

# A Basic Overview of Aquaculture

History • Water Quality  
Types of Aquaculture • Production Methods

by

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Technical Bulletin Series # 102

Funding has been provided through  
United States Department of Agriculture Grant #88-38500-3885

August 1992

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## Introduction

Are you considering aquaculture as a new business or as a way of diversifying your existing business? If the answer to this question is yes, then you should ask yourself, “How much do I really know about aquaculture?”

There are many levels of knowledge of aquaculture—from the person who has many years experience in running a successful aquaculture operation, to the beginner who has an interest in, but really no knowledge of, what aquaculture is or involves. This publication is directed to those who have an interest in aquaculture, but who lack knowledge about it or experience in the business. The reader should note that this publication is not intended to be a complete introduction to aquaculture. It does not cover many important topics such as stocking, feeding, harvesting, transport, marketing, and others. In addition, the topics that are covered are not complete. Instead, the intention here is only to introduce some aspects of aquaculture.

## History

World fish farming was first practiced as long ago as 2000 B.C., in China. The Bible refers to fish ponds and sluices (Isaiah, Chapter 19, verse 10), and ornamental fish ponds appear in paintings from ancient Egypt. European aquaculture began sometime in the Middle Ages and transformed the “art” of Asian aquaculture into a science that studied spawning, pathology, and food webs. One of the most significant developments was the invention of culture methods for trout, which were being introduced into natural waters by the mid-1800s.

Aquaculture is a form of agriculture that involves the propagation, cultivation, and marketing of aquatic animals and plants in a controlled environment. The history of aquaculture in the United States can be traced back to the mid to late 19th century when pioneers began to supply brood fish, fingerlings, and lessons in fish husbandry to would-be aquaculturists. Until the early 1960s, commercial fish culture in the United States was mainly restricted to rainbow trout, bait fish, and a few warmwater species, such as the buffaloes, bass, and crappies. Many of these early attempts at fish husbandry failed because: (1) operators were not experienced in

fish culture, (2) ponds were not properly built, (3) low-value species were being raised, and (4) selected species lacked adequate technical support.

The now firmly established catfish industry, which originated in the southeastern United States, started in the late 1950s. Since then this industry has gone through four identifiable phases. The first, or pioneering phase (1960–1970), was characterized by rapid expansion and relatively high production costs that resulted in low yields and inefficiency. The second phase (1971–1976) gave rise to major improvements in production and lower unit costs. Average annual yields increased from 1,500–2,000 pounds per acre (lb/acre) to 3,000–4,000 lb/acre. There was, however, a drastic shakeout of unprofitable and marginal producers when feed costs rose as a result of a scarcity of fish meal. The third phase (1977–1982) saw vastly improved productivity, greatly increased acreage, and lower production costs. The major sales outlet became the wholesale processing plant. The fourth phase (1982–1989) saw a decreased rate of expansion in the catfish industry, while production of other aquaculture products such as salmon, striped bass, crawfish, and tilapia increased.

The growth of the catfish industry through the four phases mentioned has resulted in an increase in the industry’s size from about 400 acres in 1960 to more than 161,000 acres and 410 million pounds processed in 1991. Economically, this production had a farm gate value of more than \$264 million. Mississippi dominates the industry with 59 percent of the acreage and 75 percent of the production. Today, the catfish industry’s growth rate has slowed somewhat, but the potential for increased demands for catfish and other aquaculture products is very favorable.

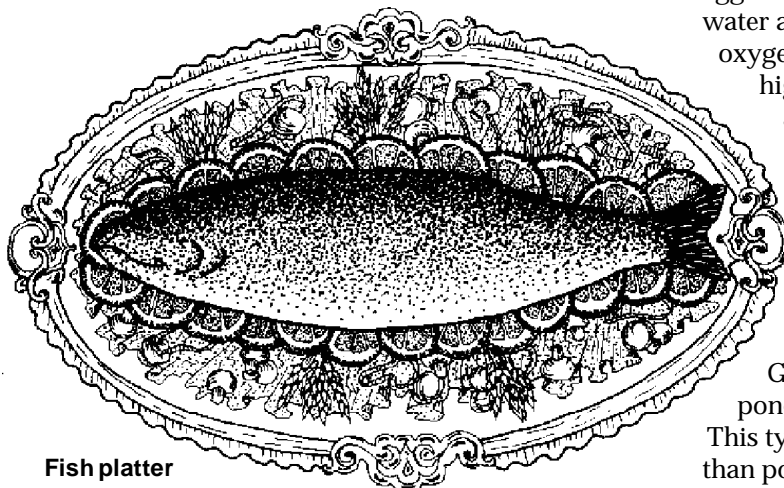
There have been significant increases in demand for fish and seafood in the United States and throughout the world. Per capita consumption in the United States rose from 12.5 pounds in 1980 to 15.5 pounds in 1990, an increase of 19 percent. With the increased health consciousness in the United States, per capita consumption of aquaculture products will continue to increase. In addition, the supply of “wild” caught fish from conventional capture sources

