them to prevent the escape of fry. The transition ponds are sometimes used as stocking ponds after the fry rearing is over. In certain types of fry farms, head ponds, which serve as water reservoirs, replace the water supply channels. These ponds can also be used for growing adult fish.

In a Philippine self-sufficient 10-hectare milkfish farm 1 per cent of the pond area is usually set apart for nurseries, 9 per cent for transition ponds, and 90 per cent for stocking ponds. The layout of ponds with slightly brackish water, in which grey mullet is cultured in association with carps in Hong Kong, is essentially the same as that of freshwater ponds.

Construction Methods

After the area has been properly surveyed, cleared and marked out, the first step is to build a strong embankment all round. The mode of construction of the embankment is essentially the same as described for freshwater ponds, but the height of the embankment is determined by the tidal height occurring in the area, generally about 30 cm above the maximum flood level. The survey will show whether or not the pond site has to be excavated. If it is not necessary, earth for the embankment is obtained by digging a marginal channel all round inside the pond site to the required depth. After the subsidiary embankments are made, further excavation, if necessary, is done. The slope of the pond bottom is so adjusted that it drains readily towards the outlet and, in large ponds, channels are dug to facilitate the draining. The sluice gates are constructed in the deepest portion of the farm. In West and Central Java, simple wooden or bamboo gates, provided with side walls and shutter boards fitted in a frame are used. More massive constructions 5 to 10 m long, 1.3 to 1.8 m wide and 2.7 to 3.7 deep are used in East Java where the tidal conditions require great strength. The sluice gate is made of heavy timber and the side walls are reinforced with wooden planks. There are five compartments in the sluice and of these four have wooden floors, whereas the fifth is kept filled with soil to the height of the average water level of the pond. Strong and well-fitting bamboo gratings, fixed on both sides of the gate, prevent the escape of fish.

In Indian brackishwater ponds, known as *bheris*, ordinary wooden sluice boxes with wooden shutters, that can easily be manipulated by hand, are used. In the Philippines more elaborate types are built for milkfish ponds. The main sluice is made of concrete or bricks, reinforced with concrete. To render the floor of the sluice strong and firm, bamboo or wood piles are driven into it. The floor is paved with stones and concrete and is often reinforced with steel bars placed over the piles. Three gates working in grooves are provided for each sluice. The central gate is made of strong wood and on both sides of it are split bamboo gates in wooden frames. The subsidiary gates for inter-connection between ponds are of the same design, but are made of wooden planks, nailed together. Wooden plank drains or cylindrical pipes are also used to connect ponds. The pipes are laid across the embankments with the ends projecting 0.5 m on both sides. These various types of drains are fitted with suitable shutters or plugs to control the water flow. Cement pipes are also used. When the pipes are in commission basket-like structures, known as *galao*, are fitted to the pipe.

It is a common practice in India to construct a V- or W-shaped bamboo grating behind the sluice gates to prevent the entry of undesirable fish or other animals. In Bengal rectangular bamboo traps with a funnel at one end, known as *atols*, are fixed in gaps left in the apex of the V or in the apices of the W. Bamboo spindles are arranged on both sides of the openings in such a way that fish or prawns can easily enter the trap but will not be able to escape from it. The atol is fixed facing the pond. When water is taken into the pond some fish swim against the current and get caught in the trap. This is a common method of collecting a few fish each day for the farmer's consumption.

Essential Conditions

Soil

The quality of the soil in a brackishwater fish pond is of even greater significance in productivity than in a freshwater pond. The quality of the underlying soil of an estuarine pond is to some extent dependent on the nature of the land drained by the river.

According to Schuster (1952) the most productive tambak soil in Java is generally obtained in the spill areas of rivers, the head waters of which are in the volcanic regions where the soil consists chiefly of ashes and incompletely weathered grit of volcanic rock. The clayey loam soil of deltaic areas in Bengal is also very fertile.

For the construction of ponds in coastal and estuarine flats the main factor to be considered is the water-holding capacity of the soil. Once the pond is made, silt is deposited quickly as a result of the stagnant conditions created. The organic matter brought in by the incoming tides disintegrates and adds to the fertility of the soil. The humus content of brackishwater ponds is generally high. Investigations conducted in Indonesia have revealed an average humus content of 4.1 per cent in the dry matter of tambak soil, and in inland ponds in West Bengal a humus content of 3 per cent has been recorded. Preliminary investigations in the Philippines have shown that algal production is best in ponds with soil having a high "solution loss" (determined by treating a sample of soil with hydrogen peroxide and washing), and high contents of clay, nitrogen and organic matter. The hydrophilic property of the mud has also been found to be of importance from the point of view of algal production, but this property is dependent on the clay and humus content and the tillage of the soil. Ponds receiving a satisfactory supply of tidal brackish water are generally rich in the various essential elements for algal growth. The nitrogen content of the soil is greatly enhanced by the nitrogen supplied by plants; Clostridium pasteurianum, Azobacter, Nostoc and Anabaena are common species which are supposed to fix atmospheric nitrogen in brackishwater ponds.

The quality of the soil in brackishwater ponds influences in a pronounced manner the type of biota that develop in them and, to some extent, the biota influence the property of the soil. For example, by prolonged inundation the pond mud absorbs large quantities of water and attains a jelly-like consistency. A soft hydrophilic and biologically active mud, containing large quantities of organic matter, develops a predominantly myxophycean flora in 1 to 50 cm depths of slightly lotic water. On the contrary, more or less solid soil, irrigated by water containing adequate quantities of nitrates and phosphates, Chlorophyceae grow more luxuriantly in 30 to 100 cm depths of stagnant water. The properties of the soil are effectively maintained by proper replenishment of nutrients absorbed from the mud by vegetation, by the dead and decaying algae and bacteria and through assimilation, fixation and absorption. In the absence of blue-green algae, certain soils lose their cohesive property and become semi-solid, and in others the fine particles of soil bind into sand-like granules which are with difficulty converted into mud again. On such bottoms the development of microflora is greatly restricted and microfauna takes its place.

