APPALACHIA - SCIENCE
IN THE PUBLIC INTEREST
Rt. 5 Box 423 ◦ Livingston, KY 40445

Aquaculture

ASPI Technical Series

This paper will examine the possibilities for freshwater aquaculture (growing food in water) in temperate North America. While primary consideration will be given to fish, we will also look at plants and animals. We will concentrate mainly on production for home use. Due to ecological and economic considerations, the emphasis will be on systems that do not require large inputs of commercial feed, oxygen or fertilizer.

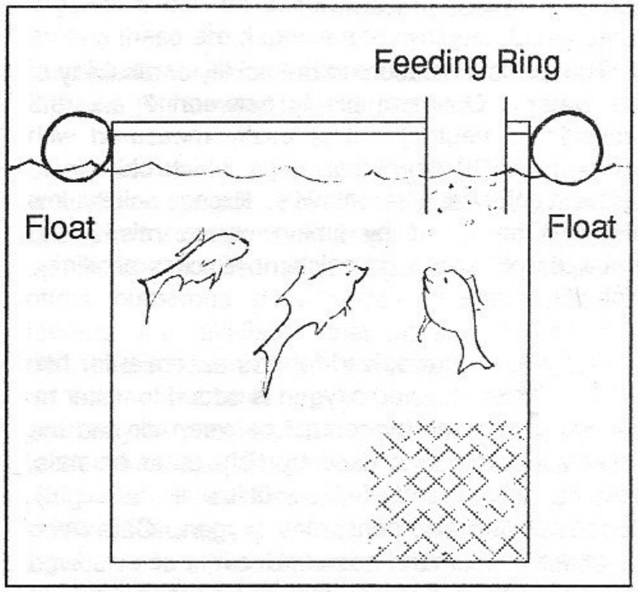
Culture Systems

Several types of culture systems are available to the small scale aquaculturist. One of the simplest is an open or flow through system. Fish are generally kept in cages that are floated in a river or lake. Benefits include protection from predators, ease of harvest, and low impact on other water uses. There can also be disadvantages to cage culture such as maintenance, supplemental feeding requirements, disease, theft, and loss from cage damage. Cages are generally built from plastic mesh on wood or metal frames and are floated with polystyrene. Other materials can be used but consideration must, of course, be given to durability in water.

The most common culture technique is the semi-closed system in which a body of water is constructed that has low flow through. The most common form of this is the pond. Fish can be added and fed or cultured as desired and can be removed with pole and hook or nets. All of the fish discussed in this paper can be grown in the proper type of pond. Ponds can be deep and hold fish year-round. They can be cold or warm and have fast or slow turnover. They can be shallow only with all fish removed for the winter (three season use).

Pond construction is generally undertaken with heavy equipment and is an art in itself. An experienced equipment operator and soil with a high clay content will simplify the process. Waterproof liners can be used in very small ponds. Information and assistance are available from your local soil conservation office.

It is also possible to raise fish in virtually closed systems or tanks. This can be done outdoors or in a greenhouse. Most of these systems are technologically complex and unsuited to home production. The solar algae tanks developed by the New Alchemy Institute are among the exceptions. Tilapia, primarily, are raised in naturally fertilized fiberglass tanks that rely on sunshine to grow phytoplankton to feed the fish. The fish are also fed plants and vegetables. These fiberglass tanks can be purchased ready-made or home-made from flat fiberglass. Rodale Research Center has developed a "home aquaculture unit" using a small swimming pool as the tank. Innovations include a water or air powered rotary biofilter, and a water clarifier. A plastic dome increases production of warm water fish and extends the growing season.



Water Management

Water, like soil, is a complex ecological system. In order to successfully raise food in water, care must be taken to maintain certain conditions. Specific physical characteristics can determine the choice of crop and the success of the system.

Water temperature -- All fish have an optimal temperature for growth and an upper and lower limit for survival. Water temperature is determined by a number of factors including water depth, solar exposure, flow, and water source.

Light -- In addition to being essential for photosynthesis, light is also important for fish that feed visually, as well as affecting sexual and other behaviors. Light is affected by natural day and seasonal fluctuations, weather, and the color and clarity of the water. Cloudiness or turbidity in water is usually caused by silt or plankton (microscopic organisms). Phytoplankton (microscopic plants = algae) are determined by the fertility of the pond, and may become a problem in aquaculture systems without adequate phytoplankton consumers. Zooplankton (microscopic animals) are eaten by many fish and do not generally cause difficulty. Some fish stir up pond sediment as a feeding behavior. If this so-called "roiling" is a problem, such species should be avoided. Excessive silt can be treated with gypsum or alum.