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has declined because of over-exploitation, pollution, and habitat destruction. These conditions will mean an ever-increasing demand for aquaculture products.

To fulfill the increased demand more people will enter the existing aquaculture industry, either at the production level or in a support position. Before doing so, the potential aquaculturist must understand more about aquaculture and what it involves. As stated, aquaculture is a form of agriculture, and many of the same management strategies are used. As in any agricultural enterprise, the aquacultural farmer tries to maximize yields (profits) while minimizing inputs (costs and labor). However, there are reasons why aquaculture can be more productive and profitable than land-based agriculture.

Meaningful comparisons of productivity are complicated, but fish have certain advantages over land animals in their suitability for farming. Being cold-blooded, fish do not have to expend energy in maintaining body temperature. Also, unlike land animals, they do not have to support their weight and should therefore be inherently more efficient at converting food into flesh. Because a fish farm uses a three-dimensional rearing area, fish have the added dimension of depth in which to grow, thus increasing yields on a per acre basis. Production in ponds can approach 10,000 pounds per acre annually compared to approximately 1,000 pounds per acre annually for beef cattle. In general, fish have a lower proportion of inedible bones and offal, which means a greater processed weight for the producer.



**Fish platter**

If there are so many advantages to aquaculture over land-based agriculture, why are more people not involved? There is no single answer to this question. Instead, one must first realize that aquaculture is still several decades behind traditional livestock husbandry in research and development. Virtually every aspect of aquaculture can still be improved. The lack of available information, the need for training in the husbandry of aquatic organisms, and the lack of suitable markets are three obstacles that impede the development of the aquaculture industry in the North Central Region.

In the following sections some of the basic concepts for the husbandry of aquatic organisms, specifically fish, will be discussed.

## Water sources

Water supply is the most important factor in selecting the proper location for an aquaculture facility. Aquatic organisms depend upon water for all their needs. Fish need water in which to breathe, eat, grow, and reproduce. Large quantities of water must be available year-round. If water is not available all the time, but there is some way to store it, then that site still may be suitable. The key, of course, is that water must always be available and in good supply.

Water sources can be classified as: wells, springs, groundwater, streams, rivers, lakes, and municipal. Of these seven possible sources, wells and springs rank the highest in terms of overall quality. Wells and springs are usually uncontaminated and have no unwanted fish or fish eggs. The only drawbacks to well and spring water are their low concentrations of dissolved oxygen (which fish need to breathe), and their high concentrations of dissolved gases such as carbon dioxide, and metals such as iron. These problems can be overcome. An example of a specialized use of well water is the warm water from geothermal wells being used to grow tropical food fish in such non-tropical areas as Idaho.

Groundwater sometimes is used where ponds are dug into the existing water table. This type of pond is generally less productive than ponds filled from other sources because of

the low productivity of the surrounding soil. Streams, rivers, and lakes also can be used to produce aquatic organisms, but they are subject to any contaminants that could wash in from the surrounding watershed. In addition, unwanted fish or fish eggs must be filtered from these existing water bodies.

## Water quality

To a great extent water quality determines the success or failure of a fish farming operation. Physical and chemical characteristics such as suspended solids, temperature, dissolved gases, pH, mineral content, and the potential danger of toxic metals must be considered in the selection of a suitable water source. Of these many water quality characteristics, only temperature, dissolved oxygen, ammonia, pH, and alkalinity will be discussed. In existing systems, a close watch should be kept on these critical characteristics.

