Best Management Practices for Responsible Aquaculture

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Chapter 1: Production Statistics

The relationship between the global capture fishery and world aquaculture production is illustrated in Fig. 1. The capture fishery steadily increased until about 1990, but since, it has remained around 90 million metric tons (mt) per year. Aquaculture production is continuing to grow; thus, total fisheries production has been increasing in spite of the stagnant capture fishery. According to statistics from the Food and Agriculture Organization (FAO) of the United Nations, total world fisheries production was 147 million mt in 2003, with 55 million mt or about 38% of total production from aquaculture.

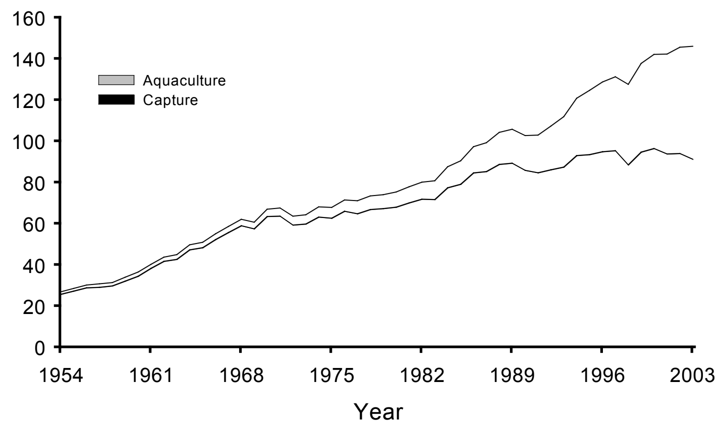

Figure 1. Statistics for capture and aquaculture fisheries production.

Aquaculture is a major source of several species/species groups popular with consumers in developed nations (Table 1). Relatively few nations provide most of the world's aquaculture production, and eleven of the top fifteen aquacultural countries are in Asia (Table 2). The fisheries statistics for China are considered by most authorities to be highly inflated – possibly by a factor of 2 or 3. Nevertheless, China still dwarfs all nations in aquaculture production.

The United States (US) consumes an estimated 2.1 million mt of seafood annually, and five species, shrimp, tuna, salmon, pollock, and catfish make up 75% of the seafood consumption (Table 3). Inclusion of cod, crabs, tilapias, clams, scallops, and flatfish in Table 3 brings the total to 95% of US seafood consumption. About 78% of all seafood consumed in the US is imported, and the percentage is even greater for some species, e.g., 90% of shrimp are imported. Among the top eleven seafoods in the US, aquaculture contributes greatly to the supply of shrimp, salmon, catfish, crabs, tilapias, clams, and scallops. It is interesting to note that only one species, channel catfish, is almost totally homegrown. The production of channel catfish from aquaculture in the US was about 288,000 mt in 2004.

Table 1. Contribution of aquaculture to the production of eleven popular seafoods. Source: FAO website.

Species/species group	Production (tons/yr) Total	Aquaculture	% from Aquaculture
Shrimp	4,271,812	1,292,476	30.3
Salmon	2,095,381	1,308,383	62.4
Channel catfish	2,879,818	2,879,818	100.0
Rainbow trout	511,000	491,000	96.1
Tilapias	2,188,443	1,505,804	68.8
Oysters	4,504,079	4,317,380	95.9
Clams	4,256,471	3,430,820	80.6
Mussels	1,708,835	1,444,734	84.5
Scallops	1,968,084	1,226,568	63.3
Abalone	113,556	2,816	2.5
Seaweed	8,500,000	7,509,960	88.3

Table 2. Fifteen major aquacultural nations and estimates of each nation's production in 2003. Source: FAO website.

Nation	Production (metric tons)	Nation	Production (metric tons)
China	28,892,005	United States	544,329
India	2,215,590	Philippines	459,615
Indonesia	996,659	Egypt	445,181
Vietnam	937,502	Republic of Korea	387,791
Japan	859,656	Taiwan	351,578
Bangladesh	856,956	Spain	313,288
Thailand	772,970	Myanmar	257,083
Norway	582,016		

Table 3. Top eleven seafoods in the United States in 2003. Source: Catfish Journal (2004).

Species/species group	Quantity consumed (kg/capita)	Species/species group	Quantity consumed (kg/capita)
Shrimp	1.814	Tilapia	0.245
Canned tuna	1.542	Clams	0.238
Salmon	1.006	Scallops	0.150
Pollock	0.774	Flatfish	0.146
Catfish	0.516	Total for top 11	6.999
Cod	0.292	Total for all seafoods	7.392
Crabs	0.276		

Chapter 2: Production Methodology

Production units

A widely-used aquaculture production facility is the earthen pond. A watershed pond is formed by building a dam across a portion of a watershed to retain direct rainfall and runoff. Many times, several ponds may be constructed on the same watershed as illustrated in Fig. 2. Watershed ponds often are called rain-fed ponds. Embankment ponds are made by building earthen embankments around the area in which water from wells, streams, lakes, estuaries, or the sea is confined. Ponds vary from less than 100 m^2 to several hectares in water surface area, and they usually are between 0.75 and 2.0 m in average depth. Ponds typically are equipped with drains that allow them to be emptied for harvest and maintenance (Fig. 3).

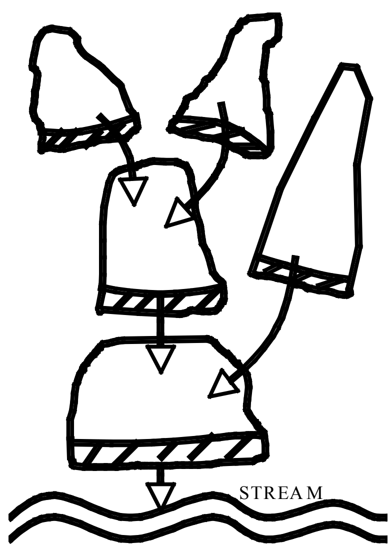

Figure 2. Series of ponds on a watershed.

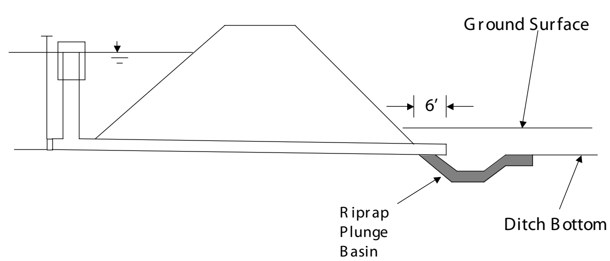

Figure 3. Cross-section of a pond embankment showing the drainage structure.

Flow-through systems for aquaculture include raceways, tanks, and other culture units through which water flows continuously (Fig. 4). Usually, an amount of water equal to 2 or 3 times the volume of the culture units is introduced per hour. Water sources for flow-through systems usually are springs, streams, or other bodies of surface water. Traditionally, these facilities have been designed to operate on gravity flow. Flow-through systems have been especially popular for the culture of rainbow trout.

Figure 4. A raceway flow-through system for trout culture.

Cages and net pens are constructed of netting secured to a supporting framework. Cages are relatively small, 1 m^3 to 2,000 m^3, and they float on or near the water surface. Pens are much larger and serve as enclosures to hold animals for culture. The organisms in pens have free access to the bottom within the enclosed area. Culture density is much higher in cages than in pens.

There are two basic types of water recirculating systems. One type is built outdoors and consists of culture units from which water is passed through a sedimentation basin and then into a conventional pond for treatment by natural biological processes (Fig. 5). Sometimes, mechanical aeration is applied in the treatment pond to enhance dissolved oxygen concentration. Water is returned to the culture unit for reuse. The other type usually is located indoors in a greenhouse or other structure and relies on wastewater treatment equipment such as mechanical and biological filters for treating water from culture units before it is reused (Fig. 6). Effluents may overflow from outdoor systems during rainy weather, and water must occasionally be discharged from indoor systems when new water is applied to lower salinity or filters are cleaned.

Bivalve shellfish such as oysters, clams, mussels, and scallops can be laid on bottom plots in coastal waters for grow-out. However, it is more common to place spat on stakes, rocks, or racks, or ropes hanging from longlines for grow-out by off-bottom culture methods. These structures are placed in coastal waters in areas often used for navigation, fishing, or other purposes. Seaweed usually are attached to ropes or netting for grow-out in coastal waters.

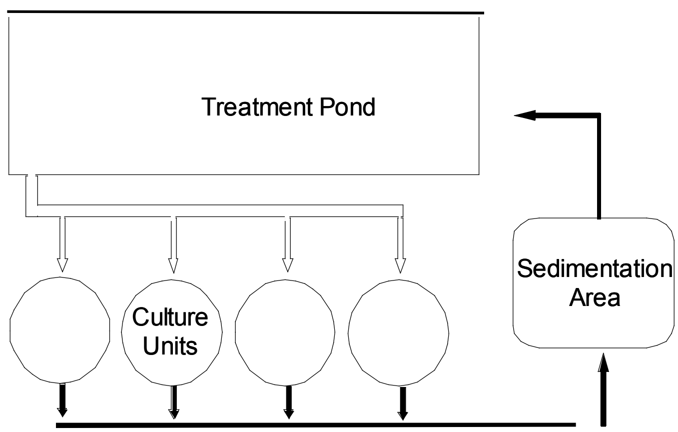

Figure 5.Illustration of aquaculture production systems with intensive culture units, sedimentation area, and treatment pond. Drawing is not to scale.

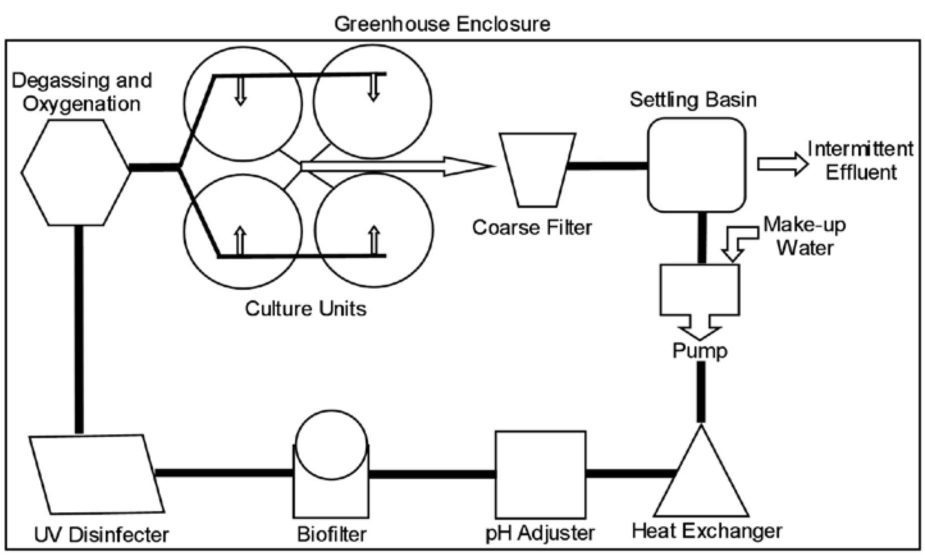

Figure 6. Illustration of an indoor, intensive aquaculture system with waste treatment processes. Drawing is not to scale.