The turbidity of brackish water shows a wide range of variability. Turbidity of estuarine water due to suspended silt is reduced in a short time in the ponds as a result of admixture with fresh water and consequent flocculation.

The water temperature of well-irrigated ponds does not fluctuate greatly. A variation between 24°C and 38.5°C has been observed in Indonesia. In shallow ponds in India a range of 14.4°C to 35.0°C has been recorded. Since in shallow ponds the water may become very warm during the summer months and cold during the winter, it is necessary to provide deep areas where the fish can take refuge at such times. In Taiwan, the fish are removed to deep wintering ponds protected by windbreaks which prevent the temperature falling to lethal limits.

Observations carried out so far in different countries show that the water in brackishwater ponds is always alkaline and that there is very little variation in the pH. The alkaline reserve is high enough to prevent wide fluctuations in pH. Preliminary experiments indicate that the pH of the water is of great significance in the growth of myxophycean algae, but further work is required to establish the optimum requirements in this respect.

The oxygen content of water in brackishwater ponds is dependent on temperature and salinity. Observations show that oxygen depletion is of very rare occurrence in these ponds. Any deficiency in oxygen on very hot days is made up by the oxygen produced by the carbon assimilation of algae. In fact, over-saturation of the water with oxygen thus produced has sometimes been noticed in tropical ponds.

Water

The two main sources of water supplv are tidal water from the estuaries and rain water. As already mentioned, the availability of tidal water is dependent on the location of the ponds with reference to the tidal regime of the estuary. This, therefore, determines to some extent the depth of water in a pond. But even where there is a plentiful supply, the depth of water in a pond has necessarily to be controlled. In shallow ponds myxophycean algae grow in profusion, whereas in deep ponds Chlorophyceae predominate. In view of this, fish culturists adjust the water supply in such a way as to maintain the optimum level in the ponds.

The salinity tolerance of fish varies greatly. But it has been experimentally found that cultivated brackishwater fish can be acclimatized to fresh water by a gradual diminution of the salinity. Mullets and milkfish have been found resistant even to direct transfer from saline to fresh water. A salinity higher than 30 to 35 ppm is lethal to the fry of *Mugil tade*.

Water salinity is a very important factor that affects fish production in ponds. There are seasonal and diurnal variations in the salinity of every pond. In ponds receiving daily supplies of tidal water, the salinity fluctuates almost daily. During the rainy months feeding with tidal water might increase the salinity, whereas during other seasons the salinity is generally decreased by it. Due to evaporation and seepage a certain amount of loss of water occurs in every pond and this increases the salt content. The process of evaporation will be more rapid during the dry months and the salt concentration will therefore be greater during this period. Portions of the bed often get dried up and small pools and puddles are formed in shallow ponds. Deposits of crystalline salt are visible on the pond bed at this time and the salinity of the water in the pools is very high. But in the rainy season large quantities of fresh water are brought into the ponds by rain which dilutes the pond water and lowers its salinity. Ground water supplies also may lower the salinity. The seasonal and diurnal changes in salinity mentioned above naturally exercise a selective action on the fish fauna and only euryhaline species are able to thrive.

Very little information exists on the other chemical constituents of water in brackishwater ponds. Schuster (1952) estimated that a tambak in Java with a surface of 1 ha receives the following quantities of nutrients in every filling to a depth of 40 cm with water of 30 ppm salinity:

Phosphate (PO_4)	9 - 14 g
Nitrate-nitrite (NO_3-NO_2)	8 -140 g
Ammonia (NH_3)	20 -200 g
Potassium (K)	1320 kg

This does not include the nutrients that would be introduced by the silt in an absorbed form nor the nitrogen brought in with the rain water.

Biota and Their Control

Flora

As pointed out in the previous chapters, the nature of flora in a brackishwater pond is of extreme importance in fish production. A main feature of the flora is the relative scarcity of phanerogamic plants. This is more so in ponds containing water of a fairly high salinity.

Algae predominate and several genera and species of Myxophyceae, Diatomeae and Chlorophyceae grow luxuriantly on the pond bed and may also be found in the pond water, and several types of bacteria grow on the bottom mud.

In view of the very shallow nature of ponds generally used for brackishwater fish culture, it is often difficult to make a clear distinction between planktonic and benthic organisms. Many benthic plants get detached from the bottom and float in the water, and several planktonic algae settle to the bottom. The hormogonia, shed by the algae, occur regularly. However, it is the benthic vegetation that is of greater significance in such ponds, as most of the cultivated brackishwater fishes subsist on it. The organisms generally found in brackishwater ponds have been described by Vaas and Sachlan (1953). A large majority of them grow on the pond bed and often cover the entire surface. Several animalcules and considerable quantities of decayed organic matter may be found among them. The milkfish culturists of the Philippines recognize two types of these plant complexes, namely, *lab-lab*, in which myxophycean algae predominate, and *lumut*, in which Chlorophyceae predominate.