Chemistry -- The most important chemical characteristics are pH and calcium, oxygen and nitrogen. Other chemical characteristics can be important in some situations and chemical pollution can be a serious problem.

The pH is a measure of the acidity or alkalinity of the water. Optimum pH is between 7 and 8.5 (considered neutral). It is easily measured with inexpensive "hydrion" test strips which change to different colors at different pH's. Excess acidity, low pH, can be cured by liming, which raises and stabilizes pH and adds calcium. Excess alkalinity, high pH, is rare.

Oxygen, in a dissolved form is essential for fish culture. This dissolved oxygen is added to water by aquatic plants and by contact between air and the water surface and is used by fish, other animals, bacteria and plants (which utilize it at night). Decomposition also consumes oxygen. Care must be taken to maintain adequate levels of dissolved oxygen. This is done by managing the quantity of consumers and where needed, by adding oxygen mechanically through aeration. Wind and solar can be used to power aeration equipment.

Nitrogen is essential for life but can also be a pollutant in aquatic systems. Nitrogen compounds enter through decomposition of waste and organisms. This organic nitrogen is generally converted to ammonia and ammonium by bacteria and chemical processes. Nitrifying bacteria change this to nitrite which is oxidized by other bacteria to nitrate, which acts as fertilizer for plants and bacteria thereby re-entering the food chain. All of these intermediate forms of nitrogen can be toxic to aquatic animals at certain concentrations under certain conditions. Nitrogen management is complex and careful control of organic material entering the aquatic system is essential. In closed aquaculture systems, nitrification takes place in special "biofilters" that harbour the needed bacteria. These can be made of clam shells, gravel, plastic net, stacked corrugated fiberglass, and other suitable substrate.

Fertilization

As with soil, water may need to be fertilized to increase production. The most important nutrient usually in short supply in water is phosphorus. It can be added as synthetic fertilizer or from natural sources (bone meal or rock phosphate).

Calcium (important for pH control, plant growth, and other important aquatic processes) is routinely added as lime to aquatic production systems.

Nitrogen may also be needed in an aquatic production system. It is usually added in the form of green or animal manure or compost. It stimulates plant growth. Where quick nitrogen is needed, synthetic fertilizers have been used.

Trace elements have been little studied and their need is not fully known. Most increase production indirectly through stimulating growth of phytoplankton. While some studies have shown beneficial effects from the addition of silicon, magnesium, manganese, and cobalt, trace element fertilizing should be undertaken with caution.

Species Selection

Ecological considerations suggest that raising several species together (polyculture) is more productive than raising a single species (monoculture), due to exploitation of different niches. We would also expect greater production from animals low on the food chain (herbivores) than those higher on the food chain (carnivores). These considerations are not always valid in the marketplace where prices distort the ecological realities. For home production it is best to follow the ecological considerations. If you want to grow commercial, market considerations must necessarily enter the picture.

Plants

Several water plants are worth considering for food. These include rice and wild rice, watercress, lotus, water chestnuts, cattails, arrowheads, and spirulina algae. Rice and wild rice culture is specialized and very little on a small scale has been done in North America. It should be possible to raise both for home use. Rice can be polycultured with fish and crayfish.

Watercress can be successfully grown in shallow flowing water. Water chestnuts and lotus can be grown in shallow water or floating containers. All parts of the lotus are edible (root, leaves, stems, flowers, and seeds) and the bloom is very attractive as well. Cattails and arrowheads are productive sources of starchy food but have been little cultivated.

Spirulina algae is harvested in Mexico and Chad for food and cultured commercially in at least a half dozen other countries. Spirulina is high in protein, beta-carotene, several important fatty acids, minerals, and pigment that may stimulate the immune system. Spirulina is cultured in tanks mixed with paddlewheels. Some work has been done on wind agitated systems.

Non-Fish Animals

Various aquatic animals other than fish can be raised for food and some can be successfully cultured with fish. Good possibilities include crayfish, frogs, turtles, and waterfowl (ducks, geese, swans, etc.). Waterfowl can be especially beneficial with fish, removing floating vegetation and adding fertilizer.

