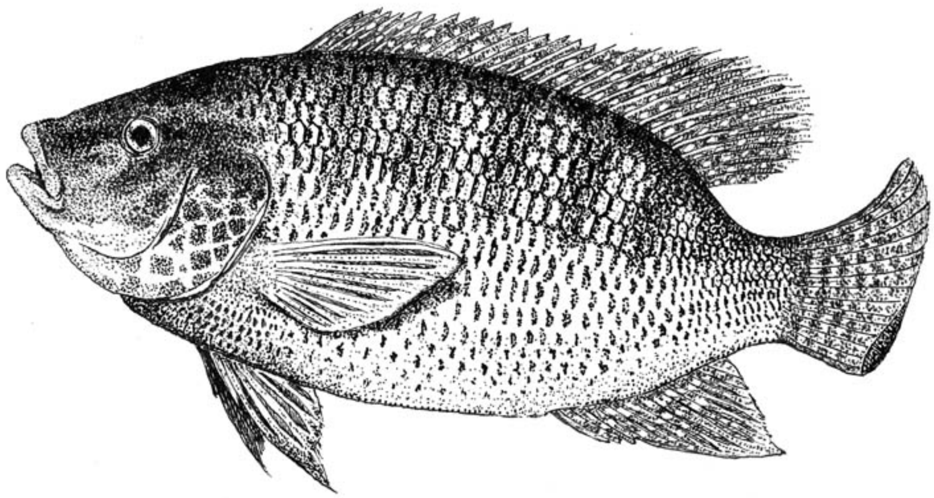

At a Crossroads: Will Aquaculture Fulfill the Promise of the Blue Revolution?

A SeaWeb Aquaculture Clearinghouse report by
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This report and the activities of the SeaWeb Aquaculture Clearinghouse are made possible with the generous funding provided by the Rockefeller Brothers Fund and The Curtis and Edith Munson Foundation.

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INTRODUCTION

There is now little doubt that the world's fisheries are in crisis. Mounting scientific evidence points to dramatic declines in global catches.[1,2] Increasingly, many are making the case that farming fish offers a solution to meeting the growing demand for seafood that catching fish cannot provide. Aquaculture now accounts for roughly one-third of the world's total supply of food fish and undoubtedly the contribution of aquaculture to seafood supplies will increase in the future. Aquaculture has the potential to become a sustainable practice that can supplement capture fisheries and significantly contribute to feeding the world's growing population. However, instead of helping to ease the crisis in wild fisheries, unsustainable aquaculture development could exacerbate the problems and create new ones, damaging our important and already-stressed coastal areas.

The vast majority of aquaculture takes place in Asia. In 2002, over 70% of worldwide aquaculture production was in China alone.[3] Most farmed fish and shellfish are grown in traditional small-scale systems that benefit local communities and minimize the environmental impact. Utilizing simple culture technologies and minimal inputs, these systems have been used for centuries. The net contribution of these traditional aquaculture systems can be great as they offer many benefits, including food security in developing nations.

However, as happened with the "green revolution" of agriculture in the last century, the current "blue revolution" of aquaculture is becoming an industrial mode of food production. An emerging trend is toward the increased development of farming high-value carnivorous fish species using environmentally and socially damaging systems. Farming fish on an industrial scale, especially carnivorous fish is rapidly expanding; the number of different species farmed and geographic regions where they are farmed increases continually. Largely controlled by multinational corporations, industrialized farming of carnivorous fish such as salmon requires the intensive use of resources and exports problems to the surrounding environment, often resulting in environmental impacts and social conflicts.

Some segments of the aquaculture industry are long overdue for reform. What is required is a paradigm shift in how we think about aquaculture, particularly its interaction with natural and social systems. This new paradigm should be based on sustainable development—"the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development conserves land, water, plant and genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable."[4] Sustainable aquaculture must consider the ecological, social, and economic aspects of development (Figure 1).

