Sources of O_2
(i) diffussion (ii) solubility (iii) Photosynthesis.

Jamal Kazam

ideal growth 25-32 °C
ideal: breeding 24-32 °C.

I
Basis of Aquaculture

PH →

7.5 - 8.5 PH of water Ideal

two sources of CO_2 (i) aspiration (ii) decomposition

If PH is acidic what will be happened?

If temp increase the solubility of the water will decrease and oxygen level decrease and water bubbles, if appear on surface algaea decomposition happened.

1.1 Scope and definition

The word 'aquaculture', though used rather widely for over a decade to denote all forms of culture of aquatic animals and plants in fresh, brackish and marine environments, is still used by many in a more restrictive sense. For some, it means aquatic culture other than fish farming or fish husbandry, whereas others understand it as aquatic farming other than mariculture. It is also sometimes used as a synonym for mariculture. However, the term aquaculture is sufficiently expressive and all-inclusive. It only needs a clarification that it does not include the culture of essentially terrestrial plants (as, for example, in hydroponics) or of basically terrestrial animals. However, when it needs to be used to denote (i) the type of culture techniques or systems (e.g. pond culture, raceway culture, cage culture, pen culture, raft culture), (ii) the type of organism cultured (e.g. fish culture or fish husbandry, oyster, mussel, shrimp or seaweed culture), (iii) the environment in which the culture is done (e.g. fresh water, brackish water, salt water or marine aquaculture or mariculture) or (iv) a specific character of the environment used for culture (e.g. cold-water or warm-water aquaculture; upland, low land, inland, coastal, estuarine), the use of restrictive terms would probably be more appropriate.

While aquaculture is generally considered a part of fisheries science, there is now a tendency to denote the distinction between the two by using the term 'fisheries and aquaculture', because of some of the basic differences in development and management.

1.2 Cultural and socio-economic basis

Man depended on hunting and gathering for subsistence until the neolithic period. Fishing developed as part of this basic subsistence activity, but has witnessed considerable technological advances in modern times in methods of capture and utilization of aquatic products. Fish production from the sea increased at a rapid rate with the expansion of fishing fleets, development of efficient methods of fishing and improvements in processing and transportation of catches. Although new fishery resources were discovered, intensive fishing efforts began to show their effects on the resource base, and the increase in production, particularly of the more valuable products, has steadily declined. Overfishing and depletion of stocks have become a living reality and the need to enhance or create new stocks by human intervention has begun to be recognized.

Over the years, human societies have adopted forms of cultivation, pastoralism and ranching that were expected to stabilize production and bring it under greater human control. For various reasons, this type of evolution in the basic forms of food production has been too slow to occur in respect of living aquatic resources. Agriculture and animal husbandry probably developed from a need to adopt more productive means to feed increasing populations. In the case of fishery resources, the need to increase production was sought to be met by discovering new resources and by adopting more efficient methods of hunting and utilization. Further, unlike in agriculture, common access rights prevailed for most of the resources. Conditions have, however, changed rather drastically in recent years. The methods so far widely adopted to obtain increased production are often proving to be counter-productive. Restrictions in access rights, brought about by the new laws of the sea, have affected the fishing industries of many nations. Increasing demands in foreign and domestic markets for some of the favoured species like shrimps, salmons, eels, sea basses and sea breams and their decline or lack of potential for expansion of natural production, have created a situation where adoption of methods of farming and ranching have become logical and inevitable. Since most forms of aquaculture can be undertaken within national jurisdiction, there are fewer chances of international conflicts relating to rights and ownership in culture fisheries, except possibly in ranching operations.

There are also other concurrent factors that have promoted enhanced attention to aquatic farming. One is the recognized need in many countries to achieve greater self-reliance in food production and greater balance of international trade. Saving or earning of foreign exchange has also become an inevitable need for economic development. Further, as will be discussed in Chapter 3, aquaculture has shown its potential to increase rural employment and improve the nutrition and income of rural populations, particularly in developing countries. The labour-intensive nature of certain types of farming and the opportunities for waste recycling and integration with crop and animal farming, have made development agencies consider aquatic farming as particularly appropriate to developing areas.

Aquatic farming is also of special significance in fish marketing strategies. Production can be organized according to market demand, in respect of quantity, preferred size, colour, preservation and processing, etc. In many markets there is a special demand for fresh or chilled fish and it may not be easy for the fishing industry to adequately satisfy such a demand. Harvesting from farms can be regulated to meet this demand and make available the product during off-seasons in order to maintain regular supplies. The species can be grown to the size most preferred by consumers, when size restrictions have to be observed in capture fisheries.

1.3 Biological and technological basis

The rationale of aquaculture is not limited merely to socio-economic and marketing advantages. There are also scientific principles that weigh very much in favour of aquatic farming of fish and shellfish. It is a relatively efficient means of producing animal protein and can compare very favourably with poultry, pork and beef in the economies of production, when appropriate species and techniques are adopted. Poikilothermic (cold-blooded) animals, especially fish, have relatively low energy requirements, except for metabolism and maintenance of body functions, as they use little energy for maintenance of body temperature and normal locomotion. Since their body weight is nearly the same as of the water they inhabit, loss of energy in supporting themselves and swimming is minimal. Little energy is used by cold-blooded animals for thermoregulation. These advantages result in higher growth rates and greater production per unit area, taking full benefit of the three-dimensional nature of water bodies. Filter-feeding sessile shellfish, such as oysters and mussels, spend very little energy in obtaining their food. Fish are highest on the comparative list in terms of gross body weight gain and high in terms of protein gain per unit of feed intake (Hastings and Dickie, 1972). When fed balanced diets under favourable environmental conditions, the feed conversion ratio (wet weight gain per unit of dry feed intake) has been found to be in the range 1:1 to 1:1.25. The protein efficiency ratio (weight gain per unit of protein intake) is either equal to or higher than that for poultry and higher than for swine, sheep and steers (Hastings and Dickie, 1972). Fish are able to utilize high levels of protein in the diet, whereas in poultry almost one-half of the amino acids are deaminated and lost for protein synthesis. A weanling pig may lose as much as two-thirds of the amino acids through deamination.

The absolute economics of a culture system depend very much on the species, production technology and market conditions. Basically, low trophic feeders can generally be raised at lower costs than those which are high in the food chain and which thus require a higher proportion of proteins, particularly animal proteins. However, the latter species usually fetch higher prices in the market place and compensate for the higher production costs. As will be discussed in Chapter 3, aquaculture offers the option to produce low- or high-cost products, and it is up to the farmer to decide which. However, it has to be remembered that many types of proteins that are not consumed by man can be upgraded through aquaculture to produce highly acceptable and well-relished products. Very often, waste products of capture fisheries and animal and crop farming form the main basis of aquaculture feeds. Also, much of present-day aquaculture is based on the natural fertility of soil and water, supplemented by organic or inorganic fertilizers and the plentiful energy of the sun.

In certain situations, the application of aquaculture technologies is an inevitable necessity and not a matter of choice. The case in point is of species or populations that have been decimated by overfishing or environmental perturbations. Culture techniques have to be used to prevent the extinction of species that are ecologically or economically important to the environment. The diminishing salmon stocks in river systems of countries in the northern hemisphere and their slow rehabilitation through environmental improvements and repopulation with hatchery-produced smolts are probably a good example of the role of fish propagation. Similarly, recreational fisheries and aquaria are largely dependent on the application of culture techniques.

Irrigation and hydropower development projects, as well as land reclamation, have seriously affected fishery resources in many areas. At the same time, some of these projects have resulted in the creation of vast reservoirs that require the development of new fishery resources to compensate for the losses incurred. The potential for the application of culture techniques in developing fishery resources has been clearly demonstrated in many countries such as the USSR (Volgogradskoya and Tzimljanskoye reservoirs), China (Taihu Lake), India (Damodar Valley Corporation and Mettur reservoirs) and the USA (TVA reservoirs).

1.4 Role in fishery management

The foregoing discussions have indicated the rationale for the increasing emphasis given to aquaculture in fishery development and management programmes. While the current emphasis would appear to be in enhancing the production of high-valued species for export, its benefits in overall fishery management are also being slowly recognized. Export-oriented farming has clearly been responsible for attracting investment from the private sector and for starting several supporting industries like feed and equipment manufacture. Because of its possible role in improving foreign trade, governments in many countries are now offering incentives, including financial support, for the aquaculture sector. Industry and scientific institutions are devoting attention to research and development for the handling, preservation and presentation of aquaculture products. Even though the enthusiasm is restricted to a small number of export products, the benefits of progress can certainly trickle down to the production of other species, as sooner or later the need for diversification will be recognized by most enterprises. Even now the newly established supporting industries can be of benefit to other types of aquaculture as well.

A major element in fishery management in many countries is to prevent any increase in, and possibly even reduce, fishing pressure in the intensively fished foreshore areas. Aquaculture would probably be the only means of maintaining the overall supplies, if fishing restrictions affect the landings. Sizeable increases in production can also be expected through aquaculture under favourable conditions.

Reduction in fishing pressure in developing countries often involves the displacement of large numbers of small-scale fishermen, who are unable to obtain a reasonable income, even when unrestricted fishing is allowed. Many of these fishermen and their families are reluctant to leave their traditional homes and change to professions unrelated to fisheries. Efforts are therefore made in some areas to assist these surplus fishermen to become aquafarmers. According to some social scientists, the fisherman, who is essentially a hunter, looks down with some contempt on those who adopt land- or coast-based production methods, devoid of the excitements of open-water hunting and the prestige that is believed to go with it. However, in many areas of the world there are large numbers of part-time fishermen farmers. Further, the origins of some of the present-day aquaculture systems, such as cage culture, are to be found in the fishermen's practice of holding live fish for marketing. That, in course of time, led to fattening before sale and then to techniques of rearing from fingerlings or fry stages. Numerous oyster farmers and some of the present-day cage-farmers of yellow tail, groupers and sea basses are former fishermen.

Conflicts can arise between capture and culture fishery sectors, but with appropriate planning these two activities can be harmonized to provide an integrated development policy and programme. For many years, extraction and reforestation have formed the basic elements in the management of forest resources which in many ways is the terrestrial analogue of fisheries, and there is no strong reason why such a development cannot be achieved in fishery management. Ways of harmonizing the two sectors will be discussed further in Chapter 4.

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2

History of Aquaculture and its Present State

Aquaculture

200BC. Vallicoltura coastal aquaculture

600BC → Australia.

300BC → India.

Despite the clear rationale for the adoption of farming as a natural evolution from hunting and gathering, the technological advances needed to achieve such a complete transformation of fishing to farming are enormous. Even though the contribution of culture to total fishery production is likely to increase steadily, and in certain cases exceed production from hunting, it is unlikely to reach the levels of human control comparable with crop and animal farming on the land, in the foreseeable future. However, what can be expected is an integrated or harmonized development of the two sectors, as in the enhancement and management of forest resources.

Large-scale aquatic farming is a relatively recent development, but small-scale aquatic farming existed in inland areas in some countries from ancient times, most likely from the time of evolution to pastoralism and land cultivation.

2.1 Origins and growth of aquaculture

Most publications on aquaculture refer to the long history of fish culture in Asia, ancient Egypt and in central Europe. The *Classic of Fish Culture* believed to have been written around 500 BC by Fan Lei, a Chinese politician-turned-fish-culturist, is considered proof that commercial fish culture existed in China in his time, as he cited his fish ponds as the source of his wealth! (Ling, 1977). Later writings of Chow Mit of the Sung Dynasty (*Kwei Sin Chak Shik* in 1243 AD) and of Heu (*A Complete Book of Agriculture* in 1639 AD) describe in some detail the collection of carp fry from rivers and in the latter publication, methods of rearing them in ponds. Even though stews or storage ponds for eels and other fish existed in Roman times and later in monastic houses in the Middle Ages, and a 2500 BC bas-relief of fish in Egypt is believed to be of tilapia raised in a pond, the earliest form of fish culture appears to be of the common carp (*Cyprinus carpio*), a native of China. It was introduced into several countries of Asia and the Far East by Chinese immigrants, and to Europe during the Middle Ages for culture in monastic ponds. From there it spread to many countries. From the 6th century AD the common carp lost its pre-eminence in China. This is said to have been due to the identity with the name of the Tang Dynasty Emperor 'Lee', which is also the name of the common carp in Chinese (Ling, 1977). Since the name of Emperor Lee was considered sacred, it was inconceivable that lee could be cultured and caught for eating. So they looked for other species of carp and that is how the culture of the so-called Chinese carps (grass, silver, bighead and mud carp) came into being. Irrespective of whether it is fact or fiction, this and probably also the practical problems of separating larvae of different species of carp caught from rivers gave rise to the celebrated system of polyculture. Until very recent times, carp culture in ponds remained the mainstay of aquaculture in China, but for the introduction of tilapia (*Tilapia mossambica*) from Vietnam and the development of simple methods of oyster cultivation in certain foreshore areas of the coast. However, a number of other fish have been added to the species combinations, with the expectation of increasing productivity in polyculture ponds.

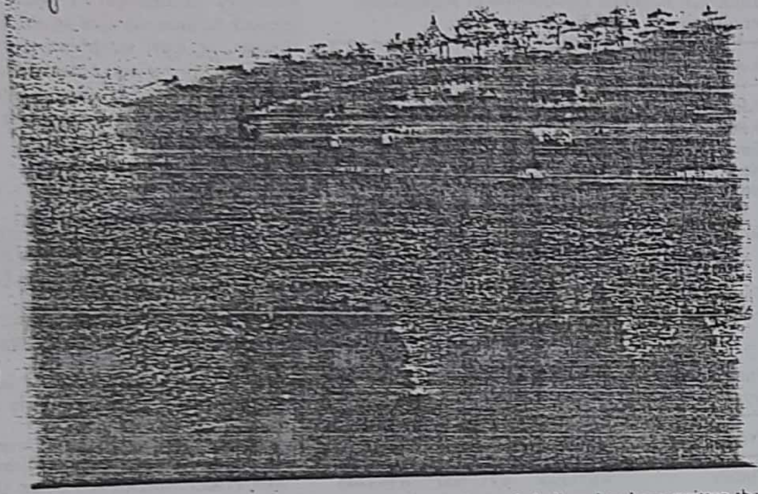

Fig. 2.1 Fan Lei Park in Wuxi, China, in memory of Fan Lei who is believed to have written there the *Classic of Fish Culture*.

While the Chinese immigrants were the focal points for most of the developments of fish farming in Southeast Asia, indigenous systems of Indian carp culture seem to have existed in eastern parts of the Indian subcontinent in the 11th century AD. Fish culture was practised in Indo-China for many centuries and the early systems of pen and cage culture of catfish appear to have indeed originated in Cambodia, present-day Kampuchea. Probably starting as a means of holding fish alive before marketing, flow-through culture from fry to market size with artificial feeding developed in the course of time. Variations of this system came to be practised in Indonesia for carps and in Thailand for the catfish *Pangasius*.

The earliest brackish-water farming in Southeast Asia appears to have originated in Indonesia in the island of Java during the 15th century AD. It is believed that the culture of the milkfish (*Chanos chanos*) and other brackish-water species in embanked coastal areas (tambaks) originated under the influence of the Hindu rule, and by the 18th century there were over 80 000 acres (32 389 ha) of ponds. The early tambaks are reported to have been constructed by convicts who were sent to the coastal areas to work on salt marshes and to guard the coastal fires.

As mentioned earlier, the history of aquaculture in Europe starts from the Middle Ages with the introduction of common carp culture in monastic ponds. Common carp attained a social and religious significance as the chosen food to be eaten on special occasions, as for example Christmas, in certain areas. However, there was also a certain amount of prejudice against it in some Western countries, particularly because of the lack of acceptance of its culinary properties, and it was considered a pest because its feeding habits gave rise to soil erosion and muddying of water, particularly water used for game fishing. Despite this, carp culture continued and flourished in almost all East European countries and from there it was introduced into the present-day Israel. In recent times, the polyculture of Chinese carp has also been adopted in many of these countries.

The propagation of trout, which has a fairly long history, originated in France and the monk Don Pinchot, who lived in the 14th century, is credited with the discovery of the method of artificial impregnation of trout eggs (Davis, 1956). Being a sport fish and of more widely accepted culinary properties, trout culture spread to almost all continents in the course of time. Even though early efforts were focused on repopulating natural water bodies for improving sport fishing, pond culture and other forms of intensive culture gradually developed to produce fish for the market. Commercial trout culture in fresh water on a fairly large scale developed in countries like France, Denmark, Japan and recently in Italy and Norway. During this period, the culture of the Atlantic salmon also became a commercial success and with the development of cage farming of salmon and trout in Norwegian fjords, salmonid culture achieved a remarkable boost in production and public attention.

The British introduced trout in their colonies in Asia and Africa, mainly to develop sport fisheries. The early development of fish culture in North America was centred on the propagation of salmon and trout, and to a lesser extent on the black bass. Starting in the 18th century, trout hatcheries were established in government stations mainly for release of fry into open waters, but in the course of time the private sector started commercial production of consumption fish. Slowly the practice of trout propagation for release in open waters or, more recently for farming, spread to the temperate and semi-temperate areas of Central and South America.

When tracing the history of fish culture, one has to take into account the rather ancient practice of breeding and rearing ornamental fish, such as goldfish by the Japanese and the Chinese. The spread of tilapia, a native of the African continent, to several countries in all parts of the world is a remarkable phenomenon. Even though there was resistance to its introduction in many countries and it was considered as a pest by some, its culture spread far and wide, especially in developing tropical countries. Tilapia culture was considered by many as an easy means of producing cheap proteins for the masses. Research and experimentation have in recent years found solutions to some of the problems of culturing tilapia, and commercial-level farming has developed in certain areas.

The oldest form of coastal aquaculture is probably oyster farming, and the Romans, Greeks and Japanese are believed to be the earliest oyster farmers. Oyster culture in intertidal stretches is said to have been practised in Japan around 2000 years ago. Aristotle mentions the cultivation of oysters in Greece and Pliny gives details of Roman oyster farming from 100 BC. The culture of other molluscs, like mussels and clams, which follow methods similar to oyster farming appear to have developed much later.

From a historical point of view, the only other culture system that needs mentioning is the large-scale farming of seaweeds, which is of relatively recent origin. The earliest text book of seaweed culture appears to have been published in Japan in 1952. After the Second World War, culture of edible seaweeds expanded and intensified considerably and spread to other countries like Korea, Taiwan and mainland China.

2.2 Present state of aquaculture

Although traditionally fish farming was part of rural life in certain areas, the present day aquaculture has a much greater significance in socio-economic development and natural resource management. Despite some temporary increases in a few areas, the total world capture fishery production appears to have plateaued around 70 to 75 million tons, with the production of preferred species remaining stationary or in some cases diminishing. The fraction of the total catch utilized for human consumption has increased from 58 to 70 per cent, due to increased demand and increased utilization through new or improved processing techniques and marketing of value-added products. The most optimistic estimates of total catch of conventional species from the wild are around 100 million tons, and any significant increase due to harvesting of new unconventional species for food is considered unrealistic due to problems of consumer acceptance, harvesting technology and costs.

If the hoped for 100 million tons catch is obtained, about 70 million tons can be expected to become available for human food at the current rate of utilization. Even if this can be increased, the maximum total catch used for human consumption cannot be expected to surpass 80 million tons. On the other hand, it is estimated that about 100 to 140 million tons of edible fishery products will be required to meet the demand of the projected world population by the year 2000. There is thus a deficit of approximately 20 to 60 million tons to be made up, and the only major means presently known for this is an accelerated development of aquaculture.

As indicated in Chapter 1, aquaculture has been historically a small-scale activity. Some spectacular successes have been achieved in large-scale commercial farming, but in the minds of many it is still a development for the future. It is true that aquaculture contributes probably not more than 15 per cent of what the capture fishery contributes on a global basis, despite the fact that in certain areas and sectors the volume of production and economic significance are much greater. Culture technologies are far from perfect and research efforts to develop and improve technologies are in the very early stages. The promotional efforts of dedicated institutions and individuals have created the recognition of its potentials and provided the climate suitable for testing theories and practices on a much larger scale than had been possible before. Being a new and emerging industry, there are bound to be more mistakes made than in established ones, for conceptual, technological or managerial reasons. But, as pointed out by Rosenthal and Murray (1986), 'under good management many of the aquaculture systems have surpassed all expectations of a decade ago'. If one prefers to take a negative approach, there are also systems, considered as real breakthroughs, which have failed to take off. It has also been demonstrated that aquaculture programmes have a relatively longer gestation period, in comparison with fishing or other forms of food production. Even when tested technologies are adopted, the construction of physical facilities (particularly pond farms), solution of site specific problems, the building up of the productivity of the system and, above all, attainment of skills by workers take considerable time. Lack of allowance for such time-lags has often resulted in the premature termination of many enterprises.

In a discussion of the worldwide state of aquaculture, individual successes and failures can serve only as indicators. The type of statistics that will be needed for an appraisal of the situation are unfortunately not available. In the absence of suitable mechanisms for the collection of aquaculture statistics in most countries, the Food and Agriculture Organization of the United Nations (FAO) has been making estimates of world production at frequent intervals, based largely on data provided by various governments. The estimates of total production were 5.0 million tons in 1973, 6.1 million tons in 1975, 8.7 million tons in 1980, over 10.5 million tons in 1983, about 10.6 million tons in 1985 and over 13.2 million tons in 1987. It is difficult to determine the accuracy of the estimates, as different types of computations have been used in certain countries, such as total production based on average yield per unit area, conversion of processed products to wet weight of harvests, isolation of harvests of cultivated species from total landings in large water bodies containing resident species, etc. It is also likely that the productions from many small-scale farming operations have been overlooked, as government institutions may have had no records of them and their harvests may not reach major markets. The possibility of some of the increases in estimates being due to better coverage also cannot be ruled out. Nevertheless, the available figures clearly show the main trends in production and demonstrate convincingly that aquaculture is a growth industry, indicating that some of the forecasts of future production may not be unattainable. It is believed that a production of over 26 million tons by the turn of the century can be achieved if the observed rate of increase is maintained and the necessary technical, financial and policy supports become available.

The regional distribution and composition of world aquaculture production for 1983, 1985 and 1987 are given in Tables 2.1 and 2.2 respectively. Asia is the largest aquaculture producer, followed by Europe. The rates of increase in production in North America and in Africa are remarkably higher, although their overall contributions still remain rather small. Available data for South America do not seem to permit any justifiable conclusions on development trends in the region. Analysis of the composition of production figures shows that major increases are due to expansion of finfish and crustacean culture, for which there is more widespread consumer demand.

Extensive, semi-intensive and intensive systems of production are adopted according to local conditions. Extensive systems are characterized by low inputs, maximum use of natural processes for the production of food, low density of stock and low harvest per unit of area under culture. In countries having large-scale operations, a gradual evolution towards semi-intensive and intensive systems can be observed. This involves higher stock densities, hatchery production of seed where feasible, greater human control of environmental conditions, at least supplementary feeding, and higher yields per unit area. Social and economic changes seem to require the adoption of semi-intensive systems in many areas to make aquaculture a viable industry.

Table 2.1 Regional Distribution of Aquaculture Production (in million tons).

Region	1983	1985	1987
Africa	43 865	61 100	62 502
Asia	8 642 377	8 928 800	11 131 302
Europe	1 277 853	1 136 600	1 340 181
Near East			23 834
North America	316 203	392 600	449 993
South America	220 478	68 200	200 104
Total	10 500 776	10 587 300	13 207 916

Table 2.2 Composition of Aquaculture Production (in million tons).

Product	1983	1985	1987
Finfish	4 671 244	4 717 500	6 793 441
Molluscs*	3 301 948	2 798 600	2 672 394
Crustaceans†	133 800	265 700	574 906
Seaweeds	2 393 784	2 777 200	3 139 473
Others		28 300	27 702
Total	10 500 776	10 587 300	13 207 916

* (Oysters, mussels, etc.)
† (Shrimps, prawns, crayfish, etc.)

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4	19	Arooj Zia
5	25	Sidra Gill
6	30	Maham Ishfaq
7	36	Saima Mukhtar
8	7	Hiba Iqbal

Undertaking: I hereby undertake that dates mentioned above are correct and I will be personally responsible for any misstatement of discrepancy.

4

Selection of Sites for Aquaculture

i) area approachable
ii) avail water, canal, river, under
iii) physco chemical should be normal
iv) area free from predators, snake, Birds,
v) market should be available
vi) Transportation
vii) labour

The history of aquaculture projects all over the world has led to the conclusion that the right selection of sites is probably the most important factor that determines the feasibility of viable operations. Even though, after many years of painful efforts and of new technology, some farms on poor sites have been turned into productive units, there are many that have been abandoned after considerable investment of money and effort. So there is no gainsaying the basic importance of selecting suitable sites for successful aquaculture. At the same time it has to be recognized that compromises have often to be made, as ideal sites may not always be available, and conflicts of land and water use will have to be resolved. In many situations good, irrigated agricultural land may be the best site for pond farms for fish culture, but national priorities in cereal food production may make it unavailable for aquaculture, irrespective of economic or other advantages. On the other hand many countries, particularly in Asia, are now giving higher priority to aquaculture and farmers are utilizing rice fields increasingly for fish and shrimp culture.

Although site selection will generally be based on the species to be cultured and the technology to be employed, under certain circumstances the order may have to be reversed. If it is decided to bring under culture certain sites, the selection may be oriented to determining the species that can best be cultured there and the most suitable technologies to be used for that purpose, if indeed the site is primarily suited for aquaculture. Limitations in any of the three factors, namely site characteristics, species and appropriate technology, obviously restrict choice of the others. However, as mentioned earlier, in the large majority of cases the species to be cultured would have been determined in advance, based on market requirements and consumer preferences.

4.1 General considerations

Although many of the factors to be investigated in the selection of suitable sites will depend on the culture system to be adopted, there are some which affect all systems, such as agro-climatic conditions, access to markets, suitable communications, protection from natural disasters, availability of skilled and unskilled labour, public utilities, security, etc. (see Chapter 3). It may be possible to find solutions when these factors are unfavourable and present problems, but it would involve increased investment and operating costs and would affect profitability. In the case of small-scale aquaculture, it is necessary to determine that the selected site has easy access to materials that cannot be produced on the farm and that the necessary extension services are available.

All available meteorological and hydrological information about the area (generally available from meteorological and irrigation authorities), such as range and mean monthly air temperature, rainfall, evaporation, sunshine, speed and direction of winds, floods, water table, etc., have to be examined to assess their suitability.

In land-based aquaculture, the most commonly used installations are pond farms and hatcheries. Since most such farms have earthen ponds, soil characteristics, the quality and quantity of available water and the ease of filling and drainage, especially by gravity, are basic considerations. For fresh-water pond farms, the land available consists mainly of swamps, unproductive agricultural land, valleys, stream and river beds exposed due to changes of water flow, etc. (figs 4.1–4.3). Land elevation and flood levels have to be ascertained. The maximum flood level in the last ten years or the highest astronomical tide (in the case of brackish-water sites) should not be higher than the normal height of the dikes that will be constructed for the farm. It will be advantageous to select land with slopes not steeper than 2 per cent. The area should be sufficiently extensive to allow future expansion and preferably of regular shape to facilitate farm design and construction.

The nature of the vegetation indicates the soil type and elevation of the water table. Obviously dense vegetation, particularly tall trees, make clearing more difficult and expensive. Land under grass or low shrubs is much better suited in this respect. However, in areas exposed to strong winds and cyclonic or similar weather conditions, sufficiently tall vegetative

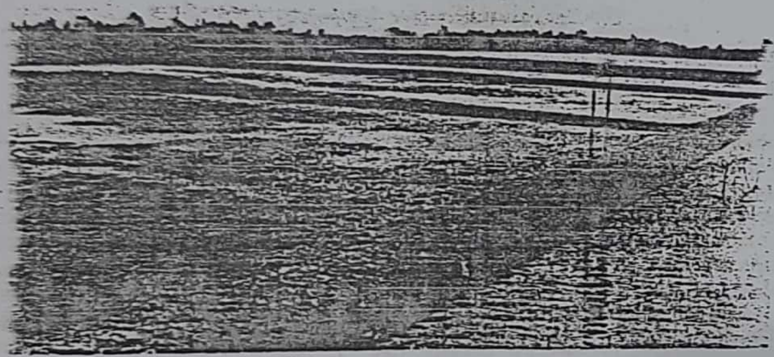

Fig. 4.1 A swampy area reclaimed into a fish farm in Indonesia.

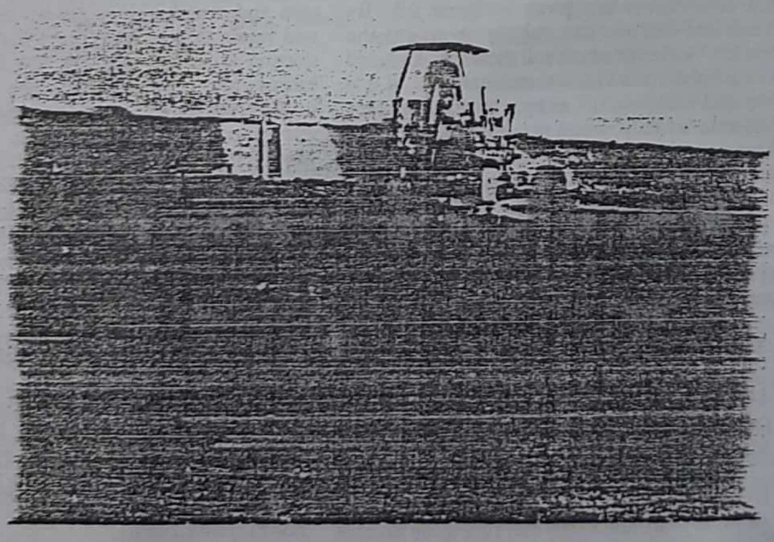

Fig. 4.2 A fish farm under construction in saline soil area, in Egypt.

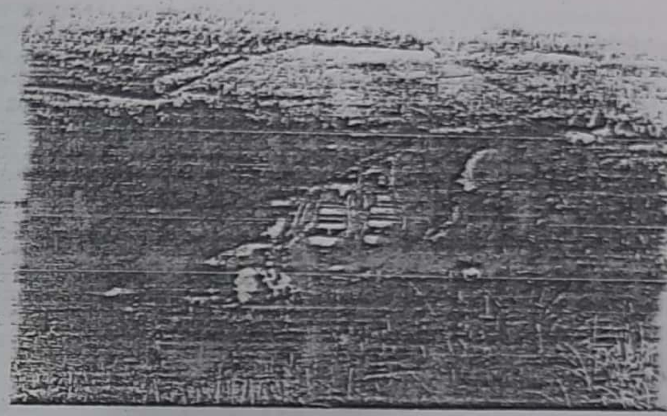

Fig. 4.3 A fish farm in a valley in Northern Cameroon.

cover around the farm can serve as effective wind breakers. High ground-water level may create problems in farm operation, as drainage will become difficult and expensive. The use of mechanical equipment for pond construction will also become inconvenient.

Among the other important general factors to be considered are the existing and future sources of pollution and the nature of pollutants. In this connection, information on development plans for the neighbourhood areas will be necessary. It will be useful to ascertain the past use of the site, if any. Croplands that have been treated for long periods with pesticides may have residues that are harmful to fish and shellfish. If the site is located adjacent to croplands that are sprayed from air or land, there is the risk of contamination occurring directly or through run-off water. Similarly, the possible effects of discharges from the pond farms into the waterways and irrigation systems in the neighbouring area should be considered. This can greatly influence the attitudes of the neighbourhood communities to the proposed farming and hence their future cooperation.

When a hatchery is planned in connection with a pond-rearing facility, the selection of its site depends on the location of the nursery and rearing ponds. The more important consideration is the unrestricted availability of good quality water, such as from springs, tube wells, reservoirs, etc. If earthen nursery ponds are to be constructed alongside the hatcheries, it is necessary to ensure the quality of the soil for pond construction and pond management. In many modern hatcheries, fry rearing is mostly done in tanks and troughs, with as much control over ambient conditions as possible. So the main consideration is the availability of essential utilities like electricity. The situation is very similar for the selection of sites for raceway farms. When the raceways are made of cement concrete the main consideration is the availability of adequate quantities of good quality water and essential utilities.

The choice of sites for integrated aquaculture – such as fish culture combined with crop and livestock farming – is governed by factors other than their mere suitability for aquaculture. Land available for integrated aquaculture is generally agricultural land, even if it is somewhat less productive. A satisfactory irrigation system is likely to have been developed for agriculture, in which case water and soil management can be expected to be easier.

Since integrated farming is based on the recycling and utilization of farm wastes, problems of pollution can be expected to be minimal.

4.2 Land-based farms

Sites generally available for coastal pond farms are tidal and intertidal mud flats in protected areas near river estuaries, bays, creeks, lagoons and salt marshes including mangrove swamps. The traditional and, in many cases, the most economical method of water management for a coastal farm is through tidal flow and so one of the essential pieces of information is the tidal amplitude and its fluctuations at the site. The tidal range along the shore line may be more easily obtained from tide tables or other sources, but in estuaries and other water bodies away from the coast the figures will be different: the mean tidal level generally becomes higher, the duration of the ebb tide becomes longer and the flood tide shorter. The diurnal tidal range, that is the differences in height between the mean higher high and the mean lower low waters, becomes less. In order to determine the relation between tidal levels and ground elevation at the proposed coastal farm site, tide measurements will have to be made on the site with a tide gauge or tide staff over a period of time. The relationship of tides between the nearest port and the tide gauge placed at the site has to be determined first for this purpose. The tide curves and other necessary tidal data at the site can be calculated from the highest astronomical tide (HAT), mean high water springs (MHWS), mean high water neaps (MHWN), mean low water neaps (MLWN) and mean low water springs (MLWS).