Culture techniques

Culture methods for shrimp, fish, and other aquatic organisms are relatively similar. Small animals for stocking ponds usually are produced in hatcheries, but they sometimes are captured from the wild. Brood stock for hatcheries may be captured from the wild or produced on farms. Production facilities are stocked with a density of animals considered appropriate for the final production objective of animal size and harvest biomass.

Ponds may be limed and fertilizer applied to stimulate phytoplankton to serve as the base of the food chain (Fig. 7). However, it is increasingly common to apply feed to increase production above that possible from natural productivity. Feed usually is applied one or more times per day. Feeding wastes cause dense phytoplankton blooms and water quality deterioration. Water exchange may be applied to improve water quality by flushing nutrients and organic matter from ponds and allow more production. Mechanical aeration is more effective than water exchange in increasing production. It also is more environmentally responsible to use mechanical aeration than water exchange, because nutrients and organic matter flushed from ponds during water exchange can pollute receiving water bodies. Various water quality enhancers such as sodium chloride, sodium nitrate, copper sulfate, zeolite, bacterial cultures, and enzyme preparations may be applied. Ponds usually are drained to harvest fish. Pond bottoms often are dried between crops, and bottoms may be limed and tilled.

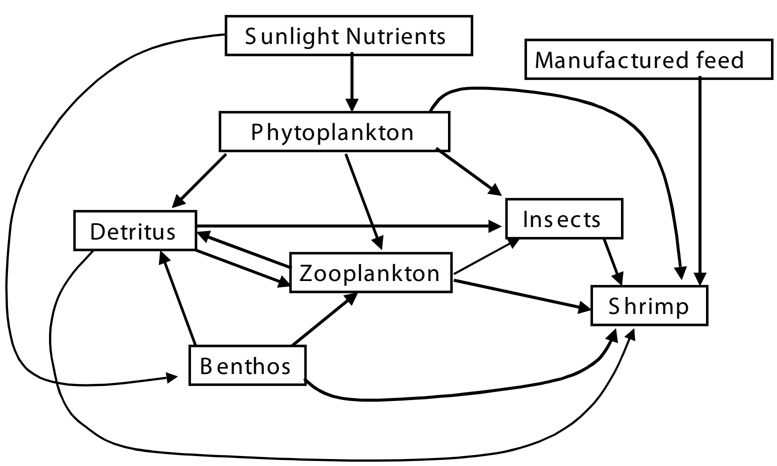

Figure 7. A food chain in a shrimp pond.

Feed is applied several times per day in flow-through systems and in cage and net pen culture. Liming materials and fertilizers are not applied, but mechanical aeration can be installed in flow-through systems and in cages. It is common to clean the bottom raceways during the culture period to remove settled feces and uneaten feed.

Feed is not used in culture of bivalve shellfish and seaweeds. These organisms basically are placed in culture plots or on culture structures and allowed to grow undisturbed to marketable size.

Antibiotics and other drugs may be used for disease control in most types of aquaculture. The therapeutic agents may be offered in feed or simply placed in the water.

Chapter 3: Resource Use

Land and water

Land-based aquaculture requires land on which to construct culture units and water must be supplied to these units. Water may be obtained from rain and storm runoff (rain-fed aquaculture), streams, lakes, springs, wells, estuaries, or the sea. Land also is necessary for storage, maintenance, and staging activities necessary to support culture efforts. Cages and net pens for fish culture and culture systems for bivalve shellfish and seaweeds usually do not divert water, and these activities do not use land other than for support activities. Nevertheless, they occupy space in lakes, streams, estuaries, and seas.

The FAO has collected annual estimates of world fisheries production since 1950. In 2002, FAO announced its intention to collect land and water use data for aquaculture (Boyd 2005). However, this effort will take time to organize, for there have been few studies of water use and even fewer investigations of land use in aquaculture. Terminology and definitions for assessing land and water use in aquaculture are lacking. Boyd (2005) proposed definitions for water use variables in aquaculture. Total water use should refer to the amount of water entering an aquaculture system in rainfall, runoff, and other natural processes and water applied by management intervention, e.g., pumping or other mechanical means. This variable can be calculated with the following equation:

Total water use = Precipitation + Runoff + Seepage in + Intentional additions.

Consumptive water use should represent the reduction in surface runoff caused by an aquaculture facility on a watershed. Consumptive water use results from increased seepage and evaporation, and the small amount of water removed in animals at harvest. Less runoff equates to less stream flow for downstream water users. In addition, all freshwater withdrawn from aquifers by wells should be included as a consumptive use, because this water would not be available to other users of ground water in the area. Although ground water is recharged by infiltration, it sometimes is removed by wells at a rate exceeding recharge. This diminishes the amount of water available from wells in the area. Ground water depletion usually is more serious in arid than in humid climates, but even in humid climates, availability of water from wells may be reduced during the dry season and especially during droughts. Consumptive water can be determined as follows:

Consumptive water use = Reduction in stream flow + Water withdrawn from wells.

The amount of ground water pumped or derived by artesian flow from wells should be indicated as a separate variable, for ground water use is a major issue in many regions. Spring flow should not be included, for springs discharge onto the land surface naturally. One method of estimating ground water use is:

$$\text{Ground water use } (m^3) = \text{Well discharge } (m^3/hr) \times \text{Hours of pump operation or artesian flow.}$$

Non-consumptive water use should refer to water that passes through aquaculture facilities and is still available to other users downstream. It can be calculated as follows:

$$\text{Non-consumptive water use} = \text{Total water use} - \text{Consumptive water use.}$$

A water use index relating the amount of water used in an aquaculture facility to production should be useful. Although this index can be calculated for both total and consumptive water use, the consumptive water use index would be most meaningful. The index can be calculated as shown below:

$$\text{Water use index } (m^3/mt) = \frac{\text{consumptive water use } (m^3)}{\text{production (mt)}}$$

An index of the economic value of water used in aquaculture should be available. This variable can be determined with the following equation:

$$\text{Water value index } (\$/m^3) = \frac{\text{production (mt) x crop value } (\$/mt)}{\text{consumptive water use } (m^3)}$$

Values for total and consumptive water use and the water value index were calculated for channel catfish culture in embankment and watershed ponds (Table 4). Considerable water can be saved by using water sources other than wells. It is interesting to compare consumptive water use with water use by traditional agriculture. Although pond aquaculture consumes more water than terrestrial crops, the consumptive water value index is markedly greater for aquaculture (Table 5). Thus, the economic value obtained from water is greater for aquaculture than for terrestrial agriculture.

Land use by land-based aquaculture is greater than the surface area of water of production systems. For example, in channel catfish farming in Mississippi (US), four ponds typically are constructed on a 32-ha plot of land (Boyd 1985). Embankments cover 4 ha or 12.5% of water surface area. Possibly another 4 ha of land is used for support activities. In shrimp aquaculture, canals, reservoirs, and embankments usually make up about 20 to 25% of water surface area of extensive and semi-intensive farms and 35 to 40% of water surface area of intensive farms. Support activities usually require around 10% as much land as devoted to ponds. Thus, for pond aquaculture, a farm with 100 ha of water surface area might use 125 to 150 ha of land.

Worldwide, pond culture possibly produces 15 million mt of aquatic animals per year. Assuming an average production of 2 mt/ha per year, the water surface area for production would be about 7.5 million ha and the total land use could be over 10 million ha.

Production is much more intensive in other systems than in ponds. Nevertheless, land use in other types of aquaculture is still an issue because of the magnitude of the endeavor.

Table 4. Total and consumptive water use index and water value index in pond culture of channel catfish in Alabama.

Pond type	Water source	Water use index		Water value index[1] ($/m^3)
		Total (m^3/mt)	Consumptive (m^3/mt)	
Embankment				
Drained annually	Well	6,080	3,667	0.390
	Stream	6,080	2,167	0.660
Undrained	Well	3,750	2,167	0.660
	Stream	3,750	2,167	0.660
Watershed				
Drained annually	Rainfed	10,750	2,167	0.660
Undrained	Rainfed	10,750	2,167	0.660

Table 5. Comparison of consumptive water use and consumptive water value index for selected crops with those for channel catfish.

Crop	Consumptive water use (cm)[1]	Consumptive water value index ($/m^3)[2]
Rice	123	0.091
Alfalfa hay	107	0.068
Corn	88	0.081
Cotton	83	0.121
Soybeans	80	0.067
Catfish	130 – 220	0.390 – 0.660

1} Source: van der Leeden et al. (1990)

2} Consumptive water value for agronomic crops based on average US yield and price as reported in the United States Department of Agriculture (1997).

Protein

Aquaculture feeds contain relatively high percentages of crude protein with a typical range of 25 to 45%. Protein for feeds is obtained from plant meals, animal meals, and especially fish meals. Plant meals are valuable and should not be wasted, but there is an abundant supply from agriculture. Fish meal is derived almost entirely by capturing and processing small fish from the ocean. In 2002, FAO reported that about 32 million mt of fish were used for non-human food purposes and mainly for fish meal. Because fish meal comes from capture fisheries, there are limits on its availability. Thus, environmental groups worry about the fate of fish meal fisheries. They also have emphasized that production of many aquaculture species requires more live marine fish for fish meal than is returned in cultured fish or shrimp (Naylor et al. 2000). Moreover, dependency of aquaculture on fish meal may impose constraints on future expansion.

Most aquaculture feeds contain fish meal, but those for shrimp and salmon have especially large amounts and often contain over 25%. Feeds for tilapias and channel catfish usually do not contain more than 6 or 8% fish meal, and some catfish feeds contain no fish meal. Environmentalists are especially concerned about production systems in which the amount of aquaculture species harvested is less than the amount of wild fish used in fish meal for the feed. For example, consider a pond where 2,000 kg of feed containing 25% fish meal results in the production of 1,000 kg shrimp. The feed contains 500 kg fish meal (2,000 kg feed $\times$ 0.25). Typically, the conversion ratio of marine fish to fish meal is 4.5. Thus, 2,250 kg live marine fish were used in making fish meal for feed necessary to produce 1,000 kg shrimp. Aquaculture detracts from total global fisheries production in situations where its yield is less than the live fish equivalent of fish meal used in feed.