### Temperature

As mentioned, fish are cold-blooded organisms and assume approximately the same temperature as their surroundings. Metabolic rates increase rapidly as temperatures go up. Many biological activities such as spawning and egg hatching are geared to annual temperature changes in the natural environment. These temperatures vary according to the particular species. Fish are generally categorized into warmwater, coolwater, and coldwater based on optimal growth temperatures. Channel catfish are an example of a warmwater species, with a temperature range for growth between 70° and 85°F. A temperature of 82°F is generally considered optimum for growth. This explains, in part, why catfish farming in the southern states, with their longer growing season, has been so successful.

Striped bass, hybrid striped bass, walleye, and yellow perch

are examples of coolwater species. Ranges for optimum growth fall between 55° and 75°F. Temperatures in the upper end of this range are generally considered best for maximum growth for all coolwater species.

Coldwater species include all species of salmon and trout. Two of the more commonly cultured coldwater species in the North Central Region are rainbow trout, and to a lesser extent, brown trout. Their optimal temperature range for growth is 48°–60°F.

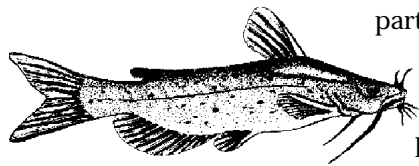
Ideally, species selection should be based partly on temperatures of the water supply. Any attempt to match the fish with improper water temperatures will involve energy expenditures for heating or cooling to within the desired range. This added expense will subsequently reduce the farmer's profits.

### Dissolved oxygen

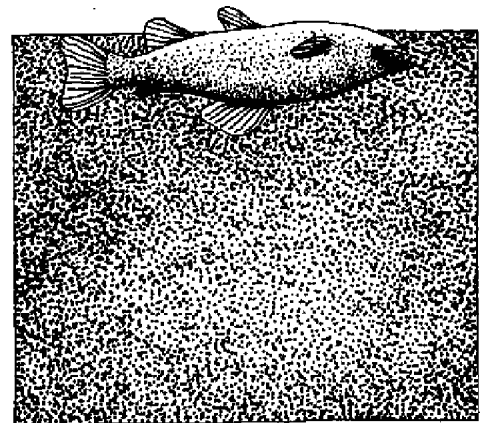
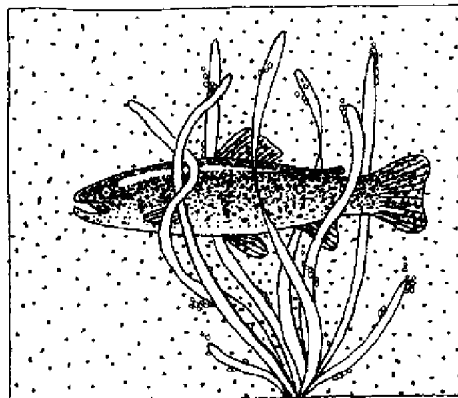
Like humans, fish require oxygen for respiration. Dissolved oxygen (DO) concentrations are expressed in parts per million (ppm) or milligrams per liter (mg/l). Both methods are the same since 1 mg/l is equal to 1 ppm. Some fish such as tilapia and carp are better adapted to withstand periodic low DO concentrations. However, concentrations greater than 4 to 5 ppm are required for good growth in fish. The oxygen that fish need to breathe also is consumed by the breakdown of fish wastes and uneaten feed.

Oxygen enters the water in three ways:

- (1) through air diffusing into the water at the surface,



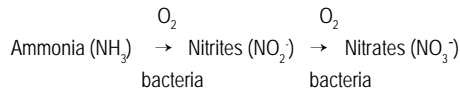
**Channel catfish**



**Plentiful vs. shortage of oxygen**

- (2) through the photosynthesis of microscopic plants (algae) in ponds. (In this process carbon dioxide is converted into food by plants and oxygen is released as a by-product.)
- (3) through mechanical means. (The levels of oxygen can be increased.)

Ammonia, nitrites, and nitrates  
 Fish excrete ammonia and a lesser amount of urea into the water as wastes. Two forms of ammonia occur in aquaculture systems: ionized ( $\text{NH}_4^+$ ) and un-ionized ( $\text{NH}_3$ ). The un-ionized form of ammonia is extremely toxic to fish; ionized ammonia is not. Both forms are grouped together as "total ammonia nitrogen." Through biological processes, toxic ammonia can be degraded to harmless nitrates as shown below.



