Chapter 1

An overview of aquaculture

Aquaculture is an old pursuit that only became common during the last 75 years. Today nearly everyone has heard of aquaculture and realizes that one can purchase either farm-reared or wild-caught fisheries products. The dictionary definition of aquaculture is "the cultivation or rearing of aquatic animals and plants." But there is no consensus—even among aquaculture experts—on the best definition of aquaculture.

Despite most people having heard of aquaculture, very few, including most professional and lay environmentalists, have much knowledge of the important aquaculture species/species groups and of the various culture systems and methodologies used to produce aquatic organisms. This chapter provides a simple discussion of aquaculture species, production methods, and associated environmental issues. Land and water requirements, nutrient sources, energy use, and water management techniques will be featured in particular, because many of the negative impacts of aquaculture result from these factors.

History

The first writings about aquaculture are from China about 2,500 years ago; the writings were about carp culture that had originated several centuries before (Stickney 2000). The Egyptians may have been involved in fish culture before the Chinese, and the Romans cultured oysters and possibly other species. Shrimp culture dates back to around 800 AD in Asia and freshwater aquaculture has been practiced in several Asian countries for many centuries (Stickney 2000). Aquaculture was fairly common in Europe—especially in central Europe—during most of the second millennium AD. For example, there were 75 000 ha of carp ponds in Bohemia alone by the end of the fourteenth century—more than exist in that region today (Berka 1986). By the sixteenth century, the pond area in Bohemia reached a maximum of 180 000 ha, but the area declined considerably soon afterward.

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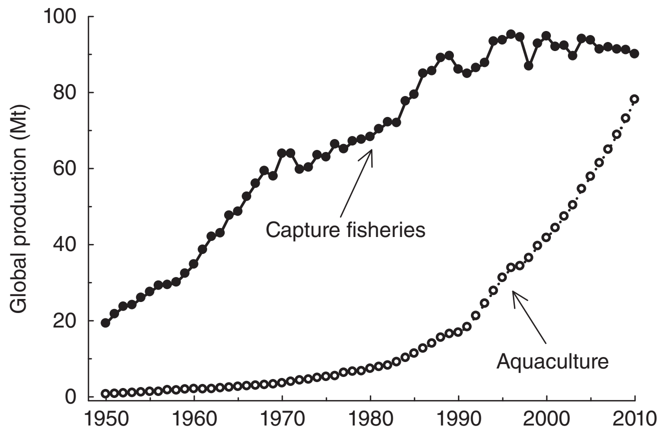

Figure 1.1 Total world fisheries and aquaculture production since 1950. *Source:* FAO (2011).

The real "boom" in aquaculture began in the 1950s and 1960s in many countries including the United States. Growth of aquaculture was relatively slow at first; in the early 1950s, it produced less than 1 Mt/year and reached only about 2.5 Mt/year by 1970. Since 1970 aquaculture has grown at an average rate of about 8% annually reaching about 63.6 Mt in 2011 (Fig. 1.1). This rapid growth in aquaculture has occurred because the capture of fish and other aquatic organisms from natural waters (Fig. 1.1) has apparently reached or exceeded its sustainable limit, and the difference in demand and wild catch must be supplied by aquaculture.

Culture species

The species for aquaculture include both plants and animals. In 2010, there were about 19 Mt of aquatic plant production and 59.9 Mt of aquatic animal production by aquaculture. The aquatic plant production was nearly all in marine water, but aquatic animal production was further separated into freshwater, brackishwater, and marine species (Table 1.1).

Aquaculture animals that will be the focus of this book consist mainly of molluscs, crustaceans, and fish. These groups also are further subdivided; for example, freshwater fish may be listed as salmonids, tilapia and other cichlids, carps and other cyprinids, catfish, etc. Nontropical aquaculture species often are classified according to water temperature optima for growth: coldwater (<10°C); coolwater (10–20°C); warmwater (>20°C). Tropical species cannot survive when water temperature declines below about 20°C for several hours or days.

A total of 527 species of aquatic organisms are reported as aquaculture species by the Statistics Unit of the Fisheries and Aquaculture Department of the Food and Agriculture Organization (FAO) of the United Nations. Finfish dominate freshwater aquaculture, and several species of carp and related fishes comprise about two-thirds of total finfish production. Although marine animal aquaculture consists mainly of bivalve mollusc production (Table 1.2), the culture of marine fish is expected to

Table 1.1 World fisheries and aquaculture production (aquatic plants excluded) and utilization for 2011.

Sector	Production (Mt)
Inland	
Capture	11.5
Aquaculture	44.3
Total inland	55.8
Marine	
Capture	78.9
Aquaculture	19.3
Total marine	98.2
Total capture	90.4
Total aquaculture	63.6
Total world fisheries	154.0
Utilization	
Human consumption	130.8
Nonfood uses	23.2
Food fish supply (kg/capita)	18.8

Source: Modified from FAO (2012).

increase in the future. Brackishwater aquaculture is mostly Penaeid shrimp culture. Although freshwater animal aquaculture production exceeds marine animal aquaculture production, in 2010 there was about 18.4 Mt of marine seaweed cultured. Add this to marine animal production and the total marine aquaculture was approximately equal to freshwater aquaculture production in 2010.