Detailed studies of the environmental preferences and seasonal fluctuations of algae in brackishwater ponds have yet to be undertaken in the Indo-Pacific Region. Preliminary work in India has indicated the importance of trace elements in algal growth. Several observations have revealed that the growth of halophytic algae is profuse and at a maximum during the winter months. Large sheets of algal growths are often buoyed up to the surface. This happens especially when there are good growths of *Phormidium* in the complex. The mucuous sheaths of the filaments of this often cover up the entire growths of algae, including diatoms. Oxygen released by the carbon assimilation of the algae accumulates inside the sheaths and ultimately lifts up the whole layer. The period of time taken for the development of a new layer of Myxophyceae on good soil is only about three days, whereas Chlorophyceae, such as *Chaetomorpha* and *Entermorpha*, need from four to eight weeks to grow to such profusion. Studies made in the Philippines show that the maximum growth of lumut is attained between the second and third months of their cultivation.

During the rainy season, when there is an admixture of large quantities of fresh water, some predominantly freshwater species of algae also may grow in the ponds. But considered as a whole, algal growth is at a minimum during this period. Some of the species of algae are found to be very resistant to high concentrations of salt. In the case of *Phormidium tenue* it has been demonstrated that it can withstand salinities up to 100 parts per thousand (Pillai, 1954).

Among the higher plants occurring in brackishwater ponds are species of *Ruppia* and *Najas*. Ruppia grows best in pure brackish waters but can withstand a salinity of up to 50 to 60 parts per thousand. Najas is less resistant to high salinities and the maximum it can tolerate is about 30 parts per thousand. The decayed leaves of these plants are eaten by milkfish and mullet. The fish culturists of Java drain off all the fresh water that has accumulated in the ponds during the rainy season, and fill the ponds with sea water of high salinity. This kills the Najas and Ruppia which are readily eaten by the fish.

The flora of the embankments is mainly of the mangrove type and consists entirely of halophytic species. In Java, mangrove trees such as *Avicennia* spp. and *Rhizophora* spp. are planted on the embankments of tambaks. The leaves of these trees are used as green manure for the ponds, the stem and branches as fire wood, and from the bark a marketable tanning material is prepared. The roots of the mangroves help to bind the soil and prevent erosion. Generally the mangroves are not allowed to grow for more than five years after which period they are cut down. By the third year, new seedlings are planted on the embankments.

Several other mangroves such as *Sonneratia*, *Bruguiera*, *Xylocarpus*, *Lumnitzera*, *Aegiceras* and *Cerias* also grow on the embankments, besides different genera and species of grasses. *Suaeda*, especially *Suaeda maritima* (family Chaenopodiaceae) is a characteristic plant of these areas and is used as a vegetable by many.

Overgrowth of vegetation in such a manner as to affect the growth of fish is a rare occurrence in well-irrigated brackishwater ponds. But weeds often occur in ponds situated inland since they receive large quantities of fresh water. The weeds have to be regularly removed to keep the ponds in a healthy condition. The need for selective growing of Myxophyceae or Chlorophyceae according to the size of fish in the ponds has already been referred to but, besides this, there is generally no need for any weed control in ponds. The areas occupied by extensive brackishwater ponds are devoid of sufficient shade and there is scope for planting tamarind trees (*Tamarindus indicus*), the nipa palms (*Nipa fructicans*) and coconut palm (*Cocos nucifera*). Tamarinds and nipa palms grow very well in brackish soils and the tamarind fruits and nipa leaves are saleable products. Coconut palms thrive well in sandy or lateritic soils.

Fauna

Vaas and Sachlan (1953) have listed the faunal elements commonly met with in brackishwater ponds. Crustaceans, such as cladocerans, ostracods, and copepods, are abundant and mysids and decapod larvae are very common. Even though there is an abundance of plankton it would appear that there is less utilization of zooplankton in these ponds, as plankton feeding animals are relatively few.

Among the macrofauna, the fishes are the most important. Besides cultivated fish several other brackishwater species of fish and economically important prawns and shrimps enter such ponds and provide a subsidiary income to the farmers. Juveniles and fry of these gain access with the tidal water. Species of *Penaeus*, *Metapenaeus* and *Leander* are the most common among these. The larval forms bury themselves in the muddy bottom and grow rapidly, feeding on the iliotrophic layer. Several species of Gobioid fishes can be seen on the muddy banks but they are of little economic value and are regarded as weed fish. It has been suggested that these and other economically unimportant species should be utilized as forage fish for culturing predatory species such as the cock-up.

The cock-up (*Lates*) and thread fins (*Polynemus* and *Eleutheronema*) and the ox-eyed herring (*Megalops*) are the common predatory fishes in brackishwater ponds. The cock-up and the ox-eyed herring, especially the former, feed voraciously on cultivated fish like mullet and milkfish and should therefore be kept out of the ponds as far as possible. The thread fins feed mostly on prawns and shrimps and are not so destructive as the cock-up. If the water fed into the ponds is properly screened it will be possible to restrict their entry. Different types of crabs are found in brackishwater ponds. Species of *Scylla* are of economic importance and fetch a good price. Other crabs such as *Varuna* and *Saesarma* are not of such value. These crabs dig holes in the embankments, weakening and eventually causing them to collapse, so too many of them are not desirable. Aquatic snakes are quite common and different types of birds live near the ponds. Otters and fish-eating birds prey on the fish. Mosquitoes, especially malaria transmitting species, are a serious menace in such areas.

Studies on the biotic interaction in Hawaiian and India brackishwater ponds have revealed that the dominant fauna are iliophagous. The benthic flora and detritus form the major item of their food. Several uneconomic species compete with the cultivated fishes for food. It is therefore essential to control the access of weed fishes effectively to render the conditions favorable for cultivated species. Selective stocking and proper screening of water supplies, as already mentioned, are necessary for preventing the entry of both predaceous and weed fish.

