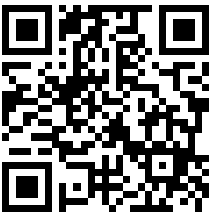
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Front cover photo.

Aerial view of the Fish Farming Experimental Station of the U.S. Fish and Wildlife Service, and (foreground) part of the Rice Branch Experiment Station of the University of Arkansas at Stuttgart.

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THIRD REPORT TO THE FISH FARMERS

The Status of Warmwater Fish Farming and Progress in Fish Farming Research

Edited by

Harry K. Dupree and Jay V. Huner

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Preface

The highly successful *Report to the Fish Farmers* published in 1970 and the *Second Report to the Fish Farmers* published in 1973 have pointed out the need for a third edition of the Report. Although certain aspects of fish farming have changed little in the past 10 years, some techniques that were unknown or little practiced 10 years ago are in common use by fish farmers today, and the size of the warmwater fish farming industry has increased tremendously. Much of this increase has been due to research and development by government agencies, universities, and others, but equal credit is due to the farmers themselves for implementing the research findings, and often providing the development phase. It is our purpose to present the information obtained through research, and tested and proved by the industry, in the language of the fish farmer and aquaculturist. All the chapters that appeared in the Second Report have been revised in this Third Report, and new chapters have been added to bring together the scientific and technical literature from the United States and (for certain subjects) other countries. Although we provide information on warmwater aquaculture in the United States that should be useful to aquacultural suppliers, lending institutions, resource managers, interested citizens, and others, our principal purpose is to tell the fish farmer what is to be done, why it is to be done, and how to do it. The reader of this *Third Report to the Fish Farmers* should be provided with the essentials of successful warmwater fish farming.

The emphasis in this report is clearly on channel catfish, ranging from maintenance of brood stock to the culture of fingerlings and the production of market-sized fish. However, production techniques are described for numerous other fishes of commercial importance, as well as for crayfish, prawns, bullfrogs, and alligators. Other topics of potential interest to practicing aquaculturists include polyculture; nutrition and feeding; harvesting, holding, and transporting of fish; parasites and diseases; and multiple use of land and water.

A mixture of English and metric terms is used throughout the report. Because this handbook was prepared primarily for the fish farmer, the measurements given are those most commonly used today in the fish farming industry. Conversion tables given in Chapter 19 will enable the reader to convert values from one system of measurement to the other.

This report was prepared in a manner that allows for the distribution of separate chapters. Fish farmers and suppliers already knowledgeable and successful in some aspects of fish farming may require only information on the techniques and methods used in other phases of the industry. As a consequence of this preparation of self-contained individual chapters, some repetition has been unavoidable. We hope, however, that it has not been sufficient to cause appreciable distraction to the reader of the entire report.

In the United States, fish that are intended for human or animal food can be treated with drugs and chemicals only in accordance with current regulations of the U.S. Food and Drug Administration, U.S. Environmental Protection Agency, U.S. Department of Agriculture, and State and local agencies. Furthermore, the status of drugs and chemicals is always subject to change due to research findings or regulatory agency rulings. Therefore the user should always read and carefully follow the instructions on the label. References to drugs and chemicals whose usefulness has been demonstrated by fish culturists appear throughout this report. Compounds that have not been approved for use with food fish, or whose use for the purpose being discussed is restricted, are marked by the superscript symbol x (e.g., Furacin^{x} is an excellent bacteriostat); compounds that have been approved for the indicated use bear no superscript. The use of trade names does not imply U.S. Government endorsement of commercial products.