Water sources and culture systems

Water is a primary requirement for aquaculture, and features of the water supply are priority considerations in selecting species and production systems suitable for

Table 1.2 World aquaculture production by culture environment—2010.

Type and culture environment	Quantity (Mt)
Fish, crustaceans, and molluscs	
Freshwater	36.9
Brackishwater	4.7
Marine	18.3
Subtotal	59.9
Aquatic plants	
Freshwater	0.1
Brackishwater	0.5
Marine	18.4
Subtotal	19.0
Total aquatic organisms	**78.9**

Source: FAO. Fishery Statistics. Yearbook of Fishery Statistics. Accessed: 10/15/13. URI: ftp://ftp.fao.org/FI/STAT/summary/default.htm a particular location. Water temperature determines whether a site is suitable for coldwater, coolwater, warmwater, or tropical species. Of course water temperature varies seasonably, and at some warmwater sites, it is possible to culture coldwater or coolwater species in winter and tropical species in summer. For example, tilapia can be cultured in summer and rainbow trout can be cultured in winter—although it has only been done in research—in central Alabama (32° north latitude) in the United States.

The range of species that can be cultured at a particular location also will be restricted by salinity, that is, freshwater, brackishwater, or marine species. Freshwater has salinity less than 1 g/L while ocean water has salinity around 35 g/L. Brackishwater is intermediate in salinity between freshwater and ocean water. Inland waters—especially in arid regions—may be brackish with salinities as high as 5–10 g/L. In extremely arid regions, some inland waters and waters in estuaries with low exchange rates with the ocean may be hypersaline with salinities above 40 g/L. At some sites, there are seasonal differences in salinity that influence selection of culture species. More often than not the kind of production system selected for the particular species at a given site results from the climate and the type of water source and its seasonal availability.

Water quality and water quantity also strongly influence selection of culture species and production systems. Moreover, water quality often changes in production systems as a result of management inputs to enhance production (Boyd and Tucker 1998).

Ponds

Ponds are used widely for culture of fish and crustaceans. A recent estimate places the global water surface area of aquaculture ponds at about 11 000 000 ha (Verdegem and Bosma 2009). Watershed ponds are constructed by installing a dam to impound runoff. Many watershed ponds (Fig. 1.2) receive only overland flow following rains. Water levels in most watershed ponds fluctuate with changes in rainfall and they may

Figure 1.2 Watershed pond showing the dam and a portion of the watershed (left); a complex of watershed ponds on the E. W. Shell Fisheries Center at Auburn University in Alabama (United States) (right).

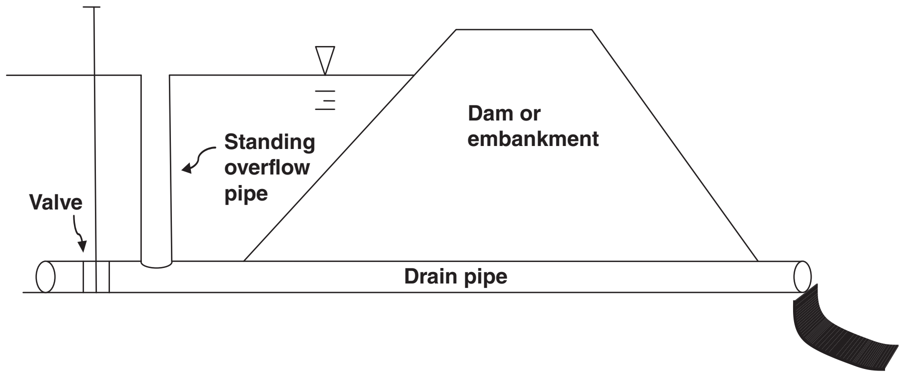

Figure 1.3 Illustration of overflow structure and drain pipe in a pond.

fall drastically during droughts. Ponds may be arranged in series to form a water-harvesting scheme (Boyd et al. 2009), and water that naturally overflows and seeps from ponds at higher elevation maintains water levels in lower ponds during dry weather. Where there is abundant groundwater, wells may be developed to supplement water supply for watershed ponds as necessary (Yoo and Boyd 1994).

Ponds usually have a water control structure to allow excess water to overflow and to drain ponds (Fig. 1.3). A grass-lined spillway should be provided to bypass large inflows and prevent overtopping of dams following unusually heavy rainfall events.

Ponds may be constructed by damming streams. These ponds have stable water levels but they also may have high flushing rates. Short water retention time may reduce the effectiveness of liming and fertilization in augmenting productivity. Overflow structures with intakes near the bottom in the deepest area of ponds sometimes are installed to avoid discharge after heavy rainfall events of plankton that inhabits the upper layer of illuminated water (Fig. 1.4).