The construction of ponds in areas reached only by the high spring tides would require excavation, leading to high construction costs and problems in disposal of the excess soil. If the dikes are made higher than necessary to deposit excess earth, the productive water area in the farm will be reduced. Excavation may also affect efficient drainage using tidal energy. Further, the removal of fertile top soil, which is important to induce the growth and maintenance of benthic food organisms in coastal ponds, will result in the loss of much time in reconditioning the pond bottom to stimulate such growths. However, in certain mangrove areas, particularly those under the red mangrove *Rhizophora*, the top layer may contain peat or a very dense mass consisting of rootlets of mangroves, which in any case will have to be excavated to make the pond bottom productive.

The selection of suitable sites, based on tidal fluctuations and elevation, is shown in fig. 4.4. A tidal fluctuation of around 3 m is considered ideal for coastal ponds. However, it has to be remembered that if the tidal energy can be replaced by other forms of energy for water management, the limitations indicated would not apply. As mentioned earlier, the main consideration then would be the cost involved and the economics of operation. Gedrey *et al.* (1984) estimate that the construction and operation of a farm with a pumped water supply system can be more economical than that of a tidal water farm.

4.2.1 Soil characteristics

The quality of soil is important in pond farms, not only because of its influence on productivity and quality of the overlying water, but also because of its suitability for dike construction. The ability of the pond to retain the required water level is also greatly affected by the characteristics of the soil. It is therefore essential to carry out appropriate soil investigations when selecting sites for pond farms. Such investigations may vary from simple visual and tactile inspection to detailed subsurface exploration and laboratory tests. Because of the importance of soil qualities, detailed investigations are advisable, particularly when large-scale farms are proposed. Sandy clay to clayey loam soils are considered suitable for pond construction. To determine the nature of the soil, it is necessary to examine the soil profile, and either test pits will have to be dug or soil samples collected by a soil auger at regular distances on the site. To obtain samples, rectangular pits (1.0–2.0 m deep, 0.8 m wide and 1.5 m long) are recommended. If available, a standard core sampler or soil auger of known capacity (e.g. 100 cm^3) can be used for collecting samples of soil from each soil horizon.

Texture and porosity are the two most important physical properties to be examined. Soil texture depends on the relative proportion of particles of sand, silt and clay. The size

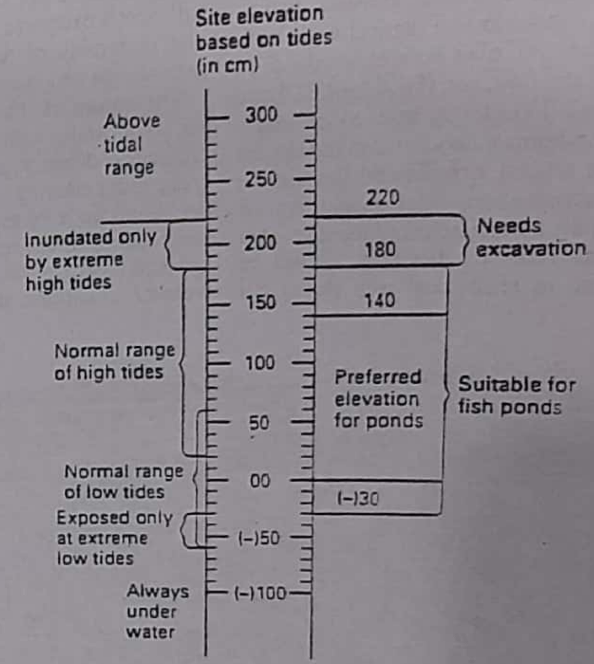

Fig. 4.4 An example of site selection based on tidal range and ground elevation.

limits and some general characteristics of the soil constituents are given in Table 4.1. By touch and feel one can roughly determine the texture. A sample of the soil should be kneaded in the hand (to make it somewhat drier, if it is wet and sticky; if the sample is dry add some water to make it moist but not sticky). If the kneaded sample can be rolled into a bar (about 6 mm thick) and bent to form a ring around the thumb, without any cracks, the soil must be clayey. If it cannot be made into a bar and remains separate with visible grains when dry, the sample is sandy. If the sample does not fall into either of these categories it can be classified as silty or loamy. Sand grains can be felt distinctly, even when not readily visible in loamy soils. Silty soils feel like flour or dough between the fingers. There are, of course, intermediate categories depending on the proportions of the constituents.

Because of their cohesive properties, the fine-textured soils (clay, silty clay, clay loam, silty clay loam and sandy clay) are more suitable for pond farms. They have a greater surface area and can therefore absorb more nutrients and retain and release them for organic production in ponds; they are also less subject to erosion and other damage. The soil structure or the arrangement of soil particles is of special importance in determining the compactness, and therefore the porosity, of the soil. Light-textured soils, particularly in close proximity to open drains can cause high seepage and percolation. Pond farms built on such soils may, however, improve in the course of time due to the blocking of interstitial pores by organic sediments produced in the pond, or introduced with the water supply or derived from manuring. Puddling is an efficient means of sealing ponds. In this process, fine particles clog the most permeable parts and in due course the bottom of the pond may be completely sealed. Compaction of soil by mechanical means during pond construction can also assist in reducing seepage. Suitable linings like polyethylene sheets have been used on pond

Table 4.1 Diameter and characteristics of soil constituents (size fractions).

Soil constituent	Diameter of particles	General characteristics
Sand	2.0–0.05 mm	Individual particles feel gritty when the soil is rubbed between the fingers. Not plastic or sticky when moist.
Silt	0.05–0.002 mm	Feels smooth and powdery when rubbed between the fingers. Not plastic or sticky when moist.
Clay	<0.002 mm	Feels smooth, sticky and plastic when moist. Forms very hard clods when dry. Particles may remain suspended in water for a very long period of time.

bottoms and water supply channels to prevent seepage with some success. But it is difficult to prevent damage to the lining and it often turns out to be too expensive for practical use. It may also greatly reduce the contribution of the pond bottom to natural productivity in the pond, even if the initial and continuing costs of the lining are acceptable.

Generally, the soil on sites selected for coastal pond farms is alluvial. It is usually porous with varying masses of fine roots of mangroves and other swamp vegetation. The preferred soils are clay, clayey loam, silty clay loam, silt loam and sandy clay loam. Sandy clay loam is the best for diking.

4.2.2 Acid sulphate soils

As mentioned earlier one of the major problems in site selection for coastal pond farms in the tropics is the prevalence of acid sulphate soils or cat-clays. Even though such soils are also found in fresh-water swamps, the problem is more pronounced in brackish-water areas. The highly acidic conditions inhibit the production of fish and fish food organisms. Elements, particularly iron and aluminium, are released into the water in toxic quantities which render phosphorus unavailable, causing severe phosphorus deficiency for algal growth. Sudden fish kills during rains after long dry periods are a common phenomenon due to leaching of extremely acidic water from surrounding dikes into ponds built on such soils.

Acid sulphate soil results from the formation of pyrite which is fixed and accumulated by the reduction of sulphate from salt water. The process involves bacterial reduction of sulphate to sulphide, partial oxidation of sulphide to elemental sulphur followed by interaction between ferrous or ferric iron with sulphide and elemental sulphur. A sufficient supply of sulphate and iron; high concentrations of metabolizable organic matter; and sulphate-reducing bacteria (*Desulfovibrio desulfuricans* and *Desulfo maculatum*) in an anaerobic environment alternated with limited aeration, are the factors that give rise to sulphate soils.

In mangrove swamp areas, the most favourable conditions for pyrite formation exist in the zones between the mean high water and mean low water levels which have limited periodic aeration due to tidal fluctuation. There is less pyrite in the better drained parts of the marshes which are aerobic most of the time.

The reclamation of mangrove swamps for pond farms with drainage results in the exposure and oxidation of pyrite and causes acidic conditions. Ferrous iron (Fe_2) is released during atmospheric oxidation of pyrite under moist conditions at an optimum moisture content of 30–40 per cent. At low pH, oxidizing bacteria convert ferrous iron to ferric iron (Fe_3). It can remain in solution in appreciable amounts only at pH values in the range 3–3.5 and is a more effective oxidant for pyrite and elemental sulphur than free oxygen. At higher pH, almost all ferric iron is hydrolysed and precipitated as ferric hydroxide. Basic ferric sulphate is also formed during pyrite oxidation. Elemental

sulphur is oxidized to sulphuric acid by bacteria.

The most harmful effect of pyrite oxidation lies in the excessive amount of sulphuric acid produced, which if not neutralized by exchangeable bases creates strongly acid conditions. In selecting sites for pond farms, one has to take into account not only the existence of acid sulphate soils but also the potential for acid conditions to develop as a result of drainage after construction. The levels of pyrite and acid-neutralizing components such as calcium carbonate from mineral deposits and metal cations have to be considered. The use of combined criteria, as for example sedimentary relationships and sulphur sources, land form, vegetation and soil characteristics, has been suggested as a basic approach for recognition and prediction of potential and actual acid sulphate soils. Although it is desirable to have both field and laboratory investigations, it is considered possible to use with confidence certain simple criteria. Potential and existing acid sulphate soils are generally found in mangrove swamps and marshy back swamps, on the seaward side of river deltas and on marine and estuarine plains (Figure 4.5). Tidal brackish-water vegetation with dense rooting systems are usually related to accumulation of pyrite. Association with the red mangrove (*Rhizophora*), *Nipa* and *Melaleuca* stands is a fair indication of potential acid soils. Soils that are likely to become acidic have a high organic matter content, such as the fibrous roots of mangroves, and a grey subsoil with dark grey to black specks or mottles with partially decomposed matter.

The detection of actual sulphate soils is easy. They can be recognized by the pale yellow mottles of the top soil, overlying pyritic subsoil. The older acid sulphate soil shows the red-brown ferric hydroxide. Their pH is generally below 4. A comparatively easy method of estimating the extent of acid and non-acid soil layers is by implanting stakes coated with red-lead paint in the soil profile. Hydrogen sulphide generated in the layer with active sulphate reduction turns the red-lead marking black within about a week, leaving on the stake a record of the upper limit of the present sulphide accumulation.

As will be described later in Chapter 6 on construction and maintenance of pond farms, it is possible to minimize the harmful effects of acid soils, but it is time-consuming and expensive. However, in many tropical areas, the available sites for pond farms may almost all have such poor soils and there may be little choice. In such cases sites that can more readily be reclaimed should be selected. Basically, reclaiming consists of removing the source of acidity by oxidizing the pyrite from the pond bottom and flushing it out of the 10–15 cm

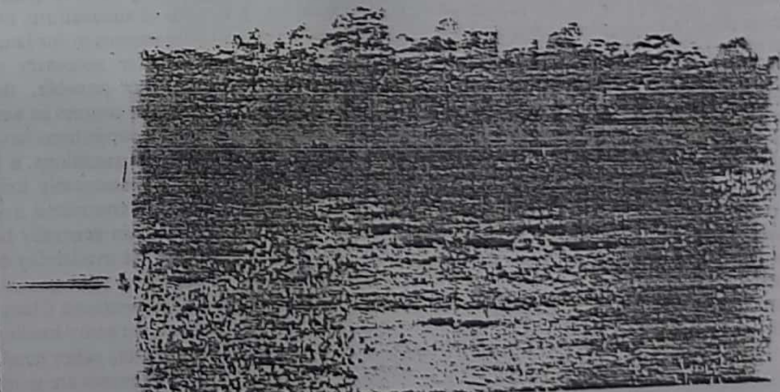

Fig. 4.5 Back-swamps with secondary growth of mangroves – potential sites for aquafarms (photograph: H.R. Rabanal).

deep surface soil and preventing further diffusion of acids, aluminium salts and ferrous salts from the subsoil. Acid and toxic elements are also leached and removed. If this is feasible, the farm can be made suitable for aquaculture within a period ranging from 3 to 5 years, depending on the extent of the problem.

4.3 Open-water farms

Open-water aquaculture includes mollusc culture in shallow salt- and fresh-water areas, seaweed farming in coastal seas and pen and cage culture in sea and fresh-water bodies. As is obvious, in selecting sites for such systems of culture the main considerations are the hydrographic and climatic conditions. In spite of some limited success in extending certain types of aquaculture to deeper and more exposed coasts, the most suitable and preferred areas continue to be sheltered bays, estuaries, lagoons, straits, lakes and reservoirs, protected from strong winds and rough seas. While moderate currents and water flows are necessary to maintain water quality and removal of waste products from farm sites, frequent storms and turbulent seas will make it difficult to practise most types of aquaculture. Winds will directly affect culture installations above water, whereas waves affect both the submerged structures and the animals under culture. In most cases low current velocities are preferred.

In systems like the ones for bottom culture of molluscs, the nature of the sea or river bed is important. Suitable stable substrates are needed for the attachment of the animals. Most modern open-water culture is of the off-bottom type, where the water conditions and quality are more important.

Since mollusc culture is based largely on natural food organisms that the molluscs filter from the environment, it is essential to select sites with high primary production. Though some experimental work has been done on artificial feeding of certain molluscs, in commercial farming production is dependent on the growth of plankton or algae. In order to make natural food available to the animals the current velocity should not exceed 5 cm/s.

Even though controlled reproduction and hatchery production of seed are possible in mollusc farming, in many places aquaculturists depend on wild spat for culture. In such cases, it is advisable to select sites where there is an abundance of spat. A breeding population of the species nearby is, of course, necessary, but it does not necessarily follow that the spat will settle in the immediate neighbourhood. The larvae may be carried away by currents, so sufficient shelters and suitable current speeds are necessary to keep the larvae in the area. Field observations, supplemented by experimental spat setting, may be a necessary basis for a decision on site suitability.

In the farming of seaweed such as laver fertilizers are used to increase growth, but naturally fertile areas are still selected as in open-water situations fertilization can only be a complement to natural productivity. Movement of water prevents the increase of pH which can be caused by the consumption of carbon dioxide in seaweed-growing areas. Therefore it is necessary to select sites with an adequate current. A current of about 10–30 cm/s is considered suitable, depending on the content of nutrients in the water. Waters deficient in nutrients should have a current of 30 cm/s and those rich in nutrients about 10 cm/s. Since periodic exposure of leafy thalli is important for growth in some seaweeds, it is necessary to select a place with a tidal range of 1–1.5 m or more.

4.4 Water quantity and quality

The availability of water of appropriate quality is important for all systems of aquaculture, but the quantity is particularly important for land-based systems. It is therefore necessary to investigate, as thoroughly as possible, the extent and seasonality of water sources as well as liability to pollution. Since predictions have to be made of long-term water conditions, it is desirable to have data for a reasonably long period of time. In areas with controlled irrigation, reliability of supplies can generally be expected. This together with the availability of cheap electricity has made water management fairly easy for fish farmers in Southern China, in spite of dense stocks of fish and heavy loading of manures in pond farms. On the other hand, when rain-fed or ground-water ponds are used, as in Eastern India, water levels in the ponds become dangerously low due to seepage and

evaporation in summer months, when the ponds have generally the maximum biomass of fish. Access to other reliable sources of water, such as rivers, streams, lakes and reservoirs or even tube wells which can yield enough water are essential for the enterprise to succeed. Loss of water due to seepage and evaporation varies considerably. For example, the average loss in Europe is reported to be about 0.4–0.8 cm per day, whereas in tropical regions it may be as much as 2.5 cm per day. When ground water is the major source of water supply, the effect of pumping on the water table and possible land subsidence have to be considered.

The need to investigate the elevation and ranges of tides for coastal aquaculture has already been referred to. This is most important when tidal movements have to be depended on for filling and draining the ponds. The constant flushing of newly constructed ponds to leach out toxic elements from the soil has also been mentioned. It is believed that if pumping were to be used for water management, the costs of construction of dikes and sluice gates would be minimized and the ponds could be constructed and operated without disturbing the acid soils, allowing a non-acidic layer of sediment to deposit on the bottom. In the long run, this may be more economical, despite the increased energy costs. However, it will be necessary to make rough calculations of the comparative costs before finally selecting the site and deciding on the system of management to be adopted.

The temperature of the water will be an important criterion as to whether the species selected can be cultured on the site. Although in hatcheries and in systems with a recirculating water supply the temperature can be controlled, it is extremely difficult, if not impossible, to do so at affordable cost in large pond farms. Industrial waste heat can to a certain extent be used to raise temperature in aquaculture areas, but very often practical problems of quality of heated water or irregularity in availability limits their use, except in well controlled environments or where the animals can stand considerable variations in temperature.

Salinity and variations thereof are also important environmental factors which have to be taken into account. Some species have wide salinity tolerance limits and it has been noted that some fresh-water fish grow faster in slightly saline water and some brackish-water fish faster in fresh water. However, they still have their limits of tolerance. Even if they survive, their growth and reproduction may be affected. For example, the common carp (*Cyprinus carpio*) can grow well in salinities up to 5 ppt, but at 11.5 ppt the salinity becomes lethal. Similarly, the tiger shrimp (*Penaeus monodon*) can tolerate 0.2 to 40 ppt salinity, but grows well only between 10 and 25 ppt.

As will be discussed in Chapter 6, salinity and water temperature are important considerations in deciding on the sites for hatcheries. Not only do these require higher water quality but the levels of salinity and water temperature required for spawning and larval rearing may differ from those needed for grow-out to market size. This may make it sometimes necessary to select separate sites for hatcheries and grow-out farms for certain species.

High turbidity of water caused by suspended solids can affect productivity and fish life. It will decrease light penetration into the water and thus reduce primary production. This would naturally also affect secondary production. In certain cases, oxygen deficiency has also been reported as a result of a sudden increase in turbidity. The suspended solids may clog the filter-feeding apparatus and digestive organs of planktonic organisms. The gills of fish may be injured by turbid water. Although the effect will depend on the species and the nature of the suspended matter, pronounced effects are seen when the water contains about 4 per cent by volume of solids. The use of turbid water in hatcheries should be avoided, as it can greatly affect the hatching and rearing of larvae.

If it becomes necessary to select sites with highly turbid water, which the candidate species cannot tolerate, suitable methods of reducing turbidity have to be adopted. The use of settling tanks, different types of filters and repeated application of gypsum (200 kg per 1000 m^3 initially, followed if necessary by an additional application of 50 g per 1000 m^3) have been recommended. All these will involve higher capital or operational cost, but in cases where there are no alternatives the possibility of absorbing the costs will have to be examined in feasibility studies. Improvements in drainage from catchment areas, often the cause of high turbidity, may also be considered.

Among other water quality criteria of importance in site selection are acidity and alkalinity. The most suitable pH of water for aquaculture farms is considered to lie in the range 6.7–8.6 and values ~~above or~~ below this inhibit growth and production, although the extent of their effect will depend on the species concerned and environmental conditions such as the concentration of carbon dioxide or the presence of heavy metals like iron.

The prevalence of low pH in brackish-water areas and the problems of improving soil and water quality in farms built in such areas have been described earlier. Water of low pH is also common in fresh-water areas with soils low in calcium and rich in humic acids. Acid water with a pH range of 5.0–5.5 can be harmful to the eggs and fry of most fish and the adults of many. Acidity reduces the rate of decomposition of organic matter and inhibits nitrogen fixation, thereby affecting the overall productivity.

The most common method of correcting low pH is by liming to neutralize the acidity. The dose will depend on the pH value and the chemical composition of the water, especially the concentration of calcium bicarbonate [$Ca(HCO_3)_2$]. It also will depend on the type of lime applied. The relative quantities of quick lime (calcium oxide, CaO), slaked lime or agricultural lime (calcium hydroxide, $Ca(OH)_2$) and limestone (calcium carbonate, $CaCO_3$) required will be in proportions of 1:1.5:2 respectively. The actual dosage has to be determined by titrating the water to neutrality and calculating the equivalent amount of lime to be added. The additional costs involved will have to be taken into account before selecting sites with acid water.

High pH, indicating excessive alkalinity, can also be harmful. However, it should be noted that in productive water pH may reach higher values of 9 to 10 due to the uptake of carbon dioxide during photosynthesis in the daily pH cycle. This is why it will be better to take pH measurements before daybreak to determine their suitability for aquaculture. A pH level of 11 may be lethal to fish.

Toxic substances in water supplies can affect aquaculture, particularly in hatcheries. Liebmann (1960) summarizes the threshold levels of toxicity and maximum permissible concentration of toxic substances in indoor fish hatcheries, as shown in Table 4.2.

4.5 Sources of pollution and user conflicts

As indicated earlier, it is essential to investigate any existing or potential sources of pollution and the nature of pollutants that are likely to affect the water supply to the proposed farm. Thorough local enquiries will be needed, as the situation at the time of the site selection studies may not represent conditions at other times of the year. Therefore data for previous years should also be examined as far as possible. Certain types of organic and harmless wastes can be used to increase the productivity of aquaculture farms. The use of waste heat in temperate and cold climates has already been referred to. Sewage effluents and properly treated animal wastes can be used successfully to fertilize aquaculture farms in order to increase the growth of food organisms. However, it will be necessary to incorporate such uses at the design stage of waste disposal (in order to render the wastes readily usable for aquaculture purposes) as well as the aquafarm (to provide for controlled use of the waste material in the appropriate form and doses to enable its safe use). The likelihood of discharges from facilities used for intensive aquaculture polluting public water bodies and spreading communicable diseases from farmed stocks to wild stocks should also be considered. Though these can be prevented in well designed and managed farms, there is still the possibility of such arguments being used by neighbouring communities who are not very appreciative of the use of the selected site.

In open-water aquaculture, particularly cage and pen culture of fish and stick and raft culture of molluscs in lagoons, estuaries, bays, fjords, etc., there is a likelihood of the organic load from metabolic wastes of cultured organisms and unused feeds accumulating, sometimes giving rise to a high biological oxygen demand and accumulation of toxic gases. The pattern of water flow may also be altered. It will therefore be necessary to consider ways of preventing this and avoiding conflicts with other uses of the area, such as navigation, recreation and fishing.

Some of the major considerations in reclaiming mangrove swamps for aquaculture have been discussed earlier. From what is known of mangrove ecology and the effect of reclamation, it would appear that if properly planned, clearing of mangroves retaining a belt of at least 50 m along the coast ensures that their ecological functioning is unimpaired. It has been suggested that clearing of mangroves should be done without changing the general morphology of the area, leaving for every hectare of mangrove cleared at least three hectares untouched, for conservation purposes.

Conflicts may arise with agriculture, as for

Table 4.2 Threshold of toxicity and maximum permissible concentration of toxic substances in the water supply of indoor fish hatcheries.

Substance	Threshold concentration (mg/l)	Maximum permissible concentration (mg/l)
Ammonia	0.2–2.0	0.05
DDT	0.02–0.1	absent
Calcium bisulphate	30–60	
Calcium chloride	7000–12 000	
Potassium chloride	700–5200	
Potassium sulphate	800–1000	
Magnesium chloride	5000–15 000	20
Magnesium nitrate	10 000	15
Magnesium sulphate	30 000	50
Manganese (nitrate, chloride, sulphate)	75–200	5
Copper (compounds)	0.08–0.80	0.005
Sodium bicarbonate	5000	
Sodium carbonate	200–500	
Sodium chloride	7000–15 000	
Cadmium	3–20	0.003
Ozone	0.02	
Mercury	0.1–0.9	
Rotenone	0.01–0.012	absent
Sulphides	0.4–4.0	0.1
Hydrogen sulphide	1.0	0.1
Iron (compounds)	0.9–2.0	0.01
Phenol	6–17	0.0005
Formaldehyde	15–30	
Tannin	15	5
Paraquinone	0.1–10	
Chlorine	0.05–0.4	absent
Carbolineum	7	
Zinc (compounds)	0.1–2.0	0.005

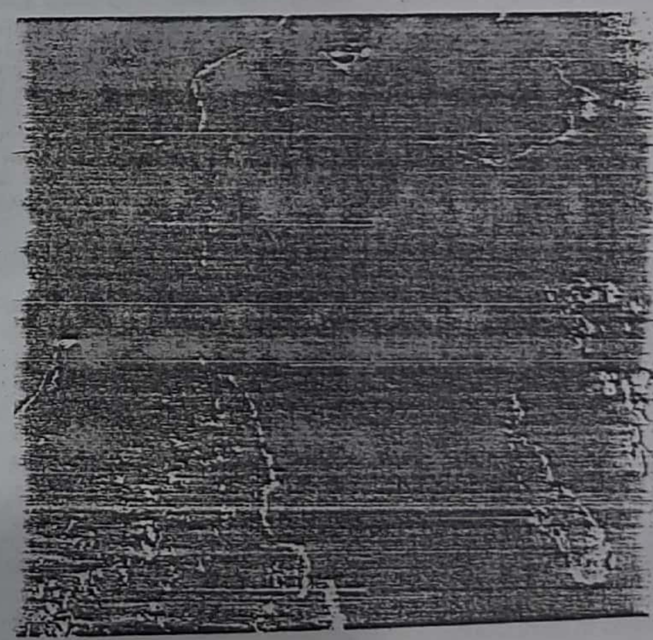

Fig. 4.6 Aerial view of a sheltered fjord used for cage culture in Norway.

example rice farming, in areas where for economic reasons rice fields may be converted into fish ponds. However, if national priorities require that they be used for rice cultivation, the possibility of integrated rice field aquaculture could be considered. In areas where crop/livestock/fish integrated farming is possible, conflicts with agriculture communities can be minimized by adopting such practices that will add to the income of the farmers.

With the expansion of aquaculture, many governments have brought in systems of licensing to regulate the enterprise. Where no such unified regulations exist, very often the prospective farmer has to obtain permits and clearances for his project from a number of agencies (see Chapter 3). Naturally these legal and administrative matters will also be major considerations in the selection of sites for aquaculture.

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5

Selection of Species for Culture

Jhingran and Gopalakrishnan (1974) include about 465 species, belonging to 28 families of plants and 107 families of animals, in a catalogue of cultivated aquatic organisms. It would probably be possible to culture almost all aquatic organisms, but the main consideration is whether it is worth the effort and how far they can contribute to the main objectives of aquaculture (see beginning of Chapter 3). The availability of a large number of aquaculture species adapted to different environmental conditions is an advantage, as it will often be possible to choose from locally occurring species and avoid the introduction of exotic ones for culture. However, this also means that aquaculture misses the advantages that crop and animal production have had in agriculture: of concentrated research on a few species that has led to the development of advanced technologies of production, and of selected high-yielding strains and hybrids. The history of agricultural research indicates the time and effort that are needed to develop such technologies. The science of aquaculture (as distinct from traditional practices), which is relatively new, will probably require a longer period of time to reach that level of advancement if efforts have to be shared among so many species. It has to be remembered that long traditional experience and scientific research, so far, have actually succeeded in domesticating, in the sense of animal husbandry practices, only a small number of species like the trout, common carp and salmon. However, one can clearly see a tendency towards limiting the number of species in large-scale commercial aquaculture, unlike in aquaculture research where an increasing number of species are still being investigated.

Despite the value of limiting species for culture for speedy technological advancement, it has to be recognized that there is a real need to have species suited for different environmental conditions and economic circumstances. Species have to be selected according to the objectives of culture, for example increasing protein supplies to the poor, export to earn foreign exchange or waste recycling in a polyculture system.

5.1 Biological characteristics of aquaculture species

A major characteristic that determines the suitability of a species for aquaculture is the rate of growth and production under culture conditions. Although certain slow-growing species may be candidates for culture because of their market value, it is often difficult to make their culture economical. Through the use of heated water growth rates of many species can be improved, but commercial growout using such methods has not yet proved very successful. In principle, a faster growth rate, as obtained in many tropical species, allows them to grow to marketable size in a shorter time, making it possible to have more frequent harvests. The size and age at first maturity is also an important consideration, as it will be preferable to have them reach marketable size before they attain first maturity, so that most of the feed and energy are used for somatic growth. Early maturity would ensure easier availability of breeders for hatchery operations, but early maturity before the species reaches marketable size will also be a great handicap, as in the case of tilapia species.

It is certainly preferable to culture a species that can be bred easily under captive conditions. This would permit hatchery production of seed in adequate quantities. If it is a species that matures more than once a year, it should be possible to have several crops of seed and possibly adults, if other conditions are suitable. High fecundity can be an advantage, as also frequency of spawning; however small-sized eggs and small larvae make hatching operations more difficult. A shorter incubation period and larval cycle often contribute to lower mortality of larvae and greater survival in hatcheries.

Larvae that would accept artificial feeds would be easier to rear in hatcheries. The raising of live foods is comparatively more difficult and often expensive.

In cases where controlled breeding techniques have not been perfected, the aquaculturist may have to depend on seed available from the wild. But as has been experienced in many situations, it proves to be an unreliable source in large-scale farming, as their abundance in nature depends on a number of unpredictable factors. Further, large-scale collection of wild spawn and fry has given rise to conflicts with commercial fishermen, who ascribe the decline in catches of the concerned species to the removal of early stages, despite the lack of any scientific evidence. So, even from a public relations point of view, it is better to select species that can be propagated in hatcheries and to start hatchery production as early as possible.

In modern aquaculture, feeding is one of the major elements of cost of production and may amount to 50 per cent or more. Nutritional requirements of aquaculture species are discussed in Chapter 7. In most traditional aquaculture practices, herbivorous or omnivorous species have been preferred as they feed on natural food organisms in water, the growth of which can be enhanced through fertilization and water management. In such cases, the cost of feeding will be relatively low and because of this, species low in the food chain are preferable for the production of low-priced products. However, even with such species, supplementary feeding with artificial feedstuffs has to be adopted in intensive culture systems. The feed efficiency in relation to growth and productivity then becomes an important criterion. Some of the low trophic level feeders can also be highly selective in their feeding habits, as in the case of filter-feeders that require plankton of a particular size and shape. The need to grow the species to market size within a limited season or period often makes it necessary to resort to artificial feeding.

Carnivorous species generally need a high protein diet and are therefore considered to be more expensive to produce, even though the costs will depend largely on local availability and price of the required feedstuffs. To compensate for feeding costs, most carnivorous species command higher market prices. Such species generally have greater export markets and therefore attract substantial investments.

Species that are hardy and can tolerate unfavourable conditions will have the advantage of better survival in relatively poor environmental conditions that may occur occasionally in culture situations. The temperature and oxygen concentration can fluctuate in ponds and other enclosures and deterioration of the water quality may occur unavoidably. In such situations, hardier species will obviously fare better. Besides the possible effects of poor water quality on the candidate species, it is also necessary to consider the influence of the species on the environment. Soil erosion that may be caused by the feeding habits of carp has been referred to in Chapter 2.1. Species that easily escape into natural bodies of water and upset their ecology would need special protective measures, leading to higher costs and environmental concern.

In intensive and semi-intensive culture, dense populations are confined in a limited space. In such cases, behaviour patterns of species in confinement are of special significance. Increases in transmission of disease, cannibalism in the early stages and accumulation of waste products are related to overcrowding. Species that have better resistance to such unfavourable conditions are better candidates for culture.

5.2 Economic and market considerations

Economic considerations are as important or even more important to an aquaculturist than biological factors in the selection of species to be cultured. Many of the relevant factors have already been referred to in Chapter 3 when discussing national priorities and investment requirements. The availability of proven technologies of culture, backed by economic viability, should guide an investor or an aquaculturist in the selection of a species or a culture system. Despite the scarcity of this type of information and the variability of economic returns of enterprises, it is of such crucial importance that even incomplete information from actual commercial or pilot operations would be useful in validating available experimental results.

Consumer acceptance and availability of markets for the species are very intimately interlinked with the economics of raising them. There are several instances where culture techniques were in existence for many years but never resulted in any large-scale production until new or improved markets developed, whether for domestic consumption or for export. Markets can, of course, be developed in places where none existed for a species, but this would require very considerable time and effort. Public and/or private organizations will have to undertake very intensive promotional activities to achieve this in a reasonable period of time.

The above considerations appear to be the main reasons for the widespread interest in introducing exotic species. The concerned species are generally those for which established culture technologies exist and the economics of production and marketability have been demonstrated.

5.3 Introduction of exotic species

The advantages of limiting the number of aquaculture species and the scarcity of really domesticated species for culture have been referred to at the beginning of this chapter. The economic and market considerations that create interest in the introduction of exotic species, have also been mentioned in the previous section. Considering the natural geographic ranges of distribution of proven species, there is a strong argument for introduction and transplantation of exotic species where necessary. However, the problem very often is how to decide whether it is necessary and, if so, what procedures and precautions should be taken to prevent possible undesirable consequences.

History reveals that several indiscriminate introductions and transplantations have been made in the past for establishing sport and commercial fisheries, for ornamental purposes and for biological control. Some of them have had detrimental effects on the local fauna and have contributed to the spread of communicable diseases. There is no gainsaying the need for preventing such consequences by following appropriate procedures and effective national regulations. However, expanding aquaculture may find it very difficult to avoid the introduction or transplantation of species, or selected strains of local species, for experimentation or commercial production. Munro (1986) lists some of the aquaculture species that have already colonized outside their historical distributional range: tilapia species, cyprinids (common carp, Chinese carps), rainbow trout, walking catfish, Japanese and European oysters and fresh-water crayfish (*Pacifastacus* sp.). The majority of them have been introduced for valid reasons, but it is most doubtful whether any of these or other successful introductions have been preceded by detailed screening procedures.

Turner (1949) suggested criteria to be considered in introducing new species. The species should

(a) fill a need, because of the absence of a similar desirable species in the locality of transplantation;
(b) not compete with valuable native species to the extent of contributing to their decline;
(c) not cross with native species and produce undesirable hybrids;
(d) not be accompanied by pests, parasites or diseases which might attack native species; and
(e) live and reproduce in equilibrium with its new environment.