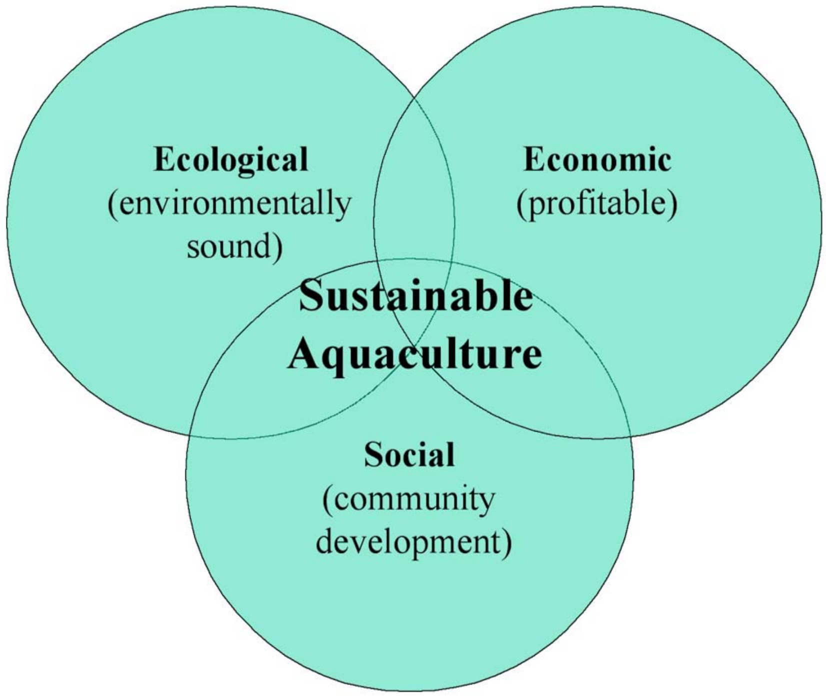


Figure 1: Elements of sustainable aquaculture.

BACKGROUND

Historical overview

As defined by the United Nations Food and Agriculture Organization (FAO), aquaculture is the "farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated…" Aquaculture is the fastest growing sector of the world food economy, increasing by more than 10% per year and currently accounts for more than 30% of all fish consumed.

While the world community has only recently viewed aquaculture as a potential solution to the dilemma of depleted oceans, it is by no means a new practice. In fact, the advent of aquaculture dates back millennia, though its exact origins are unknown. It most likely grew out of necessity – foraging and hunting were not sufficient to provide a stable source of food to local communities. While there are many parallels to agriculture, the development of aquaculture has progressed more slowly than terrestrial farming because of the unfamiliar nature of the ocean terrain and characteristics of aquatic organisms.[5]

A large proportion of organisms that humans rely on for protein and sustenance come from the sea. Currently, approximately 16 percent of animal protein consumed by the world's population is derived from fish, and over one billion people worldwide depend on fish as their main source of animal protein.[6] Worldwide consumption of fish as food has risen from 40 million tons in 1970 to 86 million tons in 1998.[7]

Once thought of as an abundant, inexhaustible resource, the world ocean faces a significant loss of essential diversity. This loss is occurring at an alarmingly rapid rate, due to the combined effects of overfishing, habitat destruction, pollution, and profound ecological and biotic change caused by global warming as well as the human-mediated transfer of marine organisms. According to the FAO "About 47 percent of the main stocks or species groups are fully exploited and are therefore producing catches that have reached, or are very close to, their maximum sustainable limits."[8] Clearly, additional means of producing fish must be developed in order to maintain a sufficient supply of food for an ever-growing population. Aquaculture offers one way to supplement the production of wild capture fisheries and it will continue to increase in importance as demand increases in the future.

It was not until after World War II that aquaculture gained much attention as a potentially large-scale industry. A shift in economic conditions in developed nations of the world led to an increase in the demand for fish such as salmon, shrimp, eels, and sea basses, all of which can be produced profitably through aquaculture.[9] In the 1960's, aquaculture became a significant commercial practice in Asia where it had mainly been used as a small-scale means of local community food production for thousands of years.[10] In the last few decades, worldwide aquaculture production has increased significantly. In 1970 aquaculture operations composed 3.9 percent of all fish production, compared to 27.3 percent in 2000. Worldwide, total fish production from aquaculture operations has increased steadily at a rate of 9.2 percent per year.[11] But, aquaculture has not yet become the large-scale global food replacement for the numerous food-poor areas of the world, as many thought it would be.