Ponds can be constructed by excavating a basin in which to store water (Fig. 1.5). Excavated ponds usually are small because of the large volume of earth that must be removed to form them. Water for filling excavated ponds may come from wells, streams or lakes, irrigation systems, or overland flow. Where the water table is

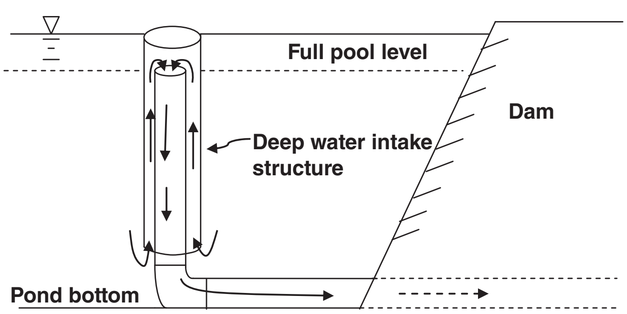

Figure 1.4 Deep-water intake structure.

Figure 1.5 An excavated fish pond in Thailand. Courtesy of David Cline.

shallow, excavated ponds may fill by groundwater seepage. Excavated ponds cannot be drained, and their water levels may fall drastically in the dry season as the water table declines. Nevertheless, small, excavated ponds are important for providing fish for poor, rural farm families in many Asian nations.

The most suitable type of pond for aquaculture is the embankment pond constructed by building an earthen embankment around an area in which to store water (Fig. 1.6). Ponds may be fitted with water control structures such as shown in Fig. 1.3, or water gates with dam boards for controlling water level may be installed. Little overland flow enters embankment ponds because the watershed is limited to the sides and tops of embankments. There are few regions in the world where rainwater and overflow will maintain water levels in embankment ponds year round. Water must be supplied from external sources such as wells, streams, lakes, irrigation systems,

Figure 1.6 Embankment ponds used for channel catfish farming in the United States.

Figure 1.7 Plastic-lined ponds on the Claude Peteet Mariculture Center, Gulf Shores, Alabama (United States). Courtesy of David Cline.

lakes, estuaries or the sea. For example, the US channel catfish industry in western Mississippi and southeastern Arkansas uses embankment ponds filled by well water. Marine shrimp farming also is conducted almost exclusively in embankment ponds. The great advantages of embankment ponds are that water levels can be controlled, ponds can be drained and refilled according to management schedules, and water exchange may be implemented to improve water quality.

Where soils are highly permeable, clay blankets or impermeable, plastic liners may be installed in ponds to reduce seepage loss (Fig. 1.7). In addition, plastic liners in heavily aerated ponds prevent erosion by aerator-generated water currents (Avnimelech 2012).

The intensity of aquaculture in ponds varies greatly (Avault 1996; Boyd and Tucker 1998). Yields of culture species based on natural productivity will be low—seldom more than 50–500 kg/ha/year but nutrient inputs are made in aquaculture to allow more production. Manures and fertilizers can be used to increase production—depending upon the species, production may reach 500–2000 kg/ha. Much greater production can be achieved using feed, and the combination of feed and mechanical aeration provides the highest production. Fish and shrimp production in ponds with feeding alone normally ranges from 1000 to 3000 kg/ha, but with mechanical aeration, production often exceeds 5000 kg/ha and may reach 15 000–20 000 kg/ha. Ponds usually average 1–1.5 m in depth, and on a volume basis the culture density is 0.033 to 2 kg/m^3.

In most kinds of pond culture, only a small fraction of the total water area and volume is necessary to support the culture species. In extensive production, the remainder of the pond space is necessary to produce food organisms for the culture species. In more intensive production with feed inputs the rest of the pond space serves as an internal waste treatment area (Boyd et al. 2007). Where water exchange is used a portion of the waste is flushed from the pond, that is, the waste load is externalized for treatment by natural waters.

Figure 1.8 Round ponds at a shrimp farm in Belize.

Shapes, water surface areas, and depths of ponds vary greatly. Topography of the original land surface strongly influences the morphometry of watershed ponds, but as a general rule, watershed ponds take the shape of an irregular semicircle, and average depth is about 0.4 times maximum depth (Boyd and Boyd 2012). Water surface area may vary from a few hundred square meters to several hectares. Embankment ponds often are square or rectangular—a shape approaching the 2:1 rectangle likely is the most common (Yoo and Boyd 1994). There has been some use of round ponds (Fig. 1.8) because some feel that this shape enhances aeration-induced water circulation. These ponds are more expensive to construct than rectangular or square ones, and as discussed by Boyd and Tucker (1998), from the aspect of water circulation, a square pond is not greatly different from a round one.

Bottoms of embankment ponds normally are constructed with gentle slopes and cross slopes to facilitate draining. Water depth quickly increases from edges to a depth of 0.75 m or more; maximum depths seldom exceed 2–3 m and average depths usually are 1–2 m. Excavated ponds normally are rectangular or square with depths of 1–3 m. Table 1.3 gives categories of typical water surface areas for the three major hydrologic types of ponds.

Flow-through systems

Rainbow trout often are cultured in raceways supplied by gravity flow with water from springs, streams, or lakes. Raceways constructed of concrete and often located

Table 1.3 Categories of ponds based on water surface area.