The basic logic of these criteria is still valid and organizations such as the American Fisheries Society (Anonymous, 1973) and the International Council for the Exploration of the Sea (ICES, 1972 and 1979) have tried to strengthen the arguments for critical evaluation and propose methods of obtaining basic data for predicting the consequences of introductions. A close scrutiny of the rationale for introductions and the advantages and disadvantages of the candidate species has to be followed by a preliminary assessment of impacts before a decision is made to introduce the species for testing. If it is decided to proceed, thorough experimental studies should be carried out and results critically evaluated to make the final decision for general introduction or transplantation. ICES (1979) recommends the following procedures for the investigations:

(a) A brood stock should be established in an approved quarantine environment. The first progeny of the introduced species, not the original import, can be transplanted to the natural environment if no diseases or parasites become evident. The quarantine period will be used to provide an opportunity for the observation of disease and parasites. In fish, brood stock should be developed from stocks imported preferably as eggs or possibly juveniles, to allow sufficient time for observation in quarantine.
(b) All effluents from quarantine units are to be disinfected in an approved manner.
(c) A continued study should be made of the introduced species in its new environment.

While it is relatively less difficult to determine whether the imported stock brings in parasites or diseases, prediction of ecological effects based on controlled experiments has many limitations. It is therefore important that monitoring of the effects of introductions should be carried out on a long-term basis, in order to adopt necessary measures as early as possible.

5.4 Common aquaculture species

As mentioned at the beginning of this chapter, there are several species of finfish, shellfish and plants that are used in experimental or commercial aquaculture. But the bulk of present-day production is based on a smaller number of species. The more important of them, along with species for which appreciable progress has been made in developing culture technologies, are listed below. The list is not claimed to be exhaustive and is based on gross evaluations as it was found not feasible to use precise criteria. It does not include ornamental and bait fish, purely game fish or amphibians.

Family	Species	Common name
Finfish		
Acipenseridae	*Huso huso*	Beluga – sturgeon
	Acipenser ruthenus	Sterlet sturgeon
	Acipenser guldenstadti	Russian sturgeon
	Acipenser nudiventris	Thorn sturgeon
	Acipenser stellatus	Starred sturgeon, sevrjuga
	Acipenser baeri	Siberian sturgeon
	Acipenser transmontanus	White sturgeon
Chanidae	*Chanos chanos*	Milkfish
Channidae (= Ophicephalidae)	*Channa marulius*	Murrel, snakehead
	Channa punctatus	Murrel, snakehead
	Channa striatus	Murrel, snakehead
	Channa maculatus	Murrel, snakehead
	Channa micropeltes	Murrel, snakehead
Heterotidae	*Heterotis niloticus*	Heterotis
Salmonidae	*Salmo gairdneri*	Rainbow trout
	Salmo trutta	Brown trout
	Salvelinus fontinalis	Brook trout
	Salmo salar	Atlantic salmon

Family	Species	Common name
	Oncorhynchus gorbuscha	Pink salmon
	Oncorhynchus nerka	Sockeye salmon
	Oncorhynchus kisutch	Coho salmon
	Oncorhynchus keta	Chum salmon, dog salmon
	Oncorhynchus tschawytscha	Chinook salmon
Plecoglossidae	*Plecoglossus altivelis*	Ayu
Coregonidae	*Coregonus albula*	Lake whitefish
	Coregonus lavaretus	Common whitefish
Anguillidae	*Anguilla anguilla*	European eel
	Anguilla japonicus	Japanese eel
Characidae	*Colossoma brachypomus*	Pirapitinga
	Colossoma macropomum	Tambaqui
	Colossoma mitrei	Pacu
Cyprinidae	*Aristichthys nobilis*	Bighead
	Catla catla	Catla
	Cirrhina mrigala	Mrigal
	Ctenopharyngodon idella	Grass carp
	Cyprinus carpio	Common carp
	Hypophthalmichthys molitrix	Silver carp
	Labeo rohita	Rohu
	Labeo calbasu	Calbasu
	Mylopharyngodon piceus	Black carp
	Osteochilus hasselti	Nilem
	Puntius gonionotus	Tawes
Siluridae	*Silurus glanis*	Wels
Ictaluridae	*Ictalurus punctatus*	Channel catfish
Claridae	*Clarias batrachus*	Catfish, Asian
	Clarias lazera, gariepinus	African catfish
	Clarias macrocephalus	Catfish, Asian
Pangasidae	*Pangasius larnaudi*	Catfish
	Pangasius pangasius	Catfish
	Pangasius sutchi	Catfish
Scophthalmidae	*Scophthalmus maximus*	Turbot
Helostomidae	*Helostoma temmincki*	Kissing gourami
Osphronemidae	*Osphronemus goramy*	Gourami
	Trichogaster pectoralis	Siamese gourami, sepat siam
Mugilidae	*Mugil brasiliensis*	Grey mullet
	Mugil curema	Grey mullet
	Mugil capito	Grey mullet
	Mugil auratus	Grey mullet
	Mugil saliens	Grey mullet
	Mugil chelo	Grey mullet
	Mugil grandisquamis	Grey mullet
	Mugil falcipinnis	Grey mullet
	Mugil cephalus	Grey mullet
	Mugil parsia (dussumieri)	Grey mullet
	Mugil tade	Grey mullet
	Mugil macrolepis	Grey mullet
	Rhinomugil corsula	Freshwater mullet

Family	Species	Common name
Carangidae	*Seriola quinqueradiata*	Yellowtail
	Trachinotus carolinus	Pompano, Florida pompano
	Trachinotus falcatus	Atlantic permit
	Trachinotus goodei	Permit
Esocidae	*Esox lucius*	Pike
	Lucioperca lucioperca	Pike perch
Siganidae (= Teuthidae)	*Siganus canaliculatus* (= *oramin*)	Rabbit fish
	Siganus rivulatus	Rabbit fish
	Siganus lurida	Rabbit fish
	Siganus vermiculatus	Rabbit fish
Centropomidae	*Lates calcarifer*	Sea-bass, Asian sea-bass
Serranidae	*Dicentrarchus labrax*	Sea-bass, Mediterranean sea-bass
	Epinephelus tauvina	Estuarine grouper, greasy grouper
	Epinephelus akaara	Red grouper
	Morone saxatilis	Striped bass
Sparidae	*Pagrus major*	Red porgy, Red sea-bream
	Sparus aurata	Gilthead sea-bream
Cichlidae	*Tilapia andersonii*	Tilapia
	Tilapia aurea	Tilapia
	Tilapia hornorum	Tilapia
	Tilapia melanotheron	Tilapia
	Tilapia mossambica	Tilapia
	Tilapia nilotica	Tilapia
	Tilapia spilurus	Tilapia
	Tilapia rendalli	Tilapia
	Tilapia zillii	Tilapia
Tetraodontidae	*Fugu rubripes*	Pufferfish
	Fugu vermicularis	Pufferfish
Crustaceans		
Penaeidae	*Penaeus aztacus*	Brown shrimp
	Penaeus duorarum	Pink shrimp
	Penaeus indicus	Indian shrimp, white shrimp
	Penaeus japonicus	Kuruma shrimp
	Penaeus monodon	Tiger shrimp
	Penaeus orientalis (= *chinensis*)	Oriental shrimp
	Penaeus merguiensis	Banana shrimp
	Penaeus penicillatus	Red-tailed shrimp
	Penaeus kerathurus	Mediterranean shrimp, triple-grooved shrimp
	Penaeus schmitti	Southern white shrimp
	Penaeus semisulcatus	Green tiger shrimp, bear shrimp
	Penaeus notialis	Shrimp

Family	Species	Common name
	Penaeus setiferus	White shrimp, common shrimp
	Penaeus stylirostris	Blue shrimp
	Penaeus vannamei	White shrimp
	Metapenaeus monoceros	Shrimp
	Metapenaeus brevicornis	Shrimp
	Metapenaeus ensis	Shrimp
Palaemonidae	*Macrobrachium rosenbergii*	Giant freshwater prawn
Nephropsidae	*Homarus americanus*	American lobster
	Homarus gammarus	European lobster
Astacidae	*Astacus astacus*	European noble crayfish
	Procambarus clarkii	Red swamp crayfish
	Pacifastacus leniusculus	Signal crayfish, American crayfish
	Pacifastacus acutus	White river crayfish
	Oreonectes immunis	Paper-shell crayfish
	Cherax tenuimanus	Freshwater crayfish
	Cherax destructor	Freshwater crayfish
Scyllidae	*Scylla serrata*	Swimming crab
Portunidae	*Portunis trituberculatus*	Blue crab
	Neptunus pelagicus	Blue crab
	Paralithodes camchatica	King crab
Molluscs		
Arcidae	*Anadara granosa*	Blood cockle, blood clam
Mytilidae	*Mytilus edulis*	Mussel
	Mytilus galloprovincialis	Mussel
	Mytilus crassitesta	Black mussel
Aviculidae	*Perna perna*	Blue mussel
	Perna viridis	Green mussel
	Perna indica	Brown mussel
	Perna canaliculus	Green mussel
Ostreidae	*Crassostrea angulata*	Portuguese oyster
	Crassostrea rhizophora	Mangrove oyster
	Crassostrea iredalei	Slipper oyster
	Crassostrea tulipa	Mangrove oyster
	Crassostrea brasiliana	Mangrove oyster
	Crassostrea belcherii	Mangrove oyster
	Crassostrea virginica	American oyster
	Crassostrea plicatula	Chinese oyster
	Crassostrea rivularis	Chinese oyster
	Crassostrea gigas	Japanese oyster, Pacific oyster
	Crassostrea commercialis	Sydney rock oyster
	Crassostrea glomerata	Auckland rock oyster
	Ostrea edulis	Flat oyster, European oyster
	Ostrea chilensis	Chilean oyster

Family	Species	Common name
Pectenidae	*Patinopecten yessoensis*	Deepsea scallop, giant ezo scallop
	Argopecten irradians	Bay scallop
	Pectinopecten maximus	European king scallop
	Chlamys [illegible]	European tiger scallop
	Chlamys farreri	Chinese scallop
	Chlamys nobilis	Chinese scallop
Mercenaridae	*Mercenaria mercenaria*	Hard clam, quahog
Veneridae	*Meretrix meretrix*	Big clam
	Meretrix lusoria	Clam
	Tapes (= Ruditapes) philippinarum	Small-necked clam
	Venerupis japonica	Japanese little-neck, Manila clam
Haliotidae	*Haliotis discus hannai*	Abalone
	Haliotis rufescens	Red abalone
Aquatic plants/seaweeds		
Chlorophyceae	*Enteromorpha compressa*	Green algae
	Caulerpa racemosa	Green algae
	Monostroma sp.	Green algae
Laminariaceae	*Laminaria japonica*	Kombu, brown algae
Lessoniaceae	*Undaria pinnatifida*	Kelp, brown algae, wakame
	Undaria undarioides	Wakame
	Undaria peterseniana	Wakame
Bangiaceae	*Porphyra angusta*	Nori, red algae
	Porphyra haitanensis	Nori, red algae
	Porphyra kuniedai	Nori, red algae
	Porphyra tenera	Nori, red algae
	Porphyra pseudolinearis	Nori, red algae
	Porphyra yezoensis	Nori, red algae
Gelidiaceae	*Gelidium amansii*	–
Solieriaceae	*Eucheuma cottonii*	Red algae
	Eucheuma edule	Red algae
	Eucheuma muricatum (= spinosum)	Red algae
Gracilariaceae	*Gracilaria gigus*	Red algae
	Gracilaria confervoides	Red algae

5.5 References

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6
Design and Construction of Aquafarms

Some of the basic information required for designing an aquaculture farm would have been collected at the time of determining the feasibility of the project. However, further investigations will usually be needed for designing the most appropriate lay-out, construction methods and operation. The design of the farm and its construction are as important as the selection of the site in ensuring the success of the project, both technically and economically. As indicated earlier, the ideal sites may not always be available. Deficiencies of the site will in most cases have to be made up by suitable designs for construction and operation. Though engineering designs may be available to meet the requirements of aquaculture in almost any adverse conditions, the economics and practicality of using them for commercial aquaculture render them of little help. In fact, the designs normally used in water or irrigation engineering works cannot be used without very considerable modifications for aquaculture constructions, because of the costs involved. This applies especially to pond farms which account for a very good proportion of present-day aquaculture.

As pond farm design is so site-specific, one cannot conceive of a design that can be of universal use. However, some of the major design features can be defined on the basis of the site physiography, the source and nature of the water supply, type of stock enclosures to be used, organisms to be cultured and the techniques of management, including feeding or food production and harvesting methods. The detailed investigations mentioned earlier should be directed towards obtaining the basic information required to determine the appropriate design features.

6.1 Inland and coastal pond farms

6.1.1 Data for pond farm design

Since the majority of aquaculture installations at present are land-based pond farms, we may first consider the procedures for designing those. Despite the similarity of basic principles involved, it will be convenient to consider inland fresh-water pond farms and coastal brackish-water or salt-water pond farms separately, mainly because of the differences in operational details.

As already indicated, the investigations prior to farm design will depend on the extent of information collected during the preliminary feasibility studies. The meteorological data relating to mean monthly temperature, rainfall, evaporation, humidity, sunshine and wind speed and direction should already be available. A contour map (scale 1:25 000 to 1:50 000) of the area will be most useful in determining the catchment area of the site and its relative location. A soil or geological map, if available, would be useful in studying the subsoil at the site.

Detailed investigations may be necessary with regard to water sources, soil characteristics and topography of the site. Topographic maps, if available, are likely to be of a small scale, which would not allow all the relevant features to be reflected. Therefore a new or updated map will have to be prepared showing the nature of the ground relief and its characteristics, such as differences in elevation, location and measurements of boundaries or fences, physical facilities if any (such as buildings, roads, canals, bridges), etc. It will assist in determining the direction of water movement, location of water control structures and quantity of earthwork needed. There are a number of methods used for surveying the land, such as

(a) gridding,
(b) plane tabling,
(c) cross-section method with transverse survey,
(d) radiating lines method with transverse survey and
(e) tachymetry.

Among these, tachymetry is relatively rapid in field surveys and more versatile in that it can be used for surveying all types of areas. Methods like gridding and plane tabling are more suited for relatively flat land, and the others cited above are especially useful for hilly terrains (Kovary, 1984). For field surveying a temporary bench mark with a convenient datum should be established. The location of this bench mark should be marked on the contour map and all the elevations of embankments, canals, ponds, structures, buildings, etc. set out from it. The contour map, which should show any structures observed or measured on the land, should preferably be scaled at 1:1000 to 1:5000, with contour lines of 10–25 cm vertical spacing, so complete pond drainage can be designed and earthwork volume estimated with the required accuracy. If the proposed construction is an extension of an existing farm, the cross- and longitudinal-sections of the adjacent ponds, drains and channels should be obtained.

Soil quality

The soil characteristics of importance in site selection have been described in Chapter 4. Based on the results of feasibility investigations, the extent of further soil samplings required will have to be determined.

One or two sample stations to each 2 to 5 ha of site should be adequate if the soil conditions are uniform. If not, more sampling stations will be needed. The minimum depth of a bore hole for soil sampling is suggested to be 2 m below the deepest intended excavation of the project area. For the building of special structures, such as large water towers, greater depths of boring, commensurate with the size of the structures, will be needed. The soil tests should be to estimate

(a) seepage loss,
(b) under-seepage conditions and the hazard of piping failure,
(c) stability of dikes constructed with the soil,
(d) the degree of compaction needed,
(e) the permissible flow velocity in the earthen supply channels and
(f) the foundation requirements of the structures.

Soil on potential borrow sites within economical hauling distance should be studied to determine the nature of the soil available for building embankments. The embankments for the farm have to be built with cohesive soils that have adequate plasticity (generally designated by the plasticity index – a measure of the interaction between water and the cohesive plastic components present in the soil), as for example soil with a plasticity index above 15 per cent. Such soils should be checked for their susceptibility to long-term changes in permeability caused by atmospheric factors, such as the development of stable density or aggregation of particles. The losses that are likely to occur due to under-seepage and infiltration have to be determined using standard methods. To estimate long-term losses through seepage it is necessary to take into account the sediment content of the water supply, which along with decaying debris, pond wastes, algal growths, etc., would cause natural sealing or colmatation in the course of time.

While embankment stability can be determined by standard methods of soil mechanics, the assessment of the possible long-term performance of structures is more difficult. Due to their relatively small size and the practice of repeated draining and filling, there is the greater possibility of entire embankments of farms becoming desiccated, causing cracks to develop and entry of water into the embankment at times of rain or pond filling. The soil will then swell, but the extent of swelling at any particular point will depend not only on the swelling potential of the soil, but also the magnitude of the confining pressure by the surrounding, especially overlying, soil masses. Repeated drying and wetting, and therefore shrinking and swelling, will produce a stable density distribution, with higher densities in the interior of the cross-section. Szilvassy (1984) describes the adverse effects of drying and rewetting fish ponds. The cracks formed by drying facilitate the entrance of water into the body of the embankment. The crack faces are saturated and the moisture penetrates into the interior by capillary action. The saturated parts become almost impervious to air and the air in the pores comes under the combined pressure of the capillary action and the hydrostatic pressure of underwater parts. This pressure on the confined air leads to spalling and subsequent sudden liquefaction of unprotected slopes. If water flows through the cracks, the liquefying soil will be scoured at a faster rate, resulting in the development of gully or tunnel erosion, which is often the cause of failure of small embankments.

Besides careful exploration of the surface layer of the area where the ponds and water supply canals are planned, the soils along the canal traces should be investigated also for their hydraulic properties to estimate slope inclinations and the allowable (non-scouring) velocity of flow in the canal. The sequence of soil strata down to the first impervious layer should be determined as accurately as possible. If the soil is impervious at least to 0.6 m thickness below the designed deepest bottom level in the ponds or the drainage channels, no further exploration may be needed. In view of the difficulties in obtaining fully undisturbed soil samples for laboratory tests, field permeability studies are recommended in the vicinity of each exploratory borehole by the infiltration method.

The buildings and other structures on fish farm sites are generally small, and so the loads acting on the foundation are not likely to be large. In cases where these are to be built on newly filled sites, special care should be taken to avoid damage due to future soil subsidence. The standard sounding methods used by building engineers should be applied.

While there is no gainsaying the importance of careful soil studies in planning aquaculture farms, it has also to be remembered that laboratory tests for design values of soil strength are costly. Even when done, the engineer has to use his judgement to decide whether to use it for the type of constructions involved in a pond farm with low dikes and dams. Because of this, in countries like Hungary, aquaculture engineers use special practical guidelines based on local experience for the construction of dikes, levees and dams lower than 3 m in height and retaining less than 3 million m^3 water (Szilvassy, 1984).

Special features of soils on coastal sites, especially mangroves have already been discussed in Chapter 4. The presence of large quantities of organic matter in the soil, particularly mangrove roots, is a special problem to be reckoned with in pond design and construction in coastal areas. There is a growing body of opinion in favour of leaving the pond beds undisturbed without any excavation and, depending on the flocculation and settling of sediments brought in with tidal water, to build up a thick top layer on the bed to reduce acid soil problems. In that case, soil to build the embankments has to be obtained from outside the pond limits. If a mechanical means of construction is planned, the necessary cohesive soil should be available within reach of drag-line excavators or similar equipment, working from the embankment base. If manual means of construction is the choice, it may be possible to cut soil into blocks and transport them on rafts or flat-bottom boats at high tides to the pond site. Besides the comparative costs, the construction time has also to be taken into account in making decisions.

Water supply

The chemical properties of the water source for the farm and the sources of pollution, if any, would already have been studied during site selection. Very often, further information would be needed on the quantity of water required, at the design stage. For a fish pond with an average depth of 1.5 m the amount of water required to fill it initially is 15 000 m^3/ha. Loss through seepage and evaporation varies considerably between areas. In an arid climate, the average loss during the growing season could amount to 1–2 cm/day or more. With proper management, the total minimum quantity required for filling and topping under such a situation is estimated to be between 35 000 and 60 000 m^3/ha per year. The size of the farm should naturally depend on the quantity of water available during the period of operations. When the source of supplies is a stream, data will be needed on the stages and flow rates to be anticipated at the diversion point in the periods of pond filling and for compensation of water losses. It has been recommended that flow rates should be designed for 80 per cent probability.

In areas exposed to floods, data on design floods and discharges will be required. Water control agencies can generally provide values for probability of occurrence of the design flood, but in cases where such values are not available, it has been suggested that 1 per cent probability of occurrence (that is once in a hundred years) should be adopted as the design flood for the spillway of a dam. In the case of smaller dams with a design volume less than 1 million m^3 and of ponds with a water area less than 20 ha built farther away from human settlements, where the dike failure would not cause other losses, a flood of 3 per cent probability may be adopted as the design flood. The runoff of the water catchment area of the site should also be calculated to determine the capacity of the farm reservoir or ponds. Data on the peak values of monthly evaporation and rainfall are necessary to estimate water demand.

Estimates of the annual volume of sediment entering the ponds would be necessary to determine desilting requirements; or in cases where it is planned to build up a top layer of silt, to estimate the time it will take for it to be accomplished. Again, where the water turbidity is undesirably high and separate sedimentation tanks are required to reduce it, this information is essential. One of the problems in ponds filled from natural bodies of water is the entry of extraneous fish and other organisms in the egg or larval stages with the water, even when the inlets are protected by small-meshed screens. Filtration of such water to remove pests and predators is extremely difficult and expensive. In special circumstances, when considered essential, sand or other filters may be designed according to the size and quantity of sediments.

The use of waste water, including sewage effluents, to irrigate and increase productivity of ponds is an age-old practice and fish culture is used now in many places as an efficient means of recycling organic wastes. Reference has already been made to the use of heated water effluents from power stations in temperate and cold climates. The main problem with the use of wastes is the possible development of anoxia in ponds, due to excessive organic loading and contamination with toxicants and heavy metals. The risk of transmitting bacterial and viral pathogens through the use of domestic wastes has received some attention. It has been shown that under conditions existing in fish ponds, actual reduction of pathogens occurs. Due to high photosynthetic rates, such ponds have high dissolved oxygen contents and high pH values, which increase the rate of disinfection of coliforms. Investigations have not yet found evidence of the transmission of any human bacterial diseases through fish. Even though fish do not suffer from enterobacterial infections, the possibility still remains that fish can harbour bacteria in their alimentary tract, tissues and mucus and hence serve as passive vectors of pathogens. Experimental studies made on artificially infected fish have shown that by holding them in clean water for an adequate period of time they can be cleansed of pathogenic vibrios. Depuration is often practised in waste-water aquaculture. So, if the use of waste water is planned, necessary facilities will have to be included in the farm design. Similarly, possible measures should be adopted to avoid incorporation of toxic substances. This can best be done at source. Detergents are often difficult to exclude from domestic and municipal wastes, but at least their concentration should be kept under permissible limits. The lethal limits of detergent for common carp is reported to be 10 ppm ABS (alkylbenzene sulphonate), but even sublethal concentrations can affect their growth (Hepher and Pruginin, 1981). The short duration of the grow-out period in aquaculture reduces the risk of accumulation of heavy metals from waste water, unless the concentration is very high. Experience so far seems to show that even when there is some accumulation, it is generally within accepted standards for safe use.

Public attitudes to eating products grown in waste water, particularly sewage effluents, can be a problem and solutions have to be found on the basis of socio-cultural ambience and should include public education and product promotion. In modern aquaculture, only pre-treated wastes are used. In some cases, the use of wastes is avoided in the final grow-out stages and when there is possible exposure to waste water at that stage the product is depurated for an adequate period before marketing. These are some of the measures that could help in meeting consumer concerns.

Salinity and tidal flows in coastal farms

For designing coastal pond farms the most important data needed are the seasonal variations in salinity of the water available and access to fresh water to reduce salinity when required. When the ponds have to be filled using tidal energy, detailed studies are needed to determine the stage/duration/frequency relationship necessary for engineering designs. Continuous data for as long a period as possible from the site will be necessary to verify calculated values from available tide tables and observations during feasibility studies. For designing proper water management in tide-fed ponds, it is necessary to determine the ground elevation, which actually approximates the tidal levels of mean lower high water or of mean high water at neap tide. If possible, the measurements should be made when the lowest critical tides of the year occur (which can be found from the tide tables). Alternatively, the measurements should be taken during the lowest and highest tides of the month. The days with the lowest tides should be selected, and the O datum or mean lower low water (MLLW) noted. A fifteen-day observation during the dry season for the mean high water and another fifteen-day observation at the height of the rainy season for mean low water, are considered sufficient to ascertain whether the pond-system will be drainable during rainy season and whether the desired depth can be maintained. Measurements may best be done in front of the area where the main gate of the farm is likely to be constructed. On the tide gauge, which can be a measuring stake driven into the ground, the point at which the water level was lowest should be marked. The O datum level, correlated with the lowest water level, should also be marked. This will serve as the base line for determination of all elevations in the farm system. A bench mark can be established by running a level to a permanent marker near the site to be developed. The elevation of points within the area can be measured as reckoned from the datum plane. It is considered uneconomical to excavate more than 50 cm for pond construction. If this is needed it will be better to resort to pumping, rather than depend on tides for water supply and drainage.

Location of hatcheries and availability of other inputs

The essential data required for hatchery design would become available through some of the investigations mentioned earlier in this chapter. Decisions as to whether a hatchery, together with nursery facilities, should be established in the same farm complex or in a different locality have to be made on the basis of the site conditions, water quality requirements, ease of operation, security, etc. As mentioned in Chapter 4, in certain types of coastal aquaculture, as for example shrimp culture, the need for unpolluted high salinity water for hatchery operation may make it necessary to site hatchery installations nearer to the sea, rather than in the brackish-water areas where the grow-out ponds may be located. Similarly for the giant fresh-water prawn (*Macrobrachium rosenbergii*) which requires saline water for spawning and larval development, the hatchery may have to be situated away from the fresh-water pond farms used for grow-out. However, in some circumstances it may be more economical to transport the necessary salt water to the inland farm site rather than maintain two separate units. In the case of salmonid culture, especially of the trout, the low temperatures required for spawning, hatching and larval development may make it necessary to establish the hatchery at high elevations with cold water, and grow-out farms at lower elevations with higher temperatures for faster growth. Smolt production for salmon in fresh-water installations may have to be done in different locations and the smolt transported and acclimatized for salt-water culture or for sea ranching.

The other input production facility that may be considered for inclusion in the farm design is for feed. For this, as well as for processing of farm products, the main requirements to be investigated are suitable land for the necessary constructions, clean water supplies and electricity.

The availability of skilled and unskilled labour in the area is an important factor in deciding on construction which would require adequate maintenance and careful operations. In many developing countries, priority is given to aquaculture development because of its potential to generate employment, and so there is a definite preference for the use of manual labour in construction and day-to-day operations. At the same time, it will be necessary to achieve cost-effectiveness and profitability. So, it will be necessary to obtain comparative information on costs of construction and maintenance, using mechanical equipment against manual labour. Besides the actual costs, the time it takes to construct the farm and bring it under production by these two methods and its economic consequences should also be considered.

6.1.2 Design and construction of pond farms

Considering the fact that the construction of farm facilities forms the major capital investment in pond farms and the operational efficiency of the facilities will largely determine the success of the project, it is fully justified and necessary to devote adequate attention to their design and construction. As mentioned earlier, pond farm designs are site-specific and so it is difficult to detail all possible variations. The aquaculturist will have to work closely with the design engineer to arrive at an economically acceptable design that will meet the operational requirements of the species and the culture technologies. Planned construction is feasible in most projects, except when existing undrainable ponds, tanks or mining pits have to be used, as is the practice in some of the South Asian and South East Asian countries. Even then, there may often be the possibility of designing a proper farm, incorporating the existing water bodies for easier management.

Size and shape

The size of a farm has to be determined on the basis of a number of factors, including quantity of water and extent of land available, technology to be followed (e.g. extensive, semi-intensive or intensive farming), production and income required to make the enterprise economically viable, and access to markets, manpower and equipment.

Even though the design of the farm will depend on several factors, there are some basic principles which are generally followed. Whether a hatchery is incorporated in the farm or not, there is usually a series of nursery ponds for growing larvae to fry stage, another series of rearing ponds to rear fry to the fingerling or yearling stage and a final series of production or stock ponds. Many farms, particularly in tropical areas, may not have the transitional rearing ponds, and fry may directly be introduced into the stock or production ponds for grow-out to marketable size. In farms incorporating hatchery operations, there is a need for brood-stock ponds to rear selected brood-stock, and in some cases also spawning ponds. Depending on the harvesting system to be adopted, there may also be a need for market ponds for holding the harvests before marketing. Instead of earthen ponds, tanks or raceways may be used for fry rearing in certain types of culture, such as of salmonids and shrimps. Tanks for culture of fry can very well be incorporated in the design of a pond farm, particularly in conjunction with a hatchery. Details of tank and raceway design will be discussed in a later section. In temperate and cold climates, wintering ponds or indoor wintering facilities may be needed.

It is possible to use some of the ponds mentioned above for more than one purpose, depending on the seasonality of operations. Spawning ponds can often be used for fry nursing after suitable preparation, and sometimes also as market ponds. Properly designed rearing ponds can, after the fry season, be used as production ponds. Thus, economy can be effected in pond area and most of the ponds can be brought under operation for a major part of the year, if the farming technology permits it. Because of these possibilities, it will not be very meaningful to suggest a particular ratio between different types of ponds. The estimated number of fry required and the number of crops of fry that can be raised to meet the requirements of the farm will decide the total area to be assigned for nursery purposes. The production target of the farm, based on markets and technology, will decide the area to be set apart for production ponds. For small-scale fish culture in tropical areas based on quick-growing species, it has been suggested that each farm should have a multiple of twelve production ponds, so that each month an equal number of ponds can be drained or harvested, ensuring a regular supply of fish for sale each month of the year (Maar *et al.*, 1966).

The size of ponds would vary according to the intensity of culture operations, but ranges of 0.05–2.00 ha for nursery ponds and 0.25–10.00 ha for production or stock ponds have been suggested. Spawning ponds could be 0.01 ha. Smaller ponds would result in a larger area covered by embankments and water supply channels. In intensive culture systems, there is an obvious preference for smaller ponds, ranging in size from 1 to 5 ha as against 3 to 10 ha in extensive systems, as small ponds allow greater control. Larger ponds take longer to fill or drain, under given water conditions. This may mean, in certain situations, sizeable loss of production time. Similarly, moderate-sized ponds facilitate safe harvesting, as too much crowding in harvesting sumps and handling can result in fish loss. It has been suggested that the harvesting of a pond should not take more than a day. This again points to the need for less extensive production ponds. However, it costs more per unit area to construct smaller ponds, because of the cost of the additional embankments and water supply structures needed.

There appears to be a greater preference for rectangular-shaped ponds in fresh-water farms. This is mainly to facilitate harvesting with seines of manageable length or through draining to a sump using the regular slope of the pond bottom. The lengths of drainage and feeder canals required will also be less. From the point of view of cost of construction, square-shaped ponds are considered preferable, as the ratio of water area to the length of embankment will be higher, but if the slope of the site selected is high it may be necessary to construct rectangular ponds, to enable easy drainage. In cases where fish culture is combined with animal production or cultivation of vegetables, fruit trees, etc., as in southern China, the cost of construction of the main embankments would not be a major consideration, as the farmers need wide land areas near the ponds for animal or plant production. Many of the new farms there have square ponds, but others are rectangular in shape. Some East European countries, particularly Hungary, have tried different shapes of ponds, such as radial ponds, all of which drain into a central sump.

The layout of coastal pond farms is largely dependent on the farming procedures. Some of the typical layout designs will be described later, but there appears to be no special shape preference in newly designed ponds, though most of them are rectangular. The shape of the traditional farms largely follow the land contours and many of them have irregular shapes. In modern designs this is generally avoided and embankments are straight where possible.

Layout of farms

The conventional classification of fish pond design into barrage ponds, contour ponds and paddy ponds can still be used to describe the major types of pond layout. The barrage ponds are constructed in flat or gently sloping valleys, or abandoned river beds, by putting a low dam at a suitable site (fig. 6.1). The dam has to be built at the narrowest point to reduce construction costs. The sides of the ponds are formed by the slopes of the valley and a series of ponds can be built on the site. The source of water is a stream or river nearby. A spillway has to be built to avoid flooding of the ponds. A feeder canal from the stream will be necessary to regulate the water supply. Suitable drainage has to be provided to prevent flooding and consequent loss of stock and damage to the pond structures.

Contour ponds (fig. 6.2) are also generally located near a stream, canal, river or reservoir and in a valley, the bottom having a slightly sloping contour. The farm is situated on one side of the valley only and floods pass through the other side. A weir diverts the water for intake through a gate to a supply canal, from which each pond can be filled and drained separately. The dikes should be built to carry the design flood safely. Such a layout is possible

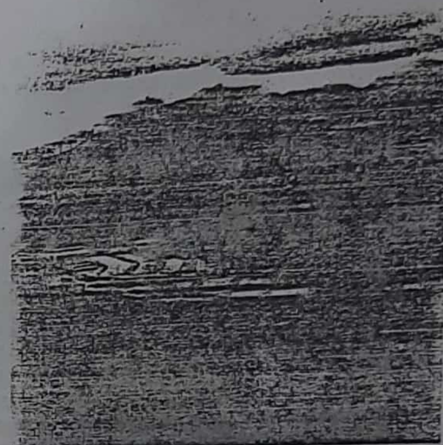

Fig. 6.1 A barrage type of pond farm.