Environmental costs

Like other forms of intensive food production, industrial-scale fish farming generates significant environmental costs. These depend on a number of factors and are rarely evaluated before farming begins or before operations are expanded. In presiding over the rules and regulations that govern the establishment of aquaculture ventures, many governments have largely overlooked the environmental problems that may arrive with the advent of large-scale fish production.

The expansion of some forms of aquaculture, particularly salmon and shrimp farms, has proven to be destructive to the natural environment and populations of aquatic animals.[12,13,14,15,16] Industrial scale farming of salmon in netpens and shrimp in coastal ponds are the most problematic because they require the intensive use of resources and export problems to the surrounding environment. Unless significant changes are made, the increasing production of high value carnivorous fish promises to be just as unsustainable.[17]

There are environmental concerns with other systems, such as inland ponds, flow-through systems, and closed systems, but they generally have fewer environmental problems overall, especially when properly managed. For a brief overview of the major environmental implications of the different systems, as well as the species commonly cultured in each, please see Appendix I.

Social conflict

The advent of industrial aquaculture has not only been a source of environmental concern, it has also been a source of social concern.[18] Intensive practices used by some in the aquaculture industry pose significant threats to traditional, community-centered societies. Shrimp, for example, is a highly valued species in such regions as the United States, Japan, and Europe. However, it is mostly farmed in tropical areas, with production controlled by multinational corporations. Because shrimp production yields such a high profit, foreign or non-local individuals tend to exploit the areas where they can best be grown, without regard for the environmental or social implications, and then market them elsewhere, taking the profits as well as the product out of the region. The ecological impacts of large-scale shrimp production can leave the farming area unsuitable for small-scale production, damage local fisheries, and as a result damage the local economy.[19,20]

Finfish farming, especially salmon, has been promoted as a means of generating socioeconomic benefits in rural coastal areas. As farming methods have become more intensive, however, employment opportunities have declined. For example, according to the Norwegian government, between 1994 and 2000 the number of people employed raising salmon from hatcheries to harvest declined by 18% while production more than doubled.[21] Additionally, as the industry attempts to further reduce costs and increase profits, it likely will become more sophisticated and employment will continue to decline. The industry has also impacted coastal communities where salmon are fished commercially. This became evident in the 1990's as salmon farms in Chile took advantage of cheap labor to grow and export large quantities of farmed salmon, depressing the prices paid to commercial salmon fishermen in the United States and Canada. Partly as a result, many fishermen along the Pacific Coast of North America lost significant sums of money or went out of business. Between 1990 and 2002, the number of commercial salmon fishermen in Alaska declined from 10,487 to 6,567 and the value of the salmon harvest fell from $559 million to $130 million in 2002.[22]

Making improvements

Recently, governments and industry have made efforts to curb unsustainable aquaculture activities.[23,24,25,26,27] Many have realized that the focus of aquaculture must evolve into the development of an industry that is both environmentally and socially sustainable in the long term.[28,29,30,31,32] Positive changes are being made with this growing interest and awareness of improving the sustainability of aquaculture. With the expected expansion of aquaculture in the coming years it will be vital that sustainable practices be implemented and further developed to avoid environmental and social problems.

SUSTAINABLE ALTERNATIVES: A PARADIGM SHIFT

Many have looked to aquaculture to fill in the gaps left by dwindling fisheries. Undoubtedly, this is a genuine possibility. Its realization, however, will depend on how the aquaculture industry develops in the future. At this point in time, the development of aquaculture is at a crossroads. Unsustainable development will only generate short and medium-term profits for multinational corporations at the expense of long-term ecological balance and social stability. More sustainable development alternatives are needed to ensure that in the future aquaculture can contribute to the growing need for seafood products.

There are a number of alternative ways forward in the development of aquaculture, which can offer more sustainable solutions. In some cases these methods have been around for centuries, but they have rarely been adopted in the modern aquaculture industry, and in other cases they are innovative practices that can be explored by aquaculture proponents. Alternatives include ecological aquaculture, organic aquaculture, polyculture, mollusc farming, and closed and low discharge systems. These alternative practices have been successfully implemented in different areas of the world; however, they must be examined for their application on a wider scale. While each of the potentially sustainable practices mentioned in the following discussion does have some environmental impacts, they can be greatly minimized if the systems are managed well. In addition to environmental considerations, social and economic aspects must be considered when assessing each of these practices.