Some species provide a more favorable ratio of live fish to aquaculture animals than obtained for shrimp and salmon. It typically takes about 1,700 kg of feed with a 6% fish meal content to produce 1,000 kg tilapia. The fish meal has a live fish equivalence of 459 kg/1,000 kg tilapia (1,700 kg feed $\times$ 0.06 $\times$ 4.5).

Fish meal can be made from the offal from processing aquaculture animals. The offal yield from tilapia processing is about 65%. Assuming conversion of 4.5, 1,000 kg of tilapia would provide 144 kg fish meal equivalent to 650 kg of live fish. This is more fish meal than used in the feed to produce the tilapia. Of course, the tilapia offal meal would be of lower quality than marine fish meal, and it is not put into fish feeds because of fear of spreading diseases. Nevertheless, it can be used in feed for chickens and other animals to spare marine fish meal.

There is much interest in replacing fish meal in aquaculture feeds with plant meals. Success in this effort rests primarily with nutrition research and improved feed manufacturing technology. Aquaculture producers have no option but to use feeds available in the market. However, they should use feeds conservatively to minimize wastes and provide efficient conversion of nutrients in feed to flesh of aquaculture species. To illustrate, in the example of tilapia production above, suppose that better feeding practices allow production of 1,000 kg of tilapia with 1,400 kg of the same feed. In this case, the live fish equivalent of the fish meal in the feed is 378 kg/1,000 kg tilapia. Moreover, less plant meals would be used in feed at the lower feed conversion ratio.

The feed conversion ratio (FCR) mentioned above may be calculated as follows:

$$\text{FCR} = \frac{\text{feed applied (kg)}}{\text{net production (kg)}}$$

It is the ratio of feed applied to aquacultural production. A value of 1.5 indicates that 1.5 kg of feed is needed for 1 kg of aquacultural production. This FCR is extremely important, because a low FCR indicates economic efficiency. Moreover, the lower the FCR, the less wastes that result from feeding and the less pollution generated. It must be emphasized that feed is about 90% dry mater while live aquaculture organisms are about 25% dry matter. Thus, in terms of dry matter, a FCR of 1.5 suggests that 1.35 kg dry matter in feed will yield 0.25 kg dry matter in aquatic animals. There is a waste load of 1.10 kg dry matter for each kilogram of aquaculture species produced. The dry matter FCR would be 5.4 (1.35/0.25).

Several other potentially important ratios can be calculated. The protein conversion ratio (PCR) is an index of the amount of feed protein needed per unit of production:

$$\text{PCR} = \text{FCR} \times \frac{\text{feed protein concentration (\%)}}{100}$$

The protein equivalence (PE) indicates the ratio of feed protein to aquaculture protein:

$$\text{PE} = \text{FCR} \times \frac{\text{feed protein concentration (\%)}}{\text{protein concentration in live culture species (\%)}}$$

The fish meal conversion ratio (FMCR) is the ratio of fish meal in feed to aquacultural production:

$$\text{FMCR} = \text{FCR} \times \frac{\text{fish meal concentration in feed (\%)}}{100}$$

The live fish equivalence (LFE) of fish meal in feed indicates the ratio of live fish needed for the fish meal in feed to aquacultural production.

$$\text{LFE} = \text{FMCR} \times 4.5$$

Aquaculture has become an increasing user of fish oil. Similar to fish meal, fish oil derives mostly from capture fisheries, thus the supply is limited. Over the past ten years, global fish oil production has stagnated at approximately one million metric tons per year (FAO). The increasing use of lipid-rich feeds and production of high-value farmed fish such as salmon, marine fish, and shrimp has led to increased use of fish oil in aquafeeds. In 1998 aquaculture used an estimated 16% of the world's fish oil, and this share grew to 54% by 2000 (Barlow and

Pike 2001). By 2010, it is estimated that consumption of fish oil by the aquaculture sector will be increased to 83% of the world's fish oil supply (Fish Meal Information Network 2007). Thus, if aquaculture is to continue to expand, suitable alternatives to fish oil must be identified. Over the past few years, significant efforts have been made to replace fish oil with plant oils in feeds for many aquaculture species.

Variables indicating the amount of nutrients resulting from feeding also have ecological significance. It is relatively easy to estimate the nitrogen (N) and phosphorus (P) waste loads from aquaculture:

$$\text{N load} = \frac{\text{N applied (kg) - N harvested in biomass (kg)}}{\text{net production (mt)}}$$

$$\text{P load} = \frac{\text{P applied (kg) - P harvested in biomass (kg)}}{\text{net production (mt)}}$$

However, actual amounts of nitrogen and phosphorus entering natural waters will vary with production system. Physical, chemical, and biological processes in ponds may assimilate large amounts of nitrogen and phosphorus and lessen loads in effluent. In cage and net pen culture, all nitrogen and phosphorus not harvested in culture species enters natural waters.

For illustrative purposes, the ratios listed above have been estimated for culture of black tiger prawn (Penaeus monodon) and tilapia (Oreochromis spp.) at two different FCR values (Table 6). The FCR is a critical variable in aquacultural production, for improvements in FCR result in more efficient use of protein, a reduction in fish meal use, and less nitrogen and phosphorus in wastes. Black tiger prawn feed is much higher in fish meal than tilapia feed. Over 2 kg of live marine fish are needed to produce 1 kg of black tiger prawn, while less than 0.75 kg is required for 1 kg of tilapia. There is a large difference in the P load between fish and shrimp because fish have bones made of calcium phosphate and contain much more phosphorus than shrimp (Boyd and Teichert-Coddington 1995).

Table 6. Ratios related to the economic and environmental efficiency of feed use in culture of Penaeus monodon (black tiger prawn) and Oreochromis spp.

Variable	Black tiger prawn		Tilapias	
FCR	1.6	2.0	1.6	2.0
Fish meal in feed (%)	30	30	8	8
Protein in feed (%)	40	40	30	30
Nitrogen in feed (%)	6.4	6.4	4.8	4.8
Phosphorus in feed (%)	1.65	1.65	1.00	1.00
Protein in animal (%)	19.3	19.3	14.0	14.0
Nitrogen in animal (%)	3.09	3.09	2.36	2.36
Phosphorus in animal (%)	0.26	0.26	0.75	0.75
PCR	0.64	0.80	0.48	0.60
PE	3.32	4.15	3.43	4.28
FMCR	0.48	0.60	0.128	0.16
LFE	2.16	2.70	0.58	0.72
N load (kg N/mt)	71.5	97.1	53.2	72.4
P load (kg P/mt)	23.8	30.4	8.5	12.5

Energy

Aquaculture, like other kinds of modern agriculture, consumes energy. At the farm level, the main uses of energy are for constructing facilities, supplying water by pumping, enhancing dissolved oxygen concentration by mechanical aeration, and powering machines during culture and harvest.

There have been few studies of energy use in aquaculture. However, pumping water and powering mechanical aerators are probably the major items in energy budgets for farm operations. In channel catfish farming in Mississippi (US), water for filling ponds and maintaining their water levels is taken from wells. Ponds are about 1.5 m deep and water loss to seepage and evaporation is around 70 cm/year (Boyd and Tucker 1995). A total of 2.20 m (22,000 m^3/ha per year) of water is needed during years when ponds are drained completely.

The pumping head often is around 25 m, and pumps typically deliver about 0.125 m^3/sec (7.5 m^3/min) at 80% pump efficiency. Using the pump power equation,

$$P = \frac{\gamma Q H}{E}$$

where P = power required by pump (kW)

γ = specific weight of water (9.81 kN/m3)

Q = discharge (m^3/sec)

H = pumping head (m)

E = pump efficiency (decimal fraction),

the pump power requirement is 38.3 kW. The pump must operate 48.89 hr (22,000 m^3 ÷ 7.5 m^3/min) to deliver the necessary quantity of water, and it will consume 1,872 kWh of electricity per hectare. Depending upon evaporation and seepage rates and the frequency that ponds are drained, electricity used to fill and maintain water levels in catfish ponds (embankment type) ranges from less than 500 kWh/ha per year in humid climates to more than 2,000 kWh/ha per year in arid areas (Boyd and Tucker 1995). Watershed ponds often can be operated without using water from wells.

In marine shrimp farming, energy use for pumping water may be especially high on farms that resort to high rates of water exchange. A water exchange rate of 15% of pond volume per day equates to 180,000 m^3/ha over a 120-day grow-out cycle.

Channel catfish farms may use about 2 to 4 hp of mechanical aeration/ha. The aerators usually are operated for 4 months/year and 12 h/day (1,440 h/year). Electricity consumption ranges from 2,160 kWh/ha per year (1,440 h/year × 2 hp/ha × 0.75 kW/hp) to 4,320 kWh/ha per year. In intensive marine shrimp farming, aeration often is used at rates of 10 to 20 hp/ha and at least some of the aerators are operated continuously.

Because of the high energy consumption for pumping water and applying mechanical aeration, particular attention should be devoted to making these operations efficient. Methods also should be sought for conserving energy in all aquaculture farm operations.

Chapter 4: Environmental Issues

The environmental and social concerns about aquaculture are listed in Table 7 for quick reference. Major issues related to these concerns will be discussed below.

Table 7. A list of environmental and social concerns related to aquaculture.

- Destruction of mangrove, wetlands, and other sensitive aquatic habitat by aquaculture projects.
- Conversion of agricultural land to ponds.
- Water pollution resulting from pond effluents.
- Excessive use of drugs, antibiotics, and other chemicals for aquatic animal disease control.
- Inefficient utilization of fish meal and other natural resources for fish and shrimp production.
- Salinization of land and water by effluents, seepage, and sediment from brackishwater ponds.
- Excessive use of ground water and other freshwater supplies for filling ponds.
- Spread of aquatic animal diseases from culture of organisms to native populations.
- Negative effects on biodiversity caused by escape of non-native species introduced for aquaculture, destruction of birds and other predators, and entrainment of aquatic organisms in pumps.
- Conflicts with other resource users and disruption of nearby communities.

Destruction of wetlands

Aquaculture projects must be located near sources of water, so it is common to find them in coastal areas, near lakes, and on flood plains of streams. Even watershed ponds filled by runoff often are located in low lying areas, parts of which may be classified as wetlands. Thus, ponds and other production facilities often infringe on wetlands.

Wetlands are extremely important as sediment traps and biofilters to reduce the pollution potential of runoff from agricultural land and other non-point sources of pollution (Mitsch and Gosselink 1993). They also serve as habitat for waterfowl and many other species. Moreover, location of too many ponds on flood plains can restrict water flow when streams overflow their banks leading to increased flooding. In the US, the Natural Resources Conservation Service limits pond construction to 60% of total flood plain area in a catchment basin.