	Hydrologic pond type		
Size category (ha)	**Watershed**	**Embankment**	**Excavated**
Small	<1	<0.25	<0.1
Medium	1–5	0.25–2.5	0.1–0.5
Large	>5	>2.5	>0.5

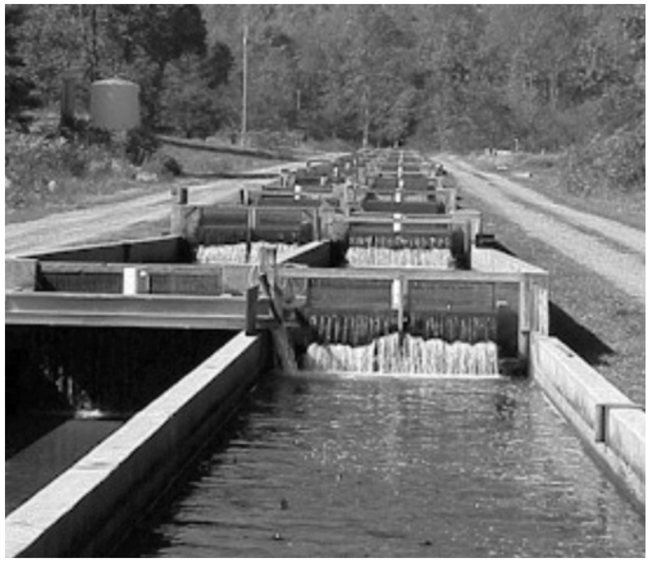

Figure 1.9 A trout raceway in the United States.

in series are probably the most common flow-through culture units (Fig. 1.9), but small, earthen ponds, tanks, or other units also may be used. Water typically is exchanged at a rate of two or three times the volume of culture units per hour by gravity flow and discharged from the lowermost culture unit into natural water bodies. Re-aeration occurs where water falls from the end of one culture unit into the beginning of the next, and mechanical aerators or pure oxygen contact systems can be installed to supplement the dissolved oxygen supply.

Raceways contain much higher densities of culture animals than ponds. For example, rainbow trout may be reared at densities of 80–160 kg/m^3 (Soderberg 1994).

Cages and net pens

Fish often are produced in enclosures placed in natural water bodies, reservoirs, and ponds. The most common types of enclosures are cages and net pens. Cages range in size from about 1 m^3 to more than 1000 m^3 (Fig. 1.10), and fish density may range from <20 to >200 kg/m^3 (Schmittou 1993). Cages typically float in the water and they are moored to the bottom. Water flows through cages to exchange waste-laden water and replenish dissolved oxygen used in respiration. Uneaten feed and feces fall through cages and settle to the bottom in the vicinity. Cages are periodically moved to new locations to allow benthic communities affected by sediment to recover—a process called fallowing.

Net pens are similar to cages but they are made by placing netting around posts inserted in the bottom (Fig. 1.11). Net pens may cover areas of a few to a thousand square meters and extend into water up to 2 or 3 m in depth. Stocking density in net pens typically is much less than in cages.

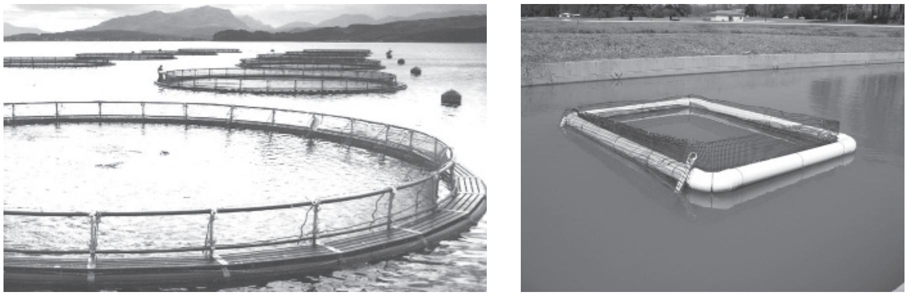

Figure 1.10 Large cages in a lake (left); a small cage in a pond (right). Courtesy of David Cline.

Water reuse systems

Water reuse systems allow greater production per unit of water volume and improve the efficiency of water use. They are particularly useful in arid regions with scant supplies of water and in areas where land for ponds is unavailable or overly expensive. Fish and other organisms grown in small volumes of water can be fed more efficiently and other treatments applied more easily than in less intensive culture. Water reuse systems also reduce the volume of effluents to lessen the pollution potential of aquaculture production facilities.

The simplest method of water reuse is to produce more than one crop of aquatic animals in the same water. Channel catfish farming in the United States is a good example of this practice. Ponds are not drained for harvest. Marketable-sized fish are removed with a grading seine and additional fingerlings are stocked to replace them. Ponds typically are drained at intervals of 6–10 years (Boyd et al. 2000).

The water passing through raceways and other culture systems can be pumped back to the grow-out units and reused. An example of this methodology is illustrated in Fig. 1.12.

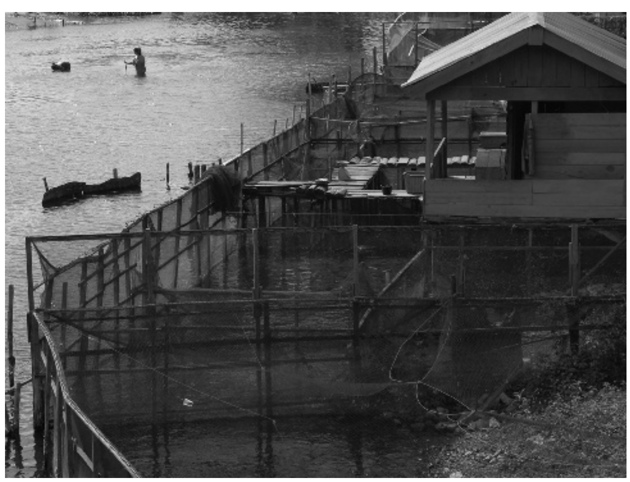

Figure 1.11 Example of a net pen culture system.