Fish

When choosing fish legal factors must be a consideration. Some exotic species are not legal in some states due to fears of escape and displacement of native species. Permits may also be required for certain species and for commercial operations.

Bass/Bluegill -- The bass/bluegill combination is the conventional recommendation for a farm pond. Comprehensive information on this combination and various alternatives is available from your extension agent. Production on the order of 100 pounds per acre can be expected. Fertilizing and feeding can increase this production. Channel catfish and baitfish may also be added to the standard farm pond mix.

Trout -- A popular food fish, trout require cool water and only grow when water temperature is between 50 and 75 F. Above 80 F could be lethal. Commercial culture is done in moving water, but it is possible to raise trout in ponds if oxygen is sufficient and temperatures are right. In the wild trout are almost completely insect eaters but it is possible to raise them on a small scale without commercial feed. Unfed in a pond of average fertility and eight month growing season, production of 50 lbs per acre can be expected. Live food can also be grown for trout (see next section). Cage culture is possible. In southern states this can be done in the winter where summer water temperatures are too hot. Trout can also be raised in fresh water raceways.

> A versatile home-scale and commercial operation is located at the Long Branch Education Center at Leicester, NC where Paul Gallimore raises rainbow trout in an 8-foot deep pool of about 1/40 an acre, which is being constantly fed water from springs further up the mountain. Paul uses a combination of natural foods (insects and worms off the bordering catalpa trees) along with special fish feed. He harvests an astounding 2,000 pounds of fish per year for both home and commercial use. For details write to Long Branch Environmental Education Center, P.O. Box 369, Leicester, NC 28748 (704) 683-3662.

Catfish -- Catfish are commonly cultured on a large scale in the lower Mississippi valley. They require warm water for growth. The primary species is the channel catfish. Others include the blue catfish and the white catfish. Catfish are omnivorous - consuming plants, algae, insects, crayfish and other fish. Commercial culture generally requires at least a 10 acre pond. Small scale culture in smaller ponds for home uses is possible. They can be grown alone in fertilized ponds or better, polycultured with other species that increase production of channel catfish including brown bullheads, grass carp, and blue catfish. Production of 150 lbs per acre can be achieved. For a small commercial operation, the best options are fee fishing sale to fee fishing operations, specialty restaurants, at farm sale of fish, and sale of fingerlings to other growers.

Bullheads -- Bullheads are small catfish that can produce good yields with lower intensity culture than the bass/bluegill combination. Commercial cultivation was abandoned in the late 50's with the rise of channel catfish culture. Bullheads accept a wider variety of food than more commonly cultured catfish but do not generally grow as large. Commercial size is 1/4 - 1/2 lb. Some problems have occurred in bullhead culture but these can be overcome with proper management.

Tilapia -- Tilapia are tropical fish native to Africa and the Middle East. They eat low on the food chain and have wide environmental tolerances. Some species prefer leafy vegetables, other phytoplankton, some are omnivorous. They grow to pan size in six months or so. Despite the fact that they cannot survive sustained temperatures below 55 F, they are illegal in many northern states. Tilapia are mouth breeders with extremely high reproductive potential. In ponds, monosex hybrids are often used to prevent overpopulation and stunting. Polyculture with a predatory fish can also control populations. Tilapia are a popular fish for tank culture, especially the solar algae tank, where a lack of dark corners normally prevents reproduction. Cage culture also prevents reproduction. New Alchemy Institute has used solar algae tanks indoors and out for overwintering and shallow outdoor ponds for summer growing with good success.

Carp -- The common carp is among the easiest fish to manage for high yields. It is a native of Europe but has been in this country over 100 years and is established in 47 states. It is little cultured in the U.S. but is popular in Europe and Asia, where strains have been selected for a variety of characteristics. Chinese carp of four or more species are commonly cultured in China. Each occupies a unique niche low on the food chain and production is impressive. No such polyculture yet exists here, but the common carp may eventually be a part of such a system. Monoculture of carp is easily undertaken. They respond well to fertilization alone and will eat virtually any grain or seed. They will also eat plankton, chestnuts, potatoes, and insects. Carp are called the hog of fish by some.

Buffalofish -- Unique among North American fish Buffalofish feed low on the food chain. They eat plankton, bottom dwellers and suspended solid particles. From an ecological standpoint this is the ideal fish for culture. Unfortunately market considerations led to its replacement by channel catfish. It is making something of a comeback in polyculture with the channel catfish. It can be monocultured or polycultured in a fertilized pond. It should do well in rotation with rice.