Ecological aquaculture

Ecological aquaculture has been defined as "an alternative model of aquaculture research and development that brings the technical aspects of ecological principles and ecosystems thinking to aquaculture, and incorporates – at the outset – principles of natural and social ecology, planning for community development, and concerns for the wider social, economic, and environmental contexts of aquaculture."[33] There are six main principles of ecological aquaculture: to preserve the form and function of natural resources; to ensure trophic level efficiency (using animal wastes and plants, rather than fishmeal as sustenance); to ensure that chemicals and nutrients from the system are not discharged as pollutants; to use native species so as not to contribute to "biological pollution"; to ensure that the system is integrated into the local economy and community in terms of food production and employment; and to share the practices and information on a global scale.[34]

Ecological aquaculture focuses on the development of farming systems that preserve the environments in which they are situated and enhances the quality of these environments while at the same time maintaining a productive culture system. All aspects of the operation are interconnected in order to minimize negative impacts on the community, both natural and social. Ecological aquaculture can also be incorporated into sustainable fisheries management and coastal zone management.[35]

Organic aquaculture

Sustainability is one of the main goals of organic food production. Aquaculturists who aim for organic farms wish to "manage food production as an integrated, whole system that is an 'organism' whose individual parts mesh together into one whole production system."[36] In organic food production, all parts of the operations are connected and integrated with each other, such as the nutrient inputs, the animals, the environment, and the wastes being produced.

Organic fish producers must comply with all of the same regulations that other organic certified producers do. Some substances or practices are prohibited from organic operations. For example, the addition of antibiotics to the fish feed is tightly regulated and the inclusion of genetically modified organisms is strictly forbidden in organic production. Rather than rely on the use of chemicals and drugs to improve the production of their fish, farmers instead optimize the living conditions, through lower stocking densities and cleaner, healthier water.[37]

Organic aquaculture standards have been developed in many nations around the world and they are in the final stages of development in the United States. Some of the basic principles of organic aquaculture according to the International Federation of Organic Agriculture Movements are as follows: to encourage natural biological cycles in the production of aquatic organisms; using feed that is not intended or appropriate for human consumption; using various methods of disease control; not using synthetic fertilizer or other chemicals in production; and using polyculture techniques whenever possible.[38] There are several obstacles to the implementation of organic aquaculture, including: farming carnivorous fish with a diet of wild (non-organic) fish, management and recycling of wastes, escapes of fish, and controlling diseases and parasites.