Preparation for Stocking

The general principles to be followed in the preparation of brackishwater ponds for stocking are essentially the same as for freshwater ponds. The first step is to ensure that the embankments are in good condition. Leaks can be stopped by digging a deep trench along the base and filling it with dry hard soil. Any undue decrease in the height of embankments must be made good. Most ponds are extensive and situated in areas which are not easily accessible, so intensive manuring is often either not possible or economically feasible. However, by regular draining and drying the pond bottom, as practised in Java and the Philippines, the fertility can be greatly enhanced. By this method it is possible to kill the predators in the ponds before stocking them with fish. Experiments indicate that drying raises the pH of the pond bottom, controls higher aquatic plants with heavy roots, reduces the concentration of bacterial parasites and enhances nitrogen fixation by blue-green algae and bacteria. In Java, green-manuring is practised to a limited extent, especially in the inland tambaks, where macro-vegetation, such as grass, is more easily available. The leaves of mangroves and other plants growing near the tambaks are distributed in small heaps over the pond bottom at the rate of about 1,500 kg per ha every three months. The soil has to be manured to stimulate the growth of Myxophyceae. In unfertile ponds two to three applications of green manure may be required to bring the fertility to a satisfactory level. The fish culturists in the Philippines often transplant algal growths and encourage them to thrive and multiply with small quantities of artificial nutrients. Green manure, which disintegrates rather slowly, will enrich the pond soil, and copra slime, applied at the rate of 450 to 900 kg per ha, has been found to be effective in enhancing the growth of blue-green algae.

More intensive pond preparation practices are followed in Taiwan. The method of preparing stocking ponds is the same as that for nursery ponds. After repeated draining, drying and proper fertilizing, stocking is done when there is 17 to 20 cm of water in the ponds. By this time a good growth of algae will have developed on the pond bottom. The ponds are drained, dried and fertilized again in August after moving the fish elsewhere.

The mullet culturists in Hong Kong also drain their ponds and manure them with rice bran, peanut cake, pig manure and night soil. Water is then run in and the ponds left for about two weeks before stocking with fingerlings.

Stocking

As already mentioned, milkfish is the most widely cultivated brackishwater fish. Mullets and prawns generally form subsidiary crops of some importance and, even though not intentionally stocked, they gain entrance into farms with the tidal water. In Java, tawes (*Puntius javanicus*) is stocked with milkfish in ponds having a salinity of 8 parts per thousand or less. Tawes has been observed to withstand salinities up to 22 ppt, but at such concentrations its growth may not be satisfactory. The presence of tawes is beneficial for the growth of the milkfish because they feed on coarse vegetation, including tough filamentous algae, grass and submerged plants, and pass out a good part of the food consumed in a semi-digested state. This is very acceptable food for milkfish which are unable to eat these plants in the raw state. Besides this, the droppings of tawes serve as a fertilizer and help the growth of myxophycean algae.

Tawes are introduced into a milkfish pond some time after the milkfish fingerlings. The stocking is generally done after the rains have started and the salinity has consequently decreased. No definite stocking rates appear to have been worked out. The number of fish is largely governed by the number of milkfish in the pond and the demand for the species in the area. Ordinarily, the stocking rate is adjusted to have 25 to 50 per cent tawes. In ponds containing large quantities of Chlorophyceae, there are possibilities of culturing tilapia along with milkfish. Intensive culture of tilapia has yielded very encouraging results in Malaya.

In Taiwan, besides mullets, the prawns, *Penaeus carinatus* and *Penaeopsis monoceros*, are collected from the sea with milkfish fry, or separately, and stocked in ponds with milkfish. To collect *Penaeus* fry, bunches of sea weeds are planted in shallow bays or inlets at distances of about 3.5 m. The young prawns that gather among the weeds are caught with a triangular dipnet. Fry of Penaeopsis are caught in the same type of dragnets used for milkfish fry. Penaeus prawns are generally grown in ponds for about six months until they reach a weight of 40 to 50 g, and Penaeopsis for a period of two to three months, until they attain a weight of 7 g each. In ponds of low salinity, common carp, grass carp, silver carp, big head and mud carp are also stocked with milkfish. As the carps' feeding habits are different from milkfish, there is not likely to be competition for food, and since they utilize food material not consumed by milkfish, and grow rapidly, the total yield of such farms is considerably improved. Grey mullet (*Mugil cephalus*) is cultured with the Chinese carps in Hong Kong.

In the fish farms of Hawaii and India, where stocking is generally done by admitting tidal water, several species of fishes and prawns get entry. The dominant species in Hawaiian fish ponds are the milkfish, grey mullet, tarpon (*Megalops cyprinoides*) and ten pounder (*Elops indicus*). Mullets, milkfish, pearl-spot and prawns are the main species in South India, whereas in East and West Bengal mullets, cock-up and prawns predominate.

Stocking may be done only once a year or up to three times depending on the fertility of the pond and the demand for small fish. Where small fish are not wanted, a longer culture period will have to be allowed.