In natural waters, such as lakes, ammonia may never reach critically high levels due to the low densities of fish. But the aquaculturist must maintain high densities of fish and therefore runs the risk of ammonia toxicity. Un-ionized ammonia levels rise as temperature and pH increase. Toxicity levels for un-ionized ammonia depend on individual species; however, levels below 0.02 ppm are generally considered safe. Dangerously high ammonia concentrations usually are limited to water reuse systems, where water is continually recycled. However, the intermediate form of ammonia – nitrite – has been known to occur at toxic levels in fish ponds.

pH, alkalinity, and hardness  
 The quantity of hydrogen ions in water determines whether it is acidic or basic. The scale for measuring the degree of acidity is called the pH scale, which ranges from 1 to 14. A value of 7 is neutral, neither acidic nor basic; values below 7 are considered acidic; above 7 basic. The accept-

able pH range for fish culture is normally between pH 6.5 and 9.0.

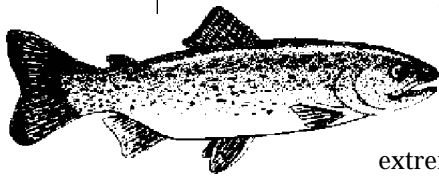
Alkalinity is a system by which wide pH fluctuations are prevented or "buffered." It is a measure of the carbonates ( $\text{CO}_3^{2-}$ ) and bicarbonates ( $\text{HCO}_3^-$ ) as expressed in terms of equivalent calcium carbonate ( $\text{CaCO}_3$ ). An example of this type of buffering system is the addition of agricultural lime to prevent decline in pH. Hardness is the measure of the calcium and magnesium portion of the buffering system. These two elements can be absorbed by the fish's gills and, in addition to other uses, they help with the bone development in fish. Fish will grow over wide ranges of alkalinity and hardness, but values of 120–400 ppm are considered optimum.

## Types of aquaculture

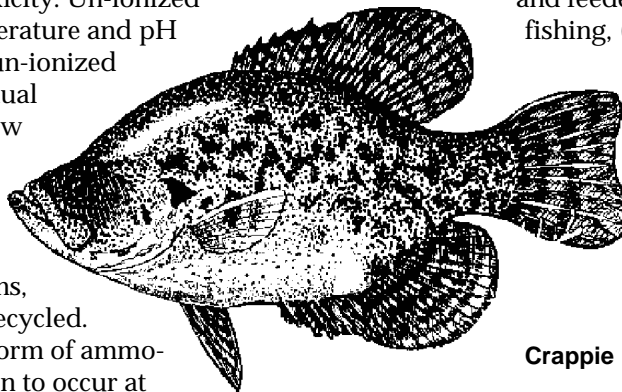
The most widely recognized types of aquaculture in the United States is the catfish industry in the south and the trout farms in Michigan and the West. Both of these industries involve the culture of a single fish species for food. Another familiar type is the production of bait minnows and crayfish for use by recreational fishermen. There are several categories for production of aquaculture products: (1) food organisms, (2) bait industry, (3) aquaria trade—ornamental and feeder fish, (4) fee fishing, (5) pond and lake stockings, and (6) biological supply houses.

Food organisms  
 The production of food organisms is the most common form of aquaculture

practiced in the United States. Of the approximately 60 species that have potential to be grown as food fish, technical support and markets limit these to a select few. The most common food fish and shellfish being grown in the United States are: catfish, trout, salmon, carp, crayfish, freshwater shrimp, striped bass and their hybrids, and tilapia.



Rainbow trout



Crappie

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### Bait industry

Sometimes known as minnow and crayfish farming, the bait industry is a surprising one. Although the exact size of the industry is not known, nearly all states east of the Rocky Mountains, as well as Arizona and California west of the continental divide, have some bait farming. Species of fish and shellfish produced include: golden shiners, fathead minnows, goldfish, carpsuckers, bluntnose minnows, tilapia, suckers, and crayfish.

