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A Basic Overview of Aquaculture

Aquaculture Extension

Illinois-Indiana Sea Grant Program
Purdue University Cooperative Extension Service
West Lafayette, Indiana 47907



- History
- Water Quality
- Types of Aquaculture
- Production Methods

A Basic Overview of Aquaculture

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 bulletin is directed to those who have an interest in aquaculture, but who lack any knowledge about or experience in the business. The reader should note that these few pages are not intended to be a complete introduction to aquaculture. It does not cover many very important topics such as stocking, feeding, harvesting, transport, marketing, and others. In addition, the topics which are covered are by no means complete. Instead, this is intended only to introduce some of the 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), while ornamental fish ponds appear in paintings from Ancient Egypt. European aquacul-

ture began sometime in the Middle Ages and transformed the "art" of Asian aquaculture into a science which 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 which involves the propagation, cultivation, and marketing of aquatic animals and plants in a more or less 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 constructed.
3. Low-value species were being raised.
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 the 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 (1971-76) gave rise to major improvements in production and lower unit costs. Average annual yields increased from 1,500-2,000 pounds per acre (lb./a.) to 3,000-4,000 lb./a. There was, however, a drastic shake-out of unprofitable and marginal producers when feed costs rose as a result of a scarcity of fish meal. The third phase (1977-82) 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 over 140,000 acres and 361 million pounds processed in 1989. Economically, this production had a farm gate value of over 290 million dollars. Mississippi dominates the industry with 63 percent of the acreage and 75 percent of the production. Presently the catfish industry's rate of growth 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

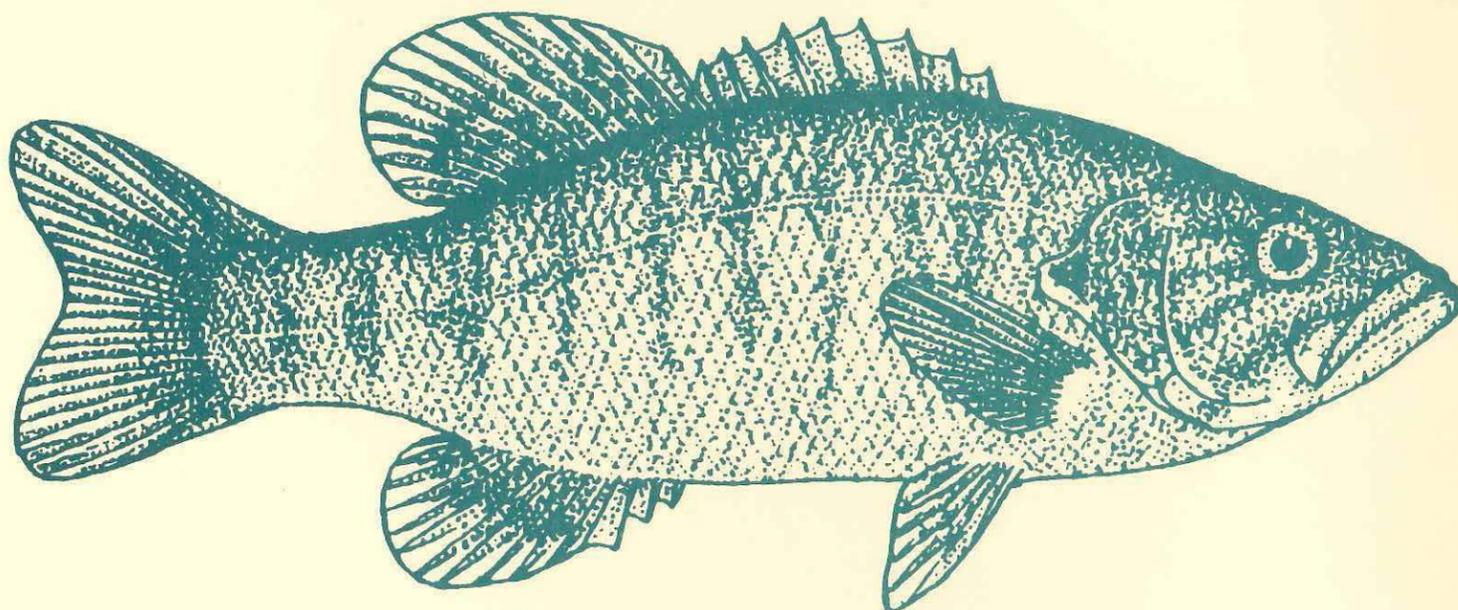


A one-tenth acre spawning pond for catfish.