The most intensive stocking procedure is followed in Taiwan where it is done thrice a year, the first in March, the second in April or May and the third in June. Fingerlings or yearlings, kept over in wintering ponds from the previous year, are stocked in March. In April and June, fresh fry or fingerlings are stocked. Fry stocked in June are transferred to wintering ponds and kept over for stocking the next year in March. The total number of fish planted is at the rate of 8,000 to 9,000 per hectare. The following table shows the stocking and fishing schedule:

	No. of fish planted per hectare	No. of fish removed per hectare
March	3000	--
April	5000	--
May	--	--
June	3000-4000	3000
July	--	--
August	--	--
September	--	5000
October	--	--

In the Philippines the maximum number of fingerlings stocked per hectare is 1,000 to 2,500 and in Indonesia about 1,500, where planting is done twice to three times a year. The stocking rate is, of course, modified according to the fertility of the pond, the availability of stocking material and the personal experience of the farmer. For example, in the Porong type of ponds in Java the following stocking and fishing procedure is adopted (Schuster, 1952) and stocking and fish are often continued for long periods.

October	About 2, 500 fry per hectare planted in the nursery ponds. The east monsoon crop remains in the deep sections of the farm.
November	Fry admitted into the stocking ponds, counting east monsoon crop and capture of marketable fish and prawns.
December	Catching part of the east monsoon crop. West monsoon crop admitted to the deep sections. Capture of prawns.
January	Capture and sale of east monsoon crop continued.
February	Repair work and deepening of channels.
March	Capture and sale of east monsoon crop and repair work continued. West monsoon crop counted.
April	Capture and sale of west monsoon crop, catching prawns. Preparation of nurseries.
May	Capture and sale of west monsoon crop continued. Planting 1, 000 to 2, 000 fry per hectare after deepening of central channels. Catching prawns.
June	Admitting east monsoon crop to stocking ponds. Catching prawns.
July	Mixing east monsoon and west monsoon crops. Catching prawns.
August	Capture and sale of the remaining west monsoon crop, leaving a few fish to grow to larger size. Catching prawns.
September	Preparation of nurseries and stocking ponds.

But in the inland tambaks of Java stocking is done only once a year. The fry planted in the nursery ponds in October are put into the stocking ponds in November. Besides cutting grass and other pond macro-vegetation to use as green manure, nothing is done until June when cropping is started. By August the ponds are completely fished and in September they are prepared for further stocking.

In the grey mullet ponds of Hong Kong, fingerling stocking is done from February to April and larger fish in the spring and autumn. Approximately 10, 000 to 15, 000 fingerlings (about 7.5 cm in length) of grey mullet and 1, 000 to 2, 000 fingerlings of Chinese carps are stocked per hectare of pond area. When the mullets grow to an average of about 140 g in weight (about five months after stocking) it is necessary to thin them to about 3, 500 per hectare. The fish removed from the ponds can be used either for stocking other ponds or for sale.

Pond Management

The general principles of management of brackishwater fish ponds are the same as for fresh water, except perhaps the handling of water supplies. Regulated inundation and draining at definite intervals are essential. To hold the required depth of water the embankments, channels and sluice gates must be in good condition. Where the tides allow there is no difficulty in renewing and controlling a flow of water in the ponds, but on inland farms this may not be possible. In such cases the salinity of the pond water will probably increase steadily due to evaporation and seepage, especially during the hot months. Therefore a vigilant watch should be kept on the salinity and when it rises to a dangerous level the ponds should be flushed with fresh water.

Crabs and other burrowing animals that damage the embankments must be controlled by fishing, trapping and so forth. The various predatory and weed fishes must also be kept under control. If the ponds are drained regularly and undesirable fish kept out by close-meshed screens their numbers can be kept under control.

Snails, mainly of the genus Cerithidea, occur in Javanese fish ponds in such abundance as to become a pest. To a certain extent they compete with milkfish and mullets for food and they also use up the calcium content of the water for shell formation. Snails can be killed by molasses which also acts as a fertilizer and increases the growth of blue-green algae, but this method is not very economical because re-infestation takes place very quickly. Schuster (1952) remarks that when there is a thick layer of blue-green algae in a pond the snails disappear. Pond bottoms covered with jelly-like mud is also not conducive to their growth, whereas they thrive in liquid mud. This evidently shows that if ponds are properly manured and stocked with the optimum number of fish to maintain a good layer of algae, the chances of infestation by snails is greatly reduced.

The polychaete worm Eunice, which is abundant in brackishwater ponds, is also harmful to cultivated species like milkfish. They also make the pond soil porous and thus adversely affect its water-holding capacity. No effective control measures have been evolved as yet.

Although the young and adults of some of the extraneous fishes, such as Aplocheilus, Oryzias and Therapon, feed on mosquito larvae they do not keep this pest and the resulting malaria in check, in some areas. Studies conducted in Java have shown that Anopheles sundaicus breeds in ponds having a salinity between 2 and 20 parts per thousand and then only where the surface is covered with floating masses of algae or other vegetation. Maximum breeding takes place in algae-filled ponds with a salinity of 10 parts per thousand, although some species, such as A. subpictus, breed in waters as salty as 80 parts per thousand. In ponds cleared of Chlorophyceae, such as Chaetomorpha and Enteromorpha, little mosquito breeding takes place and if larvae do develop they are eaten by the always-present extraneous fish. As it has been established that milkfish can be grown on Myxophyceae alone and that the growth of Chlorophyceae can be controlled by periodical draining, it is possible to check the breeding of mosquitoes by keeping the ponds clear of green algae without adversely affecting the production of fish. Mosquito breeding generally takes place in shallow parts of ponds, so if the ponds are uniformly deepened mosquito breeding can be considerably minimized. Experimental work in Java seems to show that Chlorophyceae can be effectively checked by growing fish such as tilapia that feed on these algae.

The remarks made about controlling fish-eating birds and mammals when discussing the management of freshwater ponds, also apply here.