### Aquaria trade

The ornamental fish, plant, and snail industry may be divided into two types. First, the tropical fish and plant industry, which originated in south Florida where annual temperatures are similar to those of the plant or animal's native range. The other varieties of ornamentals cultured are the goldfish and the Koi Carp, which are coolwater species. The tropical fish group does not tolerate temperatures associated with the temperate zone, and thus is unsuitable in the Midwest for pond production during most of the year.

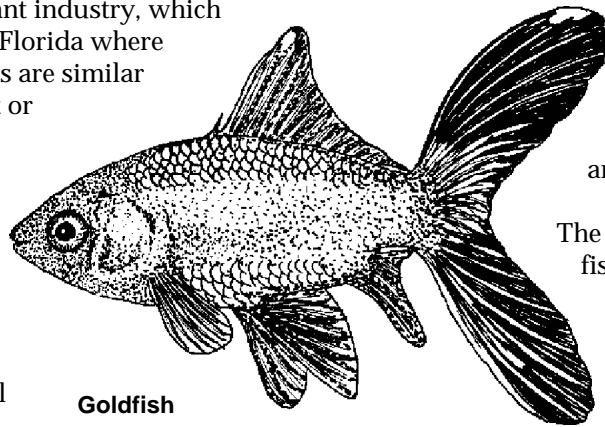
There is potential to produce several species indoors in tanks or aquaria where temperatures can be closely controlled. Species that could be produced in this way are several of the livebearers (guppies, mollies, and swordtails), gouramies, and cichlids, such as angel fish and discus fish. There is also a demand for native fish in the ornamental industry. Small garfish, sturgeon, and the bowfin are two examples of native fish that are being sold as ornamentals.

In addition to growing ornamental fish, there are farmers who grow fish for use as "feeders" for the larger fish-eating aquarium fish. Most feeder fish sold are goldfish, but other species sold when approximately 1-2 inches long can also be considered feeder fish.

### Fee fishing

Fee fishing ponds, sometimes called catch-out ponds, usually are small, heavily stocked bodies of water containing one or more kinds of fish that are of catchable size. There are three basic types of fee fishing operations: long-term leasing, day leasing, and fish-out. Exclusive long-term fishing rights to a private pond or lake can be leased to a group or individual, e.g., a hunting club. Day leasing is similar to long-term leasing but it is for a single day. Generally, the operator of a fish-out pond charges a basic fee for one-half or one day of fishing, and/or a fee for each pound or inch of fish caught. Additional

facilities provided at fish-out ponds may include snack bar, bait and tackle shop, boat rentals (for larger ponds), picnic facilities, public rest rooms, and parking facilities.

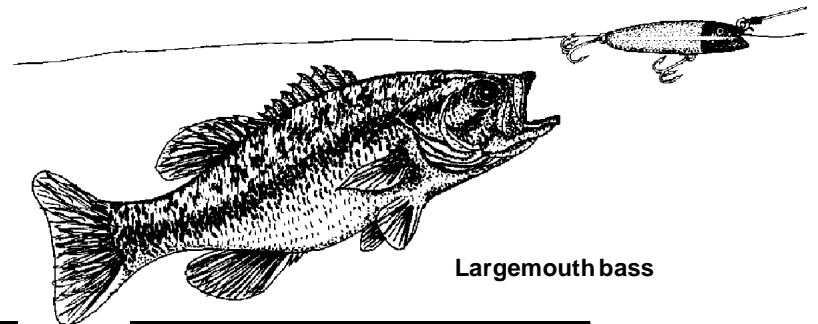


Goldfish

The type of fish stocked into fee fishing ponds depends on pond conditions. Coldwater ponds are normally stocked with trout. Warmwater ponds usually are stocked with channel catfish, bullheads, and/or hybrid sunfish. Ponds stocked with bass and bluegills usually do not supply the catch rate necessary for a successful fee fishing business unless they also are regularly stocked with catfish.

### Pond and lake stockings

With the many farm ponds found throughout the North Central Region, production of sport fish to stock them can be a very profitable business. In addition to farm ponds, fish needed for stocking city or county lakes may be obtained from the private producer. Many combinations of fish are suitable for stocking in ponds and lakes. Some of the more commonly cultured



Largemouth bass

species are largemouth bass, bluegill, redear sunfish, hybrid sunfish, channel catfish, bullheads, trouts, crappies, walleye, yellow perch, fathead minnows, bluntnose minnows, and golden shiners. Generally fish are stocked at below catchable size, and then grow more in the ponds.