The greatest concern of environmentalists over wetlands has focused on mangrove destruction by coastal aquaculture and especially by shrimp farming. A balanced discussion of effects of coastal aquaculture on mangroves by Macintosh and Phillips (1992) suggested that aquaculture has caused less than 10% of the world loss of mangrove. Much shrimp farming has been done in Asia, and very little has occurred in Africa. Nevertheless, loss of mangrove has been about 61% of the original area in Asia as compared to 55% in Africa (World Resources Institute 1996). If shrimp farming had been the major cause of mangrove cutting, the loss in Asia would have been much greater than that of Africa (Boyd 2002). Massaut (1999) discussed mangrove management strategies for aquaculture areas.

Shrimp farmers and other coastal aquaculturists have learned that mangrove areas are poor sites for aquaculture facilities. Land is low and hard to drain making construction of ponds difficult. Soils often are acidic and high in organic matter content (Sonnenholzner and Boyd 2000). Moreover, carriers of disease organisms abound in mangrove areas. Governments also have passed laws about cutting mangroves. Although aquaculture farms often were built in mangrove areas in the past, the practice is not common today.

Water pollution

Fertilizers and feeds are applied to aquaculture ponds to promote production of fish, shrimp, and other species. Fertilizer nutrients dissolve in water and can be discharged from ponds in effluents. Feeds usually are a larger source of nutrients than fertilizer as will be illustrated for tilapia production. Before ponds are stocked and soon afterwards, possibly four applications of fertilizer each containing about 8 kg nitrogen and 2 kg phosphorus/ha may be applied to initiate a phytoplankton bloom in tilapia ponds (Boyd and Tucker 1998). Possibly 10,000 kg/ha of feed containing 4.8% nitrogen and 1% phosphorus may be applied during the crop. Tilapia production might be around 6,000 kg/ha, and tilapia contain about 0.75% phosphorus and 2.4% nitrogen (Boyd and Green 1998). Inputs of phosphorus and nitrogen in fertilizer were 8 kg and 32 kg/ha, respectively. Feed inputs were 100 kg phosphorus and 480 kg nitrogen/ha, respectively. Fish harvest removed 45 kg phosphorus and 142 kg nitrogen/ha. Thus, 55 kg phosphorus and 340 kg nitrogen/ha entered the pond water. These nutrients stimulate phytoplankton blooms in ponds creating an oxygen demand. Ponds assimilate much of the waste load through microbial respiration, ammonia volatilization, nitrification and denitrification, and accumulation of nitrogen, phosphorus, and organic matter in bottom soil (Boyd and Tucker 1998). Nevertheless, overflow and intentional discharge from ponds contains higher concentrations of nitrogen, phosphorus, suspended organic matter, and biochemical oxygen demand than receiving water bodies.

Effluents from flow-through aquaculture systems and cage and net pen culture usually are a greater pollution threat than ponds. Water passes quickly through raceways and dissolved and suspended matter are flushed out. However, it is possible to capture some of the feces and uneaten feed by sedimentation in the ends of culture units (Fig. 8). The settled solids may be removed and collected in a settling basin. All components of feed that are not converted to fish biomass enter the water body in which cages and net pens are sited. Water recirculating systems also have effluents when rainfall causes outdoor systems to overflow or when water must be exchanged or filters must be cleaned in indoor units.

Aquaculture effluents contain mainly nutrients, suspended soil particles, and particulate and dissolved organic matter. Thus, the main concern in receiving waters is sedimentation and eutrophication. Toxicity seldom is an issue.

Bivalve shellfish culture does not rely on fertilizers and feed. These organisms are filter feeders and they usually cause a net removal of nutrients and organic matter from the water (Shumway et al. 2003).

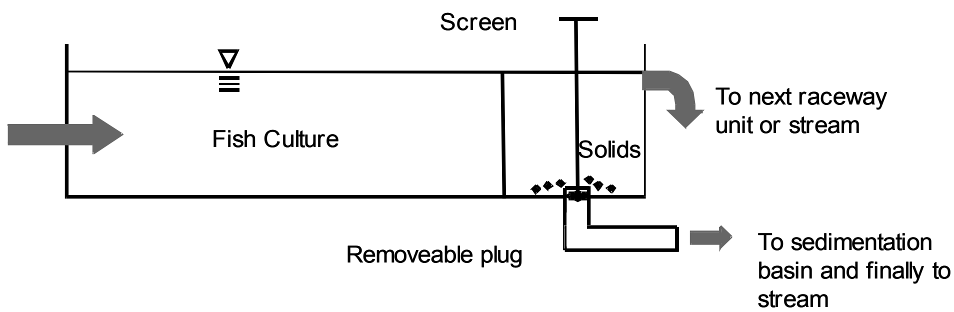

Figure 8. Illustration of the use of the end of a raceway for solids removal. Drawing is not to scale.

Salinization

In coastal aquaculture, brackishwater ponds may sometimes discharge into freshwater bodies to cause salinization. Another common problem is seepage of saline water from ponds into underlying freshwater aquifers. Sediment also may be removed from coastal aquaculture ponds and disposed in freshwater areas. Salt contained in the sediment leaches out following rainfall and can cause salinization (Boyd et al. 1994).

Inland culture of marine species may be conducted in ponds or other facilities supplied with brine solution or saline ground water from wells (Boyd and Thunjai 2003). Water discharged or seeping from these ponds obviously could cause salinization of soil and of surface water and ground water.

Biodiversity

Destruction of wetlands, eutrophication, and salinization can result in loss of biodiversity. However, aquaculture can negatively impact biodiversity in other ways.

Pumps often are used to supply water to culture systems. Larger aquatic organisms may be drawn into pumps and killed – a process known as impingement.

Capture of post larval shrimp for use in ponds was a common practice in the early days of shrimp farming and is still practiced in a few places. This practice lessens the abundance of shrimp post larvae in coastal waters, and a large bi-catch of larval fish and other species is destroyed (Sonnenholzner et al. 2002). Brood stock for use in hatcheries for shrimp and fish also may be captured from the wild. In Thailand, Vietnam, and some other Asian countries, the availability of wild-caught shrimp brood stock has declined drastically in recent years. Capture of brood stock for use in shrimp hatcheries likely has been one of the reasons for the decline.

Birds and other predators are attracted to aquaculture facilities because of the abundance of food. Some producers routinely kill predators by shooting them either legally or illegally. Lead shot that falls into ponds may be eaten by ducks and other species of birds that obtain food items from sediment. Ingestion of lead shot can be toxic to birds.

Non-native species may be cultured at aquaculture facilities, and escapees can become established in local waters. Some aquaculture species, such as tilapias, are highly aggressive and capable of displacing native species. Environmentalists feel that aquaculture animals may have different genetic characteristics than their local counterparts. If this is true, even native escapees from aquaculture projects could have adverse effects on gene pools.

Diseases are common in aquaculture facilities because animals are held under crowded and often stressful conditions. New diseases may be introduced when post larval shrimp, fingerling fish, bivalve shellfish spat, or seaweed propagules are brought from another nation or area for use in aquaculture. These diseases can spread from aquaculture populations to wild populations of the same or other species.

Chemicals

In addition to fertilizers, a variety of other chemicals are used in aquaculture. Fuels and other petroleum products can cause water pollution if spilled into water, and they constitute an explosion and fire hazard. Improper disposal of used petroleum products also can be a source of water or soil pollution.

Liming materials commonly are used in aquaculture (Boyd and Tucker 1998). Agricultural limestone is a safe product. However, burned lime and hydrated lime can result in dangerously high pH if used in excessive amounts or accidentally spilled into water. Also, because of their caustic nature, burned lime and hydrated lime can burn the skin of workers and cause serious and permanent damage to their eyes.

Copper sulfate is used to "thin" phytoplankton blooms. This product is safe at a concentration of one-one hundredth of the total alkalinity (McNevin and Boyd 2004), for it quickly precipitates to the pond bottom and does not remain in the water. Accidental overdoses or spills can cause fish mortality in ponds or natural waters. Salt often is used in channel catfish culture to counteract nitrite toxicity. Concentrations up to 100 mg/L chloride are safe, but accidental spills could cause mortality of freshwater organisms (Tavares and Boyd 2003).

Formalin, potassium permanganate, benzyl chromium chloride, provodone iodine, and possibly other compounds are used to kill bacteria and external parasites on fish (Boyd and Tucker 1998). These compounds are degraded within culture systems and usually do not constitute a water pollution problem. Antibiotics and other drugs used to control fish diseases are of concern environmentally, for they might induce resistance in native bacterial species. Antibiotic residues in aquaculture products are also potentially harmful to humans.

Sodium metabisulfate is used as a post harvest treatment of shrimp. This substance is acidic and it reacts to remove dissolved oxygen from water (Boyd and Gautier 2002). Disposal of used sodium metabisulfate solutions in natural waters can cause localized fish kills.

Other products used to a lesser extent in aquaculture include zeolite, aluminum sulfate, ferrous chloride, sodium bicarbonate, MS-222, rotenone, chlorine compounds, herbicides, insecticides, bacterial cultures, enzyme preparations, and possibly others. Boyd and Massaut (1999) and World Health Organization (1999) provided a discussion of the relative environmental and health risks associated with these products. Miscellaneous chemicals are safe if used and stored according to recommended procedures.

Chapter 5: Social Issues

The main social issues related to aquaculture are conflicts over use of land, water and other natural resources. Disputes over land rights are most common in coastal areas of countries where the right to use coastal land resides in concessions or leases from local or national governments rather than from land ownership. Influential investors may obtain the right to use land through financial or political influence, and huge tracts of land have been ceded to companies for many years at little or no cost. Local people sometimes have been unable to develop small aquaculture projects in prime areas because the land was ceded to large national or foreign companies. Moreover, in some heavily populated developing nations, many landless people live near the coast and depend upon fishing and harvest of other coastal resources for a living. These people have sometimes been forced from coastal land by aquaculture developers.

Local people with inadequate technical knowledge and capital often have developed small aquaculture projects in coastal areas without formal permission from the government. Such projects may do tremendous environmental damage, and they often are abandoned within a few years. These operations are similar to "slash and burn" agriculture seen in many tropical nations.

The siting of aquaculture projects has caused much conflict between environmental groups and the aquaculture industry. Again, most of these problems have arisen in the coastal zone of developing countries. The main social problem has been installation of aquaculture projects in places that interfere with use of traditional resources. For example, farms may block routes to fishing sites or farms may be built in mangrove areas that had been sources of fuel, building materials, and other resources for local communities. Pollution by farms also may result in a decline in fish and other aquatic organisms important as a local food source.