The presence of large quantities of organic matter on the pond bottom may result in the formation of poisonous gases like hydrogen sulphide and methane, which are injurious to fish life. If detected in time, this condition can be controlled by draining, drying and aerating the bottom soil.

Brackishwater ponds are relatively free from fish parasites. Even though some internal parasites occur in fish, hardly any of them are pathogenic. Schuster (1952) describes the only disease which has been recorded in the milkfish, namely "cold". When the water temperature suddenly falls the fish become lethargic and develop a milky discoloration of the skin, which after two or three days, peels off. During the period of attack the fish do not feed and therefore lose weight. Although mortality does not seem to be appreciable, it is probable that the fish become easy prey to predators at this time. In cold climates considerable mortality might take place if the milkfish are not transferred to wintering ponds.

The grey mullet in Hong Kong is affected by temperatures higher than 37°C. Shades will protect them from the hot sun, but should deaths occur, further mortality can be arrested by running colder water into the pond.

Foods and Feeding

While intensive artificial feeding is a common practice in freshwater ponds, it is not common in brackishwater fish ponds, mainly because of their size and the fact that the large quantities of foods necessary are not easily available at economical prices. Algae form the most important food in milkfish and mullet ponds and the farmer always tries to maintain a good growth of them. Blue-green algae are eaten by the milkfish until they are about 20 cm in length and thereafter they are also able to feed on soft green algae. Young mullet fry feed on planktonic organisms but fingerlings sustain themselves on algae. The composition of the blue-green algae, *Oscillatoria* spp. and *Phormidium* spp., is given below; they are more nutritious than green algae.

Dietetic composition of blue-green algae in g per 1,000 g of wet algae:

Composition	Proportion	
Water	829.0	
Raw protein	16.5	
Fat	3.9	
Nitrogen-free matter	13.7	
Raw fiber	14.6	
Ash	122.3	of which 32.9% is SiO_2
	1,000.0	

When the production of algae in a pond is not sufficient to feed the fish, Philippine farmers collect algae from other water areas and put them in the ponds. Besides algae, hydrophytic plants, such as *Ruppia*, *Najas* and *Halophila*, which are locally known by the collective name *digman*, water hyacinth (*Eichhornia crassipes*) and paddy straw are collected and fed in a decayed or dried form.

Another method of obtaining adequate supplies of algae is by cultivating them in separate ponds. Special "collectors", such as twigs of mangroves and bamboo poles, are fixed in the ponds and algae spores attach themselves to and grow on these "collectors". The algae are taken to the stocking ponds as and when needed. Recent experiments conducted in the Philippines have shown that the seaweed *Gracilaria* is a very suitable food for fingerlings and adult milkfish. The food values of this weed and of other plants are shown in the following table:

Food constituents of certain algae and weeds

Name	Moisture %	Ash %		Fat %		Protein %		Carbohydrates %	
		F*	D**	F	D	F	D	F	D
Gracilaria confervoides	6.92	15.31	16.48	0.4	-	11.98	12.89	65.39	70.63
Enteromorpha intestinalis	81.35	6.02	32.27	0.48	2.57	3.66	19.61	8.49	45.55
Chaetomorpha spp.	85.50	2.82	19.50	0.27	0.71	3.72	27.66	7.87	52.13
Cladophora spp.	57.20	9.90	23.16	0.84	1.96	5.16	12.07	26.90	62.81
Eichhornia crassipes	89.81	1.34	13.15	-	-	2.19	21.49	6.66	65.36

*F - Fresh **D - Dry

The weeds are scattered in such a way as to form a carpet of a uniform thickness of about 15 cm on the pond bottom. In many ponds in the Philippine Islands milkfish are now grown to marketable size fed almost entirely on Gracilaria. The required quantity of weed is introduced before stocking the ponds or it is fed in small lots throughout the period of growth. The quantity required to feed a given number of fish has yet to be established but it usually ranges between 200 and 500 kg per ha. One disadvantage of depending entirely on this weed for milkfish is that it does not provide any shade from the sun as the weeds remain at the bottom. To remedy this, the fish culturists increase the water level in the ponds as much as possible during the summer months; this does not in any way affect the growth of Gracilaria. Salinities lower than 5 ppt have an adverse effect on the weed and so their use is limited to ponds in which the salinity never falls below that level. With the use of Gracilaria as food for milkfish it has now become possible to increase the number of crops from a pond and to stock as many as 3,000 fish per hectare.

Rice bran is a suitable artificial food for milkfish and mullets. Small quantities of rice bran are generally fed to mullets in India and the Philippines, but intensive artificial feeding is done mainly in Taiwan and to some extent in Hong Kong. As already stated, the farmers in Taiwan use rice bran as a manure for the ponds, and in the early stages of growth there is a considerable quantity of rice bran for the fry or fingerlings to feed on directly. Intensive artificial feeding starts in May and only rice bran is given to the fingerlings until June, as it is believed that they are not able to feed on coarser food at this stage. By the time the rainy season sets in the salinity of the water in the ponds decreases and the natural food supplies greatly diminish. Because of the lower salinity, a sufficiently thick growth of algae does not appear. Rice bran and soya bean cake, broken into small pieces, are fed during this period. In July, August and September peanut meal is also added to the rations as it is believed that this stimulates the appetite of the fish and hastens its growth. The quantity of artificial foods necessary for one hectare of pond area is about 2,000 kg of rice bran, 500 kg of soyabean cake and 36 kg of peanut meal. The following table shows the feeding rates and the kinds of artificial foods given to grey mullet and carp in brackishwater ponds in Hong Kong. No allowance has been made in it for mortality, and when the number of fish in the pond decreases due to deaths, a proportionate reduction in the quantity of food supplied is necessary. Besides these foods, rice bran, peanut cake, pig manure and night soil are put into the ponds at intervals of two to three days; these are partly consumed directly as food and act partly as fertilizers.