Those who purchase fish for pond or lake stockings usually buy mixtures of several species and stock according to “recipes.” This procedure allows the pond to maintain a balance of predator fish (largemouth bass, walleye, and trout) and prey species (bluegill and other sunfishes) for several years. However, a pond owner will usually need to renovate his or her pond and restock every five to seven years to maintain the proper ratio for predator and prey species. This periodic restocking provides good management for the pond owner and a continual market for the suppliers of stockable-size fish.

#### Biological supply houses

Raising aquaculture products for biological supply houses covers a broad range of organisms. Everything from algae to turtles is used in some form by educational and research institutions. The producer should conduct a good deal of marketing research before attempting to specialize in only one aspect of production for biological supply houses. Instead of specializing, some producers take advantage of aquatic organisms that live with the culture of their target species. They sell these to biological supply houses as a supplemental source of revenue.

#### Production phases

Regardless of the form of aquaculture undertaken, it will involve at least one of the following production phases: (1) securing and spawning of brood stock, (2) hatching of eggs, (3) growing fry to produce fingerlings, and (4) stocking and grow-out of fingerlings to marketable size.

Some farmers will perform all phases of production while others may specialize and skip one or more of the four phases of production. These farmers may, for example, produce only fingerlings to sell to farmers who will in turn grow those fish for market as food fish. Most trout

farmers in the eastern United States purchase eggs from large western farms, thus eliminating the need to maintain broodstock for spawning. The number of production levels chosen for an individual farm usually is based on: the size of the

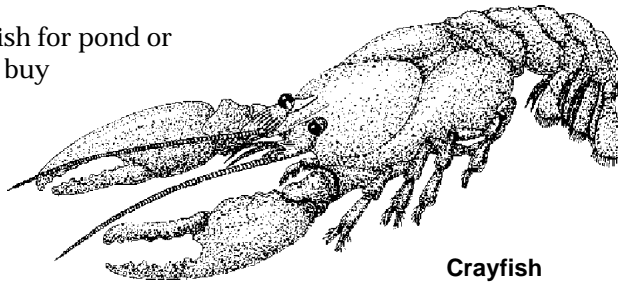
operation, expertise, amount of capital available to purchase specialized equipment, and personal preference.

Marketing is extremely important in the production of any type of aquaculture species. Without a well-thought-out marketing plan, the aquaculturist may be faced with a serious obstacle. Before attempting to go into full scale production, the producer should have several market outlets for the product.

#### Production methods

When describing aquatic production systems, the aquaculturist refers to the water-holding facility in which the organisms are grown. Several kinds of water facilities may be needed for growing fish. The kind of facility depends on the size of the farm and the type of fish farming. These facilities are grouped into four types: ponds, cages, raceways, and recirculating systems.

Further distinctions can be made within each type of facility based on the level of intensity used by the producer. The terms “extensive” and “intensive” are sometimes used when describing the amount of inputs (labor, feed, materials, or equipment) used in an operation. Extensive production usually means the addition of no or few inputs with a resulting low production level. Natural lakes and farm ponds are examples of extensive systems. Fish culture ponds sometimes are described as being extensive even when some very intensive manage-



**Crayfish**

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ment strategies are used. Intensive production, on the other hand, refers to the increasing use of inputs, which generally increases the yield.

It should be noted that a point comes when the inputs exceed the outputs. This trend for outputs to increase more slowly than inputs is called the law of diminishing returns and usually is associated with expenses versus income.

#### Ponds

The most common production system in use is the earthen pond. These ponds may be anything from a small farm pond to one specifically designed and built for aquaculture. While the non-drainable farm pond or water storage lake can be used for many types of aquaculture, it is not well-suited for others due to the lack of a drainage system, questionable water quality, and inconsistent water depths. Nevertheless, non-drainable farm ponds are used to produce fish in cages and in fee-fishing operations.