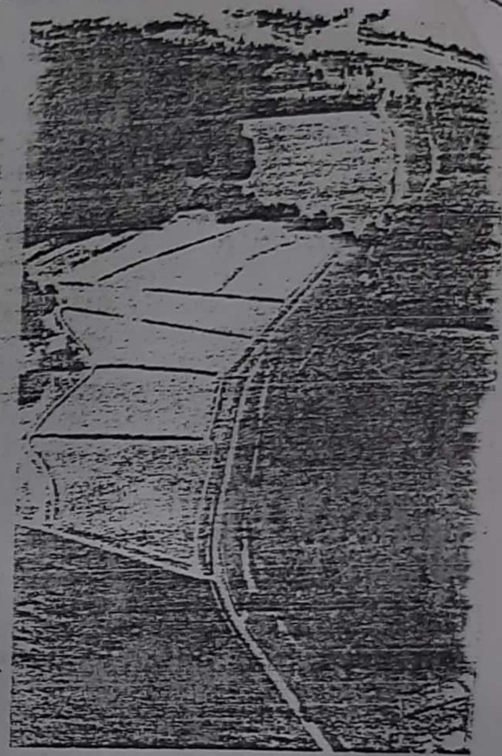

Fig. 6.2 A contour type of pond farm.

only in sufficiently wide valleys or river beds.

Paddy ponds (fig. 6.3) are constructed on relatively flat areas surrounded by a dike. Such sites make it possible to use much better layout designs, including separate supply and drainage channels, seepage and pond drains, harvesting sumps, etc. Most of the sites selected for carp, tilapia and catfish culture in fresh water and brackish water, or salt-water finfish and shrimps in coastal areas, would be suitable for this type of pond.

Dike design and construction

The most important constructions in a pond farm are the dike system and the water control

Fig. 6.3 A paddy type of pond farm (photograph: Y.A. Tang).

structures. The pond bottoms may or may not be excavated, depending on the topography and soil conditions, but the supply and drainage channels and harvesting pits have to be excavated.

As indicated earlier, the constructional details of the dike will depend upon the nature of the soil to be used, water depth required in the ponds, wave action and possible erosion, etc. Fig. 6.4 illustrates cross-sections of some typical dikes. Since cost-efficiency is the major consideration, it is necessary to determine the steepest slope inclination of the dikes that will ensure stability of the structure on a long-term basis. Where the soil conditions warrant it, the economics of lining the dike slopes with bricks, rip-rap, wood, etc. should be determined, taking into account long-term maintenance costs and the security provided. The freeboard has to be determined according to wave action and design flood levels. Table 6.1 lists the recommended side slopes, top width and freeboard of dikes (Kovari, 1984b). It is recommended that small ponds be located, if topography permits, with their long axis parallel to the prevailing winds, in order to provide maximum aeration. Large ponds may have the long axis at right angles to the prevailing winds, as the winds blowing over a long stretch of water may create higher waves and greater erosion of the dike. A minimum of 3 m top width will be required for embankments to be used by vehicles, but when heavy vehicles are to be used, the main embankments may have to be as wide as 6 m. Adjustments may be needed if the design includes a water supply channel on the crest of the dike. Secondary and tertiary dikes can be narrower and lower, according to the water depth in the enclosed ponds.

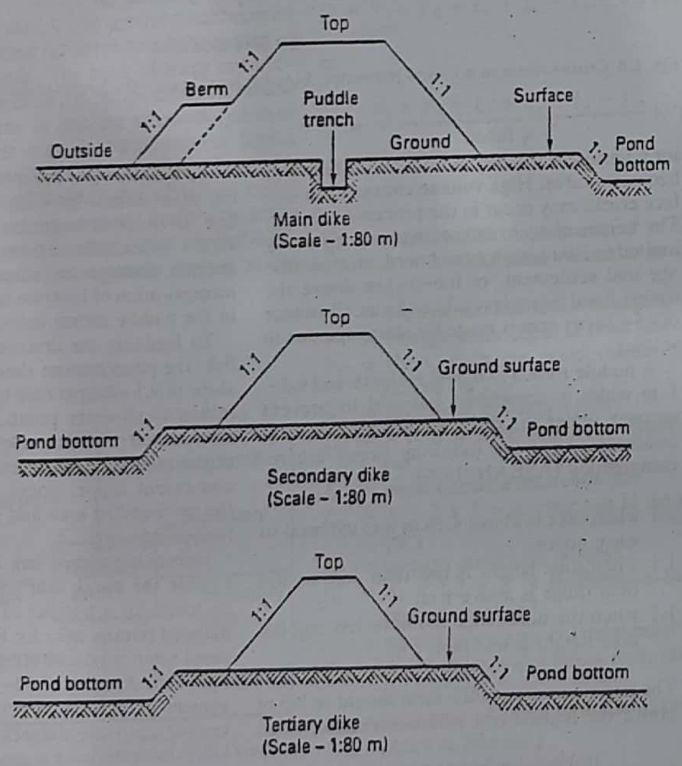

Fig. 6.4 Cross-sections of some typical types of dikes.

Table 6.1 Recommended side slopes and top width of pond dikes.

Type of soil	Inside slope	Outside slope	Water depth in the pond (m)	Top width of dike (m)	Freeboard (m)
Sandy loam	1:2–1:3	1:1.5–1:2	0.50	0.50	0.40
Sandy clay	1:1.5	1:1.5	0.50–0.80	0.50–1.00	0.40–0.50
Firm clay	1:1	1:1	0.80–1.20	1.50	0.50
With brick lining inside	1:1–1:1.5	1:1.5–1:2	1.20–2.00	2.00–2.50	0.50
With concrete lining inside	0.75–1:1	1:1.5–1:2	2.00–3.00	2.50–4.00	0.50–0.60

The depth of water to be maintained in a pond depends very much on the climatic conditions and culture practices. The recommended depth of trout ponds is 1 m at the intake, sloping to 1.5 or 2 m at the outflow. A depth of about 1 m is preferred in tropical and subtropical carp culture ponds. Beside minimizing wide fluctuations of water temperature, it assists in reducing the growth of rooted aquatic weeds which are a major problem in fertilized ponds, particularly in the tropics. However, shallower ponds will be preferable during the growing period in temperate climates, to make use of the higher water temperature for enhanced production. Because of these differences, wide variations occur in the depths and size of different types of ponds in culture systems. A range of average water depth of 0.4–1.5 m for nursery ponds and 0.8–3.0 m for production or stocking ponds have been recorded. In fresh-water fish culture, spawning ponds may have an average depth of 0.4–1 m and holding or market ponds 1.2–2.0 m. The water area of nursery ponds varys between 0.05 and 2 ha and of production or stocking ponds between 0.25 and 10.0 ha. Spawning ponds are smaller, ranging from 0.01 to 0.5 ha and holding or market ponds from 0.10 to 1.0 ha.

It is a common practice to provide an impervious core of soils of high cohesiveness, with shells of less cohesive soils on both sides or only on one side (fig. 6.5). The most important causes of deterioration of dike slopes are erosion due to wind and wave action and burrowing by aquatic animals and the feeding habits of fish like carp that rout around pond dikes. A proper grass cover is necessary to protect the exposed parts of the dike. Quick-growing and spreading varieties of grass are preferred. In East European ponds, a 4 m wide reed belt is recommended for larger stocking ponds (greater than 10 ha) to protect the sections of the dike exposed to wave action. In farms elsewhere, rip-rap placed in thicknesses of 0.25 to 0.5 m is preferred. In countries like China, blocks of concrete or bricks are used to line the slope. Lime stabilization has also been suggested as a means to improve soil compaction in dikes to resist erosive action.

The general principles of design and construction are very similar for fresh-water and coastal pond farms. However, the nature of the terrain and dependence on tidal water, as well as the practice of utilizing benthic algal pastures as food for the cultivated stock, necessitate some changes in the details of design and construction. The type of soil found in tidal areas selected for coastal farms has already been described (see Section 4.22, Acid Sulphate Soils). The construction of large embankments and heavy concrete structures on soft ground creates special problems. The fibrous or peaty top soil in mangrove areas (with roots sometimes constituting more than 50 per cent of the soil) is an additional problem. The need for, and methods of, easy drainage to leach out the acid contents of cat-clay soils have already been discussed. A system of open canals along the natural waterways will be required for this purpose. The canals should have a depth approximating the tidal level of the mean lower low water, in order to allow drainage of the maximum amount of percolated tidal flow over permeable stratum. Two to three years or more may be required to bring the pH value of acid soils to an acceptable level.

The depth of water in coastal fish ponds also varies as indicated earlier. Because of the need for easy drainage and constant changes of water in present culture practices, it is necessary to maintain lower depths of 30–60 cm. It is held

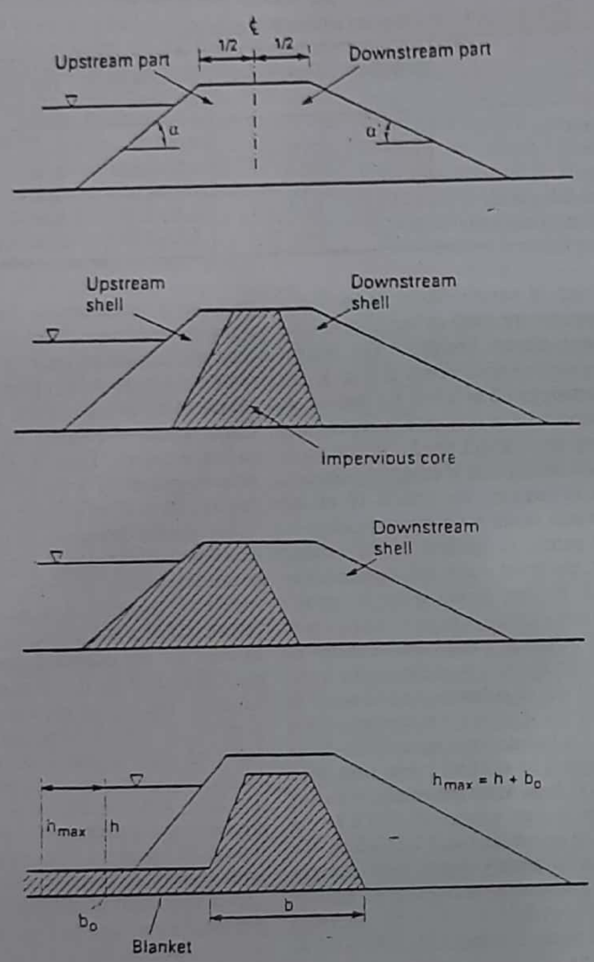

Fig. 6.5 Cross-sections of dikes with impervious cohesive soils (from Z. Szilvassy, 1984).

that production, even in coastal ponds, can be increased through increasing the depth of water, but present culture practices make it impractical to do this. When pumping proves to be a feasible means of water management in such farms, a greater depth of water should become possible.

A typical design of the perimeter dike or main embankment of a coastal pond farm located in an estuarine area is shown in fig. 6.6. The dikes are aligned along the river banks on the seaward side. If the farm is located in a mangrove area it is advisable to maintain a belt (50–100 m wide) of mangroves to protect it from waves and currents. The soft foundation soil in such swamps makes it necessary to allow

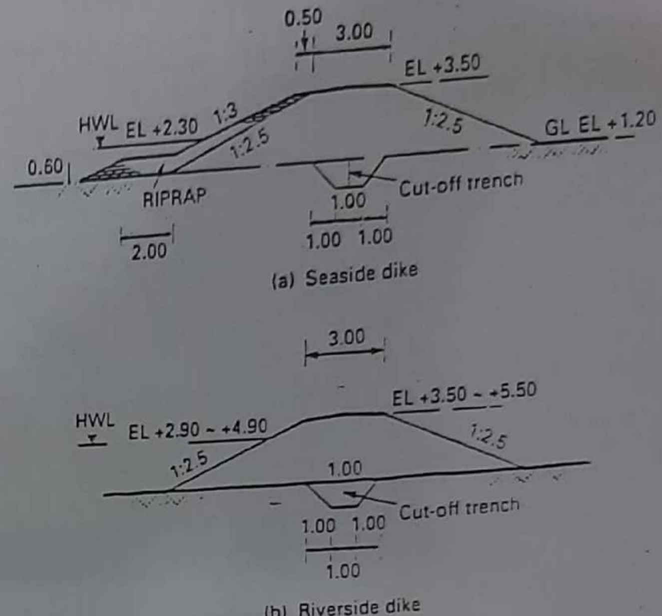

Fig. 6.6 Cross-section of a typical perimeter dike: (a) seaside dike (b) riverside dike (from Tang, 1979).

for a period of natural consolidation, before it becomes stable. High volume changes and surface cracks may occur in the process of drying. The height of such embankments is generally limited to 2.0 m, with a freeboard, after shrinkage and settlement, of 0.6–1.0 m above the design flood water level. Usually an allowance of 15–20 per cent is made for shrinkage due to settling.

A puddle trench of 0.5–1 m depth and 0.5–1 m width is considered essential to prevent seepage under the dike. For shrimp ponds in Southeast Asia, the following slopes are recommended (ASEAN, 1978):

2:1 when dike is above 4.26 m and exposed to wave action.
1:1 when dike height is less than 4.26 m and tidal range is above 1 m.
1:2 when the tidal range is 1 m or less and the dike height is less than 1 m.

The perimeter dike of the farm should be 0.5 m above the highest tide or flood level recorded in the locality. The berm built on the inside of the dike should be slightly above the water line, in order to minimize the effects of wave action on the dikes. Holes made by burrowing animals damage the dikes in coastal ponds; incorporation of bamboo screens or plastic film in the puddle trench helps to minimize this.

To facilitate the drainage and harvesting of fish, the pond bottom should have a minimum slope of 0.1–0.2 per cent towards the outlet. In inland fresh-water ponds, a harvest sump is constructed near the outlet in the deepest part of the pond as a long trench or in some other convenient shape, about 50 cm deeper than the surrounding area and with sloping sides to facilitate netting.

Harvesting sumps can also be constructed outside the pond, and a combined sump can be made for a number of ponds. The recommended bottom area for the harvesting (cropping) sump is around 40 m^2/ha, and the depth 0.6–1 m. A width of 10–25 m would be convenient for the use of nets. The external harvesting sumps are connected to outlet sluices of the ponds and fresh water has to be introduced into the external sumps at the time of harvesting. The bottom should be at least 30 cm deeper than the deepest point of the pond and an additional differential elevation of 20 cm is necessary between the two ends of the harvesting pit. In order to avoid rapid silting, the sump may be constructed 5–10 m away from the main dike of the pond. Low levees made of sandstones, gravel, bricks or concrete may be built around the sump to prevent silting.

In coastal farms using tidal flow for water management, it is common to have a central canal from which tide water is taken in through a pipe and fed into a set of two or three ponds through a common catching pond (Fig. 6.7). It is connected to the rearing ponds through sluice gates. The catching pond and the central canal serve the same purpose as the harvesting sumps in fresh-water ponds. For harvesting from nursery ponds, the catching ponds are particularly useful. The central canal becomes more important for harvesting from rearing or stocking ponds. The habit of many brackish-water fish to swim against the current is used to capture them. In fact, the elaborate system of 'lavorieri' or traps in Mediterranean lagoon farming is based on this behaviour. However, in new coastal farms, especially those meant for shrimp culture, separate feeder and drainage canals and harvesting sumps are provided. Harvesting sumps are usually located at the pond outlet.

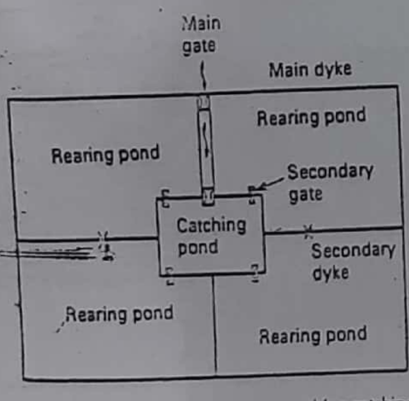

Fig. 6.7 Layout of a rearing system, with a catching pond.

Water supply and drainage

One of the most important factors that govern the success of an aquaculture operation is proper water management. Although traditionally fish farming has been done in some areas in 'undrainable' ponds, the ability to intensify operations will be greatly restricted in such waters. So the adequacy of available water should be a major criterion in selecting the site. The actual quantity required for the ponds will depend on the soil and climatic conditions, but as a rule of thumb, one may calculate it at the rate of 19 000–23 000 m^3 for a 1 ha pond with an average depth of 1.5 m, which would include an extra 25–50 per cent more to compensate for evaporation and seepage. To have a more accurate assessment of the yearly water requirement the following formula can be used (Kovari, 1984b):

$$Q_r = V_f + V_{rf} + L_e + L_s + L_c - V_{ra} \ (m^3)$$

or

$$Q_r = \frac{V_f + V_{rf} + L_e + L_s + L_c - V_{ra}}{86400 \times T} \ (\ell/s)$$

where

Q_r = annual water requirement (m^3 or ℓ/s)
V_f = $A \times h$ = the pond volume to be filled (m^3)
A = average water surface area of pond (m^2)
h = average water depth of pond (m)
V_{rf} = $N_u \times V_f$ = the pond volume to be refilled (m^3)
N_u = number of refillings a year
L_e = $A \times E$ = water loss from evaporation (m^3)
E = mean annual evaporation (m)
L_s = $A \times T \times S$ = seepage loss in the pond (m^3)
S = seepage coefficient (m/day)
L_c = $A_c \times 1.2 \times E$ = transmission loss in earthen canal (m^3)
A_c = water surface area of feeder canal (m^2)
V_{ra} = $A_{eff} \times R_a$ = water inflow from rainfall to pond (m^3)
A_{eff} = total area of pond including dikes exposed to rain (m^2)
R_a = mean annual rainfall (m)

T = operational time in days.

The water supply and drainage system have to be designed to convey the required quantities. Different designs have been adopted, obviously based on different criteria and requirements. In many designs, the same canals are used for feeding and drainage of water, so as to economize on space and construction costs. In others, it is considered essential to have separate feeder and drainage canals, as well as inlets and outlets, for operational safety and efficiency. It is generally considered necessary to locate the inlets and outlets on opposite sides of a pond, but in some farm designs the inlet is located near the outlet and the harvesting sump, so as to facilitate the supply of water to the sump when the pond is drained for harvesting.

The quantity of water conveyed through a canal depends on the area of the cross-section of the water passing through (referred to sometimes as the 'wet cross-section') and the speed of the current. This can be calculated by the equation $Q = F \times V$, where Q is the water quantity transported in m^3, F is the wet cross-section in m^2 and V is the speed of water current in m/s (Woynarovich, 1975). If the bottom of the canal is 1 m wide and the slope is 1:1.5, the wet cross-section under different water depths will be as shown in Table 6.2.

If the bottom of the canal has a slope of 0.1–0.2 m in 1000 m, the speed of water will be about 0.3–0.5 m/s. Unless such current is maintained, rapid siltation may take place in the canals. On the other hand, faster flow may result in erosion. In areas where the soil quality is poor, lining with suitable reinforced plastic films has been successfully employed to reduce erosion and seepage from the feeder canals. It is, however, more common to construct brick or cement concrete lined canals, where earthen canals are not feasible. In such cases, a higher velocity of water flow can be maintained and so the width of the canal can be smaller, for example 0.4–0.5 m, with a bottom slope of 0.5–1 m per 1000 m. When a feeder canal is built on the crest of the dikes, it is necessary to construct it with bricks or cement concrete.

The principles of designing water supply and drainage systems in coastal ponds are essentially the same as for inland fresh-water ponds.

Table 6.2 Water flow through canals at different water depths.

Water depth (m)	Wet cross-section m^2 (approx)	Water transported* ℓ/s	Water transported* m^3/day
0.1	0.11	33	2 800
0.2	0.26	78	5 700
0.3	0.43	129	11 100
0.4	0.64	192	16 500
0.5	0.87	260	24 400

* Calculations based on a water current speed of 0.3 m/s.

The only major differences are caused by the tidal fluctuations, when tidal energy has to be used for filling and draining the ponds, and by the prevalance of acid sulphate soils. The tidal range data at the site will have to be used in estimating the duration and quantity of water that the farm can extract at the site at high water for feeding the ponds to the level required. Similarly, an estimate of the quantity of water that can be drained during low tides has also to be made. The size of the feeder canals and the size and number of water intakes will depend on the tidal supply. The duration of low tides and their amplitude will determine the quantity of water that can be drained from the pond. The acid sulphate soils that occur in coastal swamp areas make it necessary to drain the seepage water from the ponds, without allowing it to contaminate the water in the feeder channels. The level of water inside the pond should be maintained at a higher level than water outside the pond, to ensure that the acidic water does not stagnate there. It will also be advisable to construct a berm near the water's edge to catch acidic run-off during rains, so preventing it from washing into the ponds.

A coastal fish farm generally has a main canal and subsidiary canals for water supply and drainage. The main canal distributes from the main water gates to the subsidiary canals and from there to individual ponds. The flow is in the reverse direction for drainage. There are many types of water control structures in use in fresh-water and coastal fish farms. The inlets may be anything from a simple pipe to a concrete sluice. A turn-down pipe, open sluice or monk, is used as outlet structures. Probably the most versatile water control structure is the monk (fig. 6.8) which can be used for inlets and also for outlets. One major advantage is that by adjusting the stoplog and fish screens, the operator can release the top or bottom layer of water from the pond. The monk consists of a vertical tower with three pairs of grooves for housing screens and stoplogs, and a horizontal conduit passing through the dike, both of which may be made of concrete, brick or a combination of the two. In recent years, monks made of fibreglass, plastic and even non-corrosive metal have been used. The selection of material has to be made on the basis of long-term costs, including maintenance and economic life of the structure. The height of the tower part of the monk depends on the highest allowable water level and the size of the pipe used under the dike. The opening in front of the tower need not be more than 40 cm wide for ponds measuring up to 5 ha. Stoplogs or flash boards are inserted into two of the grooves in the monk tower. The space between the boards can be filled tightly with wet clay, barnyard manure or compost, to prevent leakage of water. Another means of preventing lateral seepage is by attaching a rubber liner (the inner tube of an automobile tyre can be used) to the board to provide a water-tight seal. The third groove is for a suitable screen to prevent debris from entering the pond and fish from escaping. It is advisable to construct wings as support for high monks. Since they are heavy structures, particularly those built with bricks or concrete, strong bases will be needed. A base 30–50 cm deep and 30 cm wide on each side will have to be constructed with boulders and cement mortar. In the case of soft soil, the base may have to be 60–90 cm deep, and 50–60 cm wider than the actual size of the structure.

Another commonly used water control structure is the open sluice, (figs 6.9 and 6.10). It is especially useful where the discharges are higher than those which normal monks are capable of carrying or in catching ponds serving two adjacent ponds to facilitate the passage of fish or fry. The closing mechanism in open sluices can be stoplogs or vertical lift gates. Open sluice gates are commonly used on coastal fish farms in Asia. In order to avoid poor performance due to defective workman-

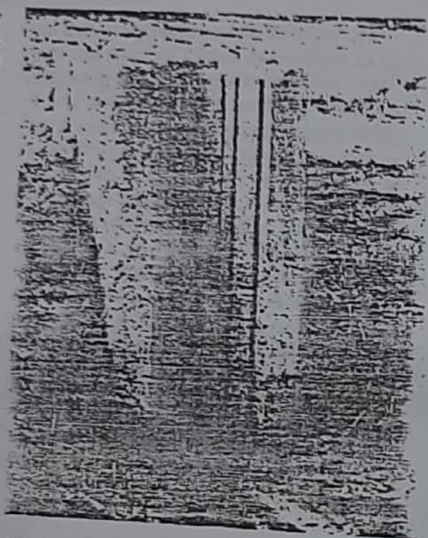

Fig. 6.8 Monks made of concrete (above) and wood (below). Outlet pipe can be seen behind the wooden monk (from Huet, 1986).

Fig. 6.9 Concrete sluice gate for a tidal pond farm in the Philippines. Note the bamboo screen.

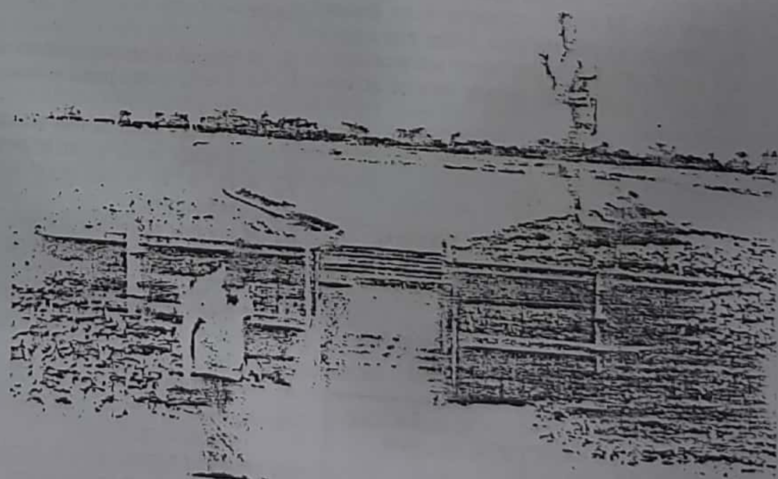

Fig. 6.10 Wooden sluice gate in a coastal pond farm in the Philippines. The attached net is for harvesting by draining.

ship and to reduce construction costs, many farmers prefer a wooden sluice although its economical life will be less than that of concrete structures.

In catfish farms in the southern USA, the most popular water regulatory system is the turn-down pipe, located at the lowest point of the base of the dike. It serves as an overflow and drainpipe. The water levels can be adjusted by pivoting the pipe, in order to increase or decrease the quantity of water flowing out of the pond (fig. 6.11). Besides providing a screen over the end of the pipe inside the pond to prevent loss of fish and obstruction of water flow by aquatic animals, it will be desirable to provide a special anti-seep collar around the drainpipe inside the dike to prevent water from seeping along the pipe and causing leaks. Some turn-down pipes are constructed with a double-sleeve device that permits water to be drained from the bottom of the pond rather than the surface (Lee, 1973). This will rectify the main disadvantage of turn-down pipes, of not being able to drain the bottom water (low in oxygen and containing a higher percentage of metabolites). The size of pipe to be used should be selected on the basis of the size of the pond, the speed at which drainage has to be done and the rate at which the pond is to be filled. The higher the diameter of the pipe, the greater the water flow capacity. Doubling the diameter of the pipe will result in an increase of over four times in the water flow capacity. Generally, an 11 cm pipe will be adequate for small ponds of 1–2 ha, but pipes of 16–32 cm are recommended for 6–8 ha ponds (Lee, 1973).

A water control structure of special importance for farms susceptible to flooding is a spillway. This serves to bypass the floods reaching the farm, without damage to the ponds, so preventing the stock of fish from escaping. Spillways are also useful in farms built on level ground, when there is a large watershed area and there is a likelihood of surplus water caused by rainfall or by filling. A wide variety of spillway designs are available. Unlined spillways (fig. 6.12) with fish screens between piers are relatively simple to design and construct.

When intensive aquaculture is practised, some form of aeration system becomes essential to enhance oxygen transfer and the dissolving of organic carbon in the water. Gravity aeration is often achieved through weirs and splash boards in ponds and raceways. Simple surface aerators like open impeller or centrifugal pumps and paddle wheels are commonly used to break up or agitate the water and increase the surface area available for oxygen transfer. Different types of aerators used in carp ponds are described in Chapter 15.

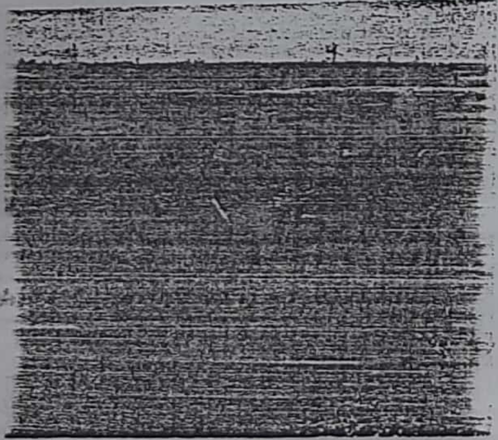

Fig. 6.11 Pond with a turn-down pipe drain (from Stickney, 1979 – by permission of John Wiley & Sons Inc).

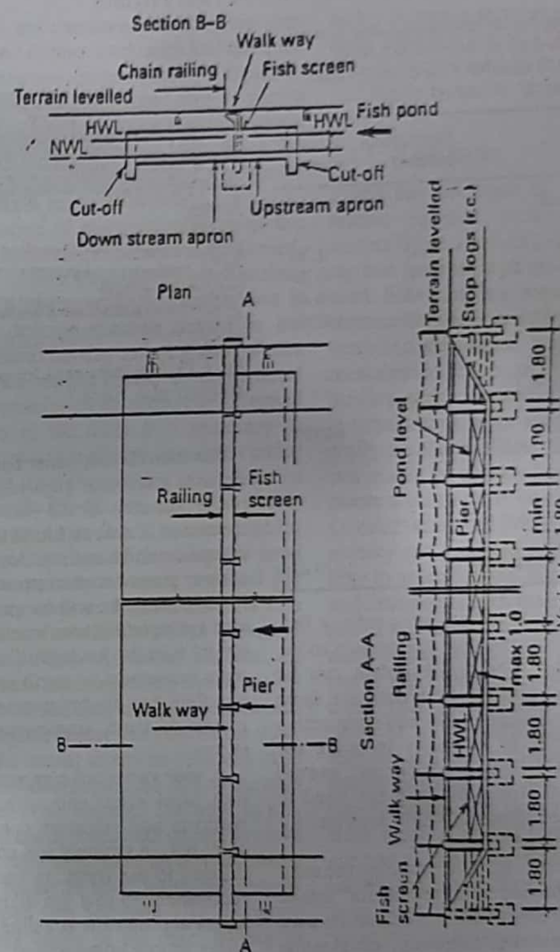

Fig. 6.12 An unlined spillway (from Elekes, 1984).

Methods of construction

In planning construction generally, there is an option to use mechanical equipment or manual labour for much of the work involved. From an economic point of view, mechanical methods of construction have many advantages. The construction period can be greatly reduced, the need for recruitment and supervision of a large labour force can be minimized and in a majority of cases more efficient structures can be achieved. Table 6.3 shows the comparative figures for earthwork in a tidal fish farm in the Philippines.

However, under certain socio-economic situations it may be necessary to select labour-intensive methods in order to generate employment in rural areas. Also, small homestead-type fish farms can probably be constructed equally or more efficiently with manual labour. On certain swamp-land areas, particularly in peaty soils in tidal lands, the use of manual labour may prove efficient. For example, it may be possible to adopt the technique of cutting earth

Table 6.3 Comparison of mechanical and manual methods for earthwork in tide-fed fish farm construction, based on a 1974 case study (from Tang, 1979).

Item	Mechanical method	Manual method
Cost of contruction (US$/m^3)		
Perimeter dike	1.15	1.38
Main canal	0.62	0.77
Partition dike	0.62	0.46
Levelling (US$/ha)	200.00	600.00
Labour requirements (man-days/million m^3)		
Skilled labour	80 000	
Unskilled labour		440 000
Construction period		
Skilled labour (500 man-days/million m^3)	160 days	
Unskilled labour (1000 man-days/million m^3)		440 days

into blocks and loading them on to rafts or flat-bottomed boats for transport at high tide to the embankment site. The embankment can be built at low tide, placing the blocks the same way as bricks for building walls and compacting them mechanically or manually to make the embankment watertight. Nevertheless, overall experience so far would indicate the need to use mechanical equipment, where feasible, for construction of larger farms.

The bulldozer (fig. 6.13) is probably the most versatile earthmoving equipment for inland fresh-water farm construction as it can be used for clearing, grubbing, stripping, excavating, diking and levelling. However, the earth will have to be compacted to prevent erosion. The economical length of haul for a bulldozer is generally between 20 and 50 m. Another piece of equipment especially preferred for embankment construction is a scraper (fig. 6.14), which can be used for stripping, excavating, diking as well as compacting. The economical length of haul of a scraper is generally between 100 and 1000 m. As a scraper does not move very easily on heavy clay, a tractor must be used to push along the cutting haul. Hydraulic power shovels and hoes can be useful, particularly in excavating trenches, drainage and feeder canals.

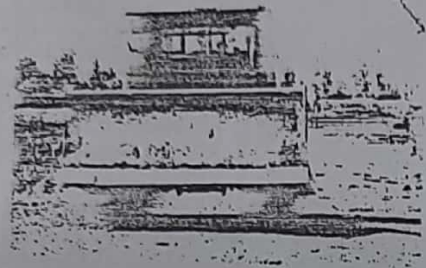

Fig. 6.13 Bulldozer used for pond construction (courtesy of J. Kovari).

For coastal fish farm construction, a small dragline excavator (figs 6.15 and 6.16) with a bucket capacity of 0.3–0.5 m^3, or a hydraulic excavator, has been found to be convenient for operation and handling. A crawler tractor, with a lower ground contact pressure, is very suitable for trimming the soil for profile formation and also for pond bottom levelling. The main constraint is in the haulage of earth in areas where mass movement of earth is required. Multiple handling has to be resorted to, as no other means of truck transportation is possible in swamps.

A wide variety of compactors, such as sheep-foot, steel wheel and rubber tyred rollers and platform and vibratory compactors, are available; but, in swampy soil conditions, it may be difficult to use them. In such cases it has been recommended that the dikes be constructed in layers and that the dragline travels on them to effect proper compaction.

Construction materials

A point that needs to be emphasized in pond farm construction is the choice of construction materials. As cost and availability of materials differ so much between areas one cannot suggest a uniform standard of materials. The guiding principle, however, should be cost-effectiveness, where durability and maintenance costs are important. Table 6.4 gives the values of durability and maintenance costs of the commonly used construction materials in pond farms.

Fig. 6.14 Tractor-driven scrapers being used in pond construction (courtesy of J. Kovari).