Fish Feed

Conventional

Commercial fish feeds are manufactured from grains and fish meal with a variety of additives. The economic cost combined with ecological considerations rules them out except for commercial production. It is also possible to grow and make your own fish feed. Fish feed is similar to most livestock feed. It is relatively high in protein. Peanuts, soybeans, or other high protein legumes can be used, as can other grains. For home scale fish production, grains are best used to supplement live feed.

Animals

Among the simplest live feed to produce are baitfish, small fish to be eaten by larger carnivorous fish. Fathead minnows, golden shiners, and goldfish are commonly grown for bait and can be used for live feed. If given enough shelter they will reproduce in ponds. Mosquito fish and guppies are other forage fish that can be raised for other fish.

Tadpoles and frogs are relished by largemouth bass and can be encouraged. Many small aquatic organisms can be cultured as fish feed. Primary among these are daphnia and cyclops. Other small aquatic organisms with potential for culture as feed includes rotifers and fairy shrimp.

Insects are a high protein feed that can be cultured or caught. Roaches and sowbugs can be raised in dry compost and grasshoppers and crickets can also be cultured. Attracting insects to fish ponds offers numerous possibilities. Commercial fish feeders are available that attract insects with ultraviolet light and blow them onto the water. Plans for homemade units are available. As pesticides give way to pheromone traps, possibilities for fish feeders increase. Pheromone traps are available for Japanese beetles, flies and yellow jackets, to name a few. Placing these over a pond can provide a significant quantity of low cost, high protein fish feed.

Insects can also be trapped over land and frozen or dried for later feeding. Some grinding of hard shelled insects may be helpful. Mosquito larvae can be cultured in the still shallow water of buckets with yeast as feed. New Alchemy has developed a midge larvae culture system using processed sewage sludge as nutrient and burlap as substrate. Fly maggots can be cultured on roadkills or other rotten meat over ponds and various fly larvae can also be cultured in household garbage. Bee hives can be placed so that dead bees disposed of by the hive fall into the pond or onto a tarp. Mealworms can be cultured on grain.

Earthworms are another fish feed that is easy to culture. Several books exist on worm composting systems. Feeding is best done by placing worms on a float with a few holes. Aquatic and terrestrial snails and slugs are another possible feed source.

Culture methods have been and can be developed for these and many other small animals. Not all fish will consume insects or other live feed and not all culture systems are worth undertaking in all situations. Specific local considerations including scale of operation, available resources, and the preferences, and feeding habit of the fish to be cultured must be taken into consideration.

Plants

Some fish will eat plants, which can be cultivated specifically for them and fed or grown along the banks for grazing. Legumes, grass, comfrey, and other greens can be used in this way. Grass, greens, weeds, and vegetables can be fed to Tilapia and grass carp.

Extensive floating or other aquatic vegetation is not generally recommended for fish raising systems. It can actually decrease oxygen by reducing the effects of wind. Vegetation also consumes oxygen when it dies and decomposes. It can also block sunlight needed by phytoplankton, a crucial link in the food chain. Other adverse effects are also possible. The small floating plants known as duckweed or ducksmeat (Wolfia, Lemna, and Azolla) and water hyacinth are used in Chinese polyculture but should be approached with extreme caution in the less highly evolved American system.

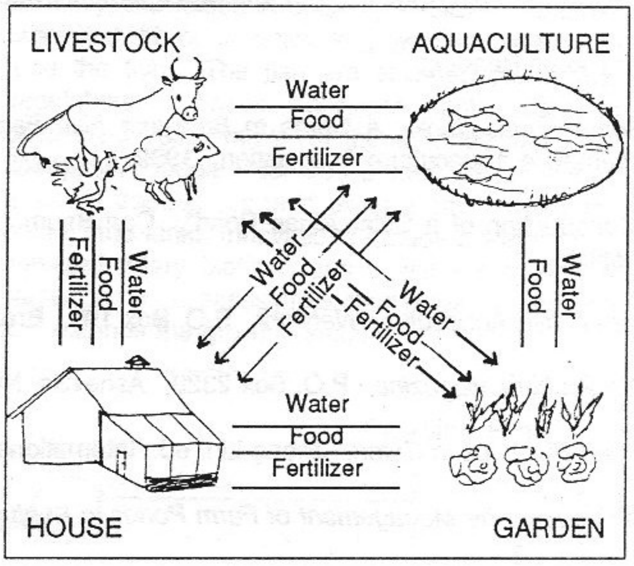
Small fruits, like mulberry, and blackberry, can be cultured on pond units to drop into the water as feed. Nuts and seeds, like acorn, hazelnut, chestnut, and honey locust, can be gathered and ground as fish feed.