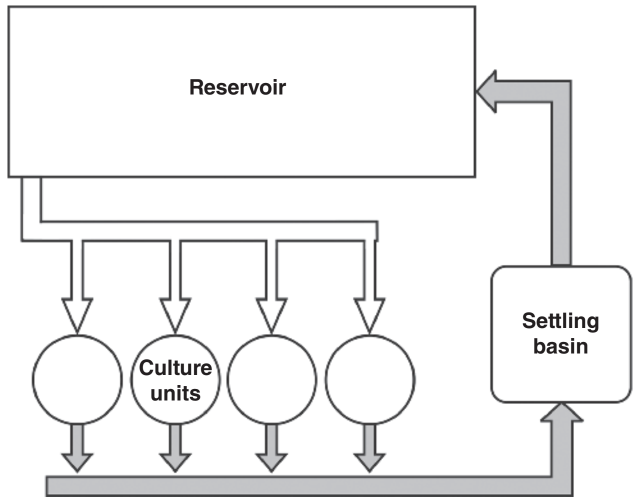

Figure 1.12 Schematic of an outdoor, water reuse system for tilapia culture.

The water from culture units is passed through a sedimentation pond to remove the coarse solids and then held in a pond for natural water purification before reuse. In some systems, one or more additional species are cultured in the treatment pond.

Water recirculation systems of much greater technological complexity are promoted by some innovators (Timmons et al. 2001). These systems rely upon physical, chemical, and biological wastewater treatment technology to purify water for reuse (Fig. 1.13). The entire system may be constructed in a green house or other heated structure to allow year-round production in temperate climates.

Biofloc technology is increasingly used for intensive culture of shrimp and a few fish species (Serfling 2000; McIntosh 1999; Avnimelech 2012). These systems usually consist of completely lined ponds with a large amount of mechanical aeration—often more than 50 hp/ha. Because of high feed input, the phytoplankton bloom diminishes and is replaced by a bacterial suspension or floc. Feed input usually consists of regular aquaculture feed plus crushed grain, molasses, or other source of organic matter. Bacteria decompose the organic carbon source using ammonia from metabolic wastes of the culture species. The bacteria floc is rich in protein and serves as food for the culture species. Thus by combining feed and organic matter and using nitrogenous wastes from the feed to stimulate production of microbial protein, the crude protein input for production of the aquaculture species can be lessened considerably in comparison with normal feed-based aquaculture. Moreover, water exchange normally is not employed, and at harvest, the water containing the floc can be transferred to another pond for later reuse.

New production technologies that are functionally hybrids among pond, raceway, cage, and water reuse systems include the in-pond raceway system (Brown et al. 2011) and the partitioned aquaculture system (Brune et al. 2003). Fish are held at high density in floating raceways through which water is flushed by paddlewheel aerators or air-lift pumps. In the simplest form of the partitioned aquaculture system, a small area of a pond is partitioned off for confining the culture species, and water is

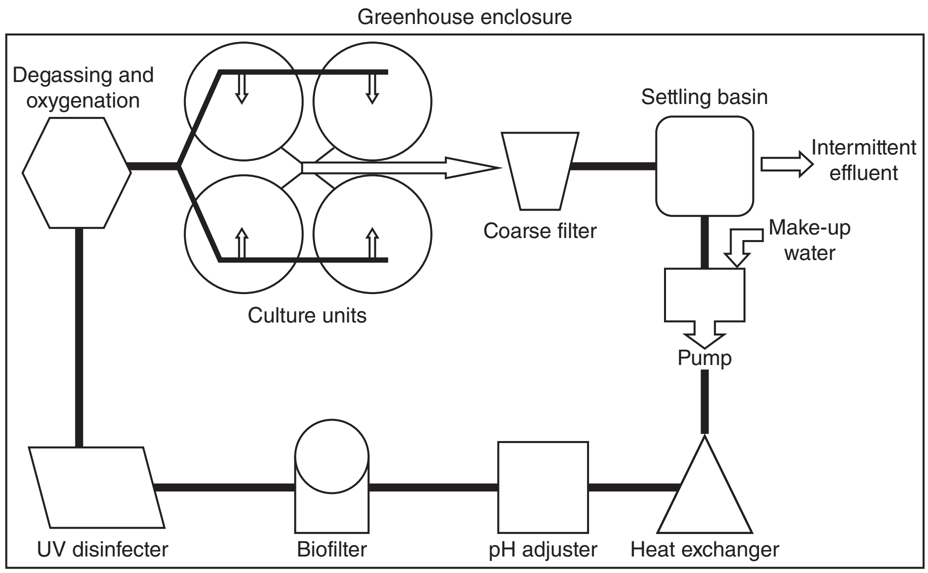

Figure 1.13 Schematic of a water reuse system with water purification equipment and enclosed in a greenhouse.

exchanged between the culture area and the rest of the pond which serves as a waste treatment area (Fig. 1.14).