Fewer disputes over land use have occurred at inland aquaculture sites. It is more common to find private ownership of land for aquaculture in inland areas than in coastal areas. Also, there usually is a smaller population of landless people in inland, rural areas than in the coastal zone. In developed countries, a well-defined protocol must be followed to obtain the right to use land. The protocol includes measures for protecting wetlands and other sensitive ecological habitat. Thus, siting of land-based aquaculture projects in developed countries usually does not result in controversy.

Land use in aquaculture can be a beneficial and valuable agricultural alternative in rural areas. Channel catfish farming is a major industry in the southeastern US, and many other crops are declining in profitability. In Mississippi, catfish farms often replaced rice and soybean farms. Heavy clay soils used for these crops were ideal for catfish ponds. Cotton, because of generous governmental subsidies, is still a viable economic endeavor. Cotton is produced on lighter soils not as suitable for ponds as rice and soybean land. Thus, there was no competition for land between cotton farmers and catfish producers (Boyd 1985). In Alabama, catfish farming developed in the Blackland Prairie region and was installed mainly on pastureland that had become unprofitable (Boyd et al. 2000).

Water use also can lead to controversy. The removal of water from surface or underground sources for aquaculture may compete with other water users. Installation of cages in streams, lakes, or the sea and bivalve culture in coastal waters may interfere with navigation, fishing, and recreational uses. Disputes are particularly likely in cases where permission to use water was granted to large companies that paid very little for their concession. Many times, negotiations for water use rights were between national or state governments and aquaculture principals, and local governments and citizens felt that they were denied participation.

There occasionally have been serious conflicts related to salinization of freshwater aquifers by shrimp farms. These disputes usually occur in areas with sandy soil near the sea. Seawater pumped into ponds seeps downward through pond bottoms into underlying freshwater aquifers that may be used as domestic water supplies. There also has been concern over salinization in areas where marine shrimp are cultured in freshwater areas. For example, in Thailand, inland shrimp producers obtain brine solution of 150 to 250 ppt salinity from coastal seawater evaporation ponds. The brine solution is mixed in ponds with freshwater from the irrigation system. Seepage and discharge from these ponds can contaminate the surrounding area with salt and adversely affect terrestrial agriculture.

Not all conflicts related to aquaculture facilities are caused by aquaculture. Many times, aquaculture is affected by water pollution resulting from other land and water users. Municipal, industrial, or agricultural pollution may have degraded the quality of water before it arrives at an aquaculture facility. One of the most publicized conflicts between agriculture and aquaculture occurred among banana producers and shrimp farmers in Ecuador in the early 1990s. In response to a fungal disease of bananas, large quantities of two fungicides were applied to banana farms. The aerial drift from fungicide application and runoff from banana plantations entered the estuaries that supplied shrimp farms with water. Heavy mortality of shrimp occurred over a 2-year period. A new viral disease was identified in the shrimp, and some feel that this was the cause of the problem. However, by the time the disease was identified, better practices were being used for fungicide treatment of bananas, and most shrimp producers in Ecuador still believe that the banana fungicides were initially the cause of shrimp mortalities.

Aerial application of insecticides on cotton and other crops have been the actual cause or the perceived cause of mortalities of fish in commercial channel catfish farms in Mississippi. In some cases, scientific evidence of the cause of the fish mortalities was not conclusive, and the conflicts were settled in court. Usually, juries find in favor of the fish producers because they can connect fish kills and pesticides in their minds regardless of scientific evidence.

At a few locations, aquaculture has become part of the urban-rural interface conflict. There is a popular trend among the wealthy to have permanent residences or vacation houses along the seacoast or beside lakes. These seaside and lakeshore residents do not want to see cages floating in the sea or lakes, racks for bivalve culture exposed at low tide, turbidity plumes from fish or shrimp ponds, bad odors, or loud noises.

Conflict resolution is difficult, and the best approach is to avoid conflicts. More studies are needed to obtain more reliable data on resource use and environmental impacts of aquaculture. These findings should be used to develop management practices to avoid negative impacts. The aquaculture industry also should be more active in informing the public about production practices and try to dispel negative perceptions of the industry. By demonstrating better environmental stewardship and being a good neighbor, aquaculture can avoid many resource use conflicts. It is much more difficult for the aquaculture industry to deal with pollution problems imposed upon it by other land and water users. Of course, coastal zone management and watershed management projects can encourage cooperation and understanding among stakeholders.

In most nations, people do not actually own land or water. They own the right to use land and water. The ownership of this right should carry some responsibility to respect the rights of their neighbors to use land and water. Owners of water and land rights also should be good stewards of the land and water so as not to lessen its benefits to future generations. Moreover, land and water rights have economic value that can be bought and sold. People have traditionally traded in land. However, it is becoming increasingly common to trade in water. Irrigation water usually is allocated to farmers and they must pay for the amount that they use. Water rights can be sold to others if the water right owner does not want to use the water. Putting water on an economic basis would be beneficial in reducing some conflicts over water, for one of the complaints is that aquaculture producers often have free use of water. Certainly, conflicts over land use in aquaculture are less in areas of private landowners than in those where land concessions are obtained from the government.

Large aquaculture facilities may be major employers and play an important role in local economies. Therefore, these companies should exhibit civic responsibility by being a good neighbor in local communities. For example, they should have regular meetings with local civic leaders. These meetings could serve as a dialogue in which farm management and local leaders could exchange information and make plans for avoiding conflicts. Aquaculture facilities should hire local workers to the extent possible, and they also should make contributions to community health and educational programs.

Aquaculture facilities also have responsibilities to their workers. Wages should be equal to or exceed national minimum wage and local pay scale. Workers should be given training on safety issues related to their jobs. At remote facilities, workers are housed on farms. These workers should have adequate and healthy food, good living conditions, home leave, and access to health care including prompt treatment for on-the-job accidents or sudden illnesses. Recreation facilities also should be available.

Sanitation is a major issue where workers live on farms. Sanitary bathrooms and bathing facilities must be maintained, and wastewater from living quarters, offices, and kitchens must be treated before discharge to the environment. Solid wastes must be collected on a regular schedule and not allowed to accumulate. These wastes should be incinerated, composted, or put in a sanitary landfill.

Chapter 6: Food Safety Issues

Products from aquaculture should not be contaminated with potentially harmful chemicals or biological agents. One of the major concerns is that residues of antibiotics or other chemicals sometimes used on farms will be present in the final product. Water used in aquaculture facilities is sometimes polluted by other water users. At some sites, aquaculture species might acquire residues of heavy metals, petroleum products, and pesticides and other chemicals from external pollution.

Contamination with microbiological agents, usually are of more concern in processing, transporting, holding, and preparing aquaculture products than in farming procedures. Nevertheless, bivalve shellfish produced at polluted sites may contain harmful microbial agents. Also, at some sites, algal toxins may be accumulated by shellfish.

Aquaculture sometimes is conducted in water fertilized with untreated animal manures or with household or municipal sewage. Products from such culture systems certainly raise human health concerns.

Consumer opinions

Although there is not a public outcry against bad agricultural (and aquacultural) practices, consumers probably would prefer food known to have come from environmentally-responsible production techniques. Some consumers also are concerned about the welfare of workers who produce their food and the influence of farming activities on local communities. This group wants to know that their food is produced on farms operated in a socially-responsible manner.

The Seafood Choices Alliance (2003) conducted a survey of US consumers. While consumers have a low awareness about seafood sustainability issues, over one-third of the respondents said that they were willing to modify seafood purchases in favor of environmentally-responsible seafood. Also, a majority of those surveyed wished for more information about the environmental impacts associated with seafood. Seafood purveyor responses were similar to consumer responses.

Some organizations have websites to provide information about fisheries, aquaculture, and sustainability issues related to seafood, and seafood safety. The Monterey Bay Aquarium's Seafood Watch Program, Environmental Defense, Eco-fish, and Blue Ocean Institute have made pocket guides to rank popular seafood species according to the environmental friendliness of the way in which they were caught or cultured. Some environmental groups have sought to prevent shoppers from purchasing certain seafood species through negative ad campaigns. However, these campaigns are not fair to responsible producers, and the ads often present inaccurate information.

Food safety often is taken for granted, and consumers seek the best quality product in terms of appearance, freshness, nutritional value, size, price, or other characteristics. However, there is increasing concern that governmental regulations and inspections do not adequately assure the safety of the food supply. Because chemical and biological contaminants may occur in otherwise attractive and fresh products, many consumers want assurance that potentially harmful chemicals were not used in the production of their food and that biological contamination is absent.

There are few simple indicators to assist shoppers in selecting seafood items originating from responsible production practices. Consumers usually know little about seafood products beyond product names in seafood counters and their previous experiences with particular seafood. The US has required Country of Origin labeling (COOL) and Method of Production (MOP) labeling since 30 September 2004, and consequently, consumers are made aware of where a seafood product originated and if it was the result of aquaculture or fishing.

We believe that the consumer would appreciate assurance about three major issues: (1) Is the product safe? (2) Is the product the result of environmentally-responsible production methods? (3) Is the producer socially aware? In addition, many consumers would be interested in the origin of the product, e.g., captured or fished by which nation.

Chapter 7: Environmental Management in Aquaculture

The goal of environmental management is to minimize, prevent or mitigate adverse environmental effects of human activities to permit sustainable use of world resources. For environmental management to be effective, possible adverse environmental impacts of human activities must be identified. Standards must be formulated to specify amounts of change in environmental variables that are permissible without causing unacceptable environmental effects. Technology-based management practices must be available for preventing excessive changes in environmental variables. Of course, in order to demonstrate that environmental management is achieving its goal, a monitoring effort is necessary to show that environmental variables remain with acceptable ranges. Finally, if monitoring reveals that environmental variables are outside acceptable ranges or environmental impacts are occurring, improvements must be made in the application of management practices. Environmental management consists of impact identification, formulation of standards, adoption of management practices to comply with standards, monitoring to prove compliance, and correction for non-compliance. As a simple example, suppose that an effluent from an aquaculture facility is high in total suspended solids (turbidity). Local regulations state that waters with more than 25 turbidity units cannot be discharged into natural waters. Sedimentation is known to be effective in reducing total suspended solids in effluents. However, after installing a settling basin, monitoring reveals that pond effluents sometimes exceed 40 turbidity units. Thus, the effluent is not in compliance with the standard, and practices for controlling turbidity must be assessed and modified to achieve compliance with the turbidity standard.