Integration

To get best use from an aquaculture system, integrations with other land plant and animal production systems is essential. Integration includes the use of aquaculture byproducts in agriculture and vice versa.

Water from ponds can be used for irrigation, animal watering, and (with filtration) as possible domestic water. Animal feeds can be provided from excess fish, fish processing wastes and aquatic plants. Fertilizer can be obtained from aquaculture through hydroponics, dredging bottom muck, composting aquatic plants, and use of excess fish. An aquaculture system can also be used for domestic and agricultural nutrient recycling. Graywater, compost and manure can all be used to improve fertility of water.

Aquaculture offers great potential for making the best use of land and water resources. It can produce high protein food with moderate inputs and is an important component of any ecological food production system.



Other Considerations

When raising large populations of fish in an enclosed space there is an increased vulnerability to disease, inbreeding and genetic abnormalities. If these captive fish escape into the wild native populations of fish are at risk due to disease and habitat competition. In 1989 the wild trout fisheries of West Ireland collapsed because of sea lice spread by caged salmon. Also of concern is possible interbreeding among wild populations and escaped reared species. This can dilute the genetic strain of native wild species.

One of the most critical ecological impacts from the increased success of aquaculture is the clearing of mangrove forests and other coastal ecosystems. Most tropical countries have lost more than 1/2 of their mangrove forests from clearing and conversion to aquaculture. These forests are vital to the marine food chain and habitat to a wide variety of species.

Aquaculture on a small scale offers significant opportunities for individuals to provide a nutritional food source for themselves and others. The problems arise when the aquaculture system is not integrated into the larger farming operation (see Integration). Large scale monocultural fish farms can cause serious environmental degradation just as other types of monocultural agriculture.

References

"Growing Fish in Fields", 1993 in *World Watch*, September/October Volume 6, Number 5.
Introduction to Aquaculture, Matthew Landau, John Wiley and Sons, 1992.

The Freshwater Aquaculture Book, William McLarney, Hartley and Marks, 1987.

"Aquaculture", in *Permaculture: A Practical Guide for a Sustainable Future*, Bill Mollison, Island Press, 1990.

"Aquaculture in Permaculture Systems", Bill McLarney, in *The International Permaculture Species Yearbook, 1986*, 1986.

"Food Supply in an Aquaculture System", Bill Mollison, in *The International Permaculture Species Yearbook: 1986*, 1986.

Freshwater Fish Pond Culture and Management, Marilyn Chakroff, Peace Corps/VITA, 1976.

Additional Reading

Home Aquaculture: A Guide to Backyard Fish Farming, Steven D. Van Gorder and Douglas J. Strange, Alternative Aquaculture Association, 1992.

"Construction of a Solar Algae Pond", Carl Baum and Ron Zweig, Technical Bulletin No. 2, New Alchemy Institute.

Alternative Aquaculture Network, P.O. Box 109, Breinigsville, PA 18031, 4/yr, $14/yr.

Aquaculture Magazine, P.O. Box 2329, Asheville, NC 29902, $17/yr, including annual buying guide.

Pond Fisheries in China, Zhong Lin, ed., International Academic Publishers, 1991.

A Guide to the Management of Farm Ponds in Kentucky, Kerry Prather, KY Department of Fish and Wildlife.

Backyard Fish Farming, Paul Bryant et al., Prism Press.

Earth Ponds, Tim Matson, 1991.

"Fee Fishing as an Economic Alternative For Small Farms", Charles E. Chichra and Lili T. Carpenter, Southern Rural Development Center, Series No. 116, 1989.

Principles and Practices of Pond Aquaculture, James E. Lannan et al., Oregon State University Press, 1986.

Culture of Non-Salmonid Freshwater Fishes, Robert B. Stickney, ed., CRC Press, 1986.

By: Robert Fairchild

Editing and Layout: Robyn Arnold

Technical Editor: Paul Gallimore