Ponds constructed for fish culture are called dike or levee ponds. Levee ponds require an adequate amount of good quality water and clay soils that retain water. The slope of the pond site also affects the selection of the site. Ponds built on a slight slope can be easily gravity-drained. Anywhere from a 2- to 5-foot rise per 100 feet is usually an acceptable slope. The shape of levee ponds is usually rectangular, but occasionally, square ponds or contour ponds are used. An advantage of rectangular ponds is the reduced length of the seine needed to harvest the pond.

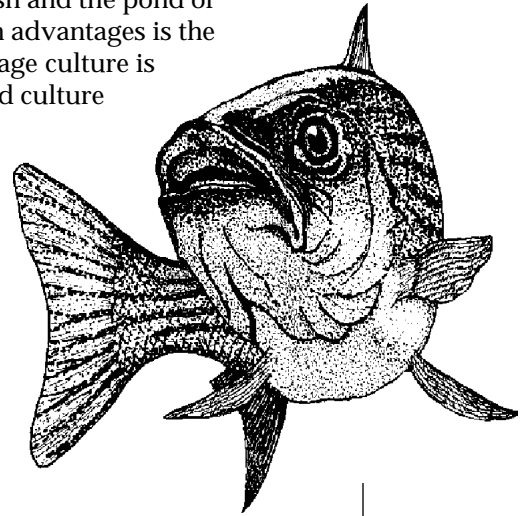
The types of levee ponds are holding ponds, spawning ponds, rearing ponds, and grow-out ponds. The size of a levee pond depends on its planned use. For example, a pond used for spawning fish will be smaller than a pond used to grow out fish to marketable size. Spawning ponds can be as small as one-fourth acre and grow-out ponds may exceed 20 acres. Smaller ponds are easier to manage; however, they are more expensive to build on a per unit area basis.

Production in ponds can range from 2,000 to 10,000 pounds per acre per year (lb/acre/yr.) depending on the level of intensity. One way to increase annual production is through continual harvesting. This is accomplished by selectively harvesting the larger fish and replacing them

with new fingerlings. When using this method, a single yearly harvest is replaced by staggered harvests.

#### Cage Culture

Cage culture of fish uses existing water resources (i.e. lakes or ponds) but encloses the fish in a cage or basket, which allows water to pass freely between the fish and the pond or lake. One of the main advantages is the ease of harvesting. Cage culture is an alternative to pond culture where typical levee ponds are not available. Small lakes, mining pits, and farm ponds may be used in cage culture. Cage culture is attractive because ponds or lakes too deep for seining can still be used to produce fish.



**Hybrid striped bass**

Though the shape and size of an individual cage can vary, some of the more common cages are rectangular, 3x4x3 feet or 8x4x4 feet; square, 4x4x4 feet or 8x8x4 feet; and round, 4x4 feet. These cages float and are placed in the open part of the pond with at least two feet of water between the bottom of the cage and the pond bottom. A key point to recognize in cage culture is that total production is no greater in cages than in ponds, even though it appears that the farmer will only be using a small part of the water. In fact, good water circulation must be assured to prevent oxygen depletion in and around the cages.

Production rates in cages is similar to ponds, with 1,000–5,000 lb/acre/yr. possible from a series of cages. The production rate can be increased from the double cropping of a warmwater and a coldwater species. For example, catfish are grown in the warm summer months, then harvested and replaced by trout in the winter. Production of up to 500 lb/year is possible from a single 4x4x4 foot cage.



## Raceways

Rectangular raceways are used almost exclusively for trout production, but it is possible to culture other species of fish in them. A raceway production facility requires large quantities of inexpensive high quality water. The water is normally obtained from a spring or stream and is passed through the raceways using gravity ("once-through" or "open" system). The raceways are arranged in a series on a slightly sloping terrain, taking advantage of gravity to move the water through each unit.

Raceways may be built of concrete, block, tile, bricks, wood, or other durable materials, or they can be earthen. Earthen raceways are cheaper to build, but the high volumes and velocity of water cause varying degrees of erosion. Thus, they are not often used. Dimensions of raceways vary, but generally a length:width:depth ratio of 30:3:1 provides favorable characteristics.