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Many private citizens, fish producers, researchers, extension personnel, and others provided technical information and assisted in the organization and preparation of this report. It would be impossible to name all, but we offer a partial list: *Alabama*—C. Boyd, Auburn University, Auburn; J. Flynn and J. Jensen, Alabama Cooperative Extension Service, Auburn; and D. Kelly, Soil Conservation Service, Auburn. *Arkansas*—J. Ayres, National Marine Fisheries Service, Little Rock; J. Chappel, Farm Fresh Catfish Co., Inc., Lake Village; M. Freeze, Arkansas Game and Fish Commission, Lonoke; L. Gray, Arkansas Cooperative Extension Service, Little Rock; and S. Newton, University of Arkansas-Pine Bluff, Pine Bluff. *California*—F. Conte, California Cooperative Extension Service, Davis, and J. Wright, Newberry Crawfish hatchery, Newberry. *Illinois*—W. Lewis, Southern Illinois University, Carbondale. *Louisiana*—J. Avault, Jr. and R. Romaire, Louisiana State University, Baton Rouge; R. A. Bean, ConAgra, Henderson; J. S. Hughes, Louisiana Department of Wildlife and Fisheries, Monroe; and L. McNease and G. Perry, Jr., Louisiana Department of Wildlife and Fisheries, Grand Chenier. *Mississippi*—R. Busch and C. Tucker, Delta Branch Agriculture Experiment Station, Stoneville; T. Schwedler, Mississippi Cooperative Extension Service, Stoneville; J. Waldrop, Mississippi State University, Starkville; and T. Welborn, Jr., Mississippi Cooperative Extension Service, Starkville. *Texas*—J. Davis, Texas Cooperative Extension Service, College Station, and R. Stickney, Texas A&M University, College Station. *West Virginia*—National Fisheries Center, U.S. Fish and Wildlife Service, Leetown.

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Personnel at the Fish Farming Experimental Station gave immeasurable assistance in providing background information and technical reviews, and in releasing the scientific director from many duties to provide time for writing. Special recognition and appreciation go to J. Cooper, G. Harris, and G. Hiryak for technical assistance in preparing the manuscript.

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1. WARMWATER FISH FARMING: A THRIVING INDUSTRY

Jay V. Huner and Harry K. Dupree

Commercial warmwater fish farming was begun in the late 1920's and early 1930's by a few persons who raised minnows to supply the growing demand for baitfish for sport fishing. Shortly after World War II, the demand for minnows increased as the result of the boom in farm pond and reservoir construction and the many water conservation projects inspired by the dust-bowl years of the 1930's. By the early 1950's the number of producers had increased enormously, and farmers had also begun to raise food fish such as buffaloes, bass, and crappies. Many of these early attempts at fish husbandry failed because the operators were not experienced in fish culture, ponds were not properly constructed, and low-value species were being raised.

From 1955 to 1959, the U.S. Fish and Wildlife Service, with funds from the Saltonstall-Kennedy Act for Commercial Fisheries, sponsored research on channel catfish at the University of Oklahoma. (Note: The common names of fishes are used throughout this report for convenience; scientific names are shown in Table 1.1.) The purpose of the research was to develop better production methods in National Fish Hatcheries and to develop a basis for commercial fish farming. Other agencies and universities also became interested in channel catfish as a commercial and sport species. During the next few years, the Service established three warmwater fish cultural research facilities: the Southeastern Fish Cultural Laboratory, Marion, Alabama (1959); the Fish Farming Experimental Station, Stuttgart, Arkansas (1960); and the Fish Farming Development Station, Rohwer, Arkansas (1963). These stations began research mainly with buffaloes, catfishes, and baitfishes, but other species were added later. Today the Marion and Stuttgart facilities are continuing that support for the expanding warmwater aquaculture industry in the United States.

Over the past decade, land grant universities, in cooperation with the U.S. Department of Agriculture, have made substantial contributions to warmwater aquaculture research through Agricultural Experiment Stations in Alabama, Arkansas, California, Georgia, Hawaii, Louisiana, Mississippi, Puerto Rico, South Carolina, Tennessee, Texas, and the Virgin Islands.