Schedule and sequence of construction

It is necesssary to plan the construction work very carefully to avoid waste of effort, funds and efficiency of the structures. Based on project financing, availability of labour and equipment and climatic conditions, the schedule of construction and farm operation should be determined in advance. Catfish farms in the USA are often constructed during summer and autumn, allowing the soil to settle during rainy seasons in late autumn and winter. Obviously it is preferable to complete the construction and start farming in the shortest possible time, as the investment would then start giving returns early enough. Where a longer construction period is unavoidable, as when manual methods are employed, the possibility of constructing the farm in sections, in order to start production while construction work of the rest of the farm continues, should be considered.

In order to plan the construction work properly, a detailed contour map will have to be prepared. This usually can be done only after the site has been cleared. Clearing presents greater problems and takes more time in marshy areas, particularly mangroves. In such cases, the clearing of the area for the perimeter dike may be done first, based on the available topographic map, and the rest of the area cleared and mapped as the work progresses. It is generally easier to fell trees and remove

Table 6.4 Durability and maintenance costs of materials commonly used in the construction of pond farms.

Material	Durability (years)	Maintenance cost (% of material cost)
Reinforced concrete (1:2:4)	20–30	100
Stone rubble in 1:5 cement mortar	10–15	150
Brick masonry in 1:5 cement mortar	5–10	250
Wood	5–8	300–400

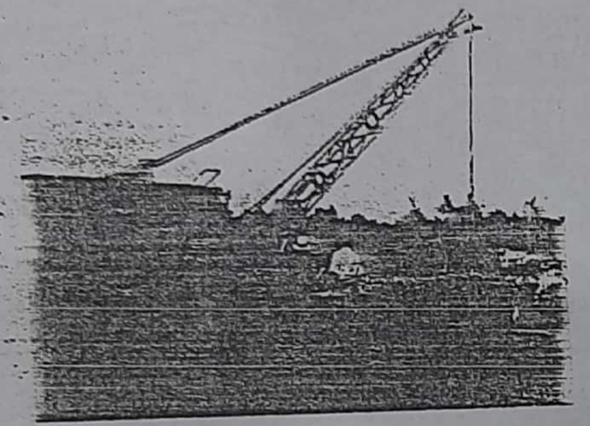

Fig. 6.15 Dragline excavator, operated from pontoons in tidal lagoons in Italy, for dike construction (photograph: Carlo Mozzi).

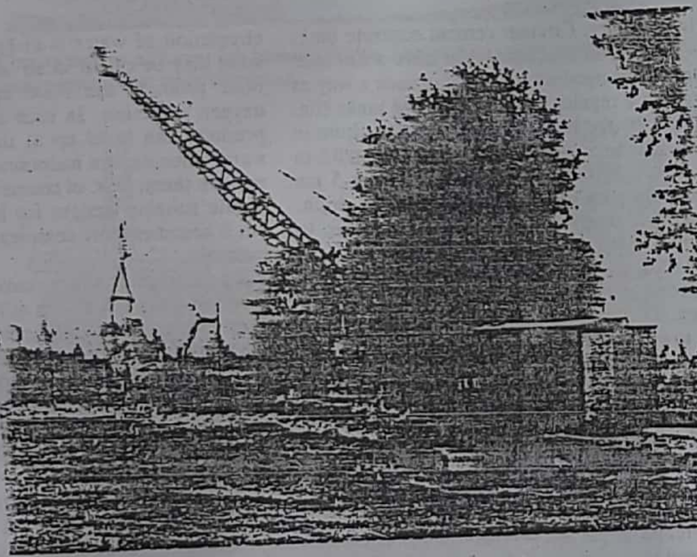

Fig. 6.16 Dragline being used for dike construction (courtesy of J. Kovari).

dense brush after the perimeter dike is constructed, as the ground can then be dried to support heavy equipment for cutting, such as chain saws, pluckers for uprooting bushes and small trees and winches for pulling the trees and brush.

The general features of the farm, including the boundary of the site, layout, number and size of ponds, main and subsidiary dikes, water supply and drainage, location of water control structures, etc., have to be shown on the detailed map to aid construction work. The area reserved for the hatchery (if one is planned at the pond site), auxiliary buildings for storage

of dry feed and chemicals, fish handling, preservation and storage, workshops and space for storage of nets and equipment and the approach road and other utilities should also be shown on the map. If feed production is to be done on the farm site, adequate space for housing the equipment, feed ingredients and storage of processed feeds has to be provided.

The sequence of construction work of the farm has to be decided in advance and followed, in order to achieve good quality construction. If flooding of the area during construction is likely, the drainage channels should be excavated before starting construction of the dikes. All the outlets should be constructed before commencing on the dikes. For the actual construction of the dikes it is necessary to estimate the quantity of earth required (taking into account also the packing coefficient of the soil, usually 20–50 per cent) and decide whether the pond area should be excavated for obtaining the earth and for levelling the pond bottom. The quantity of earth required per hectare for the construction of dikes for a 4 ha pond is estimated to be 2500–4000 m^3 (Pruginin and Ben-Ari, 1959). As far as possible, all organic matter, including roots, should be removed from the soil used for dike construction, as rotting organic matter will weaken the dike. Similarly, the humus should be removed from the base of the dike to bind the dike to the base properly and avoid seepage. The need to preserve the top soil in ponds built on cat-clay soils and allow a layer of silt to settle on it to reduce hazards of acidity in pond water has already been discussed (see Section 6.1.1). To attain the necessary height of the dike, it may be necessary to compensate for the subsidence by recapping it two or three times. It may also be necessary to make a large berm between the toe of the dike and the drainage canal, to offset the weight of the dike.

6.2 Tank and raceway farms

As will be evident from the preceeding section, pond farms, although comparatively less expensive to construct and operate, are affected by too many external factors over which the aquaculturist has very little control. Because of this, it is not generally possible to employ a highly intensive technology in pond farm culture. Tank and raceway farms attempt to bring greater human control in operations and facilitate highly intensive farming.

6.2.1 Tank farms

Tanks can be made of concrete, fibreglass, marine plywood, metal or other hard substances (figs 6.17–6.19). Durable materials that are free from toxic paints or chemicals only are used. Fibreglass is a popular material for tank construction as it is light, strong and inert to fresh and salt water. It can be moulded into most desired shapes and is strongest in tension loading, which is usually the stress experienced in circular tank walls. Fibreglass tanks are generally circular in shape. Sectional metal tanks can readily be obtained in the market in many places and can easily be erected or dismantled. Circular tanks are very commonly used for nursery and grow-out purposes. Besides being easy to assemble and install, the water supply and drainage in such tanks can be organized in such a way as to create a vortex that will sweep most of the detritus and other waste material out of the system. Ready-made plastic-coated metal tank sections can be bought to make tanks of the required size. They are bolted together and sealed with waterproof cement or similar material. The base is screeded in waterproof cement and slopes to a central drain, from which a pipe of suitable size carries discharges to the main drainage pipe; the latter collects discharges from all the tanks and conveys them to the final discharge point. The water level in the tank is controlled by a vertical pipe which is moveable and fitted in the main drain pipe, its height above the base of the tank being thus adjustable. The outflow is usually screened by a vertical, cylindrical plastic or metal mesh of the required size that projects above the water surface. A screened overflow pipe of adequate size is fitted into the upper wall of the tank. In order to protect the stock from predatory birds and other animals, the tanks are covered with suitable netting or metal screens.

Many variations on the arrangement of the water supply system and protective devices are possible in circular tank farms, including regular aeration and recirculation of water where

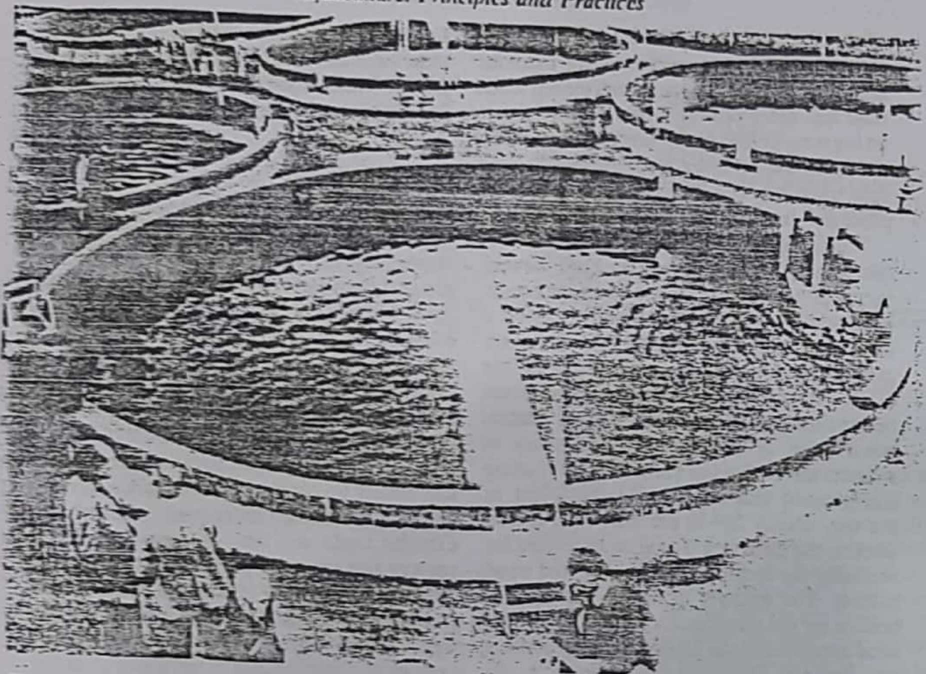

Fig. 6.17 An out-door tank farm. Tanks are made of cement concrete.

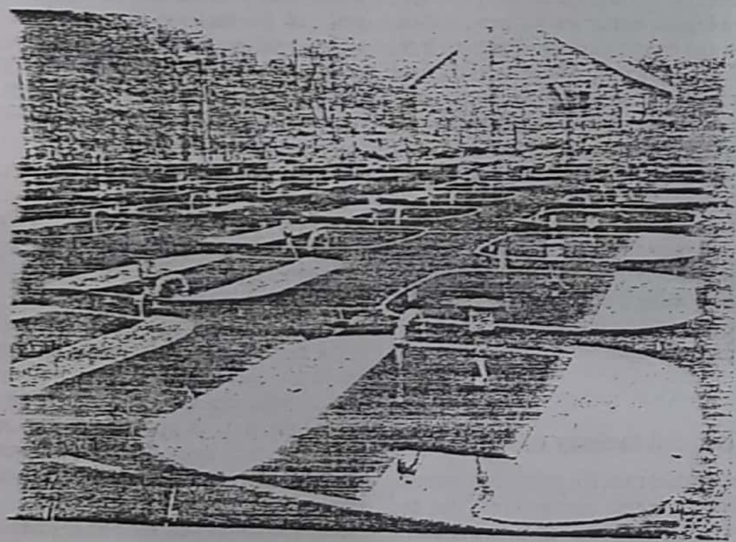

Fig. 6.18 An out-door tank farm. Tanks are made of fibreglass.

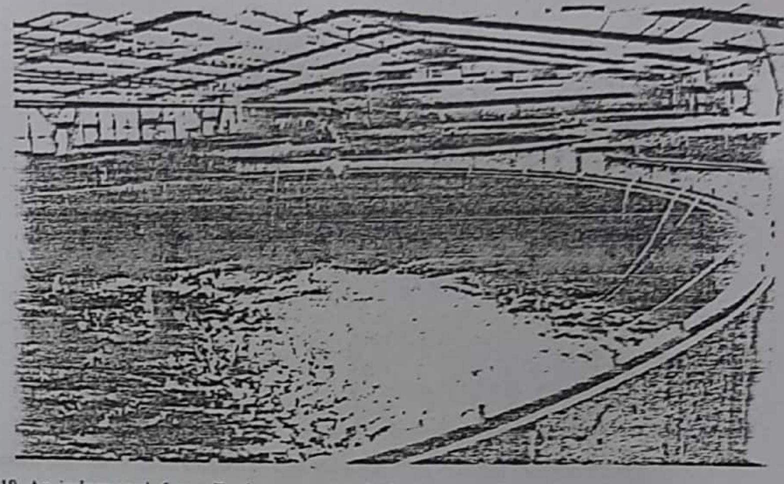

Fig. 6.19 An indoor tank farm. Tanks are made of plastic-covered metal.

it is necessary. Circular cement concrete tanks in Chinese fish breeding farms have water inlet nozzles arranged on the walls in such a way as to cause a regular circulation in the tanks (fig. 6.20). Circular tanks used for catfish culture in the USA range up to 6 m in diameter and 0.8 m in depth, with a fall of approximately 5 cm from the circumference to the centre drain, making it easier to clean. In fact they are to some extent self-cleaning.

Rectangular tanks are also used and they are approximately 8 m long, 1 m wide and 75 cm deep. The bottom may slope towards one end or towards the middle, to facilitate cleaning and draining (fig. 6.21). In tanks that drain at one end, water enters at the opposite end and flows the length of the tank, whereas in tanks that drain in the middle, water enters at each end and flows towards the middle. One advantage of a rectangular tank is that it is comparatively easier to harvest fish from it than from a circular tank. Rectangular tanks can be arranged in stacks four or five high, in which case they are made slightly smaller, with a length of 4.5–6 m, a width of 1.5–1.8 m and a depth of 40–45 cm. Such systems can be arranged indoors and it should be possible to install the necessary equipment for controlling water temperature and thus use the tanks for year-round production in colder climates.

Rectangular tanks are easy to construct, but circulation of water is often characterized by what may be called 'dead' areas, where metabolic products can build up and also cause oxygen depletion. In such tanks, solid waste products can build up at the bottom, unless water velocities are maintained high enough to remove them. It is, of course possible to incorporate suitable designs for better circulation, but it becomes more complex and expensive to maintain.

As mentioned earlier, tanks can be built of different materials and in different shapes and sizes. Though not very common, there are large cement concrete tanks of area 200–300 m^2 used for rearing salmon, trout, shrimp, etc. In Japan and Taiwan, cement concrete tanks measuring up to 0.2 ha are used for eel culture. To enable high density culture, suitable aeration equipment is provided. A more recent type of facility for aquaculture, in many ways similar to tank farms, is the silo, which has been tried largely in the USA (fig. 6.22). Essentially it is a deep tank, with water pumped down the centre through a pipe. Water flows upward in the culture tank, outside the centre pipe, and discharges into a trough constructed around the outside of the tank at the top. The flow rates are high, but higher densities of fish can be grown in a silo – as much as 136 kg/m^3 or 27.5 kg/m^3 per second of water flow (Buss *et al.*, 1970).

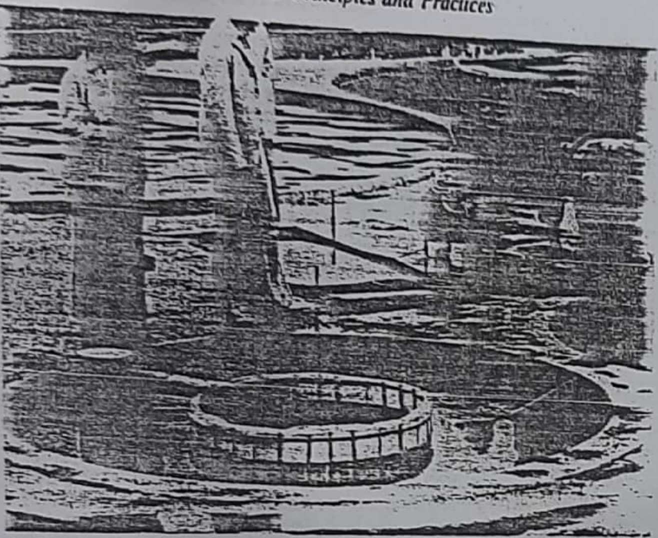

Fig. 6.20 Circular tanks in a Chinese fish breeding station. Inlet nozzles (arrow marks on the walls show their positions) ensure proper water circulation.

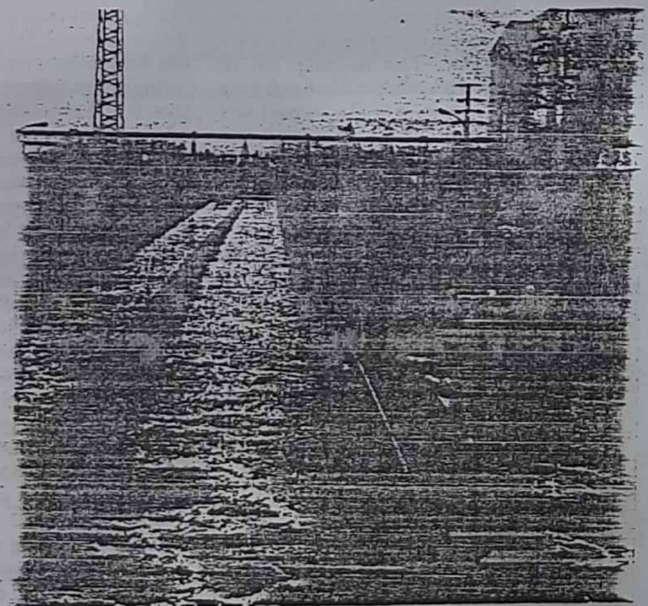

Fig. 6.21 A tank farm with cement-concrete rectangular tanks arranged on the side of the water supply system. Note the rails on the side of the tanks for transporting feed and the silos on the right for feed storage (courtesy of J. Kovari).

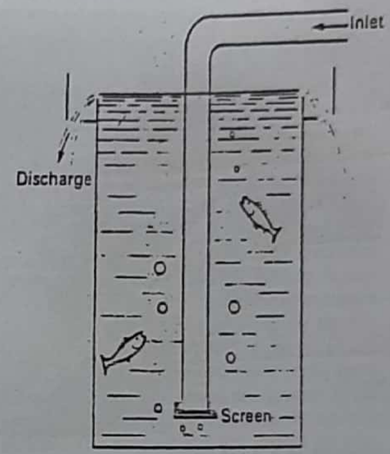

Fig. 6.22 Design of a silo tank (from Wheaton, 1977 – by permission of John Wiley & Sons Inc.).

Tank farms built in areas with limited water supply have often to resort to purification of water through biological or other filters and recycle them for repeated use. The costs involved have been rather prohibitive for commercial grow-out, but it is often possible to use the system in hatchery and nursery tanks as described in Section 6.5.2, Reconditioning and recirculation of water.

5.2.2 Raceway farms

Raceways are designed to provide a flow-through system to enable rearing of much denser populations of animals. An abundant flow of good quality, well-oxygenated water is essential to provide respiratory requirements and to flush out the metabolic wastes, particularly ammonia. The specific flow rate required to meet the oxygen consumption of organisms and the flushing out of metabolites can be determined on the basis of the temperature and oxygen concentration of the inflow water and the oxygen consumption and ammonia/nitrogen excretion of the organisms in the raceway.

Raceways are obviously smaller in size and occupy much less space than ponds. Although earthen raceways are sometimes used, the large majority of them are made of reinforced concrete, or cement blocks (figs 6.23 and 6.24). Earthen raceways can be lined with plastic material to reduce loss of water through seepage. Just as for pond farms, site selection for a raceway farm has to be done with special care. Naturally, the most important consideration is the water supply. The main sources of water are springs, streams, deep wells or reservoirs. For trout, which is probably the most common species cultivated in raceways, there is generally a preference for spring water of uniform temperature. For raceway farming of catfish a supply of 79 ℓ/s (1250 gal/min) is required for every 0.4 ha (acre) of raceway (Lee, 1973). In channels 3 m (10 ft) wide at the bottom and 1.2 m (4 ft) deep with a 1:1 side slope, a flow of 2.5 ℓ/s (530 gal/m) is often recommended. If such a flow is maintained, the water in a raceway segment of 30 m (100 ft) will be completely exchanged in about 1 hour.

In designing a raceway it is preferable to make use of the contour of the land. A slope of 1–2 per cent is preferred so that water flowing in at one end can be removed at the other. Each segment of a raceway can be about 30 m long, 2.5–3 m wide at the bottom and 1–1.2 m deep. A raceway farm consists of 15 to 20 segments or more. Many of them are constructed with side slopes of 1:1 or 1:0.5.

It is generally advisable to have a water supply reserve for emergencies. A storage reservoir near the beginning of a raceway system from where water can flow into the raceway by gravity would be most useful, in case there is pump failure. Raceways should be built straight and avoid curves, to ensure uniform flow. As many raceways as necessary can be built alongside each other. Many have a dozen or more rows. Very often the segments are built at different levels. The general practice of discharging water through a series of raceways carries with it the risk of unhygienic conditions developing in the lower level segments. However, when there are not too many segments and the water flow is sufficiently fast, the risk is not very significant, except when there are infective diseases in the upper raceways. In order to meet this contingency, it is necessary to have water control structures to cut off the affected segment and discharge the water through a separate drainage channel. Then

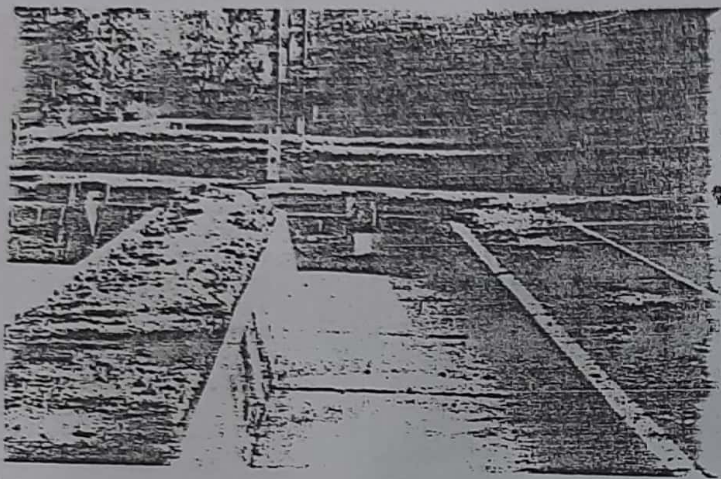

Fig. 6.23 A raceway farm under construction (courtesy of J. Kovari).

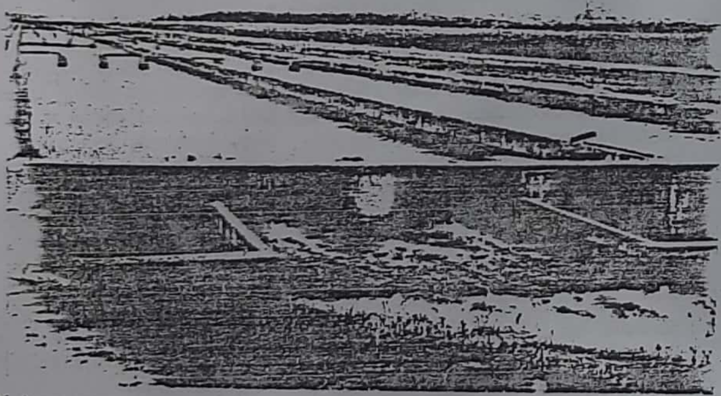

Fig. 6.24 A cement concrete raceway farm used for raising trout in Italy.

there should also be a separate feeder channel for each segment, very much as in a pond or tank.

It is important to have water control structures or weirs to regulate the flow and depth of water. They could also serve to aerate the water as it flows through. Commonly used materials for such structures are reinforced concrete, reinforced concrete blocks, wood, sheet metal and culverts with flashboards. They should permit discharge of water from the bottom of raceways and include screens to prevent loss of stock. Removal of water from the bottom helps in flushing out metabolic wastes and water low in oxygen. Other means of achieving the flow of bottom water is through a syphon arrangement or by constructing a vertically adjustable wide baffle on the upstream side of the weir, extending down into the water, so that water flows under it rather than over it. It is essential to adjust the rate at which water is pumped or flows into a raceway in order to prevent overflow or emptying. For cleaning raceway bottoms in emergencies, a suitable suction device can be used.

6.3 Cage farms

Holding or rearing fish in cages is a traditional practice in some Asian countries and appears to have originated almost two centuries ago in Kampuchea, from where it spread to Indonesia and Thailand and in recent times in a more advanced form to several other countries. Coche (1979) summarizes the historical evolution of the concept. It was a general practice in The Great Lakes area of Kampuchea to hold commercially valuable fish in bamboo cages to be sold alive. The cages were trailed in water behind a fishing boat for transport to the markets. Since this often took a long time and some of the catches were of smaller size, the fishermen began feeding them with trash fish and kitchen refuse. The fish grew well in the cages and as a result their market value increased considerably. This naturally led to longer-term rearing of catfish in Thailand, carp in sewage-fed canals in Java (Indonesia) and later on yellowtail in Japan and groupers and sea bass in Hong Kong and Singapore. Through recognition of the value of cage farms in aquaculture and the opportunities they offer for productive use of open waters, cage culture has attracted considerable research and development efforts in most parts of the world. In the last two decades it has become a major source of aquaculture production, particularly of high valued species like salmon, trout, sea bass and groupers. Several types and designs of cages and cage farms have been developed and are available commercially.

6.3.1 Types of cages and layout of cage farms

It is obviously difficult to describe the various designs of cages presently available. Detailed descriptions of different types of cages are given in Beveridge (1987). Although there are submersible and rigid-walled cages in use, the majority consist of a floating unit, a framework and a flexible mesh-net suspended under it. There are different methods of floatation and mooring, placement and attachments of individual cages in a farm, means of approach and handling of cages. The floating unit can consist of empty barrels, styrofoam polyethylene pipes, or ready-made pontoons of plastic and metal. The buoy units are often built into a framework, the material of which can be impregnated wood, bamboo spars, galvanized scaffolding or welded aluminium bars. Nylon is commonly used for the net, but weldmesh or even woven split bamboo are also used. Cage flotillas provide safer working conditions and enable storage of feed on site, as well as installation of automatic feeders. The diversity of materials used shows that the design of the cages and cage farms should be based on conditions prevailing at the selected site. Reasonably sheltered areas, with sufficient water movement to effect adequate mixing and aeration, are selected as sites for cage farms. The occurrence of typhoons, hurricanes and cyclones in the area and the vulnerability of the site to these are also major considerations in the design of cage farms. Polluted sites are generally avoided. In cold climates, areas that receive safe heated water effluents are preferred, as higher water temperatures generally improve growth and productivity.

Unused feed and fish faeces fall from the bottom of floating net cages on to the floor of the water body. Accumulated wastes decompose and cause oxygen depletion or generation of methane or other toxic gases under anaerobic conditions. Cages also increase deposition of silt on the bottom of the site. It is therefore necessary to have enough movement of clean water below the floating cages, and if the movement is not enough to clear them, provision has to be made for regular mechanical removal with suction or slush pumps and disposal of the waste at safe distances. Though the determination of precise carrying capacity of waterbodies is difficult, at least emperical estimates should be used to avoid overcrowding of cages.

Extensive testing of materials for construction of cages, supporting framework, floats, sinkers, walkways, etc. has been carried out. Despite differences in technical efficiency, different types of materials continue to be used

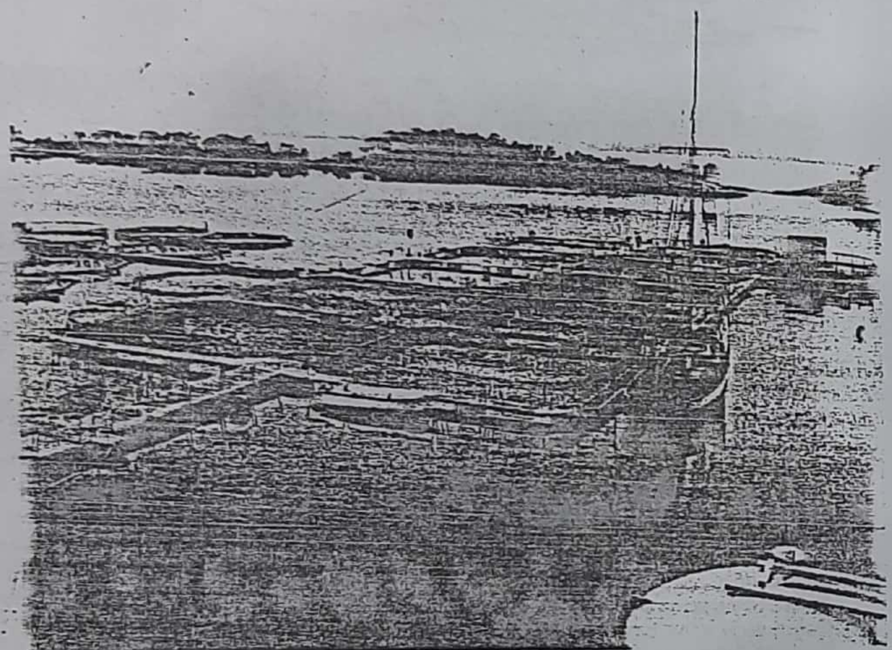

Fig. 6.25 A modern cage farm in Svanoy Island, Norway (photograph: Ola Sveen).

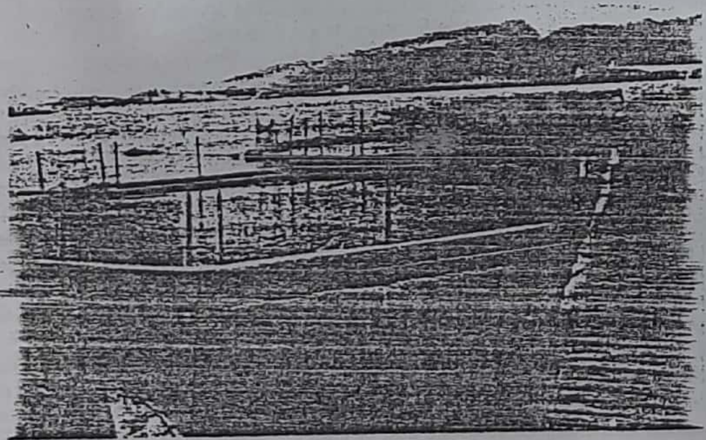

Fig. 6.26 A cage farm in Norway. Note the hexagonal cages with wooden framework moored alongside a walkway from a jetty.

depending on availability and cost. The most sophisticated designs appear to be used for sea cage farms, especially in Norway (fig. 6.25) and Scotland. Cage size can be anything up to 1000 m^3, but is normally between 100 and 500 m^3. A simple unit holds a net of four vertical sides and rectangular cross-section, but the more popular ones are circular in cross-section. When timber is used as framework it is not easy to have a perfectly circular shape and an approximation is achieved with six- or eight-sided structures. A commonly used cage in Norway has an eight-sided floating framework of timber, which is impregnated to reduce rotting. They are linked together by flexible joints to reduce the rigidity of the structure (fig. 6.26). Planks 12 cm × 5 cm or larger form the sides of the section and are spaced 30 cm apart by wooden slats nailed across the top and bottom. The slats on the top should be positioned close together, as the framework has also to serve as the walkway around the net. Expanded polystyrene or other flotation material is inserted between the two layers of slats and held in place by nails driven through the timber. The joint between two sections of the frame is formed by bolting strips of heavy rubberized machine belts. For further safety, all the sections are securely fastened together by suitable nylon rope or reinforced plastic piping. In every alternate corner of the frame a loop is provided to attach the anchoring devices. Inside the collar, four 120 cm long laths are nailed to each of the eight units. A nylon net is stretched between the laths to prevent leaping fish from escaping.

Another common type of cage system used in Norway employs rectangular cages suspended from a rectangular float (as in fig. 6.25). The float consists of four PVC pontoons in iron frames. The two frames, made of 25 mm galvanized iron tubes, are connected to a wooden frame made of 5 cm × 10 cm impregnated planks with galvanized bolts and nuts. The wood frame is made in two sizes (4 m × 1 m and 5 m × 1 m), depending on the length of the two types of elements. On top, the wooden frames are covered by 2.5 cm × 12.7 cm impregnated planks. The elements of the two different lengths are joined together to form a rectangular float with a network of 4 m × 4 m square openings. The bag net, equipped with

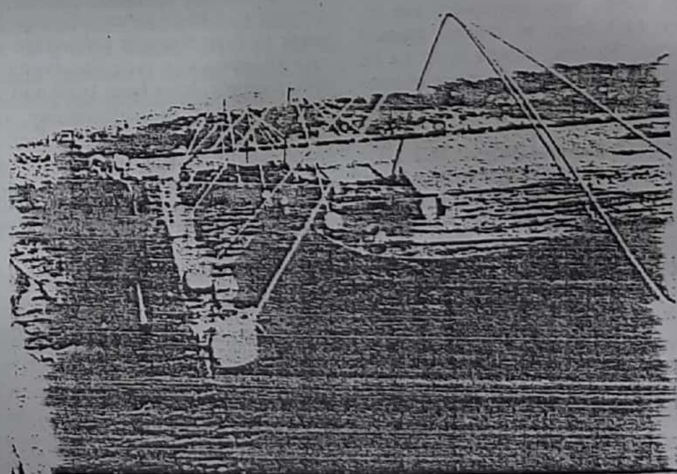

Fig. 6.27 A farm in Norway, which uses a different design of floating six-sided cages. Flotation is provided by six inflatable rubber buoys kept in place by six fibreglass poles radiating from a steel plate above the cage, looking like an inverted umbrella frame.

headline and leadline, is fixed to the rafts with brass hooks screwed into the wooden frame. Fence poles are erected from pedestals. The raft is usually moored by its four corners and can easily be towed.

When welded tubular metal or PVC or fibre-glass tubing is used for the framework, there is greater flexibility in shapes and sizes of cages (fig. 6.27). Besides cost and safety of the structures, a major consideration in designing cages is the ease with which they can be handled. Obviously, large cages, though cheaper to buy and install, are not very convenient in this respect and would need a larger labour force or special mechanical equipment to handle. Cages with an underwater net volume of more than 1000 m^3 are not recommended; the preferred size is between 200 and 500 m^3. It is common practice to have double netting: the outer one serving as a predator net to protect the inner one and the fish stock in it.