throughout the world. Per capita consumption in the U.S. rose from 17.1 pounds in 1980 to 20.2 pounds in 1987, an increase of 18 percent. With the increased health consciousness of Americans, per capita consumption of aquaculture products will continue to increase. In addition, the dwindling supply of "wild" caught fish from conventional capture sources has declined due to 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 into the existing aquaculture industry, either at the production level or in a supportive position. Before doing so, the potential "aquafarmer" 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). But, there are reasons why aquaculture can be more productive and profitable than land-based agriculture.

Meaningful comparisons of productivity are complicated, but fish do 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,





Pond aeration with a paddlewheel aerator is used to raise low-dissolved oxygen.

unlike land animals, they do not have to support their weight and should therefore be inherently more efficient at converting food into flesh. A fish farm uses a three-dimensional rearing area. This means a fish has the added dimension of depth in which to grow, thus increasing yields on a per acre basis. Production in ponds can exceed 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.

If there are so many advantages to aquaculture over land-based agriculture, then 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 which impede the development of the aquaculture industry in the Midwest.

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 may still be suitable. The key, of course, is that water must be available at all times and in good supply.

Water sources can be classified as: wells, springs, groundwater, streams, rivers, lakes, or municipal water supplies. 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 as well as metals such as iron. These problems can be easily 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.

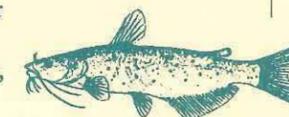
Groundwater is sometimes used where ponds are dug into the existing water table. This type of pond is generally less productive than ponds filled from other sources, due to the low productivity of the surrounding soil. Streams, rivers, and lakes can also be used to produce aquatic organisms, but are subject to any contaminants which 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, 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 each 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 its temperature range for growth being between 75°-90°F. A temperature of 85°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.



Channel Catfish

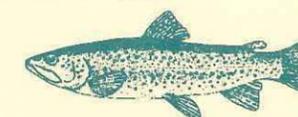
Striped bass, hybrid striped bass, walleye, and yellow perch are examples of coolwater species.



Hybrid Striped Bass

Ranges for optimum growth fall between 60°-80°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 Midwest are rainbow trout, and to a lesser extent, brown trout. Their optimal temperature range for growth is 48°-65°F.



Rainbow Trout

Ideally, species selection should be based in part 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

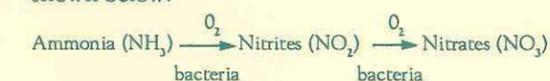
Like humans, fish require oxygen for respiration. Dissolved oxygen (DO) concentrations are expressed in parts per million (ppm) or milligrams per liter (mg/l). Both methods are the same since 1 mg/l is equal to 1 ppm. Some fish such as tilapia and carp are better adapted to withstand periodic low DOs.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

Oxygen enters the water in three ways:

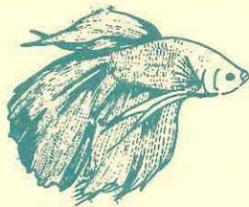
1. Through air diffusing into the water at the surface.
2. Through the photosynthesis of microscopic plants (algae) in ponds. In this process carbon dioxide is converted into food by plants and oxygen is released as a by-product.
3. Through mechanical means the levels of oxygen can be increased.

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 and un-ionized. The un-ionized form of ammonia is extremely toxic to fish while ionized ammonia is not. Both forms are grouped together as "total ammonia." 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 are usually 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 will determine if 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 acceptable pH range for fish culture is normally between pH 6.5-9.0.