Technology has been provided to farmers through intensive extension effort involving the Fish Farming Experimental Station, State cooperative extension services, and the Extension Service of the U.S. Department of Agriculture. Various research laboratories, National Fish Hatcheries, and Fish Cultural Development Centers of the U.S. Fish and Wildlife Service throughout the country have also provided technical assistance to fish farmers, as have the agricultural experiment stations, Sea Grant Programs, the U.S. Soil Conservation Service, universities, Tennessee Valley Authority, National Marine Fisheries Service, State Departments of Conservation, various private foundations, and others.

Four major warmwater aquaculture industries blossomed during the 1960's. These involved baitfish, food fish, hobby (ornamental) fishes, and crayfish. The baitfish industry, which produces mainly golden shiners, fathead minnows, and goldfish, is centered in south-central Arkansas. The term "food fish" is generally synonymous with channel catfish; however, buffaloes enjoyed early popularity and are again coming into favor, and the production of Chinese carps

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Table 1.1. *Common and scientific names of fishes mentioned in this report.*[a]

Common name	Scientific name
Sturgeons	Acipenseridae
Shovelnose sturgeon	*Scaphirhynchus platorynchus*
Bowfins	Amiidae
Bowfin	*Amia calva*
Tarpons	Elopidae
Tarpon	*Megalops atlanticus*
Freshwater eel	Anguillidae
European eel	*Anguilla anguilla*
Japanese eel	*Anguilla japonica*
American eel	*Anguilla rostrata*
Snakeheads	Ophicephalidae
Snakehead	*Ophicephalus* spp.
Herrings	Clupeidae
Gizzard shad	*Dorosoma cepedianum*
Threadfin shad	*Dorosoma petenense*
Pikes	Esocidae
Northern pike	*Esox lucius*
Muskellunge	*Esox masquinongy*
Trouts	Salmonidae
Coho salmon	*Oncorhynchus kisutch*
Chinook salmon	*Oncorhynchus tshawytscha*
Rainbow trout	*Salmo gairdneri*
Atlantic salmon	*Salmo salar*
Smelts	Osmeridae
Rainbow smelt	*Osmerus mordax*
Carps and minnows	Cyprinidae
Bighead carp	*Aristichthys nobilis*
Common carp (koi carp, leather carp, scale carp, mirror carp [Israeli], and line [Zeil] carp	*Cyprinus carpio*
Goldfish	*Carassius auratus*
Mud carp	*Cirrhina molitorella*
Grass carp	*Ctenopharyngodon idella*
Silver carp	*Hypophthalmichthys molitrix*
Black carp	*Mylopharyngodon piceus*
Golden shiner	*Notemigonus crysoleucas*
Red shiner	*Notropis lutrensis*
Fathead minnow	*Pimephales promelas*
Suckers	Catostomidae
Smallmouth buffalo	*Ictiobus bubalus*
Bigmouth buffalo	*Ictiobus cyprinellus*
Black buffalo	*Ictiobus niger*
Loaches	Cobitidae
Oriental weatherfish	*Misgurnus anguillicaudatus*
Bullhead catfishes	Ictaluridae
White catfish	*Ictalurus catus*
Blue catfish	*Ictalurus furcatus*
Black bullhead	*Ictalurus melas*
Yellow bullhead	*Ictalurus natalis*
Brown bullhead	*Ictalurus nebulosus*
Channel catfish	*Ictalurus punctatus*
Flathead catfish	*Pylodictis olivaris*

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Table 1.1.—Continued

Common name	Scientific name
Livebearers	Poeciliidae
Mosquitofish	*Gambusia affinis*
Temperate basses	Percichthyidae
White bass	*Morone chrysops*
Striped bass	*Morone saxatilis*
Sunfishes	Centrarchidae
Green sunfish	*Lepomis cyanellus*
Bluegill	*Lepomis macrochirus*
Redear sunfish	*Lepomis microlophus*
Redeye bass	*Micropterus coosae*
Smallmouth bass	*Micropterus dolomieui*
Spotted bass	*Micropterus punctulatus*
Largemouth bass	*Micropterus salmoides*
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
Perches	Percidae
Sauger	*Stizostedion canadense*
Walleye	*Stizostedion vitreum vitreum*
Cichlids	Cichlidae
Oscar	*Astronotus ocellatus*
Blue tilapia	*Tilapia aurea*
Mozambique tilapia	*Tilapia mossambica*
Redbelly tilapia	*Tilapia zilli*