Although environment management is undertaken to protect the environment and allow for sustainable use of resources, individual perceptions of environmental quality differ and sustainable use is difficult to define. There also are many opinions about how much change in the environment should be allowed and about the best methods for regulating this change. Furthermore, many environmental effects of a project are expressed off-site and within the public domain. Project managers often are reluctant to invest in treatments to prevent or mitigate effects unless they benefit directly. To illustrate, a shrimp farm takes high quality water from an estuary, and by using it, causes its quality to deteriorate. However, the manager may not want to treat the effluent because it passes downstream, and treatment will be an added expense that does not contribute to shrimp production.

The government should be responsible for establishing standards for environmental management and enforcing compliance with the standards, because both activities involve regulations and laws. The cost of making evaluations of activities to determine possible ecological impacts should be the responsibility of the private sector, but governments should provide guidelines describing how an acceptable evaluation is to be conducted, and they should approve the evaluation. The private sector should bear the costs of installing management techniques for preventing or mitigating adverse environmental effects, but again, the government should be responsible for approving the mitigation or treatment plan. Development of technology-based treatment or mitigation often exceeds the capabilities of the private sector and public funds must be spent on development of effective environmental management procedures and in the educational effort to disseminate information about these procedures. The cost of monitoring on-site environmental variables should be the responsibility of the private sector, but the government should verify the validity of the monitoring effort and determine if compliance with standards is occurring. Off-site monitoring can best be achieved by governments or by private associations with governmental oversight, because many human activities combined usually result in off-site impacts and a single activity should not bear the entire cost of monitoring. Finally, the government is the only party that can enforce regulations and laws. The only exceptions are private groups who have imposed standards upon their members.

The action of governments is subject to national public opinion, lobbying efforts of special interest groups, and world opinion expressed by other governments, intergovernmental agencies and non-government organizations (NGOs). In the US, Canada, Australia, western European nations, New Zealand, and a few other countries, environmental management is highly developed with sufficient regulations and laws to protect the environment and national resources. However, these regulations and laws may not be applied uniformly by industry or region because of various reasons, but primarily because of funding and manpower shortages, political favoritism or influence, and judgment of regulatory agencies. In many developing nations, regulations and laws are insufficient to provide adequate protection of the environment and natural resources. In others, laws and regulations may be adequate, but be un-enforced because of the lack of funds and manpower.

Possible regulations of aquaculture include bans, restrictions, land use classification and zoning, environmental impact assessment, mitigation plans, permits, user fees, and monitoring requirements. The most important regulations for aquaculture would be requirements of environmental impact assessments, effluent discharge permits, limitations on non-native species, restrictions on drug and chemical uses, standards for feed composition and restrictions on feed use, and restrictions on certain management practices.

Environmental impact assessment

One of the most common reasons for failure of aquaculture farms and for adverse environmental impacts is location of farms on inferior sites (Boyd and Clay 1998). Site evaluation to determine the availability and quality of water, climatic conditions, tidal patterns, water flows to include flood levels and frequency, terrain, vegetative cover, soil characteristics, and related factors should be performed to determine if site characteristics are suitable for construction and sustainable operation of aquaculture facilities. In cage culture operations, the characteristics of bodies of water into which cages will be installed are critical factors. It should be determined if the cage culture operation will be jeopardized by poor water quality and especially by sudden thermal destratification. It should also be determined if the cage culture operation will cause the water body to become more eutrophic and less biologically diverse. Factors such as possible conflicts with other water users, effects of storms on cages, and potential sources of pollution should also be considered.

Sites for culture of bivalve shellfish and seaweed in coastal waters also should be subjected to site evaluation. In addition to suitability for the culture species, these farms should not interfere with established navigation routes or cause conflicts with other resource users. Sites should not be in areas with frequent toxic algae blooms or in waters with high concentrations of coliform organisms.

All of the information required in a proper site evaluation must be obtained in an environmental impact assessment (EIA), but EIAs also must provide a detailed description of the ecosystem to be affected, describe the proposed project, predict negative environmental impacts, and provide a mitigation plan and monitoring program (Wood 1995). Farm layout and design can be modified to exclude areas of the site with unfavorable characteristics or to avoid or mitigate potentially-negative environmental impacts. Thus, site evaluation, environmental impact assessment, and farm layout and design for aquaculture projects should be integrated. By doing so, the developer can determine if it is technically and economically possible to develop a sustainable project on a given site.

The magnitude of an EIA will increase as project size increases, and sensitive or more complex ecosystems will need more detailed EIAs than less fragile or simple ecosystems. It might be possible to develop simple checklists for conducting EIAs of small projects of a few hectares in size, but a team of scientists representing several specialties may be needed to do EIAs of larger projects.

Effluent regulations

There are several ways of regulating effluents to include: discharge not allowed; discharge allowed only if effluent quality is within specified limits (water quantity restrictions also may apply); discharge allowed only if BMPs are used; discharge is allowed but user fees are applied to effluent pollution loads. The first option of no discharge is unsuitable for many types of aquaculture facilities because of overflow after rains, water exchange often is necessary to maintain suitable water quality, and ponds must be drained for harvest. Discharge permits with water quality criteria and water volume criteria require monitoring and reporting at regular, specified intervals to show compliance. This kind of discharge permit is suitable for large operations. The cost and expertise required for monitoring make water quality (and water volume) based permits impractical for aquaculture effluents where there are many small farmers and effluent outfalls. Likewise, the system of assessing a fee for effluents based on concentration and volume (load) requires much monitoring, and this system does not seem applicable to aquaculture. The best system appears to be the use of general discharge permits that require farmers to use specified BMPs with little or no monitoring required. It is interesting to note the US Environmental Protection Agency made a study of aquaculture in the US and did not recommend effluent limitation guides (Federal Register 2004). In other words, they did not impose water quality limits for effluents. Instead, they will require National Pollution Discharge Elimination System (NPDES) permits for aquaculture facilities that qualify as concentrated aquatic animal production facilities (Table 8). They recommended that compliance with these permits should require implementation of BMPs.

The Global Aquaculture Alliance (GAA) developed standards for certification of shrimp farms and licensed these standards to the Aquaculture Certification Council (ACC). The standards include effluent monitoring to demonstrate whether or not BMPs are effective in improving effluent quality. The ACC decided to establish and enforce an effluent quality standard for participants in its program. The water quality criteria of the GAA/ACC effluent standard are listed in Table 9.

Table 8. Criteria for determining a concentrated aquatic animal production facility in the United States. Source: Federal Register (2004).

Coldwater

Facilities that culture coldwater species in ponds, raceways, or other similar structures that discharge at least 30 days per year but does not include:

(1) Facilities which produce less than 9,090 harvest weight kilograms of aquatic animals per year or,

(2) Facilities that feed less than 2,272 kg of food during the calendar month of maximum feeding.

Warmwater

Facilities that culture warmwater species in ponds, raceways, or other similar structures that discharge at least 30 days per year but does not include:

(1) Closed ponds which discharge only during periods of excess runoff or,

(2) Facilities that produce less than 45,454 harvest kilograms of aquatic animals per year.

Table 9. Effluent limitation guidelines of the Global Aquaculture Alliance shrimp certification standards. Source: Aquaculture Certification Council website.

Variable (units)	Initial standard	Target standard	Measurement frequency
pH (standard units)	6.0-9.5	6.0-9.0	Monthly
Total suspended solids (mg/L)	50 or less	25 or less	Quarterly
Soluble phosphorus (mg/L)	0.5 or less	0.3 or less	Monthly
Total ammonia nitrogen (mg/L)	5 or less	3 or less	Quarterly
5-day biochemical oxygen demand (mg/L)	50 or less	30 or less	Quarterly
Dissolved oxygen (mg/L)	4 or more	5 or more	Monthly
Salinity (ppt) *Less than 1 ppt salinity or specific conductance less than 1,500 μmhos/cm.	No discharge of water above 1.5 ppt salinity into freshwater*	No discharge of water above 1.0 ppt salinity into freshwater*	

Best management practices

Practices thought to be the most effective practical methods of reducing environmental impact levels to those compatible with resource management goals are called BMPs (Hairston et al. 1995). The term practice refers to the structural, vegetative, or management activities needed to solve one aspect of a resource management problem. In some situations, a single practice may solve the problem, but usually a collection of practices or a "system of BMPs" is needed to provide effective environmental management. There has been widespread application of BMPs in traditional agriculture to prevent soil erosion and resulting turbidity and sedimentation in streams and other water bodies. In the US, BMPs are the main feature of regulations of animal feedlot operations (AFOs) and concentrated animal feedlot operations (CAFOs). BMPs are most commonly associated with agriculture and other activities that cause non-point sources of pollution. However, BMPs also may be included in permits for non-agricultural, point source effluents (Gallagher and Miller 1996).

Importations

Non-native species can escape into the environment and possibly create a biological nuisance. Countries should have policies about importation, quarantine, and distribution of non-native species. These policies should be based on reliable scientific information and bans should not be imposed unless there is justification for them. Where non-native species are allowed, culture systems should be designed to prevent escape, but experience indicates that it is difficult if not impossible to assure that no animals will escape.

Importation of species that already occur in a country is often done to provide brood stock or small animals for stocking. Diseases have been introduced by importations. These diseases are a threat to aquaculture crops, and they also may infect native populations. Therefore, strict guidelines for disease inspection and quarantine should be established and enforced.

Antibiotics, drugs and other chemicals

A wide variety of antibiotics and other drugs are used to control diseases of fish and other aquatic animals, and a variety of chemicals to include fertilizers, liming materials, disinfectants, oxidants, coagulants, pesticides, piscicides, adsorbents, and minerals are applied to aquaculture systems. Most of the products have a long history of safe use in food production, but some compounds, and especially drugs, pesticides, piscicides, and antibiotics may be toxic, bioaccumulative, or both. Release of water containing some substances might result in ecological damage, and some compounds could contaminate the flesh of fish and shrimp and pose a hazard to consumers.

Nations should develop a list of approved drugs and chemicals for use in aquaculture. These lists also should give the approved use of each drug, methods of application, and withdrawal time. Drug and chemical regulations for aquaculture have already been made in the US (Federal

Joint Subcommittee on Aquaculture 1994) and several other nations, and these regulations could be used as a model for countries wanting to develop regulations. Equally important, manufacturers should be required to provide labels with the composition of chemical products, the permissible uses, methods of application, environmental hazards, and restrictions.

Feed regulations

The government should require manufacturers to present the proximate composition of feeds on the feed bags. It would be possible to ration the amount of feed that farmers can purchase, but this might lead to use of low quality feed stuffs that cannot be regulated. Therefore, feed rationing does not seem feasible for general use in limiting nutrient inputs to aquaculture facilities. It seems likely that governments could regulate the composition of feed and thereby prevent higher concentrations of nitrogen, phosphorus, and other nutrients than needed.