Feeding Schedule for Milkfish Ponds in Hong Kong

Number of days after stocking	Food per ha	Average daily ration in kg
1 - 10	-	-
11 - 30	Rice bran	1.0 - 1.5
31 - 60	Rice bran	1.5 - 3.0
61 - 90	(Rice bran	3 - 5
	(Peanut cake	1 - 3
91 - 150	Rice bran)	5 - 8
	Peanut cake)	3 - 8
151 - 210	Rice bran	8 - 12
	Peanut cake	8 - 14
211 - 300	Rice bran)	12 - 16
	Peanut cake)	19 - 24

In Taiwan, Java, and the Philippines, where two to three crops of milkfish are raised every year, the fish are seldom allowed to grow to a large size. In Taiwan, when they are caught for sale, the fish weigh 150 to 300 g and the rate of mortality ranges from 8 per cent to 20 per cent. During winter the water temperature may fall to 10°C and the growth of the fish is greatly decreased. In the Philippines, when the fish are caught at the end of 6 to 9 months, they have reached an average weight of 400 g and the estimated mortality is 50 per cent to 70 per cent. In Indonesian ponds, where the growing period ranges from 6 to 10 months, they are caught when they attain an average weight of 350 g. The mortality might be 50 to 80 per cent.

Capture and Marketing

Methods of Catching

Partial harvesting is done in many ponds for a major part of the year. It is not always possible to drain the ponds to catch the fish, but the water level can be considerably reduced by shutting off the supply for a few days before fishing is done. Drag nets of various lengths and depths, depending on the pond dimensions, can be used. In Java, a number of fishermen wade through the pond in a row, using cast nets.

The tendency of adult milkfish and grey mullet to swim against the current is taken advantage of to capture them. Water is taken in through the sluice gates at high tide, the fish swim against the current and gather near the sluices, making frantic efforts to escape, where it is easy to capture large numbers with nets. If the deep area adjacent to the sluice gate is made into a "catching pond", as is done in the Philippines and in Indonesia, all the fish swimming against the current can be trapped by closing its entrance from the stocking ponds. A deep channel or "fish race" will also serve the purpose equally well. When the fish are thus enclosed it is easy to catch them with nets. This type of capture has been developed to a considerable extent in the Philippines where "catching ponds" with several compartments are sometimes used for the purpose. The fish entering the "catching ponds" are held over at least 24 hours before removal so that their guts will be cleared of all food consumed. This is done to improve their keeping qualities.

Use is often made of bamboo gratings for catching milkfish from ponds in Java. The area is dragged with a rectangular grating, the fishermen using hands and feet to push it and the fish are thereby enclosed near the pond outlet from where they are removed with dip nets.

Different types of nets and traps are used for catching prawns and shrimps. These generally swim in the direction of the current. Shrimps are often collected by operating a long-handled net against the current. Or, when draining the pond, they are caught in a small purse net fixed to the sluice gate.

Prawns have a tendency to move along the sides of embankments and this habit is taken advantage of to capture them by fixing bamboo screens in the pond bed at right angles to the embankments. The catches can be increased with lure lamps hung over the traps. Prawns are also caught by running the pond water through a pipe with a trap fixed at the outlet end.

The atols in front of sluice gates in the bheris of Bengal catch fish and prawns. Baited lines are widely used for catching crabs, and hooked tools to catch burrowing eel-like fishes and crabs from holes in the embankments.

Marketing

As most brackishwater ponds are situated away from towns where the major part of the produce is marketed, there is need for ice as a preservative for fish and prawns, but crabs can generally be transported alive. Boats and trucks are used to carry the catch to the markets.

When ice is not available the fish farmers in Java boil milkfish in strong brine with a few roots of *Curcuma domestica*. The spice imparts a bright yellow color to the product which is greatly favored by consumers, and fetches a better price than fresh fish.

A special method of curing is practised in certain parts of Java. Earthen pots about 25 cm wide and 30 cm high are filled above the brim with fish arranged in layers. Brine is then poured to 5 cm below the top and the pots are heated until the brine has boiled down to half its original quantity, and then drained off and some dry salt added. After heating again for a few minutes the pots are covered with leaves and tied. This process needs great skill and care. The cured fish keeps for about three months. The boiled brine contains fish juice and when the liquid is evaporated over a fire a paste, known as *petis*, is left which commands a good market among Indonesians.

Prawns are cured in the same way.

Smoking milkfish has now become fairly common and it has been found that by adding a small quantity of potassium nitrate and by carefully regulating the heat, the whitish crust that often develops on the fish during smoking can be avoided. Other processes of curing and drying can be adopted, depending on consumer preferences and demand.

Marketing

The marketing arrangements will, of course, depend on the magnitude of the supplies. In the tambak area of Java, which is situated far away from trade and cultural centers, pedlars barter rice and other provisions in return for fish, prawns, shrimps, etc. When there are a large number of ponds in an area, it will be possible to organize cooperative marketing, and thus reduce overhead expenses, such as transport, and to ensure that catches are sold in a more satisfactory condition.

Economics

In assessing the economics of brackishwater fish culture the fact that it generally is only a stage in the reclamation of waste lands for agriculture has to be taken into consideration. While no income may be available to the farmer during the period of reclamation, he is able to derive a substantial income by utilizing the area for fish culture and to produce food for himself and his family.