There are many ways of arranging cages in a cage farm. Where possible, it is preferable to moor cages to a jetty with direct access to a quay, in order to facilitate work and reduce labour costs (fig. 6.28). However, environmental and site conditions may require them to be located farther away from the coast, in which case a work boat will be needed for access (fig. 6.29). In either case, the cages should be installed on the sides of a central walkway to facilitate day-to-day work on the farm. In many modern cage farms, feed dispensers are installed above each cage; in others, manual feeding is done. Mooring blocks have to be sufficiently heavy and are usually made of concrete with heavy galvanized bolts. Cages should be attached to the mooring by chain or, for lighter structures, by nylon rope.

While the arrangement of cages in a battery is the most common practice, in cases where infection of diseases is feared they may be moored separately and workers use boats to attend to feeding and the care of the cages and fish stock.

Most of the presently available cages are designed for use in protected areas like bays, fjords and lakes. In order to utilize more open waters and high seas, special cages with a flexible rubber framework have been recently developed. Some of these designs have twin rubber booms for increased stability in rough seas. It is claimed that the low weight of the cage reduces strain on the moorings and contributes to all-weather capability and high durability. Other types of very large cages made of high strength galvanized steel, fitted with all accessories including even independent power supply, have been tried and are claimed to be capable of withstanding very severe storms. If such cages prove technically and economically successful, an enormous expansion of unpolluted potential sites for cage farming can be expected.

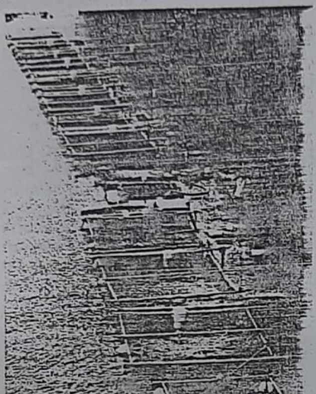

Fig. 6.28 A series of cages moored to a jetty along the shore (courtesy of Ola Sveen).

6.3.2 Submersible cages and cage maintenance

One of the advantages of a cage farm is that it can generally be towed away to a different location for harvesting or if unfavourable weather or other environmental conditions occur. In areas subject to typhoons or cyclones, submersible types of cages can be useful. Such cages are used in Japan for yellowtail rearing.

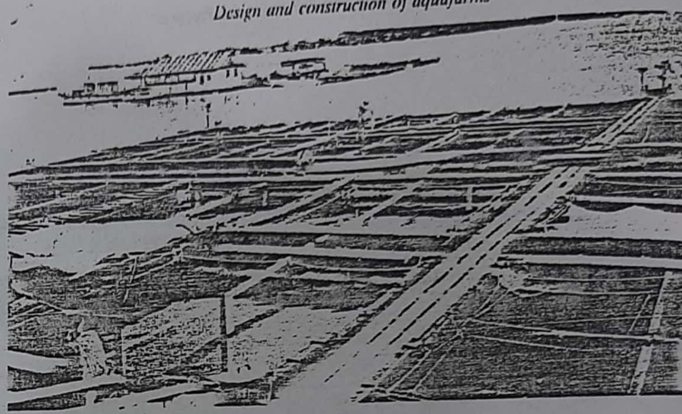

Fig. 6.29 A cage farm moored in Johore Straits, Singapore. Note the floating house of the caretaker and work boats.

They can withstand wind and waves much better than floating cages and can often also be used in open sea areas. The headropes of the cages, constructed on more or less the same design as floating cages, are attached to taut mooring ropes suspended from plastic surface buoys. Under normal conditions, the mooring ropes will be only about 2–5 m from the surface, but in rough weather the ropes are dropped to 10 m or more. By attaching weights of about 10 kg at each corner of the cage bottom, the shape of the cage is maintained. Additional weights may be added if the currents are too strong (Fujiya, 1979). The net is raised to the surface at feeding time, and the feeds conveyed through the feeding passage attached to the top of the net. A more sophisticated version of this type of cage uses variable buoyancy synthetic rubber floats that can be filled or emptied with compressed air or sea water from the surface.

A different type of submersible cage has been designed for use in hurricane-affected seas in the Caribbean. It is a spindle-shaped collapsible net cage held in position by circular PVC rings of different diameters (the largest rings in the middle and progressively smaller rings towards the ends) (figs 6.30 and 6.31). It looks very much like an enlarged and modified version of a fyke net. There are funnel-shaped pockets through which fish in the cage can be fed. Under normal weather conditions, the cage floats with the top above the surface, but when there is a hurricane warning it can be sunk to the bottom by increasing the weights and removing the floats. When the hurricane has passed, the cage can be raised again by removing the extra weights and replacing the floats. The spindle shape helps in rotating the cage and exposing the submerged parts to the sun for drying and removal of fouling organisms on the net.

Two of the major problems for cage farms are fouling of cage materials, particularly nets and mesh, and susceptibility to easy poaching. Fouling makes the net heavier and prevents easy exchange of water. Antifouling coating, which does not harm the fish, is a solution, but the most practical way at present is regular change of nets. Clean nets are installed at regular intervals (the frequency of change will depend on the rate of fouling at the site) and the old nets cleaned and dried for further use if they are sufficiently strong. Generally, the economic life of nets in cages is two to three years, depending on local conditions. Constant watch has to be kept of deterioration in the framework and other structures of the farm.

Fig. 6.30 Framework of a collapsible net cage. Note the PVC rings and the central beam.

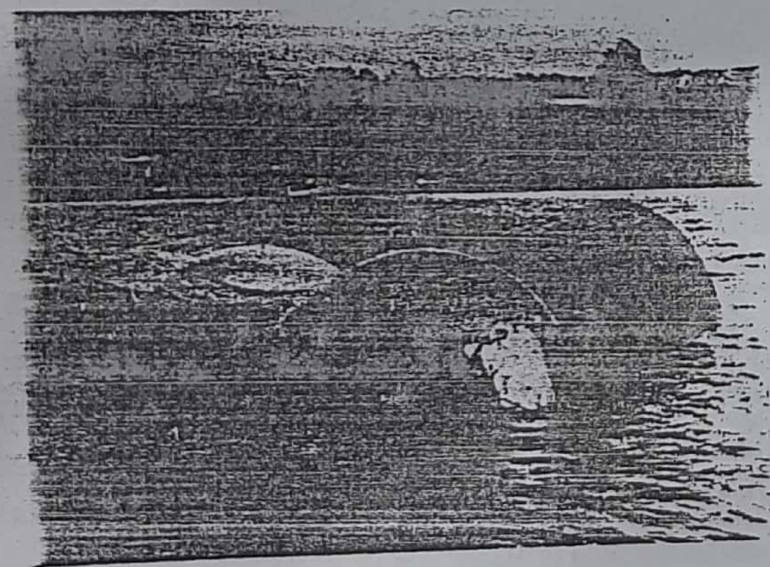

Fig. 6.31 Submersible cages under operation in Martinique.

and repairs or replacements have to be in proper time to avoid unnecessary risks. Besides fouling, cage farms have to be protected from floating debris, rotten tree branches and drift wood. Unless they are exceptionally heavy, no damage may be done to the strong frameworks.

However, they can tear the nets sometimes and any such damage should immediately be repaired. Even though floating booms are sometimes erected with old netting slung beneath them to protect the cage, they can hinder routine operations.

There are different types of alarms that can be used to warn against poachers, but there appears to be no better means of looking after a cage farm than by the owner or a watchman on the spot, possibly with the help of trained dogs. In cage farms in Singapore, there is a floating house for the operator attached to the cage complex and a good number of guard dogs, for round-the-clock watch and constant care of the cages.

6.4 Pens and enclosures

Pens and enclosures can in some ways be considered as transitional structures between ponds and cages, in so far as environmental and stock control are concerned. While enclosures or pens continue to be used as in the culture of yellowtail in Japan, milkfish in the Philippines and salmon in Norway, attempts to introduce these systems have not met with much success in many other countries. This can probably be ascribed to the difficulties in the use of intensive techniques and in some cases the rather high costs of embankments and water management, such as through pumping. Experience seems to indicate that the success of enclosures for culture, to a large extent, depends on the hydrological conditions of the site. The design of the structures and operational procedures have to be based on adequate knowledge of water quality, floods, waves and currents, prevalence of predatory animals, etc.

Probably the simplest and relatively most efficient type of enclosure used for aquaculture is the one formed by damming a bay, cove, fjord or arm of the sea, estuary or river (fig. 6.32). Sites are selected where the barriers can be constructed across narrow sections, or channels, in order to reduce costs and increase the ease of operation. Most of the perimeter of the enclosure is formed by the natural shoreline. When the blind end of a water area is enclosed, there may be only one or one series of barriers, but in enclosures that permit direct flow-through there may be two or two series of barriers: one upstream and another downstream. The dams are constructed with stones, earth or concrete, depending on the availability of materials and exposure of the site to storms and other natural disasters. They hold screens consisting of vertical aluminium or galvanized metal bars, with about 1 cm gaps between them to allow free flow of water. The screens, which are removable, can be located in the concrete by moulded guideways. Two guideways are provided, one behind the other for each screen, to enable a duplicate to be placed in position

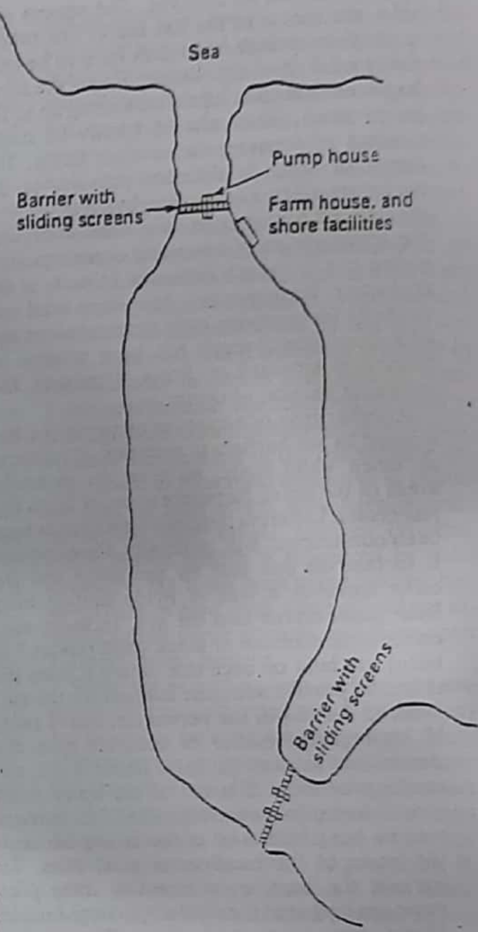

Fig. 6.32 Diagram of an enclosed fjord.

-before removal for cleaning. The screens prevent the escape of the fish stock. For proper management these enclosures have to be relatively small (2–7 ha), although there are much larger enclosures in Japan, measuring up to 120 ha or more, which should strictly be called ranches or reserves, rather than farms. The depth of water in different portions of the enclosure differs and the circulation of water in the deepest parts may be insufficient to prevent the accumulation of waste and organic matter, giving rise to oxygen depletion in parts of the enclosure. Suction pumps have been used successfully for removing such accumulations and additional flow-through has been created by propellers mounted on floats. Obviously this increases the cost of operation.

Another type of enclosure or pen is the one formed by net barriers to partition off areas of an open water body, such as the intertidal areas of the sea or foreshore areas of lakes and reservoirs. Different designs of enclosures have been constructed. But, generally, the enclosure is formed on one side by the shore and the other three by a wall of nylon netting hung from poles driven into the sea. In many such enclosures, concrete or stone walls (about 3 m wide) are built on each side where it joins the shore, to provide adequate support for the net. Around the rest of the perimeter, heavy posts of impregnated timber or concrete piles are driven into the bed (at least about 3 m), extending for about 2 m out of the water at all times (during floods and high tide). Net barriers may be hung from steel cables strung between the poles or the concrete or steel piles. To prevent the lateral movements of these piles some are anchored fore and aft, to large anchor blocks using strong steel cables. The nets are generally made of knotless nylon netting material. In some cases, two walls of netting are used, the outer one to protect the enclosure from floating debris and to prevent the escape of fish if the inner wall gets damaged. However, this has been found to be a hindrance to free flow-through of water and now in most enclosures only one net wall is used. Though not so common as nylon nets, galvanized wire mesh or chain links are also being used as barriers. At the bottom of the poles or pilings under water, the net barrier is fixed by a rope along the sea bed for about 1 m, until it terminates in a lead line. Normally the net embeds itself in the sand or silt at the bottom, forming a good seal. As a further precaution to prevent escape of fish, heavy rubble may be piled at the bottom of the net or in some cases a net bottom may be provided.

A unique system of pen culture has developed in the shallow eutrophic Laguna de Bay in the Philippines and in lakes in China. Using bamboo scaffolding, enclosures of different sizes have been made in the lakes (fig. 6.33). Because of the shallow nature of the lakes, enclosures can be fairly easily constructed. The average depth of Laguna de Bay at low water is only 3 m and at high water 5 m. The netting is taken above the surface to prevent the escape of fish by jumping (fig. 6.34). An improved floating net enclosure has been developed, where the net enclosure is held in place by concrete block sinkers (about 500 kg in weight), with a series of small weights on the foot rope which is secured to a chain link between the sinkers. The net is kept afloat by floats attached to the headropes. There is a horizontal net at the top of the enclosure to prevent fish from jumping. To spread the load exerted by water movement and wave action, a lattice work of nylon rope is provided. The enclosures are generally assembled on land, then taken to the site on barges where they are installed by attaching them to the sinkers. Such floating enclosures are now used in lakes for tilapia and milkfish. It is reported that a similar system of pen culture of the giant fresh-water prawn has developed in the Songkhla Lake in Thailand. Several circular pens consisting of a bamboo framework and perlon nets have been built in the fresh-water portion of the lake by small-scale farmers.

6.5 Design and construction of hatcheries

Methods of seed production in aquaculture differ considerably with the species under culture and the state of technology, as well as with the level of operation (as, for example, extensive or intensive and the number or frequency of crops). Where the techniques for artificial propagation are still to be developed or perfected, or where it is feasible and economical to collect eggs, larvae or fry from natural breeding areas, sophisticated hatchery systems are not often used (see Chapter 5). However, even in such cases it is generally accepted that, eventually, hatchery production of seed will be necessary to stabilize and ensure regular supplies and introduce breeding techniques to raise improved seed for better growth and production.

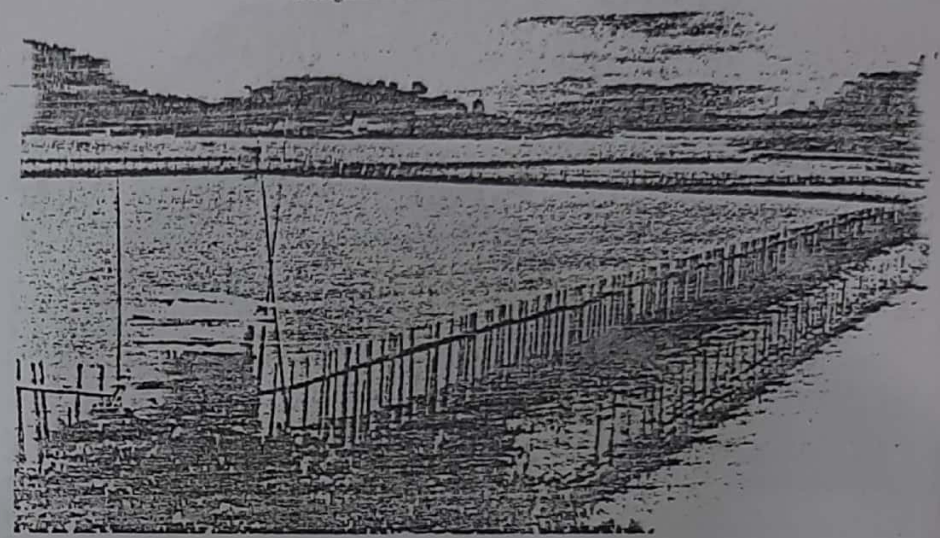

Fig. 6.33 A fish pen made of bamboo in Tahoe Lake in China.

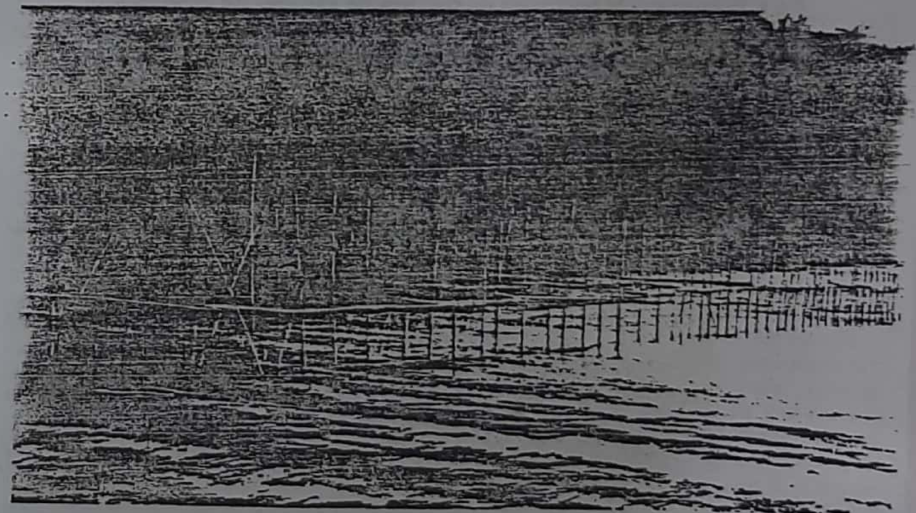

Fig. 6.34 A fish pen in Laguna de Bay in the Philippines. Note the bamboo scaffolding (courtesy of Y.A. Tang).

As is only to be expected, there are different types of hatchery facilities in use, depending on the species, locality and investment capabilities of the aquaculturists. However, the basic requirements are about the same: there has to be the necessary facilities for holding or rearing an adequate brood stock, spawning or stripping and fertilization of ova, incubation of fertilized ova and rearing of larvae to the required stage for transfer to nurseries or other culture facilities.

6.5.1 Source and supply of water

The selection of a suitable site for a hatchery is very important for its successful operation. Although, for various reasons, it is preferable to have it located near the grow-out farm, often a different site may have to be selected because of the water quality and quantity requirements. There are also cases where the hatchery forms an independent enterprise or is meant to produce seed for a number of grow-out farms. In principle, surface or ground water can be used in hatcheries, if it satisfies the necessary water quality criteria. Surface water from streams, rivers, lakes and the open sea may be relatively less expensive to utilize. However, very often there will be the need to filter the water and where there is a high content of silt it may be necessary to have a settling tank. Generally, sand or gravel filters with backflushing will make the water suitable for the hatchery. In salmon and trout hatcheries, where stricter water quality conditions are maintained, spring or borewell water is preferred, to eliminate the risk of contamination. As far as possible the source of water, or at least the entire course of the water supply system from the intake, should be under the control of the hatchery manager. Well water often has an excess of gas, which can cause gas bubble disease, but through adequate aeration (fig. 6.35) before use in the hatchery, this problem can be overcome. A large reservoir of properly aerated water from a spring can be a suitable source for a controlled water supply to a hatchery.

Water temperature is of special importance in a hatchery system, as the maturation of the brood stock, spawning, development of fertilized ova and growth of larvae are all directly affected by it. Spring water has often the advantage of constant temperature conditions. The temperature to be maintained in different units of the hatchery installation will depend on the requirements of the propagated species. It may be necessary or desirable to have provisions for regulating the temperature, as for example by mixing cold and warm water from separate supply lines or by the provision of an in-line heat exchanger, including a thermostatically controlled boiler which can be bypassed if heat control is not needed. While 20–30°C is generally the temperature requirement of warm water fishes, trout and salmon hatcheries maintain a temperature between 7 and 15°C. In tropical shrimp hatcheries, a temperature ranging between 20 and 29°C is suitable, but for the majority of species a temperature not lower than 25°C is considered optimal. In the giant fresh-water prawn hatchery a higher temperature of 30–31°C is recommended for better growth and survival. In oyster hatcheries a temperature of about 29°C is maintained.

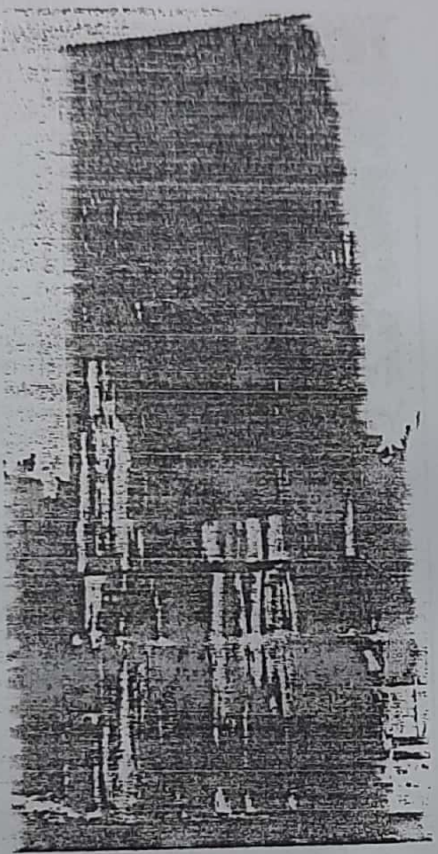

Fig. 6.35 Deepwell water being aerated through a tower for hatchery use in Poland (photograph: J. Walugo).

Dissolved oxygen and pH are other important properties of the water for hatcheries. The lowest safe level of dissolved oxygen for trout hatcheries is about 5 ppm, but a higher concentration of 7 ppm is preferred. According to Wickins (1981), salmonids and warm water crustacea should not be exposed to levels of dissolved oxygen below 5 mg/ℓ for more than a few hours. Equivalent levels for eels and carp range from 3 to 4 mg/ℓ. In other warm water species of fish and shrimp, slightly lower oxygen contents may be adequate. Oxygenation of water in a hatchery is relatively simple and is generally achieved by the manipulation of water flow from the source or the use of appropriate aerating devices. In salt-water hatcheries, maintenance of the required salinity can be important, although many species are quite tolerant of fluctuations within limits. In order to be able to regulate salinity when required, salt-water hatcheries generally maintain supplies of fresh water as well as sea water.

6.5.2 Reconditioning and recirculation of water

Where the availability of good quality water is limited, hatcheries have to resort to reconditioning and recirculation. In certain circumstances, it may also be considered necessary to reduce risks of infection by pathogens and parasites through continued use of water from external sources. When the water has to pass through a series of tanks, it has often been the practice in hatcheries to pump the water through an aerator, after it has passed through a certain number of tanks, before further distribution. Naturally, there are intrinsic dangers in such simple systems of recirculation. Though oxygen can be replenished through aeration and most of the carbon dioxide dissipated, the removal of metabolic products like ammonia will involve more complex systems, which besides reaeration and mechanical filtration may involve biological treatment. Recent designs of semi-closed systems employ one or more by-pass treatment units, such as for denitrification, oxygenation, ozonization, etc. In principle, such recirculation should make it economically feasible to grow warm water species in temperate climates by reducing the cost of heating. In practice, there are many constraints to its application in commercial aquaculture, but it can be used in hatchery situations, when essential.

Ammonia can be removed by nitrifying bacteria. Ammonia is first converted primarily by *Nitrosomonas* to nitrous acid, then by *Nitrobacter* to nitric acid. The acid combines with an available base to form nitrites and then nitrates. Nitrates are harmless in the recirculating system. Even in prolonged exposures in culture systems, no toxic effects have been reported below 100 mg/ℓ nitrate nitrogen (Wickins, 1981). Nitrite toxicity is influenced by water chemistry, but it has been suggested that concentrations in hard fresh water should not exceed 0.1 mg/ℓ nitrite nitrogen, and in sea water 1.0 mg/ℓ nitrite nitrogen.

There are several systems and designs employed in waste-water treatment for hatchery use as well as for intensive aquaculture. Many of them have been described in recent literature (for example Tiews, 1981). The most commonly used and relatively more economic treatment would appear to be biofiltration, which may incorporate downflow filters (e.g. trickling filters), upflow filters or horizontal flow filters. Several types of filter media are in use, such as sand, gravel, oyster shells, plastics, anthracite, activated carbon, diatomaceous earth and their combinations. Besides serving as strainers, they provide surface area for biological growth. Through biological growth and oxidation, ammonia is converted into nitrite and nitrate. The nitrate may be further combined with ions in water to form salts or reduced to nitrogen gas through a denitrification process. According to Liao and Mayo (1974), with a retention time of about 30 minutes and a hydraulic loading rate of 1.0–3.7 ℓ/s per m^2, about 48 per cent of the initial ammonia load can be removed.

A rotating biofilter process is employed as a secondary treatment. The basic unit consists of a half-cylinder tank, through the ends of which a horizontal shaft is mounted. As waste water flows through the cylinder, the discs, which are half submerged, are rotated. A layer of micro-organisms grows on the discs and acts as the aerobic biochemical agent to remove the dissolved wastes from the water. By arranging the discs in a series of stages, the rate of oxidation of the organic materials is increased by improved residence time. A surface area loading of 0.06–0.1 m^3/day per m^2 will be needed to achieve a better than 95 per cent removal efficiency for biological oxygen demand (BOD) decrease and nitrate nitrogen.

Ion exchange is an efficient and reliable means of ammonia removal, but it is much more expensive than biological filtration. Clinoptilolite, one of the zeolites used in water treatment, is an effective natural ion exchange material for the removal of ammonia from hatchery water. It has a high selectivity for ammonia. The minimum depth of an ion exchange bed is 0.61–0.76 m with a flow rate in the range 1.4–3.4 l/sec per m^2 (Liao, 1981). The regeneration is achieved by passing 5–10 per cent brine solution through the exchange bed, with a flow of 0.68–1.36 l/sec per m^2.

Although in principle it is possible to use aquatic plants, including algae, to remove metabolites and nutrients from water through assimilation or biological conversion there are practical difficulties, particularly for use in connection with a hatchery system. Another means of reconditioning water is through the use of an activated sludge process, in which biological oxidation occurs in the fluidized suspension of the sludge. Mention may also be made of the use of ozone, which is a very strong oxidizing agent and oxidizes the organics in the water and at the same time serves as a disinfectant. However, its use in hatcheries has not progressed beyond the experimental stage.

In all these systems there is the need for a regular supply of make-up water, at a rate of at least 5–7 per cent of the total volume, to replace the losses due to filter back-flushing, draining of the sludge and evaporation.

6.5.3 Hatchery equipment

Besides the installations for an adequate supply of water of the required quality, the other general equipment required in a hatchery includes tanks for brood stock; implements for collecting and handling breeders, for stripping and fertilization; spawning tanks where necessary, jars, troughs, tanks or other containers, net cages or 'hapas' (mesh cloth tanks) for incubating and hatching fertilized eggs; food dispensers; larval rearing tanks and aeration systems.

The brood tanks are very similar to the ones described in Section 6.2. There are a variety of implements used for collection, handling and transport of breeders in the hatchery. The main consideration is to avoid damage during collection and transport. In the case of large finfish, special hammocks have proved very efficient (fig. 6.36). Scoop nets are commonly used for catching brood stock for spawning. The simple tools used for stripping and fertilization are referred to in Chapter 15.

In shrimp hatcheries, circular maturation tanks of about 12 m^3 capacity made of fibreglass or cement concrete are used. The substrate consists of a layer of gravel (about 10 cm thick) separated from a 5–10 cm thick second layer of coral sand by a permeable synthetic cloth to prevent gravel from mixing with sand (AQUACOP, 1983). Concentric perforated plastic pipes fitted in a PVC tube (10 cm diameter) are embedded in the gravel. Water

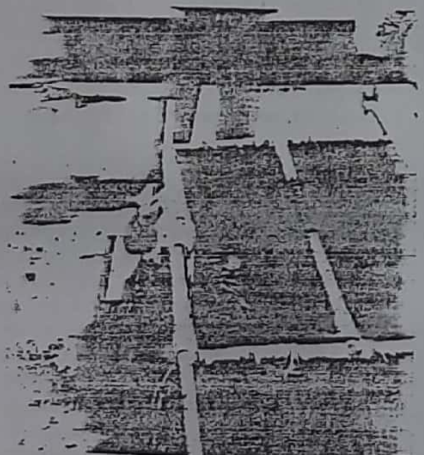

Fig. 6.36 Hammock used for transporting large brood fish.

that flows into these pipes passes through the sand, preventing the accretion of wastes and sediments in the sand. Water is discharged through two concentric tubes, allowing the bottom water to be drained first. Water exchange is achieved two or three times a day.

Spawning tanks may be built in the open, of concrete, with adequate arrangements for water circulation, as in the case of Chinese carp hatcheries (fig. 6.37). In shrimp hatcheries, indoor tanks of concrete or fibreglass are commonly used for spawning (fig. 6.38). Cylindroconical, 150 l capacity fibreglass tanks have been found to be very convenient (AQUACOP, 1983). The overflow passes through a concentrator provided with a 100 µm mesh that retains the eggs. A perforated plastic plate fitted over the conical bottom prevents the spawners from eating the eggs accumulated.

Different types and designs of incubators are used for hatching fertilized eggs, ranging from improvised earthen and polyethylene jars to sophisticated batteries of jars and troughs. To a certain extent, the degree of sophistication depends on the species, the size of the eggs and the magnitude of operations. However, the general principle involved is the provision of a regulated flow of good quality water of the required temperature, for the development and hatching of fertilized eggs and prevention of infections that will affect the hatching rate.

Troughs made of wood, concrete, aluminium, plastic or fibreglass are commonly used in many types of hatcheries (figs 6.39 and 6.40). The size varies, but an average size may be about 3 m × 0.5 m × 0.25 m. They are generally screened at the intake to prevent the entry of detritus and at the outflow to prevent the escape of larvae. By the use of vertically adjustable screens, the depth of water in the trough can be regulated. As an alternative, the water depth can be regulated by adjustable elbow pipes.

In the case of trough-type incubators, such as the ones used in trout and salmon hatcheries, there are egg baskets fitted in the tray. The perforations are of the shape and size to retain the eggs, but allow the hatchlings to fall through to the water below in the trough (fig. 6.41). In order to allow aeration of the eggs, water is forced upward through the perforations.

Special glass jar incubators (known as Zuger jars, Weiss jars or Zug-Weiss jars and MacDonald jars) and plexiglass or other plastic funnels (figs 6.42 and 6.43) as well as less expensive sieve-cloth funnels and even earthen jars are used for incubating non-adhesive eggs (figs 6.44 and 6.45). Even in cases like the common carp, these devices can be used after removing the sticky layer.

In oyster hatcheries, mature male and female oysters are spawned individually in battery jars containing filtered water of the required temperature (about 27°C). The spawned eggs and milt are filtered out and the ova fertilized. Larval tanks are provided for the development and hatching of the ova and for rearing through various larval stages.

Different types of larval rearing troughs, tanks and pools are in use and some types are readily available from manufacturers. The basic requirements are proper circulation and drainage of water to keep them well supplied with clean oxygenated water and prevent accumulation of waste products. For rearing carp larvae, circular cement pools built on the ground are commonly used. For hatching and larval rearing in Indian carp culture, meshed cloth tanks (hapas) fixed on the pond bottom by means of stakes (fig. 6.46) are widely used. It is common to have double tanks (fig. 6.47), the inner smaller tank with fine mesh holds the fertilized eggs for hatching. The hatched larvae fall into the outer larger cage, leaving behind the egg shells and debris. The inner cage can easily be removed after hatching. Rectangular cement cisterns, with an adequate water supply and drainage, are also used in many places.

6.5.4 Layout and accessories

Although some of the simple and improvised hatchery systems such as the carp hatcheries in China and India are built in the open, modern hatcheries are installed indoors. In some cases the larval rearing may be carried out in tanks, pools or ponds outdoors, but where water temperature has to be controlled they are generally provided with at least a protective roofing.

There are many ways of arranging the installations in a hatchery. Some have maturation, spawning and fertilization, hatching and larval rearing in different sections. Others have most of them in one area, particularly when there are limitations of space. An important factor

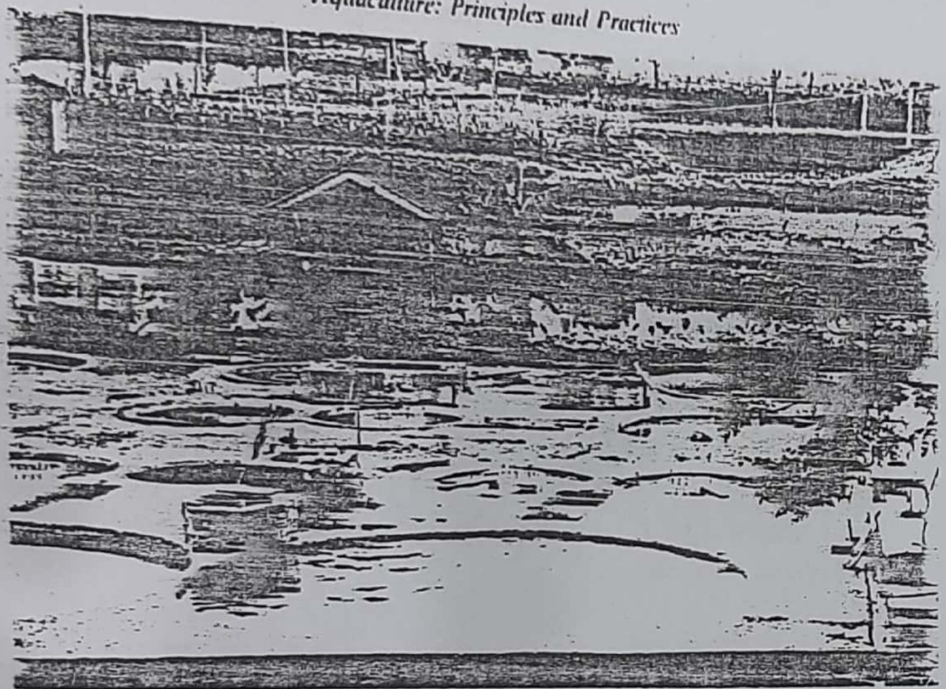

Fig. 6.37 Cement concrete spawning tanks in a Chinese hatchery.