Restriction of certain practices

It would be difficult to regulate most activities at aquaculture facilities. However, some especially damaging practices can be controlled. The government should have regulations on ground water use. Additionally, the use of freshwater from wells to dilute salinity in brackishwater ponds should be regulated. Discharge of brackishwater into freshwater bodies or onto agricultural land usually should not be allowed. Shrimp farms should not be permitted in mangrove areas or other wetlands. Some birds prey on fish and other aquatic animals, and heavy economic losses from bird predation sometimes occur. Nevertheless, aquaculturists generally should not be allowed to kill birds, because there are non-destructive means of controlling birds.

Chapter 8: Codes of Practice

Aquaculture usually has not been considered in national planning related to soil and water conservation, water pollution, plant and animal quarantine programs, and other aspects of environmental management. However, nations must now consider aquaculture because it has become a major endeavor with the potential to cause adverse impacts. Public and scientific opinion is demanding better environmental stewardship, and wiser use of dwindling world resources. This increased environmental concern has resulted in formation of many environmental activist groups that are putting pressure on governments and the private sector. In spite of the fact that aquaculture is a necessary activity to meet world food demands and environmental damage by aquaculture is no greater than that of many other human activities of equal or smaller scale, there are several reasons why culture methods should be improved which are listed in Table 10.

Table 10. Forces driving the responsible aquaculture movement.

- Consumers are concerned with food safety and want food produced by environmentally- and socially-responsible methods.
- Environmental groups seek to relieve pressure on natural fisheries through responsible aquaculture.
- Developed nations are depending more on imported food and want to assure that good production practices are used in exporting nations.
- Aquaculture industry wants to assure its markets.
- Governments want to protect the environment and to promote exports.

Although some problems may exist in developed countries, governments are slowly but surely devising satisfactory systems of aquaculture regulations. The status of aquaculture regulations in developing nations varies greatly both in terms of suitability of regulations and in their enforcement. Therefore, the aquaculture industry needs to respond to environmental concerns proactively by voluntarily developing more ecologically responsible production systems.

An effective approach to voluntary regulation of an industry is for its members to adopt codes of practices that contain BMPs designed to minimize adverse environmental impacts. Systems of BMPs will be required for aquaculture, and the systems will have to be customized for site characteristics, production goals, and national interests. The most practical procedure appears to be for an industry group to develop a general code of practice for a region or a nation, and this code of practice can be satisfied through application of site-specific BMPs. Efforts on BMPs focus on the farm level where there is the greatest likelihood of negative environmental impacts. Moreover, there are regulations or policies in effect at other levels to safeguard the public (Fig. 9).

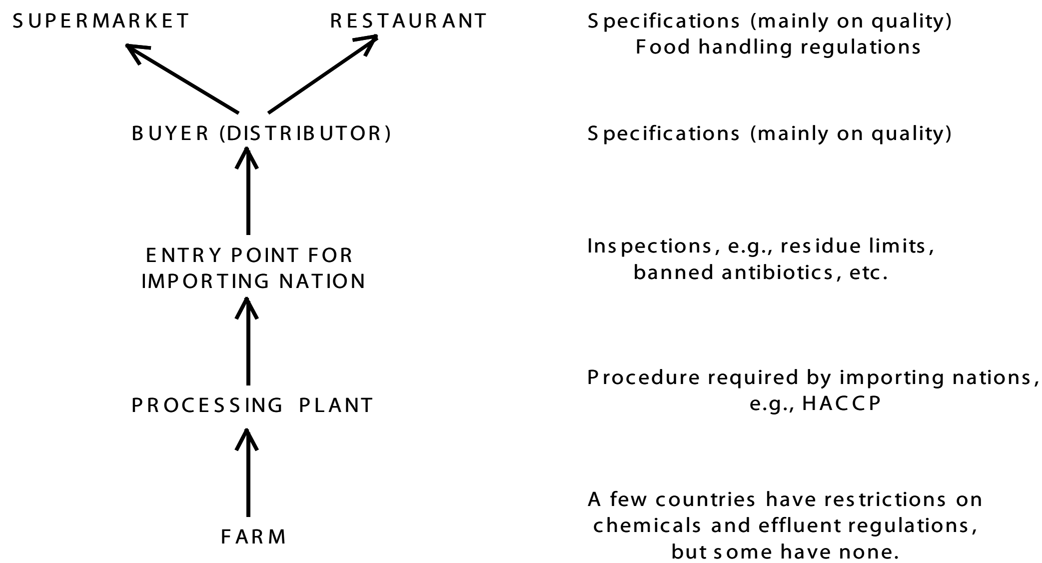

Figure 9. Layers of protection for seafood safety.

Considerable effort already has been made towards aquaculture codes of practice for shrimp culture. Tookwinas (1996) considered ways of lessening the environmental impact of intensive shrimp ponds in Thailand, and the Association of Southeast Asian Nations (1997) prepared a manual for harmonization of good shrimp farm management practices. Donovan (1997) prepared an environment code of practice for Australian shrimp farmers, and Dixon (1997) presented a similar code for shrimp culture in Belize. A set of BMPs for semi-intensive shrimp farming in Central America was prepared by the Coastal Resources Institute of the University of Rhode Island (Boyd et al. 2001). The Thailand Department of Fisheries and the World Bank cooperated to develop a code of practices for shrimp farming in Thailand (Tookwinas et al. 2002). The GAA prepared general codes of practice for shrimp farming (Boyd 1999). The GAA also developed standards for shrimp aquaculture and the ACC uses the standards as a basis for environmental certification of shrimp farms. The GAA and ACC are presently developing standards for other aquaculture species. The FAO is in the final stages of developing international guidelines for aquaculture certification. A list of selected organizations that have developed aquaculture codes of practice or BMPs is provided (Table 11), and other organizations also have prepared codes of practice.

Table 11. Partial list of organizations that have prepared codes of conduct for aquaculture.

Alabama Catfish Producers

Agro Eco Consultancy

Aquaculture Foundation of India

Auburn University, Alabama Department of Environmental Management, and Natural Resources Conservation Service (catfish)

Australia Aquaculture Forum (general)

Australian Prawn Farmers Association

British Trout Association

Catfish Farmers of America

Coastal Resources Center (University of Rhode Island) (shrimp)

Florida Department of Agriculture and Consumer Services (general)

Food and Agriculture Organization of the United Nations (general)

Global Aquaculture Alliance (shrimp)

Industrial Shrimp Action Network

Irish Salmon Growers Association

Louisiana State University AgCenter (general)

Malaysia Department of Fisheries (shrimp)

Marine Shrimp Farming Industry of Thailand

Massachusetts Department of Agriculture and Resources (shellfish)

Missouri Department of Natural Resources (general)

Naturland (organic)

Ornamental Fish Industry (United Kingdom)

Shrimp Farming Industry of Belize

Soil Association (United Kingdom) (organic)

Texas Natural Resources Conservation Commission (shrimp)

United States Environmental Protection Agency (general-draft)

Washington Fish Growers Association (salmon)

West Virginia University Extension Service (trout)

Chapter 9: BMP Development

There clearly has been much effort towards developing general documents containing BMPs for a number of aquaculture species and especially for marine shrimp. Individual farms and local producer groups also have become interested in improving management practices. For example, the Alabama Catfish Producers (ACP) that consists mainly of producers in a five-county area of west-central Alabama followed a formal procedure to develop BMPs (Boyd et al. 2003). The ACP is cooperating with Auburn University, the United States Department of Agriculture Natural Resources Conservation Service, and the Alabama Department of Environmental Management in developing aquaculture effluent regulations based on BMPs (Boyd and Hulcher 2001). Supermarket chains and other large purchasers of seafood have expressed interest in aquaculture species produced by good practices. In response to this potential market, World Wildlife Fund (WWF) and ACC are considering programs for certification of several aquaculture species. There is likely to be a proliferation of efforts to develop BMPs and possibly certification programs for many aquaculture species.

Environmental survey

The initial step in developing BMPs for production of a particular species in a given area is to conduct a survey of production activities and their potential effects on the environment and nearby communities. There may be so many producers that a sample of farms must be selected for the study. The sample should be a random selection of farms to assure that it is representative of the production activity. The survey probably should include farms accounting for 10 to 25% of total production within the area of interest.

The survey should be conducted by a small team of individuals having collective expertise in aquaculture, environmental science, and social science. These individuals should be responsible for designing the survey instrument for capturing the information needs listed in Table 12. The return on surveys through the postal mail or via electronic mail is small. Therefore, the investigators should visit each farm and fill in the survey instrument during interviews with the farmers.

Environment assessment

The findings of the environmental survey should be summarized in a report, because the information will be used later in stakeholder meetings. The report should describe the industry and how it has been superimposed on landscapes and communities. Production facilities and methods should be described. Published research findings and extension recommendations on feed use efficiency, aeration, effluents, etc. should be summarized. A careful description of water use within the culture facilities is necessary. There should be a thoughtful analysis of resource use and possible environment impacts in which wasteful practices and environmentally-harmful practices are identified. In addition, the possibility of negative social aspects of farms should be ascertained. Investigators should prepare lists of BMPs that could be useful in preventing wasteful use of resources and negative environmental and social impacts. The BMPs also should include practices for preventing contamination of aquaculture products at the farm level.

The report should be sent to three to five external reviewers (not local stakeholders) and the reviewers' comments incorporated in the final draft. Examples of reports on the environmental status of aquaculture industries are available for marine shrimp farming in Thailand (Tookwinas 1996) and channel catfish farming in Alabama (Boyd et al. 2000).

Table 12. Suggestions for information to be obtained from aquaculture producers for use in developing BMPs.