Mollusc and seaweed culture

Bivalve molluscs are produced by bottom culture methods in which spat are laid on sediment, rocks, or other solid surfaces for grow-out (Fig. 1.15). However,

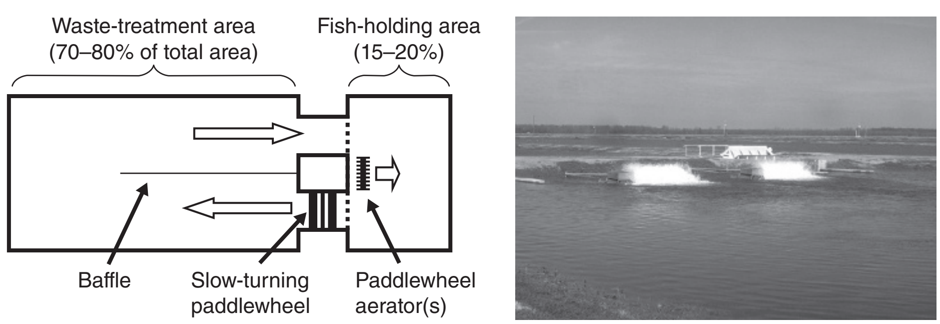

Figure 1.14 A simple, partitioned aquaculture system at the Delta Research and Extension Center, Stoneville, Mississippi (United States). Fish are held in the smaller part of the divided pond and water is circulated between the waste-treatment area and the fish-holding area by a slow-turning paddlewheel. The standard, paddlewheel aerators prevent low dissolved oxygen concentration in the fish-holding area at night.

Figure 1.15 Oyster culture in off-bottom cages in the intertidal zone. Courtesy of David Cline.

off-bottom culture for bivalves other than clams is more efficient for it prevents benthic predators, eliminates impaired sediment quality as a limiting factor, and allows three-dimensional use of the water column. Spat may be transferred to longlines attached to rafts, stakes, or racks for grow-out (Boyd et al. 2005).

Floating or suspended culture of many species of seaweed is achieved by fixing seaweed propagules on ropes or nets and attaching them to rafts, nets, or longlines (Boyd et al. 2005). A few species of aquatic plants such as *Gracilaria* and *Caulerpa* normally are cultured in ponds.

Environmental issues

Many entities to include primary, secondary, and higher educational institutions, governmental agencies, international development organizations, and nongovernmental organizations (NGOs) are interested in promoting wise resource use, pollution abatement, and environmental sustainability. There has been growing concern for several decades over excessive resource use, pollution, and overpopulation leading to unsustainability of the earth's ecosystems. The large environmental NGOs (eNGOs)—Sierra Club, World Wildlife Fund, Greenpeace, The Nature Conservancy, Environmental Defense Fund, and The Audubon Society to name a few—have lead the charge for environmental responsibility.

The eNGOs initially had little or no interest in aquaculture. The growth of aquaculture during the mid-twentieth century was mainly in Asia and it consisted mainly of production of filter-feeding fish in manured ponds for family use or sale in local markets. Environmentalists saw such aquaculture as a way of producing food in rural areas of poor countries that required little input of resources and allowed use of agricultural wastes for a beneficial purpose. In fact environmentalists were initially enamored with aquaculture and dubbed it the "blue revolution"—this name obviously was inspired by the term "green revolution" given to greater grain yields resulting from use of improved varieties of wheat, rice, and other grain species and large inputs of fertilizer nutrients and water for irrigation.

In the 1960s and 1970s, it became apparent that many fisheries products popular with consumers in wealthy countries could be profitably produced by aquaculture. This revelation led to the emergence of various kinds of feed-based aquaculture, for example, production of trout, salmon, marine shrimp, and channel catfish, for the markets in the United States and Canada, Europe, and Japan. The increasing demand for fisheries products in wealthy countries opened up the possibility for a lucrative export market for certain aquaculture species—particularly marine shrimp and salmon. Large areas of coastal land in certain South American and Asian countries were converted to shrimp ponds, and cage culture of salmon in coastal waters became common in a few countries—Norway and Chile in particular. The aquaculture industry suddenly was no longer so appealing to eNGOs; it had taken on many of the features of large-scale agribusiness (Bailey and Skladany 1991; Khor 1995).

The complaints against aquaculture by environmentalists have focused on feed-based aquaculture for export markets (Naylor et al. 1998, 2000). Relatively little criticism has been directed at aquaculture for domestic markets—other than in developed countries where high value products are produced using feeds, for example, trout or salmon production in the United States or Europe. Tilapias, although often cultured in developing countries for domestic consumption, have become important export products that are increasingly produced with feeds. Thus tilapia production also has drawn the ire of eNGOs. The eNGOs, however, do not appear to be greatly concerned about the culture of seaweed and molluscs.

The main issues in the aquaculture–environment controversy are listed in Table 1.4. These general areas of concern are not unlike the list of concerns that eNGOs would have for terrestrial agriculture, or for that matter, most other industries. Of course, the concerns listed in Table 1.4 do not apply equally across all aquaculture species or all production methods.