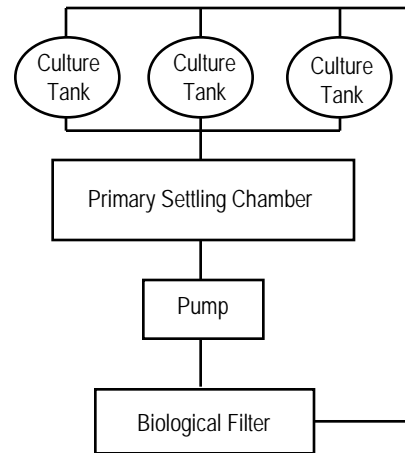
Recirculating raceway facilities also are possible. In this type of raceway, culture water is pumped back to a processing reservoir where wastes are removed. This type of facility is more expensive to operate and more complicated because of the energy needed to run the pump and the equipment needed to remove the waste.

Production in raceways is greater than that of ponds or cages because of the continual exchange of fresh water, which removes the wastes. Because production is partly based on flowing water through the raceways, yields are measured in pounds per gallon per minute (lb/gal/minute). Yields exceeding 20 lb/gal/minute have been obtained in intensive raceway production.

## Water Recirculating Systems

A closed recirculating system refers to a production method that recirculates the water rather than passing it through only once. As a result, less water is needed for this type of system than for ponds or open raceways. Most recirculating systems are indoors, which allows the grower to maintain more control over the water (i.e. temperature) than in other production methods. Even though recirculating systems have many advantages over other production types, their overriding disadvantage is the initial capital investment.

Closed recirculating systems are generally composed of four components: the culture chambers, a primary settling chamber, a biological filter, and a final clarifier or secondary settling chamber. Each of these units is important to the system, although some closed recirculating water system designs have eliminated the secondary settling chambers. The components may be separate units or they may be arranged



**Schematic diagram for water recirculating systems.**

in combinations that make the system appear to have only one or two compartments. Each component may be very large or relatively small, but each must be in proper proportion to the others if the system is to perform properly. Production rates in closed recirculating systems vary considerably and usually depend on the type of system used and the user's expertise. Therefore, an accurate range of production could be very misleading. With this in mind, estimated yields range from 0.25 to 0.8 pounds per gallon (lb/gal). Producers interested in water recirculating systems should construct and test small-scale pilot systems before attempting large-scale production systems.

## Summary

Aquaculture is a form of agriculture which involves the propagation, cultivation, and marketing of aquatic plants and animals in a

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more-or-less controlled environment. World fish farming started as early as 2000 B.C., but United States aquaculture started in the late 19th century. The firmly established catfish industry started in the early 1960s and has gone through four phases. The current phase shows a slowing in the expansion of catfish farming, and an increase in the production of other species.

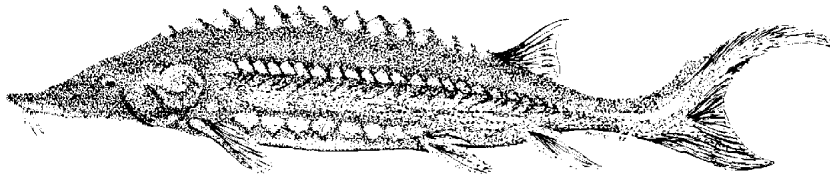
Water supply and quality are the most important factors in selecting the proper location for an aquaculture facility. Wells and springs are the best sources of water, but other sources are acceptable if the quality and quantity are adequate. Important water quality characteristics to consider are temperature, dissolved oxygen, ammonia, nitrites, nitrates, pH, alkalinity, and hardness. In respect to temperature, fish

may be classified as warmwater, coolwater, and coldwater species, with each type having an optimal temperature range.

Of the six types of aquaculture, the production of food organisms such as catfish, trout, and hybrid striped bass are the best known. Others include: bait, aquaria, fee-fishing, lake stockings, and biological supply houses. Organisms from each of these six types will be produced using one of the following methods: ponds, cages, raceways, or water-recirculating systems.

Before considering aquaculture as a business, much research on requirements should be done. This research should include marketing, stocking, feeding, harvesting, transport, and capital investments.

**Shovelnose sturgeon**



***Printed on  
Recycled Paper***

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Series Editor: Joseph E. Morris, Associate Director, North Central Regional Aquaculture Center.  
Artwork by Mark Müller.

Design by Valerie King, King Graphics, Grand Junction, Iowa,  
and Dennis Melchert, Ames Best Communications, Ames, Iowa.

Originally published by Iowa State University, Ames, Iowa.