- General information on the aquaculture activity
  - Species, total area in production, total annual production, value of production, size of farms, employment opportunities, major milestones, future prospects, and climatic information.
- Specific information for individual farms
  - Site and farm
    - Location
    - Significant features – terrain, soils, elevation, vegetation, nearness to neighbors, possible natural disasters, and likelihood of pollution from other land and water users.
    - Area in production
    - Source of water
    - Culture species
    - Annual production
  - Production system
    - Type – e.g., ponds, raceways, cages, etc.
    - Description of system
    - Water use
    - Water intake and distribution
    - Water release – frequency, volume, quality
    - Retention time
    - Water discharge – frequency, quantity, and quality
    - Condition of facilities – maintenance of facilities, erosion control, general tidiness
  - Production methodology
    - Species
    - Source of seed and stocking density
    - Fertilizers and liming materials – types, amounts, application frequency
    - Feed – type and protein, fish meal, and phosphorus content
    - Feeding – frequency, amount per day, method of application, amount per crop
    - Mechanical aeration – type of aerators, amount of aeration per pond, operating schedule
    - Water exchange – method of application, amount per day, use in response to water quality emergencies, total water use

    + Health management (including information of the use of therapeutants)
    + Water quality conditions, eg., copper sulfate, zeolite, sodium chloride, etc. – doses, frequencies, and methods of application
    + Harvest data – harvest method and harvest statistics (survival, net production, FCR, etc.)
- Effluents
    + Annual volume and frequency of discharge
    + Average quality and maximum concentrations of nutrients, suspended solids, biochemical oxygen demand, dissolved oxygen, and pH
    + Annual loads of N, P, TSS, and BOD_5
    + Treatment of effluent before final discharge
    + Conditions around final discharge point
    + Receiving waters – area, volume, flushing rate, quality, other users, other pollution sources
    + Permit conditions and monitoring
- Miscellaneous
    + Use of pesticides
    + Predator control method
    + Storage of materials – feeds, fertilizers, liming materials, fuels, etc.
    + Waste disposal – used oil, expired or unwanted chemicals, refuse, sewage, etc.
    + Observations of surrounding environment – evidence of eutrophication or sedimentation in receiving water body, damage caused by improper waste disposal, ecological nuisances, etc.
- Community and worker relations
    + Procedures used to communicate with community leaders
    + Assistance provided to local communities
    + On-going conflicts
    + Origin of workers
    + Pay scale and incentive pay for workers
    + Living conditions on farms
    + Medical care
    + Recreational activities

Stakeholder meetings

The credibility and effectiveness of BMPs are increased greatly by the involvement of a variety of stakeholders. These stakeholders should include producers, local extension specialists, local environmentalists, and representative of communities situated near farms. In addition, the team responsible for the environmental survey and report, aquaculture specialists, representatives of international NGOs, representatives of processing plants, and possibly others should be invited. Typically, the most contentious relations in multi-stakeholder meetings have been between environmentalists and industry representatives. There have been heated debates concerning the environmental and social impacts of aquaculture. These debates effectively have polarized arguments pertaining to aquaculture impacts, thus resulting in extreme views and little compromise. It is interesting to note that in the aquaculture industry some of the staunchest opponents to environmentalists' claims are trying to address these concerns through BMPs and codes of conduct. In doing so, the industry is essentially collaborating with environmentalists, thus it is quite sensible to involve environmentalists more formally in BMP development processes. The number of participants can be limited according to the judgment of the organizers, but 20 to 25 participants would be a typical group. However, restricting attendance to these meetings is very difficult because many stakeholders have a vested interest in the BMPs being developed. Thus, the person or persons planning the meetings should have a good, general understanding of the people who would be most affected and interested in the particular type of aquaculture being discussed. In many cases, consultants are hired to specifically do this job. Nevertheless, thorough research is required, for excluding a concerned party may be detrimental to the credibility of the BMPs in the future.

The discussion at the first stakeholder meeting, in which all representative stakeholders are present, should be reserved to scientific discussions on what issues are important to address. It is helpful to maintain a workshop setting and record concerns on a blackboard to make sure stakeholders are aware that their concerns are being taken into consideration. There is a certain level of trust that needs to be established at multi-stakeholder meetings, and if this is achieved early in the process, a sense of team work and unity often develops.

It is unlikely that mutually agreeable BMPs can be developed in a single meeting. Committees should be given assignments related to the process, and these committees could work separately in preparation of material for discussion by all stakeholders in finalizing BMPs.

Guidelines for writing BMPs

In developing BMPs, it is most convenient to consider several categories of possible impacts and give a suite of BMPs under each category. Producers would select the BMPs appropriate for individual sites and operations. For example, Boyd and Hargreaves (2004) suggested eight categories of BMPs for channel catfish aquaculture as follows: site selection and pond construction; liming and fertilization; feeds and feeding; solids management and disposal; use of drugs and chemicals; mortality removal and disposal; management of escapees; general facility operation and maintenance. However, the Alabama catfish farming BMP effort (Boyd et al. 2003) required 15 categories in order to satisfy all stakeholders.

The environmental assessment report provided to stakeholders should have BMPs arranged by categories. However, this presentation of BMPs should be considered a basis for discussion in order to arrive at the final BMPS. The categories can be altered according to the judgment of the stakeholders, and the individual BMPs can be selected or rejected based upon the opinions and experience of the group.

Previous studies about the effects of various treatments and management strategies for the particular aquaculture activity should be considered in selecting appropriate BMPs. The input of producers is especially important, because they can provide opinions on the degree of difficulty and costs of implementing individual practices. The goal of the practices is to reduce impacts, and where possible, benefits should be estimated. For example, calculations of reduction of nutrient loads in effluents resulting from improving FCR through the use of better feed management can be calculated. The likely effect of sedimentation basins on effluent quality also can be calculated. Environmentalists will want assurances that the practices will have a positive effect; thus, there should be a scientific basis or experience from previous applications of practices in other kinds of aquaculture or other industries to support efficacy.

Examination of BMPs recommended in other types of aquaculture can be especially useful. Boyd (2003) discussed farm-level issues in environment management of aquaculture effluents. He emphasized the need to categorize the BMPs and gave an example of BMPs for preventing erosion of pond watersheds, embankments, bottoms, and discharge canals that may be a significant source of suspended soil particles in effluents. The BMPs were as follows:

(a) Use proper slopes and compaction to minimize erosion potential on embankments;

(b) Design discharge structures and canals to prevent erosion by impact of water or scouring by excessive water velocity;

(c) Provide vegetative cover on embankments and above water slopes of canals to prevent erosion.

(d) Provide grass cover on watersheds and gravel on farm roads and tops of embankments to prevent erosion;

(e) Position aerators to prevent erosion of insides of embankments and pond bottoms by aerator-induced water currents;

(f) Do not leave the drain open in empty ponds to prevent rainfall erosion and discharge of suspended solids;

(g) Do not allow livestock to walk on pond embankments or to wade in ponds; and

(h) Do not remove sediment from ponds and place in spoil piles on embankments of surrounding area; Use sediment to repair pond embankments or dispose of it in a responsible manner.

Boyd (2003) also provided a list of BMPs that could be adopted to minimize nutrient loads in aquaculture effluents and lessen the likelihood of eutrophication in receiving water bodies. The recommended BMPs were as follows:

(a) Use fertilizers only as needed to maintain phytoplankton blooms;

(b) Select stocking and feeding rates that do not exceed the assimilation capacity of ponds;

(c) Feeds should be of high quality, water-stable, and contain no more nitrogen and phosphorus than necessary;

(d) Apply feeds conservatively to avoid overfeeding and to assure that as much of the feed is consumed as possible;

(e) Do not use water exchange or reduce water exchange rates as much as possible;

(f) In intensive aquaculture, apply enough mechanical aeration to prevent chronically low dissolved oxygen concentration and to promote nitrification and other aerobic, natural water purification processes;

(g) Provide storage volume for heavy rainfall to minimize storm overflow;

(h) Deep water release structures should not be installed in ponds, for they discharge lower quality water from near pond bottoms;

(i) Where possible, seine-harvest fish without partially or completely draining ponds;

(j) Where possible, discharge pond draining effluent through a settling basin or a vegetated ditch;

(k) Reuse water where possible.

Information to support some BMPs may be lacking, and it may be necessary, as it was in developing BMPs for Alabama catfish farming, to conduct special studies. For example, studies of sedimentation (Osbay and Boyd 2003, 2004), persistence of copper residues (McNevin and Boyd 2004), effects of sodium chloride treatment (Tavares and Boyd 2003), estimation of water budgets and effluent pollution loads (Boyd et al. 2000), and impacts of farm effluents on stream water quality (Silapajarn and Boyd 2005) were made to support the selection of BMPs for Alabama catfish farming.

Presentation of BMPs

The final BMP document should explain the environmental, social, or conservation problem that each category of BMPs will address and provide the producer guidelines for implementing the practices. Each category of the Alabama catfish farming BMPs (Boyd 2003) was presented according to the format given below:

(1) Title – the name of the BMP category, e.g., feed management or worker safety.

(2) Definition – a paragraph to define the environmental, social, or safety problem being addressed by the BMP category.

(3) Explanation – several paragraphs to elaborate on information provided in the definition and to explain why and how the problem should be solved.

(4) List of practices – the BMPs for the category are listed.

(5) Implementation notes – suggestions to help the producer decide which of the BMPs are appropriate for a particular operation and to provide specific details on implementation of the BMPs.

(6) Selected references for further reading.

The final draft BMPs should be placed on a website and also published as a manual. There should be a program to encourage the adoption of the BMPs by producers. Where funds are available, producers meetings should be held to explain the benefits of BMPS and provide advice on their adoption. The suggested process for developing BMPs is provided in a flow chart (Fig. 10).

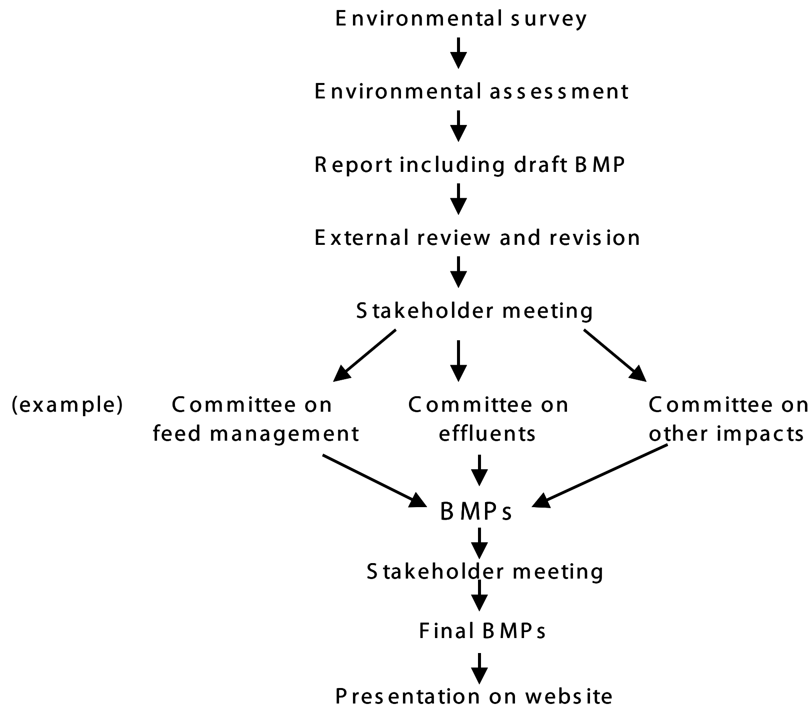

Fig. 10. Flow chart for BMP development.

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