Table 1.4 Major issues that concern environmentalists about aquaculture.

Land use modifications
Wetland alterations, cropland conversion
Excessive use of freshwater
Water pollution
Eutrophication, turbidity and sedimentation, and salinization
Excessive energy use and greenhouse gas emissions
Wasteful use of fish meal
Negative effects on biodiversity
Pollution, capture of wild aquatic animals for broodstock, exotic species, genetically modified species, bird and other predator control, entrainment of small aquatic organisms in pumps, spread of diseases to wild populations
Antibiotics and other chemicals
Antibiotic resistance in organisms, toxicity of certain compounds, residues in aquaculture products
Socioeconomic issues
Conflicts with other resource users, worker safety and other rights, etc.

In later chapters, considerable attention will be given to the relative impacts of different culture species and methods. However, for now a few examples will suffice. Channel catfish *Ictalurus punctatus* and Pacific white shrimp or whiteleg shrimp *Litopenaeus vannamei* are both produced in earthen ponds to which feed is applied and that may be intensively aerated. However, there is much more environmental concern over *L. vannamei* culture than *I. punctatus* culture for the following reasons:

- Shrimp ponds tend to be sited in more ecologically sensitive areas than are catfish ponds;
- Wild-caught postlarvae and broodstock have been used in shrimp culture, but broodstock and fingerling catfish have been farm-reared;
- Compared to shrimp feed, catfish feed is very low in fish meal content;
- Water exchange is not commonly used in catfish farming as it is in shrimp farming;
- Shrimp ponds are drained for harvest of every crop (1–2 times per year); catfish ponds are drained for repairs at an interval of 6–10 years.

Pond culture is often considered more environmentally responsible than cage culture because:

- All wastes from cages enter directly into the water body containing the cages, but in ponds, a large proportion of the wastes is assimilated by natural processes before discharge;
- Cages often are placed in public waters, while ponds tend to be located mainly on privately owned land;
- Fish escapes from cages are more difficult to avoid than are those from ponds.

It already has been mentioned that culture of aquatic animals without the use of feeds is usually considered by environmentalists to be more environmentally desirable than feed-based aquaculture. However, this assumption should not be accepted *a priori*. There are many "trade-offs" that should be considered when evaluating the environmental effects of aquaculture (Boyd et al. 2007). For example, low-input aquaculture in ponds does not require feed and aeration or produce highly polluted effluent, but production is low. More land area must be converted to water surface area in ponds for extensive culture than in those for intensive culture for the same amount of production. The reduction in energy, feed ingredient use, and waste discharge resulting from low-input aquaculture must be weighed against the greater amount of land and water needed per unit of production.

Governments are increasingly interested in environmental protection and most governments have imposed environmental regulations upon aquaculture. The nature of these regulations varies from country to country as does the level of enforcement. Of course eNGOs are well aware of the role of national priorities and "special interests" in governmental regulations, and they tend to feel that governments cannot be trusted to put environmental sustainability ahead of these interests. Therefore, the eNGO lobby works hard to influence legislation related to the environment. For example, the US Environmental Protection Agency (USEPA) recently made an effluent rule for US aquaculture (Federal Register 2004). This rule-making process was the result of a report on US aquaculture that was published by the Environmental Defense Fund (EDF) (Goldburg and Triplett 1997) and subsequent lobbying by this organization.

There is increasing public awareness of environmental issues, and this environmental awakening can do more to promote wise resource use and environmental sustainability than possibly any other factor. If consumers want products produced by environmentally responsible methods, it places demands on producers, governments, importers, wholesalers, and retailers to supply these products. Aquaculturists are beginning to use better production practices, governments are becoming more serious about environmental regulations, importers are seeking products resulting from environmentally responsible methods, and retailers want to cater to the wishes of their clientele who are increasingly concerned about environmental, social, and food safety issues. The upshot is that there is a growing demand for product labels that tell where and how products were produced (Boyd and McNevin 2011).

Conclusions

Aquaculture is essential in meeting future needs for aquatic animal protein because most capture fisheries have reached or exceeded their sustainable limit. The majority of freshwater aquaculture and a considerable amount of coastal aquaculture production come from ponds of which there are about 11 000 000 ha worldwide. In addition, raceways, cages and net pens, and water recirculating systems are important in freshwater, and cage culture is important in the marine environment. Much marine aquaculture is for molluscs and employs open-water systems. The intensity of aquaculture is being increased through use of fertilizers, feeds, and mechanical aeration.

Aquaculture can result in wasteful resource use and negative environmental impacts; thus, it has recently been subjected to much criticism by environmental advocate groups. Much effort is currently being made to improve resource use efficiency and reduce the negative environmental impacts of aquaculture. The collaborative efforts between eNGOs and some large-scale seafood buyers in sourcing aquaculture products is leading to a greater understanding of environmental and resource use issues by both parties.

The eNGO perspective

Most of the eNGOs engaged in issues related to aquaculture are driven by a broader ocean conservation mission. Most eNGOs have taken stances on aquaculture which are driven by the desire to conserve the world's ocean.