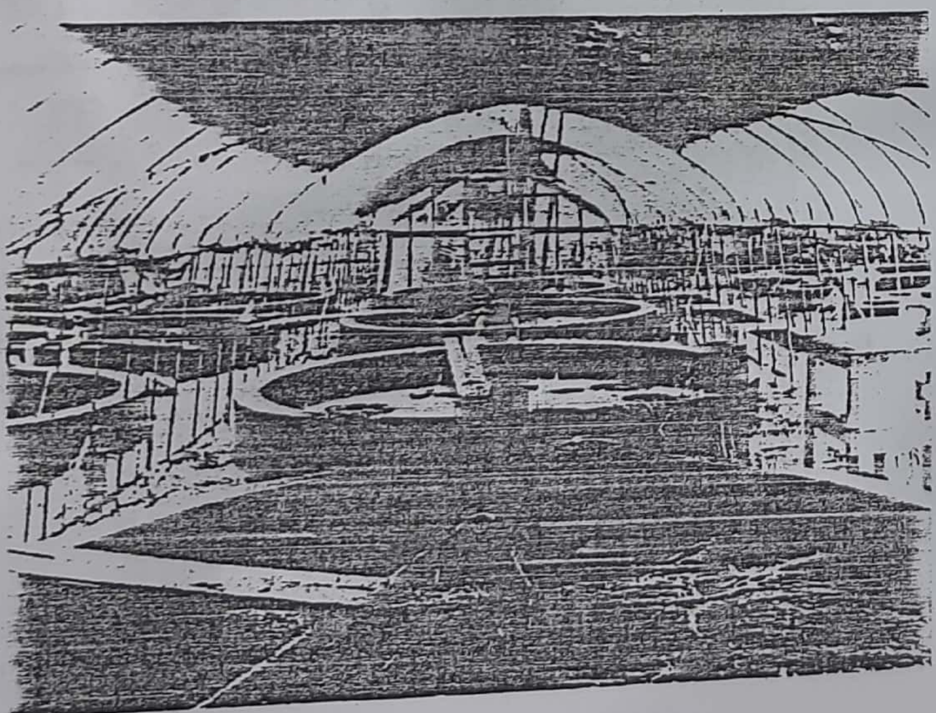

Fig. 6.38 Indoor shrimp spawning.

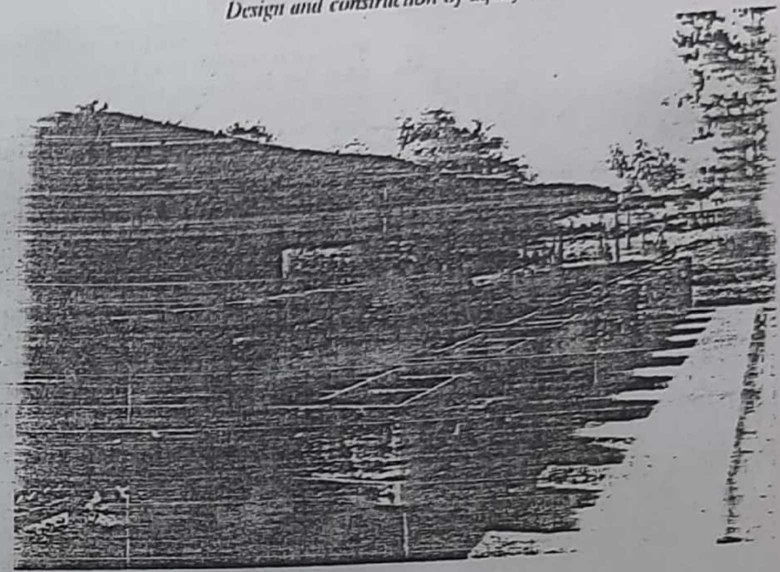

Fig. 6.39 An example of simple hatchery troughs made of wood.

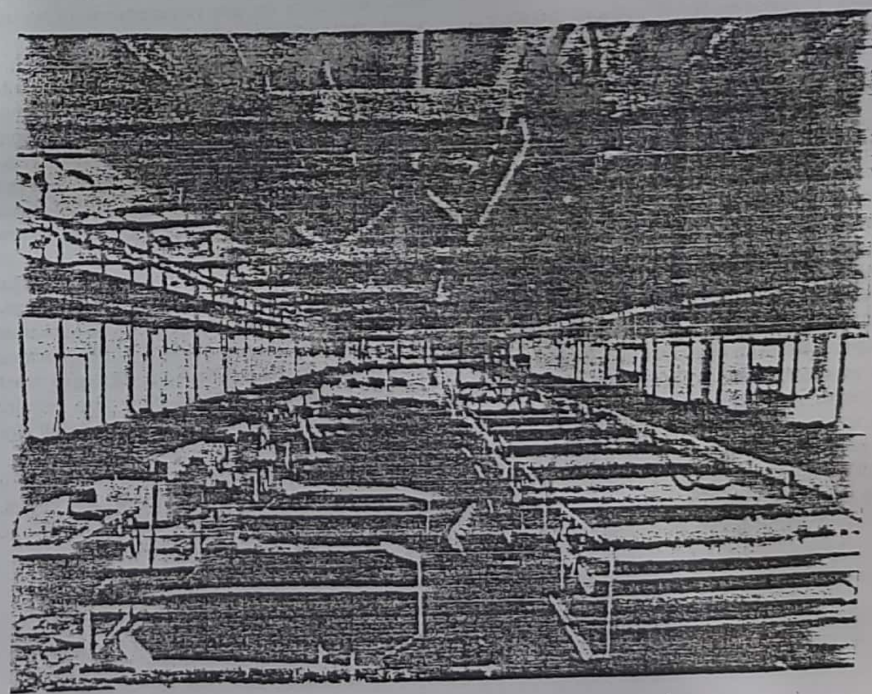

Fig. 6.40 Troughs made of fibreglass and aluminium used in a modern carp hatchery in Hungary.

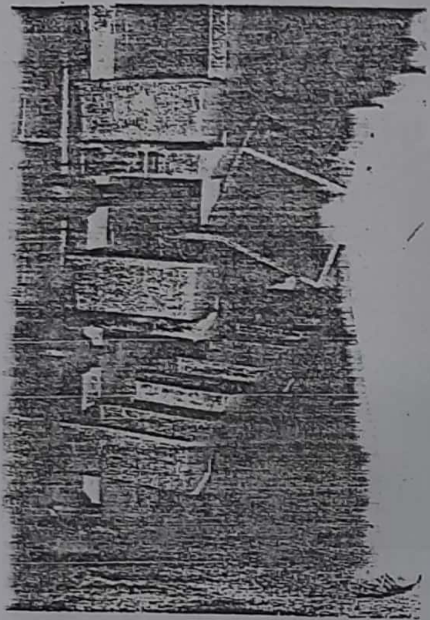

Fig. 6.41 Trough-type incubators with egg baskets, used in a salmon hatchery (courtesy of Ola Sveen).

that would determine the arrangement of the equipment is the convenience of water distribution and drainage. The main supply channel or pipe could run along one wall of the hatchery building or along its centre. The latter is more common, when the tanks and incubators can be installed on either side of the supply system, with drains along the walls. The size of the water supply system should be adequate to carry one and a half times the quantity of water required for operation of the hatchery. When siting supply lines, it will be advisable to take into account possible future expansion of the hatchery. An overhead reservoir or a head tank from which the water flows by gravity will be very useful in maintaining a constant water pressure in the system and consequently a uniform flow in the hatching units. It also serves as a stand-by in times of power failure.

In order to save space and reduce the use of water, it is possible to stack the troughs or trays used for incubation and larval rearing, one above the other. Battery incubators are available from manufacturers. They consist of vertically stacked troughs, each having an egg tray and a cover. Each trough can be pulled out separately for inspection. The water flow will pass downwards through each vertical trough stack, trickling through each one from top to bottom.

As indicated earlier, control of water temperature is an important factor in all stages of hatchery operation. If the natural supplies of water need to be heated or cooled for maintaining the required temperature, it will be necessary to install equipment for this purpose. Electrical heating and cooling would probably be the best, but economic considerations and availability may make it necessary to look to other sources such as heated water from industries and power stations. Most hatcheries would require some type of aeration system. Air blowers and air stones are commonly used to provide the aeration that will be needed to meet the extra oxygen requirements in brood stock and nursery tanks.

Suitable means of dispensing feed in maturing and larval tanks have to be provided. Different types of automatic feeders are available (see Chapter 7), but in many hatcheries manual feeding is still the common practice. In crustacean and mollusc hatcheries, there is also the need to have facilities, for algal culture to feed the larvae, besides an artificially lit room for maintaining algal cultures. Large concrete or fibreglass tanks can be used to grow the algal food required. The algal tanks can be outdoors, but if kept indoors there has to be adequate lighting. The tanks should also be provided with proper aeration through air stones or other devices. Shrimp hatcheries may also require similar tanks for hatching Artemia cysts, for feeding the larvae.

Besides suitable storage space for feeds, it is desirable to have, in large hatcheries, some laboratory space for routine tests and examinations.

Fig. 6.42 Glass jar incubators.

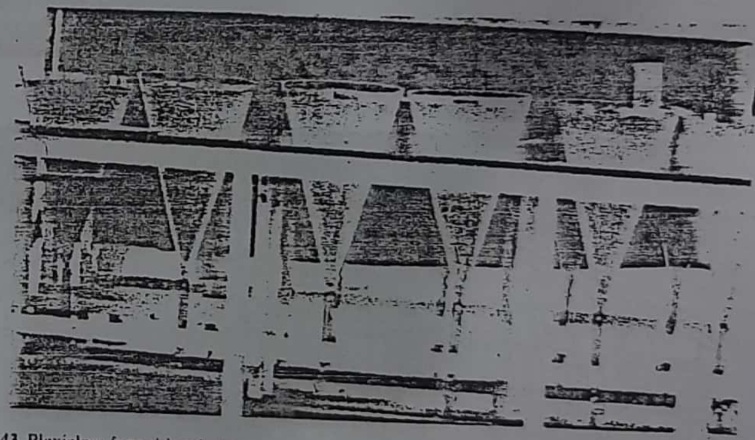

Fig. 6.43 Plexiglass funnel incubators.

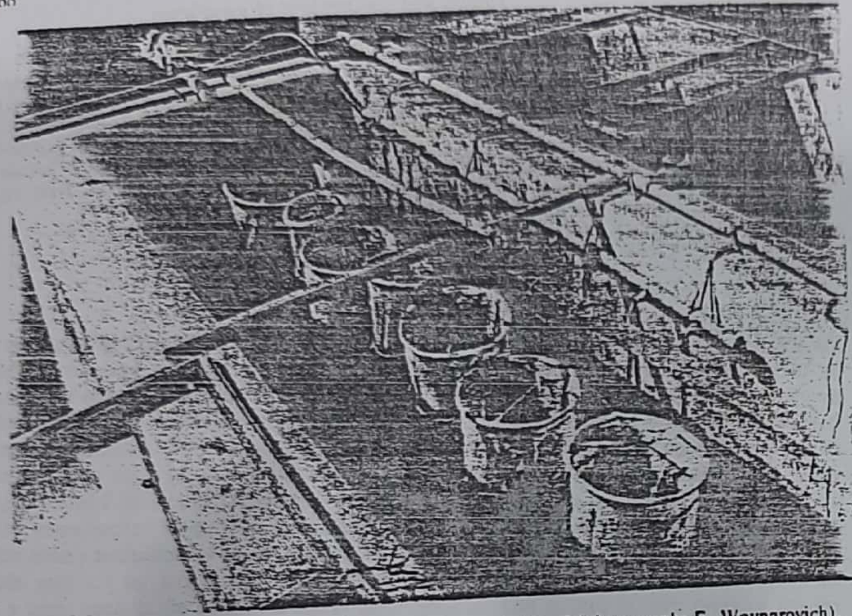

Fig. 6.44 Sieve-cloth incubators used for hatching carp eggs in Nepal (photograph: E. Woynarovich).

Fig. 6.45 Earthen jars used for carp egg hatching in Nepal (photograph: E. Woynarovich).

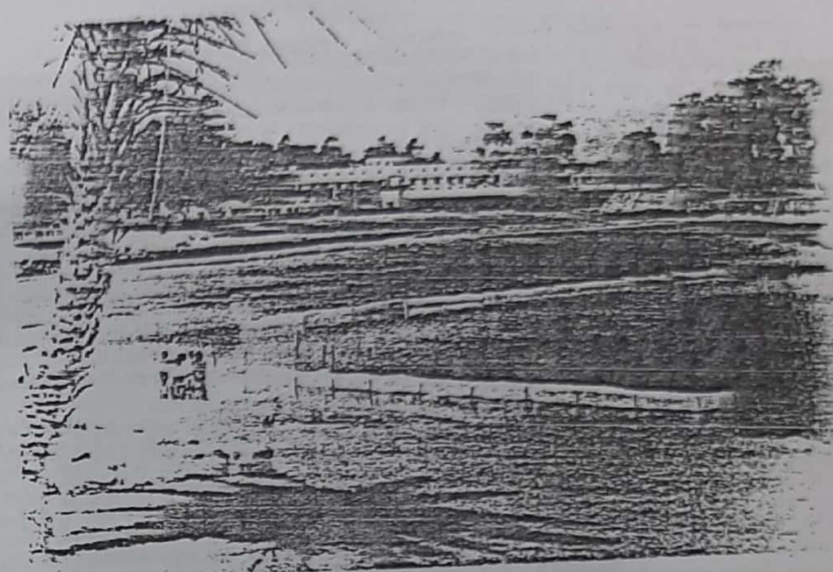

Fig. 6.46 Hapas (cloth tanks) used for rearing carp larvae in India.

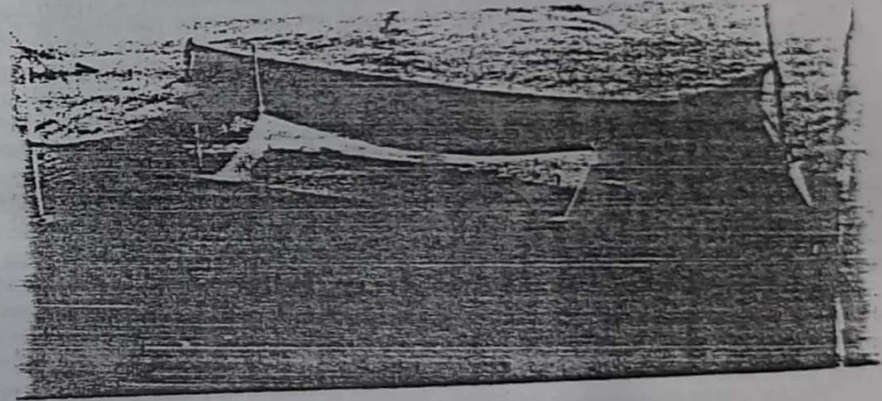

Fig. 6.47 A double hapa for hatching carp eggs.

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8
Reproduction and Genetic Selection

As discussed in Chapter 5, one of the major criteria in selecting a species for culture is the existence of either suitable techniques for controlled breeding or easy availability of spawn, larvae or juveniles from natural breeding grounds. Even when culture can be initiated using 'wild seed', it is essential to achieve controlled reproduction as early as possible, to ensure timely availability of young ones in adequate numbers for large-scale rearing. It is also a basic need in the domestication of the animal and for taking advantage of the benefits of genetic selection and hybridization that have contributed so much to terrestrial agriculture and animal husbandry.

Controlled breeding will obviously be possible only if there is adequate knowledge of the factors governing reproduction of the animal and its breeding behaviour. Lack of such knowledge has hampered the progress of aquaculture of several important species. The extensive culture of Chinese carps, Indian carps, mullets, milkfish, sea-bass, sea-bream, penaeid shrimps, oysters and mussels has been based until recently on 'seed' obtained from natural breeding. Despite advances made in techniques of controlled or semi-controlled breeding, the techniques have not been sufficiently perfected or adapted for large-scale production of seed, with the result that the aquaculturist has still to depend partially or entirely on natural seed resources. There are also species like the eels for which no propagation technique has so far been developed, even though some progress has been made in maturing and spawning under laboratory conditions.

Among the aquaculture species, finfish as a group has received greater research attention in controlled reproduction. The reproductive cycles of almost all fish are regulated by environmental stimuli. Appropriate sensory receptors convey the environmental stimuli to the brain in the form of neural inputs. This neural information, on reaching the hypothalamus, causes the release of hypothalamic peptides known as releasing hormones, which in turn stimulate the pituitary gland to release the gonadotropic hormone(s), which act on the gonads. The gonads in turn produce the sex steroid hormones which are responsible for the formation of gametes, as well as for the regulation of secondary sexual characteristics, nuptial coloration and breeding behaviour. This pattern of reproductive mechanism provides the basis for methods of induced reproduction, namely the provision of appropriate environmental stimuli and the administration of hormones for maturation and release of gametes.

8.1 Reproductive cycles

The large majority of aquaculture species are seasonal breeders, although some breed intermittently or continuously. Seasonal breeding is generally related to climatic seasons. For example, most fresh-water fish of temperate zones spawn in spring and early summer, but the salmonids spawn in autumn. Rainy season and flood waters are associated with the spawning of fresh-water fishes of tropical and subtropical regions of Latin America and Africa. Obviously the fishes integrate their own reproductive functions with environmental cycles. The breeding season appears to coincide with environmental conditions that are most conducive to the survival of the offspring. These favourable factors, that act as cues for a suitable

breeding season, affect the central nervous system and through it the pituitary and the gonads. Photoperiod, temperature and rainfall are important factors involved in regulation of the reproductive cycles.

Mechanisms of reproductive timing vary very considerably among species. For example, in salmonids that spawn in the autumn, gradually increasing photoperiods followed by short photoperiods or decreasing photoperiods have a major role in regulating the cycle. Temperature has an important role in the reproductive cycle of cyprinid species. Gonadal recrudescence takes place in Indian carps during the period of the year when both photoperiod and temperature are increasing. Changes in the volume and velocity of water, flooding of shallow areas and dilution or replacement of water are also considered to be important factors. Warm temperatures and long photoperiods appear to affect also the reproductive cycle of Chinese carps. A review of available information would appear to show that in the majority of cases gonadal recrudescence is regulated chiefly by seasonal variations in photoperiod and temperature, while spawning may be controlled by temperature and/or rainfall.

The age of sexual maturity varies widely between species. For example, tilapia species become mature within a few months, whereas others may take a few years. The same fish may mature earlier in a warm climate and much later in colder climates: examples of this are the common carp and the Chinese carps. The common carp, which takes three to four years to mature in Europe, takes only a year to attain maturity in tropical regions. Chinese carps that take five to seven years to mature in Europe become mature in one to three years in tropical and subtropical conditions.

Some species have only one spawning season, during which they may spawn several times. Others may have two or more spawning seasons. Some species of finfish exhibit well developed parental care, which may consist of incubating fertilized eggs in the buccal cavity of the parent, or guarding the eggs and larvae during development. Many of the species that exhibit parental care lay eggs in nests made of plant or other available material or in hollows dug out on the bottom.

Some of the species like the Chinese and Indian carps that are essentially riverine spawners would not spawn in the confined waters of fish ponds or other enclosures. Their gonads develop only up to a certain stage and then remain dormant until resorption sets in. They have however, been observed to spawn in special types of ponds (called bundhs in India) that have a flow of fresh rainwater, inundating shallow marginal areas where the conditions are favourable for the fish to breed. The simulation of conditions in natural spawning grounds may serve to induce certain fish to breed in confined areas. The provision of nest-building material for nest-breeding species and the provision of artificial substrates for the attachment of eggs required for certain species are also believed to induce spawning.

8.2 Control of reproduction

In aquaculture, the main purpose of controlled reproduction is to achieve sexual maturation and spawning at the time of the year which is normal to that species. As mentioned earlier, some species will not breed in the confined waters of an aquaculture facility. In other cases, maturation and spawning are unpredictable, because of the culture conditions or environmental factors. Controlled reproduction can also be of considerable importance in advancing or retarding the spawning period as required. This can help in making available young ones at appropriate times or of appropriate sizes. A higher level of reproduction control would involve development of the capability to mature and spawn a species at any time of the year, in order to enable continuous production and marketing throughout the year.

The two major types of control that are possible, consist of (i) manipulation of the reproductive cycle and (ii) induction of gonadal gamete release (ovulation and spermiation). The reproductive cycle is manipulated so as to have gametes available when needed. This may be initiated in the juvenile stage, or advanced or retarded in the adult stage. Altered gonadal gamete release can be achieved by hormonal supplementation, manipulation of environmental factors or the use of special selected strains.

... egg yolk for their nutritional requirements. Vitellogenesis, or the process of yolk deposition in oocytes, is a seasonal or cyclic phenomenon. All stages of it, starting with the mobilization of lipid from storage sites, the synthesis in the liver of a female-specific glycolipophosphoprotein, vitellogenin, and its eventual deposition in oocytes are known to be gonadotropin-dependent.

The interaction between the brain, pituitary gland, testis and ovary largely mediates the influence of environmental factors on the reproductive development of finfish. The thyroid and interrenal may also have a less important role. The substance formed by the nucleus lateralis tuberis in the hypothalamus, which is responsible for such influence is the gonadotropin-releasing factor or releasing hormone. In the case of mammalian luteinizing hormone (LH) and follicle stimulating hormone (FSH), the releasing activities for these two hormones have been shown to be present in the same peptide, which consists of a chain of ten amino acids (Schally and Kastin, 1972). The molecule is referred to as LH-RH. The presence of LH-RH has been demonstrated in certain species of fish (Crim *et al.*, 1978) and it has also been demonstrated that mammalian LH-RH or its analogues in large doses bring about the release of gonadotropin.

Even though attempts have been made with salmonids, the induction of a completely new reproductive cycle has not yet been successful. Chronic administration of gonadotropic hormones can, however, initiate a normal reproductive cycle and assure its progress. By pellet implantation of hormones, it has been possible to advance normal spawning by one year in pink salmon. The release of gametes can be advanced by a single dose of hormone. Similarly, it has been demonstrated that hormone injections can induce late ovulations, as in brown trout, when maturity is blocked by adverse environmental conditions.

As mentioned earlier, the two major environmental factors that affect maturation and spawning are the photoperiodic regime and temperature. Although any definitive conclusions regarding the independent influence of photoperiodism have not been possible, there is enough evidence of the combined effect of ... species. When, by manipulation of these factors, early maturation is achieved, egg-laying can more easily be synchronized by hormonal injection. This helps in predicting ovulation more precisely and in avoiding ageing of ova, which may occur at high summer temperatures. There is considerable experimental evidence of the independent role of temperature in maturation and spawning. It is believed that spawning is timed to ensure that gametes are released into water whose temperature is within the appropriate stenothermal conditions for embryonic development. While the precise mechanisms by which temperature regulates reproductive development are not known, it is presumed that it acts as a triggering mechanism at the hypothalamic level or alternatively exerts a generalized stimulatory effect on metabolic rate. The influence of rainfall on the spawning of certain species, as referred to earlier, is also ascribed to the combined effect of temperature and photoperiod, plus the dilution of inhibitory elements in the water.

Another means of reproductive control, oriented to spreading egg production over the year, is through the use of selected strains for early or late spawning. Strains have been developed that spawn for much longer periods than normal for the species. There is also the possibility of using in a farm several strains, reproducing at different times of the year, in order to ensure the availability of young throughout the year.

8.3 Induced reproduction

As explained in the previous section, the hypothalamus regulates the reproductive functions of the pituitary gland. The correct combination of environmental factors required for maturation, ovulation and spawning, brings about an accelerated release of gonadotropin from the pituitary into the bloodstream. Ng and Idler (1978 a, b) and Idler and Ng (1979) have isolated two gonadotropic hormones: one with a low carbohydrate content that induces vitellogenesis and the other which is rich in carbohydrates, inducing maturation and ovulation. The surge of gonadotropins that occurs brings about maturational changes culminating in the act of spawning. Environmental conditions required for the initiation of oocyte maturation, ovulation and spawning are much more complex than those for gametogenesis.

Very often under culture conditions, the required environmental conditions may not be available, or may not persist for a sufficient length of time for spontaneous maturation to occur. This has led to the development of induced reproduction or hypophysation techniques (Houssay, 1931; Von Ihering, 1935 and 1937). By the injection of pituitary homogenates (fig. 8.1), the natural gonadotropin surge is simulated, by-passing to some extent the environmental variables of temperature, rainfall, photoperiod, etc. Besides the advantage of regulating the time of spawning, it enables the adoption of other methods of artificial propagation, including hand-stripping (fig. 8.2), fertilization, incubation, hatching and larval rearing. While hypophysation techniques have been demonstrated to be effective in a large variety of fish species, its major contribution in respect of aquaculture technologies, since its first field application in Brazil in 1935, has been in the inducement of spawning in fishes that do not ordinarily breed under conditions of confinement or do so only under specific environmental conditions. It has now become a common practice in many countries and utilized widely in the reproduction of finfish, despite the fact that the relevant mechanisms are not fully understood and little standardization of the techniques has been achieved.

Vitellogenesis in decapod crustacea, particularly Penaeid shrimps and lobsters, has been shown to be mediated by hormones. Male shrimps mature fully under captive conditions and spermatophores can be seen through the carapace. Female shrimps often do not mature fully, even though maturing eggs can be found in the ovaries. The maturation process seems to be inhibited by a gonad-inhibiting hormone (GIH), secreted by the medulla terminalis ganglionic x-organ (MTGX) and stored in the sinus gland. The y-organ, which secretes the moult hormone crustecdysone, also has an influence on maturation. The ablation (surgical removal) of eye stalks, which have the glands containing the inhibitory hormone, has been shown to accelerate vitellogenesis in many crustaceans. Besides environmental factors like temperature, photoperiod, salinity and pH, the state of nutrition of brood animals seems to be an important factor in the maturation and spawning of shrimps.

8.3.1 Hypophysation

A more detailed description of the techniques of induced spawning, including environmental control employed for the breeding of important aquaculture species, can be found in Part II. Only some of the common features of induced spawning, with special reference to finfish, will be discussed here.

The mammalian gonadotropic hormones, LH and human chorionic gonadotropin (HCG), are effective in inducing maturation and ovulation in fishes. Although a number of species have been induced to breed by the administration of HCG or a combination of HCG and mammalian pituitary extract, there are certain refractory breeders, like the Indian and Chinese carps, where fish pituitary homogenates or extracts are needed to induce spawning. There are reports of successful breeding of even these species, by using HCG under certain circumstances. The Chinese carps, which have been bred two or three times by administration of fish pituitary extract, will respond positively to injections of HCG. Bhowmick (1979) has reported on the use of crude HCG for induced spawning of one species of Indian carp, *Labeo rohita*. It has, however, been reported that repeated injections of HCG could induce a 'drug resistance effect' related to the production of antibodies against foreign proteins. Nevertheless, it would appear that homogenates and extracts of whole pituitary glands and partially purified fish gonadotropins are more potent in inducing maturation and ovulation in fishes than mammalian gonadotropins, and can be used extensively in commercial fish culture.

While the administration of the appropriate hormone is basic to the success of induced breeding, the condition of the brood fish and the environmental conditions are also equally important. The large number of failures in induced breeding can often be traced to poor condition of the brood fish, including their health and nutrition and stage of gonadal development, as well as to environmental conditions in spawning tanks or enclosures.

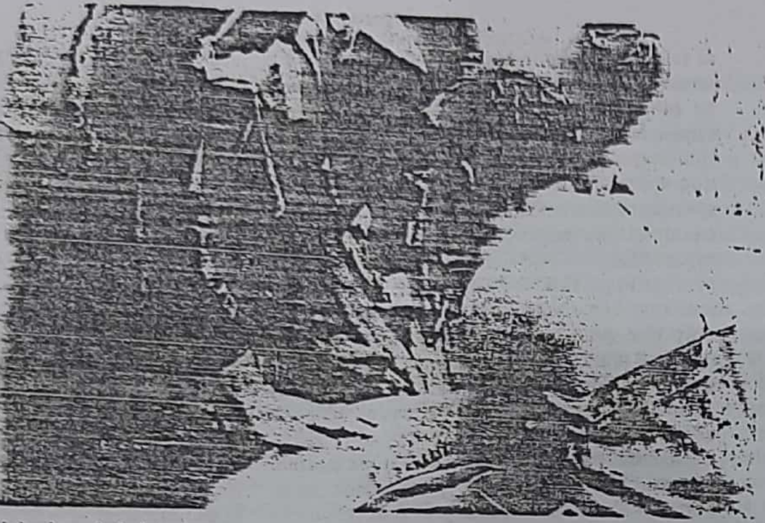

Fig. 8.1 Injection of pituitary homogenates to induce spawning.

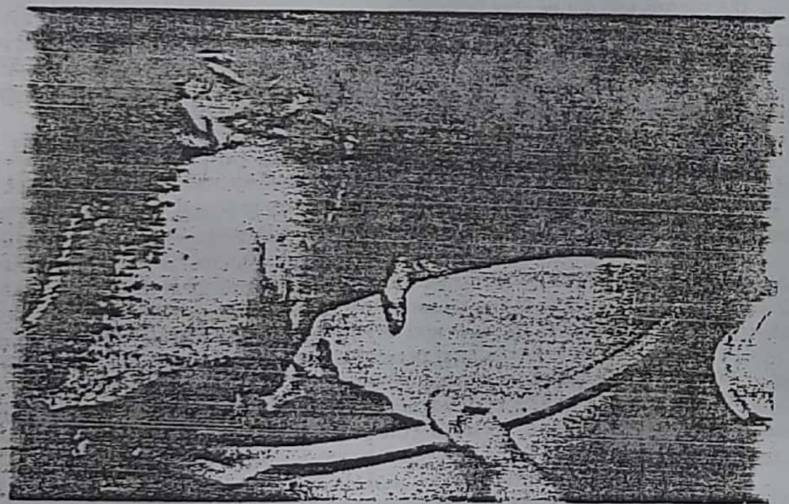

Fig. 8.2 Hand-stripping of a mature female fish.

Chinese farmers believe that it is more difficult to breed wild Chinese carps, as well as carp that have attained maturity for the first time. They prefer to rear spent fish in special holding ponds, fed on a special protein diet, for future breeding.

The identification of sex is another important requirement for successful induced breeding. Many species do not have distinctive and permanent sex characteristics. When there are no secondary sex characteristics, detailed morphometric characteristics will have to be

used to separate sexes, particularly in the pre-puberty stages. After sexual differentiation, it may be possible to distinguish the sexes through examination of the gonads. This will involve the use of endoscopy or biopsy, which is difficult to use on a large scale. Siphoning of eggs and their examination under a microscope, to determine the stage of maturity of females, have been described by Chen *et al.* (1969) but the adoption of this method in large-scale breeding work is not always very practical. Other possible methods, such as the use of serum markers or detection of circulating vitellogenin, are also difficult to use in the field. Aquaculturists have therefore to depend largely on practical experience and field observations to distinguish the sexes and determine the stage of maturity of breeders. Brood female fish ready for spawning are identified by the well-rounded and soft abdomen and swollen genital opening. The male releases a few drops of thick milt when its abdomen is slightly pressed.

As indicated earlier, several species of fish respond to injections of HCG and other mammalian hormones, and these hormones are commercially available to aquaculturists. Many species, which are more difficult to spawn under confinement, need injections of fish pituitary for maturation and spawning. There are differences of opinion regarding the species-specificity of the pituitary, but aquaculturists generally prefer to use the glands of the same or closely related species. It is recommended that pituitaries from phylogenetically close donors should be used, when there is a choice. However, common carp is considered a universal donor and its pituitary is being used very widely for both experimental and commercial breeding purposes for several species. Salmon pituitary is also used for breeding a number of species. Though commercially available on a limited scale, a large majority of aquaculturists have to depend on local arrangements for the collection and preservation of the glands. Glands of the recipient species or of other proven donor species are used. Fractionation and purification of teleost gonadotropins are still in experimental stages. Though potent gonadotropic preparations have been made from fish pituitaries by means of chemical/ethanol fractionation, they have not been used widely in spawning refractory fish.

Glands extracted from catches of the selected mature donor species are preserved in alcohol or acetone or frozen for storage. Freshly collected glands are first desiccated in absolute ethyl alcohol (changing the preservative several times) and then stored in fresh alcohol at room temperature or under refrigeration. The glands remain active for a period of about two years. Instead of alcohol, the glands can be desiccated in acetone, changing it several times as for alcohol. The desiccated glands are dried in vacuum and stored in that condition or sealed in vials and stored in frozen condition. Acetone-dried glands retain their activity for 6–10 years. The glands can also be preserved by quick freezing, but the most common method of preservation is acetone drying.

Though a number of methods of preparing pituitary homogenates and extracts have been tried, the most commonly accepted method is extraction with distilled water or saline solution. The glands are macerated in a small volume of water or saline solution and brought up to the desired volume. Distilled water, common salt solution (0.3–1 per cent) and physiological saline can be used, as they all seem to give equivalent results. The homogenate can be used as such for injection, or filtered or centrifuged to obtain filtrate or supernate which can be injected. Extraction with trichloracetic acid (TCA) at low concentrations of 1.25–2.5 per cent for short time-periods of 3–6 hours, is reported to provide more complete extraction and better results. But this practice has not received wide acceptance, probably because of the specific requirements of concentration and extraction time. It is reported that higher concentrations and/or longer extraction, can result in denaturation of glycoproteins.