[a]For species occurring in the United States, the names are from "A list of common and scientific names of fishes from the United States and Canada" (fourth edition, 1980), issued as Special Publication 12 of the American Fisheries Society, Bethesda, Maryland. For foreign species, the names given are those most widely accepted in the regions where the species occur. The scientific and common names of a number of aquarium fishes, not included here, are given in Table 9.1.

and tilapias is increasing. The channel catfish industry was originally limited largely to south-central Arkansas, but is now centered in the delta region of northwestern Mississippi. Hobby (ornamental) fish include all those sold for use in home aquaria and decorative pools or ponds, such as the many flashy tropical fishes and the hardy goldfish and koi carp. Southern Florida retains its preeminence in tropical fish culture because of the favorable climate there; many goldfish are produced in Arkansas, Indiana, Maryland, Missouri, and Pennsylvania; and koi carp are important aquaculture products of California. Crayfish culture first developed as a significant industry in southern Louisiana but has spread into eastern Texas and the delta region of Mississippi.

History of the Channel Catfish Industry

The development of the channel catfish aquaculture industry followed a pattern seen, to some degree, throughout commercial aquaculture. The industry has gone through three identifiable phases. The first, or pioneering phase (1960–70) was characterized by rapid expansion and relatively high production costs that resulted from low yields and inefficiency. High processing costs were largely a result of chronic underutilization of processing capacity. There was severe competition from channel catfish caught in rivers by commercial fishermen and from imported fish. The markets were fragmented. Low product acceptance outside the principal market areas of the

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deep South, and the lack of an effective marketing strategy, effectively limited expansion.

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 to 3,000–4,000 or more pounds per acre. Processing, which had been typically limited to the fall, became less seasonal. There was a drastic shakeout of unprofitable and marginal producers when feed costs rose as a result of a scarcity of fish meal. Competition from river fish and imports continued, but supplies of these fish became stabilized while the total demand for catfish rose. Marketing strategy improved, and Mississippi emerged as the clear leader in channel catfish production, processing, and related activities.

The third phase (1977–82) saw vastly improved productivity, greatly increased acreage, and lower production costs. The major sales outlet became the processed fish market. These developments were coupled with a more sophisticated marketing approach that led to single companies being involved in culture, processing, and marketing. This vertical integration arose as a result of the need for processors to handle a nearly constant volume of fish throughout the year. However, a fall production peak is a built-in feature of catfish farming because most of the fish stocked as fingerlings in spring reach harvest size in fall.

The 1973–75 shakeout period cannot be overemphasized, as many catfish ponds built throughout the United States in the late 1960's and early 1970's lie idle even now. Unfortunately, many farmers constructed ponds and started producing fish without considering two critical factors—management expertise and identifiable, dependable outlets. Even when catfish farmers in areas like Georgia and South Carolina produced fish, they often had no ready markets. Local oversupply was especially critical when high feed prices reduced profit margins in 1973–75. In Mississippi, however, processing technology grew with the industry to provide a market for the crop.

Aquaculture Versus Agriculture

All major forms of warmwater aquaculture are normally more profitable than regular forms of agriculture. By 1982 more than 276,000 acres were devoted to the culture of warmwater species for food and recreation. This total included about 100,000 acres of food fish ponds, 60,000 acres of baitfish ponds, 2,000 acres of ornamental fish ponds, and 114,000 acres of crayfish ponds. The wholesale value of the fish produced exceeded $350 million.