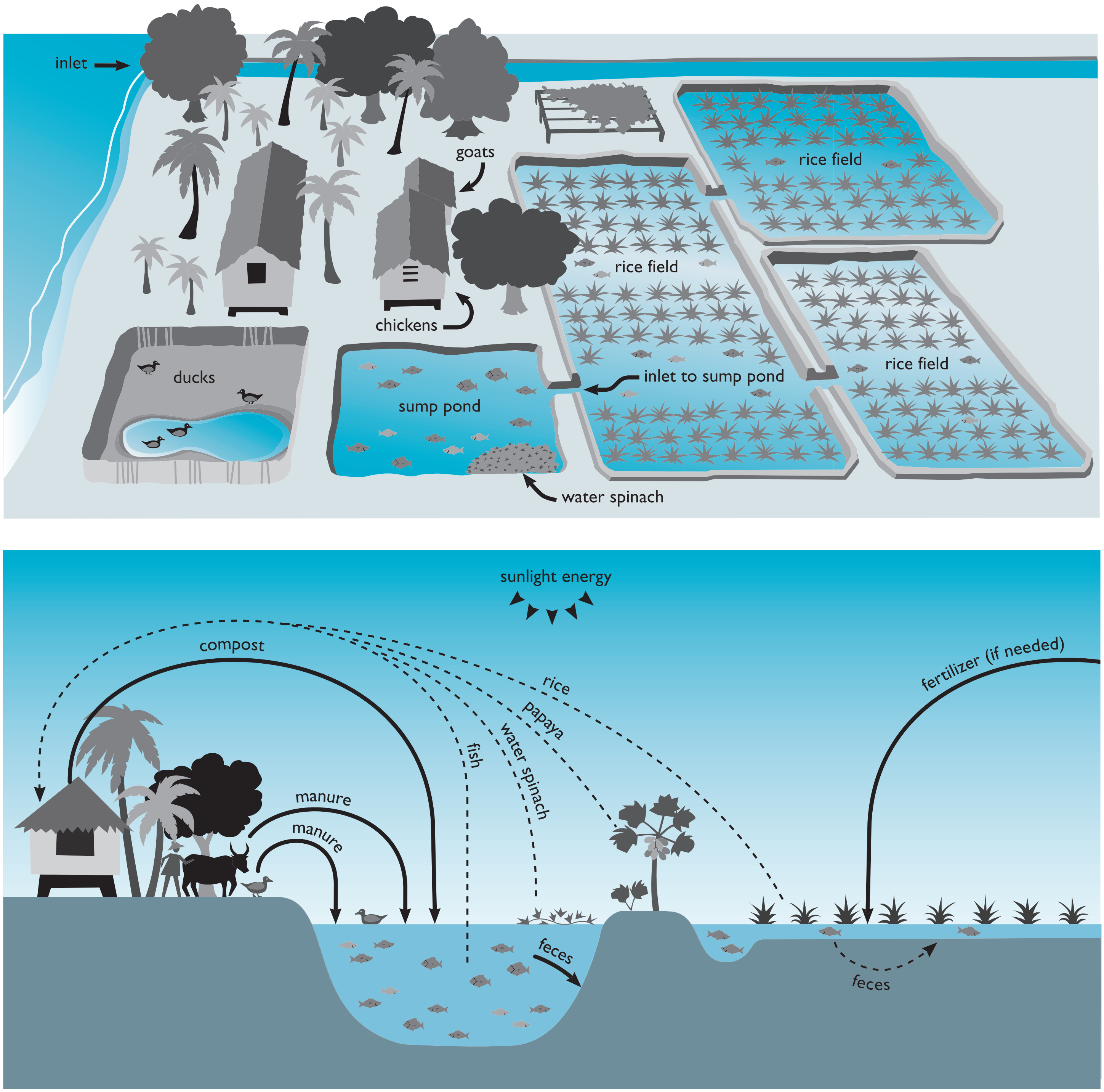
Similar to organic certification, other certification and labeling programs also are under consideration. These "ecolabels", together with organically farmed seafood, have great potential for allowing consumers to know that the fish they purchase were farmed in environmentally friendly ways. Additionally, they could provide responsible farmers with a way to take advantage of the increasing consumer demand for food grown with environmentally friendly practices as well as receive a premium price for their product.

Polyculture and integrated aquaculture

Polyculture and integrated aquaculture are methods of raising diverse organisms within the same farming system, where each species utilizes a distinct niche and distinct resources within the farming complex (Figure 2).[39] This may involve the rearing of several aquatic organisms together or it could involve raising aquatic organisms in conjunction with terrestrial plants and/or animals. In either case, the wastes from one organism are used as inputs to another, resulting in the optimal use of resources and less pollution overall.[40]

Polyculture systems can provide mutual benefits to the organisms reared by creating symbiotic relationships while allowing for a balanced use of the available aquatic resources, whereas intensive monoculture systems extract resources from the system and place more stress on the surrounding environment. In addition, integrated systems can increase the economic efficiency of fish farms through improved conversion rates of input materials.[41] Polyculture and integrated

Figure 2: **TRADITIONAL INTEGRATED AQUACULTURE** USING PRACTICES FROM THE PAST FOR A SUSTAINABLE FUTURE



Integrated aquaculture, such as this traditional rice-fish system, can provide mutual benefits to all the organisms. Interdependent relationships are established and allow for a balanced use of available aquatic resources. An additional benefit of the system is reducing the net production of waste.

Source: Food and Agriculture Organization of the United Nations, Fisheries Technical Paper 407.

aquaculture have the potential to address some of the problems that arise from the intensive rearing of single finfish species. For example, the integration of fish culture with the culture of algal and/or shellfish species shows potential for reducing the risks of eutrophication and also for exploitation of the large amounts of wastes produced by fish farms. Further research is needed however, to determine the effectiveness of such systems, especially in open marine environments.