Alkalinity is a system by which wide pH fluctuations are prevented or "buffered." It is a measure of the carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) as expressed in terms of equivalent calcium carbonate (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 type of aquaculture in the U.S. is the catfish industry in the south and the trout farms in Michigan and the West. Both these industries involve the culture of a single species of fish 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
 - a. Ornamental
 - b. Feeder fish
4. Fee-fishing
5. Lake stockings
6. Biological supply houses

Food Organisms

The production of food organisms is the most common form of aquaculture practiced in the U.S. Of the approximately 60 species which have potential to be grown as food fish, the current technical support and markets limit these to a select few. The most common food fish and shellfish being grown in the U.S. are:

1. Catfish
2. Trout and Salmon
3. Carps
4. Crayfish
5. Freshwater shrimp
6. Striped bass and their hybrids
7. Tilapia

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 every state east of the Rocky Mountains, as well as Arizona and California west of the continental divide, has some bait farming. Species of fish and shellfish produced include:

1. Golden shiners
2. Fathead minnows
3. Goldfish
4. Carpsuckers
5. Bluntnose minnows
6. Tilapia
7. Suckers
8. Crayfish

Aquaria Trade

The ornamental fish, plant, and snail industry may be divided into two types. First is 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 Koi Carp, which are coolwater species. The tropical fish group is intolerant to temperatures associated with the temperate zone, and thus is unsuitable for production in ponds for most of the year in the Midwest. There is potential to produce several species indoors in tanks or aquaria where temperatures can be closely controlled. Species which could be produced in this

fashion are several of the livebearers (guppies, mollies, and swordtails), gouramies, and cichlids, such as angle fish and discus fish. There is also a demand for native fish in the ornamental industry. Small garfish and the bowfin are two examples of native fish which 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 one-two inches long can also be considered feeder fish.

Fee-Fishing

Fee-fishing ponds, sometimes called catch-out ponds, are usually 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, such as is done with a hunting club. Day leasing is similar to long term leasing except it is for single days. 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,



Fee-fishing businesses usually charge a daily fee and/or a charge for every pound caught.

bait and tackle shop, boat rentals (for larger ponds), picnic facilities, public rest rooms, and parking facilities.

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

Pond and Lake Stockings

With the numerous farm ponds found throughout the Midwest, production of sport fish to stock them can be a very profitable business. Besides farm ponds, fish needed for stocking private city or county lakes may be obtained from the private producer. There are numerous combinations of fish which are suitable for stocking in ponds and lakes. Some of the more commonly cultured 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 sub-catchable size, and additional growth occurs in the ponds.

Those who purchase fish used for pond or lake stockings usually buy mixtures of several species and stock according to "recipes." This enables 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 need to renovate his pond and restock every four to five 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

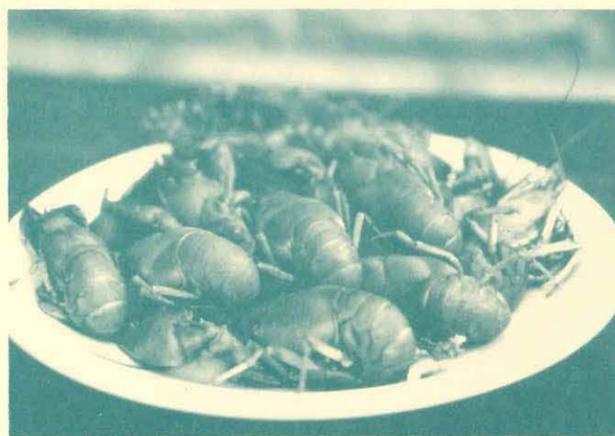
Producing aquaculture products for biological supply houses covers a broad range of organisms. Everything from algae to turtles is used. These products are used in some form by educational and research institutions. A good deal of marketing research should be done before attempting to specialize in only one aspect of the production of organisms for biological supply houses. Instead of specializing, some producers take advantage of aquatic organisms which occur in association with the culture of their target species. They sell these to biological supply houses as a supplemental source of revenue.