Although most eNGOs started to raise the issue of the effects of aquaculture on the oceans only peripherally, their efforts have increased dramatically over the past two decades. The eNGOs' concerns with conservation of the ocean have also provided a strategic framework for this group of stakeholders to prioritize certain aquaculture species and production systems. The prioritization is rooted in the impacts that could be realized in the marine environment.

With this background, it is easier to understand why the eNGOs first started their engagement in aquaculture with marine shrimp and salmon farming. Marine shrimp farming, up until the late 1980s, relied on wild postlarvae collected from estuaries. Further the earlier practices of constructing shrimp ponds in coastal zones gave rise to concerns because of the importance of these areas for nursery and breeding areas for a variety of aquatic and terrestrial organisms.

There are few places left in the world where significant natural runs of Atlantic salmon can be found, most notably in Russia and Iceland. Atlantic salmon farming which increased rapidly in the 1990s was another obvious concern for the eNGOs as cages were being placed throughout the coastal waters of Europe, Canada, and the United States. Later in the 1990s, Chile became a major player in farmed salmon industry. The salmon industry relies primarily on the production of Atlantic salmon. This species is sparsely found in the natural environment and placement of Atlantic salmon farms in regions that have existing and healthy populations of Pacific salmon (Canada and the Pacific Northwest of the United States) has raised concerns over the impact of these nonnative species on the natural salmon populations.

Shrimp and salmon aquaculture also tend to have two other common characteristics that raise concern for eNGOs. The first is the release of effluents into the natural environment, thus posing a pollution threat to the marine environment. The second impact is the utilization of fish meal and oil made from wild fish as a component in manufactured aquafeeds.

While shrimp and salmon farming were among the highest priorities of eNGOs, much of the rest of aquaculture was tainted by these two sectors for many years. However, in recent years, there has been a growth in interactions between the eNGOs and the aquaculture industry and there is a greater understanding that aquaculture is a varied industry with some forms of production posing greater environmental risk than others. Part of the drive for understanding aquaculture to a greater degree resulted from partnership agreements that some eNGOs have with large seafood buyers where the eNGOs are to comment on, review, or suggest purchasing strategies that are more environmentally benign. Examples of specific aquaculture agreements include Monterey Bay Aquarium's Seafood Watch Program and Bon Appetite Management Company; New England Aquarium and Darden Restaurants; World Wildlife Fund and Costco Wholesale Corporation; Environmental Defense Fund and Wegman's; Conservation International and Wal-Mart; Sustainable Fisheries Partnership and High Liner Foods.

Some of these agreements involve the exchange of funds for services or resources provided by the particular eNGO. Some of the eNGOs listed above also have multiple retailer or buyer partner agreements.

Part of the challenge for the eNGO community working on aquaculture issues is the lack of funding available to them. Most eNGOs obtain funding from grants to work on aquaculture issues. The grants of any sizeable nature have come mainly from the David and Lucile Packard Foundation. The Packard Foundation has a long history of funding many of the abovementioned organizations for ocean conservation work, but they were probably the only large foundation that was willing to fund mainstream eNGOs to address threats from aquaculture.

It is important to point out that the eNGOs in the United States have the luxury of large private foundations such as Gates, Packard, Moore, Hewlett, MacArthur, etc. The magnitude of financial support by private foundations in other parts of the world to fund eNGOs is miniscule. Thus, the traditional mechanism for fund-raising in other parts of the world is through membership. Interestingly membership compels an eNGO to act or carry out projects in a manner that would please the bulk of the members. Most of the large eNGOs in the United States have members but do not feel the same pressures as those outside the United States because of the private foundation cushion.

As the aquaculture industry has matured so have the eNGOs working toward a more sustainable vision of aquaculture. There is a prevalent recognition within the eNGO community that much of aquaculture is better than its wild fishery counter-part. However, the perception of aquaculture by the eNGOs will likely be driven by key impacts identified through the examination of the shrimp and salmon farm-ing industry. These main impacts include water pollution, utilization of wild fish as a feed ingredient, introduction of exotic species or escapes and habitat conversion (particularly in coastal environments) and chemical use. An ideal aquaculture facility would be one that is closed from the environment (addressing escapes, introductions and exotic species and water pollution) and one that cultures a species that does not require a high protein diet (to address wild fish utilization). Additionally a system that is low enough in intensity (often "organic") tends to be the eNGO solution for reductions of chemical or therapeutic inputs into a particular system.

There are few examples of these ideal systems that supply a significant amount of aquaculture to global markets or to domestic markets. This complicates the position of many eNGOs that have mainstream and large-scale private sector partnerships with the large seafood buyers of the world. These eNGOs are effectively pigeon-holed into making some level of concession to aquaculture operations that are viewed as "sub-optimal" but not "bad" players in their eyes. Some of the more extreme factions of the eNGOs such as Mangrove Action Project, Sea Shepherd, Greenpeace, the Coastal Alliance for Aquaculture Reform and other grassroots organizations see the large eNGOs as "selling out to" or "green-washing" industry by making these concessions, and in a few cases some of these concessions have been egregious and have been nothing more than a means to generate publicity. Nevertheless with the growing cooperation of the aquaculture industry and the eNGOs, there is a greater need to understand the utilization of natural resources in the aquaculture industry relative to other large food production activities such to prioritize and coordinate activities and targets.

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