Although warmwater aquaculture is generally successful, it is still several decades behind traditional livestock husbandry in research and development. Virtually every aspect of aquaculture can still be improved. Hundreds of thousands of acres of land are still available for expansion of fish farming, and the water supply, if properly used, is adequate. The cooperative efforts of Federal and State governments, private agencies, universities, and industry will be necessary to overcome the barriers that prevent the development of that acreage.

The Future of Aquaculture

A landmark event for the U.S. aquaculture industry was passage of the National Aquaculture Act of 1980, which provides for the consolidation of Federal support for aquaculture and the development of a planning document called the National Aquaculture Development Plan. Work on the Plan had begun before the signing of the Act by the Joint Subcommittee on Aquaculture, which included representatives of industry, research institutions, and Federal agencies involved with aquaculture. The Plan describes the status of aquaculture in the United States, the barriers to its expansion, and the actions that must be taken to reduce or eliminate those barriers. It is to serve as a guide for the formation of a national policy, and to identify the actions that should be taken by Federal and State gov-

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ernments, universities, and industry to enhance aquaculture as a major industry contributing substantially to the benefit of the Nation.

It is virtually certain that aquaculture will increase in the United States. Its citizens are eating increasing amounts of fish and other aquatic animals and plants, and since the harvest from marine and fresh waters appears to have stabilized, the increased supplies must come from aquaculture. Economics of production will surely be greatly benefited by a vigorous research and development program that results in improvements in feeds, as well as in various other aspects of production: disease control, water quality management, development of new genetic strains of fish and other organisms, harvesting, processing, and marketing. Improved and more broadly based technical assistance will enable user groups to remain informed of the findings.

We believe that the major warmwater species farmed during the next 10 years will continue to be the channel catfish and crayfish. However, polyculture involving the Chinese carps and the culture of tilapias, common carp, and buffaloes will become increasingly important.

There will surely be an increase in sport fishing, and thus an increase in sales of bait products. Increased travel costs may bring about increased fee-fishing programs near major population areas. The demand for hobby fish should remain strong as leisure time increases.

The reader will observe a tremendous increase in available information between the *Second Report to the Fish Farmers* (1973) and the present *Third Report to the Fish Farmers,* and will be astounded as well, we are sure, by the progress that will be made during the coming decade.

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2. POND CULTURE SYSTEMS

Jay V. Huner and Harry K. Dupree

Water of good quality in adequate amounts, and clay soils that retain water, are the basic requirements for warmwater pond culture. Specific water quality and quantity requirements, and desirable and undesirable soil characteristics, are discussed later. The present introductory statements are intended to encourage the prospective fish producer to determine whether his water resources and site are suitable for the construction of usable ponds. Both water and ponds must be available at affordable prices. Technical assistance and advice relating to site selection and construction are usually available from the Soil Conservation Service, U.S. Department of Agriculture. Other timely and essential aquacultural information can be obtained from the persons and organizations listed in Chapter 20.

Basically, two types of earthen ponds are used in warmwater fish culture: dike ponds and hill ponds. Dike ponds have four raised levees, are usually rectangular, and have relatively level bottoms; maximum water depth is usually 4 to 8 feet. Hill ponds usually have one main levee that dams a gully or valley, have an irregular shape, have a relatively steep bottom slope, and are 10 to 20 feet deep near the dam. Dike ponds are preferable to hill ponds in intensive culture, but production in hill ponds can sometimes be profitable.

Pond Site

Selection of a suitable pond site can be difficult. Often land that is considered to be marginal for field crops, or even wasteland, can be used. (Caution: If an area is considered to be a "wetland," a construction permit issued by the U.S. Army Corps of Engineers is required.) The soil must hold water. The pond must be drainable and accessible. If these criteria are not met, unnecessary expenditures of capital and labor, or other problems, will result.