Production Phases

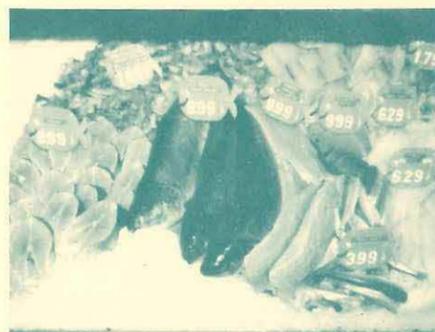
Regardless of which form of aquaculture is undertaken, it will involve at least one of the following production phases:

1. Securing and spawning of brood stock
2. Hatching of eggs
3. Growing fry to produce fingerlings
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 for sale to farmers who will in turn grow those fish for market as food fish. Most trout farmers in the eastern U.S. now purchase eggs from large western farms, thus eliminating the need to maintain broodstock for spawning. The number of production levels chosen to include in an individual farm



Midwestern species of crayfish are not only used for bait, but are also good to eat.



Farm-raised fish are popular in supermarkets today due to increased seafood consumption.

usually are based on: the size of the operation; expertise; amount of capital available to purchase specialized equipment; and/or personal preference.

Marketing is an extremely important consideration 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 to a successful operation. Before any attempt is made to go into full scale production, it is advisable for the producer to have several market outlets for the final product.

Production Methods

When describing aquatic production systems, the aquafarmer 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 constructed will depend on the size of the farm and the type of fish farming program to be followed. These facilities are grouped into four types: ponds, cages, raceways, and water reuse 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 are sometimes described as being extensive, even though some very intensive management 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 will be

reached where the inputs will exceed the outputs. This trend for outputs to increase at a slower rate than the rate at which inputs are added is called the law of diminishing returns and is usually 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 constructed 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.

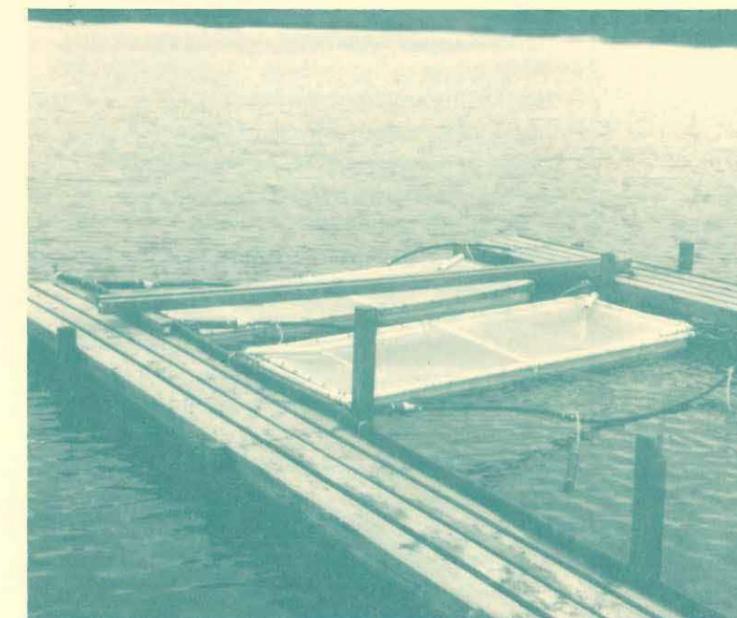
Ponds constructed for fish culture are called dike or levee ponds. The basic requirements for levee ponds are: water of good quality in adequate amounts; and clay soils that retain water. Slope of the pond site is also a factor that affects the site selection for ponds. Ponds constructed on a slight slope can be easily gravity-drained. Anywhere from a two-to five-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 will depend 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 construct on a per unit area basis.