As pituitary extracts are subject to rapid enzymic deterioration, they have to be prepared fresh every time fish are to be bred. This is obviously inconvenient. Methods of preserving extracts have been tried with some success. One method involves the extraction of pituitary glands in a small volume of distilled water, and refrigerating it for 24–48 hours, after which glycerine is added to make a 2:1

ratio with water. The suspension is again refrigerated for 24–48 hours, centrifuged and the supernate stored under refrigeration in air-tight vials. Another method consists of grinding acetone-dried pituitaries, sieving them through 40–60 mesh/mm² sieves and storing in sealed vials at 5°C. Both these techniques are aimed at achieving homogeneous preparations of uniform potency.

Despite its wide use, the dosage frequency and latency period of pituitary administration remains more or less at a trial-and-error stage, and sometimes leads to poor results. This is mainly on account of the variations in the gonadotropic content of the pituitary material used and the stage of sexual maturity of the brood fish, besides the environmental conditions and the stress to which the breeders are subjected. The mode of injection (intraperitoneal or intramuscular) also appear to affect results. Development of an acceptable method of assessing gonadotropic content should greatly assist in determining practical dosages. Though several biological units have been proposed, none seems to have gained wide acceptance.

8.3.2 Gametes and fertilization

Injection of pituitary homogenate or extract is usually given into the dorsal muscles above the lateral line and below the anterior part of the dorsal fin, or the dorsal part of the caudal peduncle. Injections into the body cavity are considered less efficient. The required quantity of the gland is generally administered in two to four doses (one or more preparatory injections followed by one or more final doses). As indicated earlier, suitable environmental conditions, besides pituitary injection, will be needed for ovulation to take place. Temperature, high dissolved oxygen levels and lack of stress are some of the important requirements. The process of ovulation takes some time, depending on the species and environmental conditions. Maturation of the ovum starts when its nucleus starts to migrate from the centre toward the micropyle and undergoes hydration by absorbing fluids. Ovulation starts with the disappearance of the nuclear membrane and ends with the first meiotic division. At the same time, the follicle which attaches the eggs to the wall of the ovary splits and releases the eggs into the cavity of the ovary, from where it can freely flow through the genital opening.

Many of the fish that are treated with gonadotropic hormones start to spawn in the presence of active males after normal ovulation. The eggs are fertilized by the male breeders and the fertilized eggs can be collected easily for hatching. Where such induced spawning does not occur, it becomes necessary to strip the sex products from the females and males and artificially fertilize them. Ripe ova remaining unspawned for long periods after ovulation become over-ripe and do not develop normally. It is also not uncommon for the phenomenon of 'plugging' to occur in gravid females subjected to overdoses of hormone. In such cases, natural spawning cannot be accomplished, since a mass of ovarian eggs forms a plug at the urinogenital opening, preventing the free flow of eggs. Stripping will be necessary to obtain eggs from such fish. Stripping and artificial fertilization are necessary also for fish with sticky eggs like the common carp. Such eggs will have to be treated to dissolve the sticky layer, so that they can be incubated in suitable incubators. A quick washing with a weak tannin solution after the eggs have swollen will be effective in removing the stickiness of the eggs. Common salt and carbamide (urea) solution can also be used for removing the sticky layer.

The ovulated egg which has undergone the first meiotic division will have the second meiotic division when the sperm penetrates it, ending in the extrusion of the second polar body. Further embryonic development leading to the formation of the first somatic cell completes the process of fertilization. The time available for the ripe egg to become fertilized is rather limited in most fresh-water fish, as the eggs swell rapidly in water and this results in the closure of the micropyle. The time available for common and Chinese carps is about 45–60 seconds. In saline solution the eggs seem to remain fertilizable for longer periods, up to several minutes.

The sperm, which is immotile in the testis, becomes motile on contact with the medium in which fertilization takes place. The duration of the activity of spermatozoa varies with the species, but is generally not longer than a couple

of minutes. In the males of most species, dense semen having highly motile spermatozoa can be obtained without hormone injection. Administration of pituitary extracts brings about thinning of the seminal plasma and would facilitate spermiation. Relatively large numbers of spermatozoa are needed to ~~fertilize an egg~~. For example, the requirement of a trout egg is reported to be 10 000–3 000 000 spermatozoa and of a carp egg 13 000–30 000. This is due to the fact that the spermatozoon can penetrate at only one place, i.e. the micropyle, and the distance that can be covered by a trout spermatozoon during its life span (2 mm) is often less than the circumference of the ovum which is about 15–20 mm. The probability of it reaching the micropyle is therefore low, if the motility is less. The number of spermatozoa compensates for the low motility. It is necessary to take special care in regulating the quantity of water added to the sexual products during fertilization. If too much water is added, many of the sperms will not be able to reach the micropyle. On the other hand, if sufficient water is not added, the micropyle of an egg may get blocked by other eggs, due to crowding, preventing the sperm from entering it.

8.4 Preservation of gametes

In many species, the maturation of gonads in the two sexes is not synchronous. Males often show testicular recrudescence earlier during the season. Because of this, ripe males occur during the beginning of the season, when the females are not yet mature and ready for spawning. The reverse situation occurs during the end of the breeding season. Under such circumstances, it will be most advantageous to have a suitable means of preserving the gametes for artificial fertilization, when needed. Methods of gamete preservation would also help in the initiation of genetic selection programmes, by providing easy access to a reserve of genetic material of known and desired qualities.

Cryopreservation with liquid nitrogen, used widely in the preservation of cattle and livestock sperm, has been tried for the preservation of a number of species of fish. Blaxter (1955) reported successful fertilization of fresh eggs with cryopreserved (−79°C) sperm of *Clupea harengus*. Sections of ripe testis were stored in 80 per cent sea water containing 12.5 per cent glycerol as a protector, and the mixture frozen quickly or slowly at 1°C/min to −30°C, then quickly to −79°C (using dry ice). Besides the sperm of rainbow trout, spermatozoa of the common carp, Chinese and Indian carps and grey mullet are among the cultivated species which have been subjected to cryopreservation, which consists of cooling and storing at sub-zero temperatures of liquid nitrogen (−196°C), using dimethyl sulphoxide, glycerine, ethyl glycol or other cryoprotectants and diluents (Harvey and Hoar, 1979). Attempts at cryopreservation of ova have not been as successful as for sperm. Zell (1978) reported the first successful cryopreservation of unfertilized ova and zygotes of salmonid fish. Ova frozen in liquid nitrogen at −20°C for 5 minutes proved to be fertile, and zygotes frozen at −50°C survived the exposure. All subsequent attempts have failed. While it is difficult to predict possible advances in cryopreservation of fish gametes, it would appear that the results so far indicate only the feasibility of short-term preservation of semen or the prolongation of embryonation.

8.5 Use of sex steroids for sex reversal

In certain situations and species, it will be advantageous to restrict fertility. A well-known example is the cichlid tilapia, which attains maturity at an early age and breeds repeatedly at short intervals, overpopulating ponds and other rearing facilities. This results in stunted populations, as energy is expended for reproduction rather than growth. Among the techniques that can be employed for restricting fertility is the application of hormones to produce monosex populations. Androgenic and oestrogenic steroids are used for masculinization of genotypic females and feminization of genotypic males (Jalabert *et al.*, 1974; Guerrero, 1975, 1979; Shelton *et al.*, 1978). Genotypic female fry of the species of *Sarotherodon* (= *Tilapia*), when fed on methyltestosterone and ethynyltestosterone have become males. Similarly, monosex female tilapia have been produced by treatment with oestrone, ethynyloestradiol and stilboesterol. While the feasibility of sex reversal by steroid administration has been demonstrated, the percentage of fish that underwent sex change in any treated group varied greatly. Since the presence of even a small percentage of the opposite sex in a population is sufficient to initiate uncontrolled breeding, the value of the results achieved so far becomes less significant. Similar experiments to produce monosex fish have been conducted with salmonids and other species. Sex inversion of the protogynous species of *Epinephelus* (*E. tauvina*) has been accelerated to produce male brood stock from three-year-old females, by oral administration of methyltestosterone. Production of all-female eggs is now a common practice in a number of rainbow trout hatcheries (see Chapter 16.1.2). The initial functional males required for fertilizing ova from normal female brood stock are obtained by sex reversal, by treating with 17 methyltestosterone through immersion or incorporation in starter feed in the fry stage.

8.6 Genetic selection and hybridization

The use of genetically selected strains and hybrids has contributed very substantially to modern agriculture and animal husbandry. But aquaculture has so far benefited very little from efficient breeding and selection programmes. Among the many reasons for this are the delays in the development of suitable techniques for controlled reproduction of many farmed species and the paucity of genetic expertise among aquaculturists. Genetic improvements usually require long-term experimentation with a large number of individuals and generations, and so considerable time may elapse before useful results become available. Moreover research on farming technologies has not reached that level in most cases, when the only way to improve production is by genetic improvement of the stocks. Except in a few cases, the present technologies are too inefficient to benefit from the use of selected stocks.

In traditional aquaculture, certain strains have evolved as a result of environmental or farming conditions without much conscious effort by the aquaculturist, as in the case of the common carp, or as a result of the rule-of-thumb selection. These more or less accidental strains can seldom be used with confidence for commercial farming.

There is no doubt that effective selective breeding programmes are expensive and require more facilities than are presently available in most aquaculture farms or even institutions that can function as central stations for breeding and distribution of aquaculture species. Though the economic benefits of selection programmes have been worked out for domestic animals, comparable evaluations are few in aquaculture.

As pointed out earlier, the number of domesticated species used in aquaculture for food is limited (unlike in the culture of ornamental species), but the number is steadily growing. Opportunities to increase the production properties and adaptation to a new environment of species through selection can therefore be expected to expand in the future. Kirpichnikov (1966) gives some of the main aims of fish selection as follows:

(1) To increase the growth rate by better utilization of food (physiological decrease of food expenditure per unit of growth increment);
(2) to increase the growth rate by fuller utilization of natural food in ponds and higher consumption of feed mixtures;
(3) to increase resistance to oxygen deficiency, to high or low temperature, to higher salinity or to other deviations from the normal environmental conditions;
(4) to improve resistance to infectious diseases and to infestation of parasites (to develop new breeds resistant to particular diseases);
(5) to improve the nutritive properties of fish (to increase the calorie content, to decrease the proportional weight of non-edible parts, to decrease the bone content, to increase or decrease the fat content, etc.).

Other aims may include speeding up of sexual maturation, the ability to reproduce at relatively low temperatures and the slowing down of maturation to prevent early switching over of metabolism to develop sex products, affecting growth and resulting in prolific reproduction.

The relative advantages of a fish in genetic breeding schemes are brought out by Skjervold (1976), using salmonids as an example. Among the most important of these are:

- Very high fertility, leading to high 'litter' of considerable importance in selection work.
- External fertilization, which makes it possible to have several combinations of matings and the production of many 'litters' of large numbers of half-siblings.
- The high fertility of females, which enables:

(a) some types of family selection, even when the heritability of the selected trait is low, as large family groups will in practice result in rather accurate estimation of the breeding value;
(b) progeny testing among females, which can be carried out by using mixed sample of semen, or semen from sires of known breeding value;
(c) the improved possibility of estimating non-additive genetic components, because of the combination of high female fertility and external fertilization;
(d) artificial manipulation of chromosome content, which is facilitated by external fertilization, and
(e) easier hybrid production due to high female fertility and the remarkable ability for crossing as observed in nature.

The main disadvantages of fish for genetic breeding are the rather long generation interval of many species, particularly in cold climates, and the hierarchies that may develop in fish populations and which may contribute to size variations.

Genetic gains through selection, as in the case of salmonids, are dependent on selection differentials and genetic variance of the relevant traits, which are inversely related to the length of the generation interval. Gjedrem (1983) presents average estimates of heritability and a coefficient of variation (CV = $(\sigma_p/x) \times 100$) (see Section 8.6.1) of several species, as shown in Table 8.1.

The high phenotypic variance of the body weight of adults, together with the medium heritability as seen in Table 8.1, show that there is a large genetic variance for this trait for these species. Though mortality shows low heritability, resistance to specific diseases shows medium to high heritability. Similarly, the meat quality traits show some genetic variation, though it is low in the dressing percentage. Age at sexual maturation shows medium heritability in rainbow trout but a high one in the Atlantic salmon. The conclusion is that the possibility of

Table 8.1 Average values of coefficients of variation (CV) and heritabilities (h^2) based on the sire component for economically important traits (superscripts give number of estimates involved) (from Gjedrem, 1983).

Economically important trait	Rainbow trout		Atlantic salmon		Common carp		Channel catfish		Tilapia		Oyster		Prawns	
	CV	h^2	CV	h^2	CV	h^2	CV	h^2	CV	h^2	CV	h^2	CV	h^2
Body weight, juveniles	33^{7}	0.12^{4}	78^{1}	0.08^{1}	0.15^{1}		46^{1}	0.42^{4}	26^{4}	0.04^{1}		0.36^{3}		0.12^{3}
Body weight, adults	22^{7}	0.17^{2}	27^{2}	0.36^{3}	22^{1}	0.36^{2}	27^{3}	0.49^{4}						
Body length, juveniles	14^{3}	0.24^{3}	23^{1}	0.14^{2}				0.12^{1}	8^{1}	0.06^{1}		0.47^{2}		
Body length, adults	9^{2}	0.17^{2}	8^{2}	0.41^{4}			8^{2}	0.61^{3}						
Mortality/ resistance		0.14^{1}		0.11^{4}	28^{1}									
Carcass traits														
Meatiness	20^{1}	0.14^{1}	19^{1}	0.16^{1}										
Meat colour	23^{1}	0.06^{1}	16^{1}	0.01^{1}										
Fat (%)	10^{1}	0.47^{1}				0.14^{1}	8^{2}	0.23^{1}						
Dressing (%)	6^{1}	0.01^{1}	4^{1}	0.03^{1}			2^{2}	0.08^{2}						
Age at maturation		0.18^{1}		0.41^{2}										

genetic gains from selection programmes in aquatic animals is high and compares favourably with terrestrial animals and plants.

8.6.1 Methods of genetic selection

As pointed out at the beginning of the last section, the development of some of the earlier strains of common carp and trout has not always been as a result of planned selection. Carp farming in different regions has led to the establishment of strains which appear to have adapted to the general climatic conditions under which they are grown, and which grow faster than the wild strains. In rainbow trout, the usual practice has been to pick the best-looking fish from a stock to be the parents of the next generation. These common-sense approaches cannot be depended upon in a cultivation programme to achieve genetic improvement.

Most economically important characteristics of cultivated organisms are measurable and their variation within a population usually takes the form of a 'normal' distribution (Purdom, 1972). Such a distribution of measurements occurs because the magnitude of a characteristic is determined by a large, often variable, number of factors, some of which are environmental and some genetic. The separation of environment and heredity has been one of the main aims of studies on population genetics. The reliable models of the inheritance of the measurable characteristics can be used for predicting and controlling the gains from genetic selection within cultivated species.

The variation of a character between individuals can be expressed as 'variance', the mean square deviation of individual values from the mean. This is called the phenotypic variance (V_P) of a sample or population and is the sum of two components, the environmental variance (V_E) and the genotypic variance (V_G). Hence $V_P = V_E + V_G$. The proportion of phenotypic variance that is genetic (V_G/V_P) is approximately equal to the value of 'heritability' which measures the proportion of additive genetic inheritance in the phenotypic variance. It is a measure of the degree to which multiple genes control resemblance between offspring and their parents in the face of a particular set of modifying environmental factors. Heritability can be used to predict selection gains in the formula $R = h^2S$, where R is the response, measured as the change in the mean from one generation to the next, and S is the 'selection pressure', or the difference between the mean of the selected parents and the mean of the population from which they were chosen.

As indicated, the ratio of V_G to V_P is only an approximate measure of h^2. More reliable values can be obtained through parent/offspring correlations or by the use of the above formula in a selection. Though laborious and time-consuming, it is essential to have an indication of the magnitude of h^2 before starting an extensive selection programme.

The primary reason for desiring estimates of heritability is to enable prediction of results expected from a given level of selection. The effectiveness of selection depends upon:

(1) heritability of the attribute (h^2),
(2) degree of variation in the attribute (σ_P), and
(3) intensity of selection applied in (1).

According to Falconer (1981), the anticipated response to selection (R) can be stated algebraically as

$$R = i\sigma_P h^2$$

where

R = mean of offspring from selected parents minus mean of all adults before selection

$$i = \frac{\text{mean of group selected minus mean of all adults before selection}}{\sigma_P}$$

σ_P = phenotypic standard deviation of the attribute

h^2 = heritability estimate for a particular attribute

Mass selection

Mass selection, or individual selection, is based on characteristics of the individuals under selection as opposed to selection based on the performance of their relatives. It is one of the simplest and most common methods employed in breeding programmes, where the characteristic to be improved is easy to measure. It can be used efficiently in selection for growth rate and to some extent for age at maturity.

As stated above, response in mass selection (R) is determined by the general equation

$$R = i\sigma h^2 = Sh^2$$

where

S = selective differential (the difference in a certain trait between the individuals selected and the population as a whole),

h^2 = heritability of the differences (the share of additive genetic variation in the general variation of the character), and

i = intensity of selection.

The high fecundity of cultivated fish causes high selective potential and intensity of selection compared to domestic animals and poultry. In performing mass selection in fish breeding, the selection severity coefficient or the rejection rigidity factor (V) is calculated by the equation:

$$V = \frac{100\ n}{N}\%$$

where

n = the number of individuals selected and
N = the total number of fish grown.

In fig. 8.3 the intensity of rejection is plotted against its severity on a semi-logarithmic scale. The curve obtained shows that there is a sharp increase in the intensity of selection with decrease in the severity coefficient within the range 100–10 per cent. A further decrease in V (down to 1 per cent) results in a considerably lower increase in i; with further decrease in V (0.1–0.01) there is hardly any increase in i. For fish with high fecundity, selection gives best results when the severity of selection is 1–0.1 per cent.

Response to selection is directly proportional to the heritability of the character (h^2). In many cases, a rather accurate estimate of the value of heritability of the character can be obtained from the equation:

$$h^2 = \frac{R}{S}$$

To obtain the estimate, selection has to be conducted in several successive generations.

For increasing response in mass selection, the values of i, σ and h^2 have to be increased. The value of i can be raised in fecund fish by

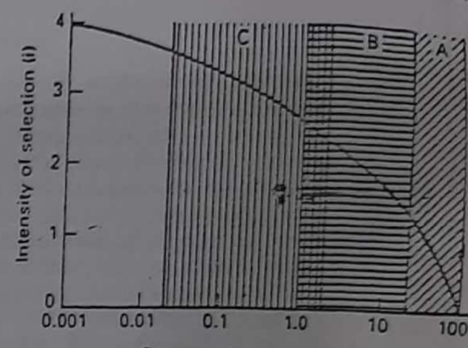

Fig. 8.3 Relation between intensity of selection and its severity in cattle (A), poultry (B) and fish (C) (adapted from Kirpichnikov, 1971).

increasing the number of individuals and, through this, increasing the severity of selection. Variability should relate only to genetic and not environmental variation, as the latter is conditioned by the non-additive genetic variation. To increase h^2 values, non-related individuals have to be crossed. Outbreeding increases the degree of heterozygosity, i.e. increase in genetic variation, but inbreeding results in higher homozygosity. A sufficient number of fish should be available every year for crossing, to enable selection of fish from different crossings for breeding purposes. Another method of increasing genetic variation is by speeding up the process of mutation through irradiation and chemical mutagens.

Non-hereditary variation can be depressed by following special rearing methods such as growing spawners under favourable conditions for maturation, simultaneous crossings, incubation of all eggs under identical physico-chemical conditions, growing larvae and young ones under conditions that do not promote food competition, avoiding the mixing of stocks grown in different ponds or enclosures, and by selection at the age when the animal is more susceptible to improvement by selection.

It is necessary to point out here that a long period of one-way selection for certain characteristics may bring about changes in other morphogenetically or genetically correlated characters. There are many observed

...mples of correlated responses in selection ...non-selected characters, such as physio...ical and biochemical factors (Steffens, ...4), growth rate (Moav and Wohlfarth, ...37), fecundity, etc.

...notypic selection

...ividual or mass selection can only be used ... traits that can be recorded on live animals ...d is not very efficient for traits with low ...itability. In such cases, other types of ...ection have to be resorted to. The two ...pes of genotype selection that have ap...cations in aquaculture are family selection ...d progeny testing.

...mily selection and sib-selection

...mily selection is of special interest in selec...on for characteristics of low heritability, such ...survival, meat quality and age at maturation. ...e of full and half sib families in a selection ...ogramme has the advantage that the gener...tion interval will not be increased, compared ...individual selection. However, a dis...antage is that usually each family has to be ...ared in separate tanks, as it is generally dif...ult to mark newly hatched larvae or fry. This ...ll introduce environmental and tank effects ...characteristics, such as body weight, be...en families. Because of this, Falconer (1981) ...ecommends a combination of individual and ... selection.

...mily selection, several families are grown ...identical conditions to determine the ...be maintained for breeding. To obtain ... progeny (family), either one male/ ...air or a small group of spawners can be ...e response equation is essentially the ...in mass selection:

$$R_f = i_f \sigma_f h^2_f$$

...ensity of selection appears to be lower ...mass selection, as it is not possible to ...a large number of families. Similarly, ...ion can be observed in the standard ...as this denotes the variation in the ...and not individual variation. However, ...ability is much higher. ...individuals have to be sacrificed for examination, the brothers and sisters of the individuals from the best families can be maintained for breeding. This is known as sib-selection. Kirpichnikov (1971), in his description of the methods of family selection, underlines the importance of carrying out crossings, egg incubation, larval rearing and grow-out of families separately, under as identical timings and conditions as possible. The main disadvantage of family selection is the practical difficulty in simultaneously growing many families under identical conditions. Marking of individuals will reduce some of the problems, as communal growing will then become possible. Fin clipping and cold or hot branding have been used in many large-scale selection programmes. Molluscs can be marked more easily on their shells, whereas in crustaceans moulting habits make marking difficult.

Progeny testing

Progeny testing enables the assessment of the breeding qualities of separate spawners or pairs of spawners and the selection of the best for further selection work. However, progeny testing will increase the generation interval very markedly. For example, in carp breeding it requires one or two years, which would mean a slowing down of selection work by 20 to 30 per cent.

Three methods of progeny testing are applicable in aquaculture. The first method is testing of pairs, without testing males and females separately (fig. 8.4a). The second is to test spawners belonging to one sex, as for example females only as shown in fig. 8.4b, and the third is the testing of both females and males (complete diallele crossing) (fig. 8.4c).

The equation to measure selection response is the same as in family selection. Intensity of selection is limited by the number of families. Variability of family means (σ_f) is also the same in both cases. Heritability of family means (h^2_f) in progeny testing is high, as in family testing. This may occur only if the breeding conditions of all progenies are practically identical or if breeding proceeds with a three- or four-fold reiteration.

By comparing the response values in the two equations ($R = Sh^2$ and $R_f = S_f h^2_f$), it should be possible to determine which method

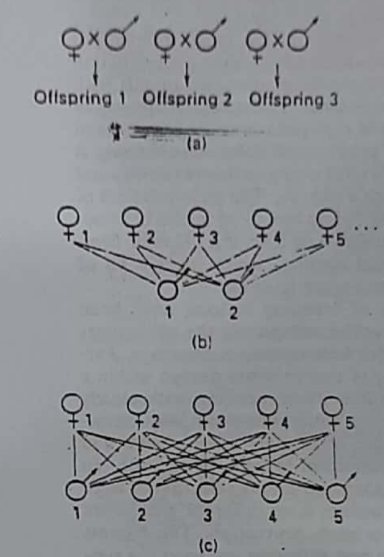

Fig. 8.4 Progeny testing in fish breeding a = Comparison of pairs without testing sexes separately, b = Testing spawners belonging to one sex only, c = Testing of both sexes (diallele crossing). (from Kirpichnikov, 1971).

is more efficient in a given programme. If Sh^2 is greater than $S_f h^2_f$, mass selection is more effective than selection for relatives. The selection for relatives is only advantageous when the increase in heritability is not accompanied by a proportionally greater drop in the selection differential.

Combined selection

Even though mass selection has been found to be more efficient than selection for relatives in fish, the advantages of the latter in selection for certain characteristics like fat content has been demonstrated. For characters like weight, it appears possible to follow a combined selection programme, which may consist of:

(1) performing mass selection among fingerlings or two-year-old fish with a great severity coefficient,
(2) progeny testing of males through to maturity, since males often mature earlier than females,
(3) family selection with a simultaneous breeding of five to ten families and
(4) repeated performance of mass selection in the best families.

Such a scheme allows summing up of the efficiency of mass selection and selection for relatives in a relatively short time.

Cross-breeding

Cross-breeding is another well known means of genetic improvement which has application in aquaculture. Heterosis or hybrid vigour enables an offspring to surpass its parents for one or more traits. On the other hand, inbreeding depression caused by mating of closely related parents has a deleterious effect on the progeny.

The inbreeding measure is the coefficient of inbreeding, incorporating the degree of the animal's homozygosity. It shows what part of the genes in a group of individuals are in the homozygous state. Close inbreeding, especially sib mating (brothers and sisters and parents with offspring), causes homozygosity to increase rapidly, to as much as 0.9–0.95 (expressed as fractions of one) or even more. In most animals, inbreeding results in inbreeding depression, characterized by a drop in viability, growth rate and often fertility. Such depression has been observed by many workers in common carp, brook trout and other fish species. Outbreeding, on the other hand, is accompanied by heterosis in growth rate and viability, especially when fish from different highly inbred groups are crossed. The main types of crossings undertaken are:

(1) Commercial crossing, directed towards breeding of the first-generation hybrids for commercial purposes. Only the first generation, that has the heterosis of productive qualities or incorporates the advantageous characteristics of both the parental forms, is used. They are maintained for further reproduction.
(2) Synthetic or distant crossing, in which distant parents, including those of intergeneric origin, are crossed to develop a new breed.

in the course of long selection. It may attempt to combine the qualities of parents of several breeds, species or even genera. Such crossings to produce new breeds should ensure the preservation and perfection of the productive qualities of the breed, the preservation of genetic variability and the prevention of inbred depression.

Distant outbreeding is indispensable in the selection of aquaculture species. The aims of such crossings are as follows (Kirpichnikov, 1971):

(1) an overall increase in genetic variability, resulting in an increase in selection response,
(2) achievement of a combination of characteristics of two or three breeds or two (rarely three) species,
(3) improvement of the productive quality of the local breed by making use of the few valuable traits of another breed,
(4) increase in the viability of the breed by introducing genes responsible for resistance to environmental factors and diseases.

Kirpichnikov (1971) describes different cross-breeding patterns to achieve these aims.

Reproductive crossing is suggested when valuable properties from both parents are to be combined in the hybrids. It can be done with complete fertility of the hybrid and requires only meticulous selection in the subsequent generations.

Introductory crossing will be advantageous when one or only a few characteristics from a breed have to be incorporated in the hybrid. Each generation of the hybrid has to be crossed with the local breed and so there is the risk of losing the useful characteristics of the improved breed in back crossing, particularly in the case of polygenic inheritance of properties selected. This type of crossing is of considerable use in selection for increased resistance to certain diseases, which is often dependent on the presence of one or a few genes. These genes can be preserved by means of proper selection in each generation.

Absorptive crossing differs from introductory crossing only in that its purpose is a nearly complete substitution of the local breed of genotype by the genotype of the improved breed. Only some features of the local breed, such as viability, are preserved.

Alternate crossing is the most complicated system which is most useful when a combination of many characteristics from two breeds with polygenic inheritance is required. It allows the preservation of high genetic variability through a number of generations. Selection efficiency is kept at a high level owing to this variability and does not reach a plateau. The main problem of obtaining new hybrid breeds by means of crossing (interspecific or intergeneric) is their complete or partial sterility, which takes a lot of time-consuming work to overcome.

A number of breeding systems have been proposed to utilize completely the advantages associated with heterogeneous crossings. Parallel breeding of two or more groups within a breed is possible when working with slowly maturing species, without intermingling, allowing a moderate inbreeding among each and carrying out selection in each generation. In breeding in groups for family selection, a large number of crossings from different groups are carried out for each generation. The parents producing the best offspring are used for subsequent commercial crossings. This system suffers from the drawback that the genetic variability gradually decreases during family selection. Moav and Wohlfarth (1967) recommend that a reserve group of a sufficient number of individuals should be kept for each group when selecting two groups marked by certain genes. In case of a drop in genetic variability, additional gene pools can be introduced into the exhausted group.

Another possible system is alternate inbreeding and outbreeding. After two or three generations of close inbreeding, the evaluation of hybrids from different inbred lines is performed. The best combinations are used for commercial rearing and among the offspring new inbred lines are established. Linear selection involving inbreeding for superior ancestors and top cross, where crossing is done between the best inbred individuals (say males) and individuals from the outbred population (say females) to preserve the genetic variability, are other methods that have applications in aquaculture.

One of the most complicated techniques of breeding is reciprocal recurrent selection (RRS), where the combining capacity of the parents from each of the two groups is evaluated by means of a cross with parents from the other group. The individuals thus selected are reproduced without recrossing and their offspring again tested for combining potential.

The basic feature of all the systems described is the utilization of heterosis in crossing individuals from different groups, lines and breeds. Along with this, moderate to very close inbreeding is employed. The most appropriate system would naturally depend on the species and the traits that are of importance in commercial culture. Gjedrem (1985), however, proposed a cross-breeding scheme for fish farming as summarized below:

(1) Test all possible crosses between different strains or species for the economic traits in question and select crosses that are likely to give useful results. It may be better to use strains with very different origins and which, in combination, have favourable traits.
(2) Develop inbred lines and test the crosses under natural conditions to find the most valuable cross for farming.
(3) Start an RRS programme to ensure continuous genetic improvement, utilizing both general and specific combining abilities simultaneously.

Chromosomal manipulation

As mentioned earlier, the sex of fish that are not differentiated into males or females at hatching can be controlled by the use of sex steroids at the time the gonads are differentiating. While direct masculanisation is frequently easier, feminisation has also been possible in some species. Methods employed for commercial production of all-female rainbow trout by using sex-reversed functional males and genetic females is summarised in Section 16.1.2. An alternate method of producing monosex stock is to induce sterility, and this can be done by the administration of high doses of sex steroids or by chromosomal manipulation.

Chromosomal manipulation for inducing polyploidy, gynogenesis and androgenesis has been studied with a view to controlling sex, as well as for rapid inbreeding. Manipulation becomes feasible during the nuclear cycles of cell division, and since fertilisation in fish is external, artificial means can be employed to either gamete before fertilisation, or to the fertilised egg at any period during the formation of the zygote.

The chromosome number can be increased by subjecting the egg to a pressure or temperature shock shortly after fertilization. The normal expulsion of one set of maternal chromosomes is prevented, and so after fusion of the chromosomes from the sperm, the developing embryo contains three sets of chromosomes instead of the normal two sets. The extra set of chromosomes in the triploid individuals interferes with gonad development. Such induced triploidy is also useful for producing individuals with increased heterozygosity.

Gynogenesis, the parthenogenetic development of eggs after activation with genetically inert spermatozoa, is a very effective means of achieving relatively rapid inbreeding. It can be used to generate all-female stocks and for gene-transfer.

By exposing milt to a very high dose of atomic radiation (for example by using the radioactive isotope cobalt-60), the chromosomes of the sperm cells are destroyed. The milt is kept on ice at 0°C during radiation and can be stored thus for several days without loss of vitality. When the irradiated milt is mixed with eggs, the sperm cells penetrate the eggs but play no further part in the development of the egg. The embryo develops from the egg material only, without any male chromosomes. Since the egg is haploid (with only a single set of chromosomes), the developing embryos are also haploid. Though most of them die at or soon after hatching, there will usually be some gynogenetic diploids (with a double set of chromosomes), as a result of spontaneous diploidization of the female chromosome complex. To increase the frequency of diploidization of the female chromosome complex, temperature shock can be used. Treatment of eggs with low and high temperatures at the time of meiotic divisions results in disturbances in the process, such as disintegration of the spindle, due to which none of the chromosome sets can form the polar body, or the return of the polar body into the plasma of the ovum. The output of genetic diploids varies greatly, being high under favourable conditions according to the strength and duration of the temperature shock and the stage at which it is administered.

Interspecific and intergeneric hybridization

Several interspecific and intergeneric hybridizations have been carried out for different purposes. In many cases the offspring have proved to be viable and fertile, combining some of the desired qualities. Several species of trout and salmon, cyprinids, cat fish and sturgeons have been used in such crossings, for special traits. Transplantation of nuclei of one species (common carp) into the cytoplasm of another species (crucian carp) has been tried to bring together superior characteristics of the two species. Of late, interest in the production of monosex hybrids through interspecific crossing has increased, for improving the culture of the species of tilapia that reproduce rapidly and overpopulate ponds. As will be described in Chapter 19, selected species were crossed for the purpose of obtaining all-male progeny (Pruginin, 1968; Pruginin *et al.*, 1975). The progeny consisted of a high percentage (98–100 per cent) of male offspring. However, commercial production of all-male hybrids has been difficult to maintain over a long period of time due to contamination of pure brood stock lines (Lovshin, 1982). There has also been considerable interest in breeding mutant forms of tilapia, such as the red tilapia which has better consumer acceptance.

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