The construction of embankments, sluice gates, excavation of the pond site and the like, involve an initial outlay of considerable sums of money, depending on the cost of labor in the area, but a major part of this expenditure has to be incurred for reclamation, even if the land is not used for fish culture. When milkfish are cultured the fry have generally to be bought from dealers and this is a recurring expenditure. Fry of grey mullets, prawns and other species are usually available in the vicinity of the farms in areas where they are cultured, and can usually be easily collected. Artificial feeding and pond manuring is seldom done on a large scale. But when manure is applied it usually consists of the grass and mangrove leaves collected from the embankments or marginal areas. In view of this the total investment as such in brackishwater fish culture is very small. It should, however, be stressed that by investing a little more than is now done and intensifying the operations the income can be considerably increased, as has been shown in Taiwan.

One great advantage of brackishwater fish farming is that the farmer does not have to wait until the end of the year or for a couple of years to get some income. On the contrary, right from the stage of constructing the pond he will be able to get an income by selling mangrove stems for fuel, bark for tanning fishing nets and leather, birds eggs that may be collected from the area, lizard and snake skins and so on, depending on the enterprise of the farmer. The leaves of the nipa palm cut from the pond site will also fetch a good price. Once the farm has been constructed and fish culture operations begun, fishing for extraneous fishes and prawns is soon started. The embankments of brackishwater ponds are often suited for cultivating economically important plants. Besides preventing soil erosion and providing leaves for green manuring, some of these can be eaten and others sold. In the Sunderban area of West Bengal the fish farmers cultivate paddy in adjacent fields that have been reclaimed for the purpose. Salt making by sun drying is also undertaken when the conditions are suitable. Thus it is evident that a farmer with the necessary capital can have a number of profitable side lines on his land. Further, such farms give employment to more people. Industries such as metal box, net and implement factories, fish curers and canners benefit from the activities of fish farmers. Transport services also derive profits from the trade in fish. A certain amount of cooperation among the fish farmers in the matter of help in times of emergency and financial strain exists at present, but there is ample scope for the organization of the entire industry on sound cooperative lines.

In view of the peculiar conditions that exist it is often difficult to assess with any degree of accuracy the production from brackishwater ponds. On an average about 10 per cent of each farm consists of very shallow areas that do not contribute in any large measure to its productivity, and only about 73 per cent of the area is of direct significance in this respect. As already mentioned in a previous chapter, the production of fish in a pond will depend to a large extent on the type of soil. Schuster (1952) has given the following as the average production of milkfish in brackishwater ponds in Java.

Production of Ponds in Java

Soil type of ponds	Production in kg per ha
Juvenile volcanic soil	250 - 450
Colloidal clay	200 - 350
Juvenile lateritic soil	150 - 300
Calcareous clay	100 - 150
Senile lateritic soil	80 - 120
Rocky or sandy soil	50 - 80

The yield of prawns and shrimps varies from 25 to 80 kg and of other extraneous fishes, 16 to 35 kg per ha.

In the Philippines a production of 350 to 750 kg of milkfish is obtained when only one crop is raised. In Taiwan where the most intensive culture of milkfish is carried out the production is 1,000 to 2,000 kg per ha. In slightly brackishwater ponds in Hong Kong, an average of 1,500 kg of mullets and 1,000 kg of carps are produced per hectare of pond area.

The profit that a farmer can get out of brackishwater fish culture is dependent on so many factors that it is impossible to generalize on it. Based on the statistics collected on the operation of such ponds in Java, the following figures of receipts and expenditure have been compiled:

Receipts and Expenditure of Ponds in Java in Percent

Receipts (Percentage of total)		Expenditure (Percentage of total)	
Milkfish sold	70	Purchase of fry	5 - 20
Prawns sold	20	Maintenance of ponds	8 - 25
Extraneous fish sold	5	Miscellaneous	1 - 5
By-products sold	5	Land rent	3 - 7
		*Caretaker's share	25 - 35
		Owner's profit	58 - 8

---

* In Java, very often the pond owner does not himself culture fish but a "caretaker" does the work on a share basis.

Owners of brackishwater farms sometimes lease them out for short periods. This adversely affects the productivity of the ponds as the lessees are generally interested only in getting the maximum return in the period and do not pay sufficient attention to the maintenance of the farm and its installations. In Taiwan, where the ponds are small, a fish farmer and his family are usually able to operate one to two hectares of milkfish ponds. He may own the ponds, take them on lease from the landlord or work on the farms as an employee. Under conditions existing in Taiwan the financial gain from such ponds is quite considerable, in spite of the large amounts that have to be spent on fish poisons, fertilizers, artificial foods, etc. The following figures of receipts and expenditure relating to every hectare of pond area in the Kangshan Fish Culture Cooperative (1952) is of interest in this context.

Receipts and Expenditure of Ponds in Taiwan

Receipts in Taiwan dollars *		Expenditure in Taiwan dollars	
Sale of fish from the first crop (540 kg)	3,429	Stocking material (1,200 kg)	2,400
" " " " the second crop (780 kg)	4,680	Rice bran (3,000 kg)	1,800
Extraneous fishes and prawns (150 kg)	315	Peanut meal (720 kg)	612
		Tea seed meal (180 kg)	257
		Depreciation of nets and gear	118
		Repair and improvement work	240
Total:	8,424	Total:	5,427

---

* About 23 Taiwan dollars equal 1 U.S. dollar.

INDEX

This index is limited to references to specific fishes. The Table of Contents is considered adequate for topics of broad coverage.