Production in ponds can range from 2,000-10,000 pounds per acre per year (lb./a./yr.) depending on the level of intensity employed. One way that annual production is increased is through continual harvesting. This is accomplished by selectively harvesting the larger fish in the pond 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 utilizes existing water resources such as 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 in situations where typical levee ponds are not available. Small lakes, mining pits, and farm ponds are water sources which could be utilized in cage culture. Cage culture is attractive because ponds or lakes too deep for seining can still be used to produce fish. While the shape and size of an individual cage



Hybrid striped bass fingerling production using net pens.

can vary, some of the more commonly constructed cages are rectangular, 3x4x3 ft. or 8x4x4 ft.; square, 4x4x4 ft. or 8x8x4 ft.; and round, 4x4 ft. 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. One key point to recognize in cage culture is that total production is no greater in cages than ponds, even though it appears that the farmer will only be utilizing a small part of the total water

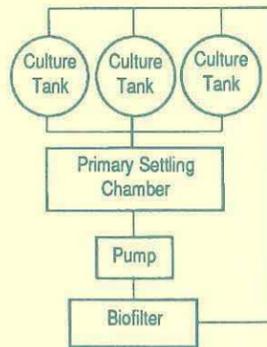


Fig. 1 Schematic diagram of a water reuse fish culture system.

in the pond or lake. In fact good water circulation must be assured to prevent an oxygen depletion in and around the cages.

Production rates in cages is similar to ponds, with 2,000-5,000 lb./a./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 600 lb./yr. is possible from a single 4x4x4 ft. 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 slightly sloping terrain, thus taking advantage of gravity to move the water through each unit.

Raceways may be constructed of concrete, block, tile, bricks, wood, or other durable materials or can be earthen. Earthen raceways are cheaper to construct, 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 are also 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 due to the energy needed to run the pump and the equipment needed for the waste removal.

Production in raceways is greater than that of ponds or cages as a result of the continual exchange of freshwater, which removes the wastes. Because production is in part based on flowing water through the raceways, yields are measured in

Raceways are used almost exclusively on trout and salmon farms.

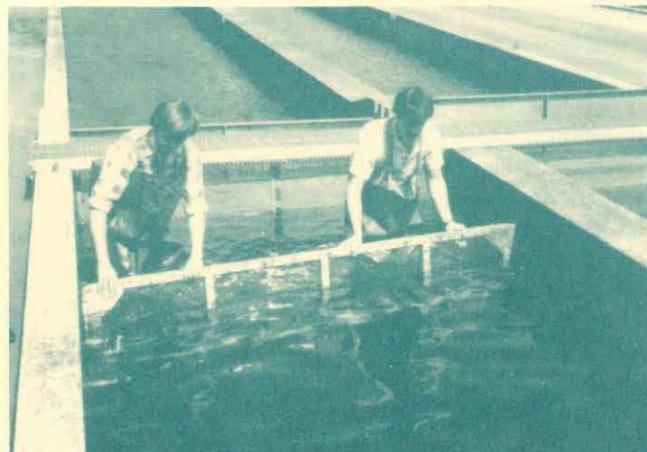
pounds per gallon per minute (lb./gal./min.). Yields exceeding 82 lb./gal./min. have been obtained in very intensive raceway production.

Water Reuse Systems

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 reuse systems are located indoors, which allows the grower to maintain more control over the water (for example, temperature) than in other production methods. Even though reuse systems have many advantages over other production types, their overriding disadvantage is the start-up costs.

Closed reuse systems are generally comprised 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 one or more of the four components. The components may be separate units or they may be arranged 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 other if the system is to perform properly.

Production rates in closed reuse systems will vary considerably and really depend on the type of system employed and the user's expertise. Therefore, an accurate range of production could be very misleading. With this in mind, estimated yields range from 0.25-1.5 pounds per gallon (lb./gal.). Someone with little experience in aquaculture probably should not try large-scale reuse systems as their first attempt.



Summary

Aquaculture is a form of agriculture which involves the propagation, cultivation, and marketing of aquatic plants and animals in a more-or-less controlled environment. World fish farming started as early as 2000 B.C., while U.S. aquaculture started in the late 19th century. The firmly established catfish industry started in the early 1960's and has gone through four phases. The current phase shows a slowdown 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.

There are six types of aquaculture, with the production of food organisms like catfish, trout, and hybrid striped bass being best known. Others include: bait industry, aquaria trade, fee-fishing, lake stockings, and biological supply houses. Organisms from each of these six types will be produced in one of the following methods: ponds, cages, raceways, or water-reuse systems.

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

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