Polyculture systems are not a new concept; on the contrary, they have been used for centuries. For over one thousand years fish farmers in China have produced four of the most widely cultivated fish species together in the same pond: silver carp (a phytoplankton filter feeder), grass carp (a herbivorous plant feeder), common carp (an omnivorous feeder), and bighead carp (a zooplankton filter feeder). This type of system utilizes available food and water resources, with the effect of reducing costs and increasing efficiency and production. Although still experimental, other systems, such as the integration of seaweed, fish, and abalone culture, and the polyculture of shrimp and tilapia, have proved to be ecologically efficient methods for growing a variety of organisms and may increase profits at fish farms.[42, 43]

It should also be noted that although polyculture systems based on netpens may prove beneficial for waste reduction, they fail to eliminate other problems associated with netpen aquaculture, specifically escape of fish, disease transfer, and discharge of chemicals.

Mollusc farming

While not a new activity, mollusc farming offers an excellent alternative to finfish farming. With proper siting and planning, mollusc farms can have minimal impact upon coastal ecosystems and communities. In some cases the presence of mollusc farms can actually improve the water quality of the existing environment. Oysters, mussels, clams, and scallops are some typically farmed mollusc species.

In most cases mollusc farming does not have the same impacts upon the aquatic environment that finfish culture does, such as nutrient loading and eutrophication.[44] Unlike other farmed species, shellfish remove organic particulates, suspended matter, and nutrients from the water and tend to improve the overall quality of the water. Because shellfish are filter feeders they act as natural biofilters in the water, removing phytoplankton, sediments, and organic particles. For example, it is estimated that every kilogram of shellfish meat harvested results in a removal of 16.8 grams of nitrogen.[45]

While relatively benign when properly planned and managed, in some instances, mollusc farming has been responsible for the introduction of non-native species and diseases as well as conflicts with other user groups.

Closed and low discharge systems

Recirculating systems

Concerns for water conservation and reduced waste discharges have prompted the increased use of closed recirculating aquaculture systems.[46] Recirculating systems generally consist of land-based tanks with constantly flowing water.

The systems are made up of three basic components: culture chamber, settling chamber, and biological filter. Water enters the culture chamber, flows through the settling chamber and then moves through the biological filter to remove additional particulate matter. The water is then circulated back through the systems' culture chambers.[47] Recirculating systems conserve water and allow producers to control all of the environmental factors that might affect their plants and animals.[48] For example, aquaculturists have complete control over temperature, salinity, oxygen, predators and introduction and transfer of diseases.

Recirculating systems, however, can be costly to operate, as they are highly dependent on electricity or other power sources. Pumps must be used in order to maintain the constant flow of water and often water must be heated or cooled to the desired temperature. Backup systems must be in place in case of a power failure. A less expensive and more environmentally friendly option would be to take advantage of alternative energy and heating sources. Solar, wind and geothermal power are being considered as is heated water obtained from the waste products of manufacturing, electricity production, and composting. For example, tilapia farms can use the cooling water from power plants as a low cost warm water source. The warm water, which is necessary for growing tilapia, would otherwise be wasted.

Recirculating systems have less of an impact upon the environment because of their closed nature – wastes and uneaten feed are not simply released into the ambient environment in the manner that they are with netpens and exotic species and diseases are not introduced into the environment. In recirculating systems, wastes are filtered out of the culture system and disposed of in a responsible manner. Recirculating systems can be built just about anywhere, including in urban settings where they can use existing structures and be placed close to markets, thereby reducing transportation costs. Recirculating systems can be used to grow a wide variety of fish species year-round in controlled environments. Species commonly grown in recirculating systems include hybrid striped bass and tilapia. Additionally, much research has been dedicated to developing recirculating systems for marine species of fish and this technology holds much promise.

Inland pond culture

Pond aquaculture was the earliest type of aquaculture to be practiced, dating back several thousand years. It remains one of the most common systems used to farm fish. Over 75 percent of the farmed freshwater fish in China are produced in constructed ponds and in the U.S. nearly all of the farmed catfish are raised in ponds.[49] Other species commonly farmed in ponds include tilapia, hybrid striped bass, and crayfish.

When properly managed with little or no water exchange, wastes are not continuously released from the culture system as they are in netpens or flow through systems.[50] Wastes, including solids, organic matter, and nutrients that are discharged can be released into settling ponds or constructed wetlands to further reduce their impact. In low or zero discharge pond systems, the pond itself develops a sort of ecosystem. Natural biological, chemical, and physical processes in ponds remove much of the wastes from the water. Waste accumulation and subsequent discharge from ponds is minimal as long as production is maintained within the limits of the natural processes to remove or assimilate wastes.[51]

FUTURE DIRECTIONS AND RECOMMENDATIONS

It is clear that there are ways to approach aquaculture that allow for the production of healthy seafood while avoiding the numerous pitfalls of some current aquaculture practices. It is also apparent that despite some progress, much needs to be done to reach a point where aquaculture can become a sustainable method of providing food for the world's growing human populations. Unfortunately, some of the efforts to further develop aquaculture are currently being focused on practices that are most damaging, such as salmon netpen culture and shrimp culture in coastal ponds.

In order for aquaculture to develop into an environmentally and socially responsible food production endeavor, we recommend the following:

Implement more ecologically sustainable practices.

- Possibilities include:
    -Raising different species together in polyculture and integrated systems. For example, finfish with molluscs, vegetables, or seaweeds.
    -Treating wastewater by using settling ponds, constructed wetlands, filters, or other methods.
    -Raising molluscs and other low trophic level species.

Transition to the use of more closed systems and low discharge systems, especially those that provide total containment of fish and recovery/reuse of wastes.

- More efforts should be made to improve recirculating aquaculture systems and other closed and low discharge systems.
- Funding agencies should place greater emphasis on further developing closed systems and other environmentally friendly aquaculture techniques.
- The use of renewable energy sources should be further explored.

Significantly decrease or eliminate the dependence on wild fisheries.

- Research should continue into the replacement of fisheries products with plant-based ingredients in the feeds for farmed animals.
- Government policy should foster reduced use of fishmeal and fish oil in feeds for farmed animals.
- Greater emphasis should be placed on growing molluscs and other low trophic level species, which do not require fishmeal or fish oil in their diets.

Establish organic standards and other eco-labels for aquaculture products.

- Standards should be developed that address each of the issues associated with fish farming without simply watering down the concept of "organic" production for the sake of applying it to aquatic organisms.
- Organic standards should start with low trophic level fish and shellfish since standards for carnivorous fish will prove to be problematic because of issues with feeds.
- Organic aquaculture systems for some species may have to be land-based to be consistent with organic principles, such as the management and recycling of wastes.
- For public acceptance, labels and certification systems must have independent 3rd party involvement at all stages of development, implementation, assessment, and control.
- Criteria for certification should be objective and verifiable; and information about the certification process and the product should be available to consumers.

Develop sustainable aquaculture operations that provide long-term social and economic benefits to communities.

- Traditional farmers should be encouraged to diversify their sources of income by raising fish in addition to terrestrial crops.
- Recirculating aquaculture systems should be constructed in urban areas. Government should promote efforts to renovate or retrofit old factories or other existing buildings for aquaculture purposes.
- The social impacts of an expanded aquaculture industry should be considered so as not to negatively impact communities through the loss of jobs in other sectors.

APPENDIX I:

Aquaculture systems and their environmental impacts

System Type	Common Species	Environmental issues	Overall Impact
Mollusc culture	Oysters, clams, mussels, scallops, abalone	Introduction of exotic species (target and non-target) and diseases.	Minimal, especially with proper planning and management. Sometimes positive as farmed animals can actually improve water quality.
Recirculating/closed	Tilapia, hybrid striped bass, sturgeon	Small amount of waste discharge. Energy intensive.	Minimal. Can be improved with greater focus on alternative energy sources.
Inland pond	Catfish, carp, yellow perch, tilapia, hybrid striped bass	Some waste discharge. Some use of exotic species.	Moderate. Can be minimized with proper management.
Flow-through/raceway	Hybrid striped bass, trout	Some waste discharge.	Moderate. Can be minimized with best management practices.
Coastal pond	Shrimp	Discharge of wastes. Destruction of mangroves.	High environmental impact.
Netpen and/or cage	Salmon, sea bass, sea bream, grouper, tuna, snapper	Discharge of biological and chemical wastes directly to the natural environment. Escapes of fish. Introduction of exotic species and transfer of diseases.	High environmental impact.

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