Materials

If ponds are to be built in an old floodplain or in an outwash plain in hilly country, special scrutiny of the substrata is advisable. Gravel beds or sand streaks can cause severe seepage problems that are impossible (or at best very costly) to correct. Sandy or aggregate soils are usually unacceptable. Limestone or shale areas can leak excessively because fissures may be present in the underlying rock layers. Although swampy areas are often chosen as pond sites because of their lack of utility for other uses, they may be costly to drain, and the movement of dirt for pond construction may be cumbersome.

Accessibility and Drainage

The time of fish harvest often coincides with rainy weather. This fact must be considered when one selects the pond site. Heavy trucks used to haul fish require all-weather travel levees. Little or no aggregate is in the soil at good pond sites, thus making levee topping with gravel a major construction cost. Corners of levees should be wide enough to allow vehicles to turn.

Provisions must be made for complete drainage of all ponds in any season. Low-lying areas or floodplains require careful study if later problems in draining the ponds are to be

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avoided. The tops of the levees must be above maximum flood levels.

Residual Pesticides

Soil at pond sites must be analyzed for pesticides before the ponds are built. The prior use of the land at the site should be determined before the first shovelful of dirt is turned. If cotton was grown there at any time after 1940, the soil should be analyzed for chlorinated hydrocarbon residues, especially toxaphene and endrin. If cotton was never grown on the site but was grown on adjacent land, the soil still should be checked for those pesticides.

Three areas in a field must receive careful attention because residue levels are potentially high there:

- Low areas in the field where runoff water collects could have significant levels of pesticides, even when adjacent areas are pesticide-free or contain low concentrations that would not be harmful to fish.
- Any area in the field where spray equipment—either aerial or ground—was loaded with pesticides can have lethal concentrations of pesticides as a result of spillage.
- Any area in the field where pesticide containers were stored, or empty containers were disposed of, is a potentially dangerous site for pond construction.

Soil samples should be collected from several locations within the proposed pond site, including especially the areas just mentioned. The sample should represent the soil from the surface to a depth of about 5 inches, except at washed-in sites, where the sample should include soil from the surface to the bottom of any deposits that accumulated after 1940.

The County Cooperative Extension Service Office can provide advice on procedures for collecting samples, and assist in providing soil sample containers and in contacting the State soil testing laboratory. Commercial testing laboratories can also make these analyses. Samples should be checked for chlorinated hydrocarbons with special emphasis on toxaphene and endrin.

Ideal Site

With the above precautions and criteria in mind, one can evaluate the potential pond site. The area should be large enough to enable construction of the desired number of ponds, for both the present and future. Topographically, the field should be flat or gently sloping. The soil should contain at least 20% clay to a depth of several feet below the finished pond bottom to prevent excess leakage. The availability and cost of water must be considered at this time, as well as accessibility to paved or all-weather gravel roads.

Pond Size and Shape

Most farmers who raise catfish in dike ponds seem to prefer 20-acre units. Larger ponds are less expensive to construct on a per-acre basis, but are more difficult to manage. Hill ponds are restricted in size and shape by local topography, although 20-acre units, when available, show much more profit potential than do smaller ones. Areas of catfish fingerling production ponds usually are 5 to 10 acres. Brood ponds for spawning range from 2 to 20 acres.

Production ponds are usually rectangular, and about twice as long as they are wide. The length of the pond is often controlled by the topography. If the land is nearly flat, the pond may be long and narrow and built parallel to the direction of the slope; in hilly country, ponds often are built parallel to the contour. There is considerable latitude in choice of dimensions.

As a means of reducing the effects of wave action on levees, the pond can be built at right angles to the prevailing wind direction. However, construction of the long levee parallel to the direction of the prevailing wind increases the wave action on the water surface and thus increases the mixing of the water and aeration, both of which are conducive to good fish production. All trees, brush, and stumps must be removed to a point below the finished pond bottom. A gentle slope (about 2.5 inches per 100 feet) should be built into the bottom to permit complete drainage and drying of the

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pond. Loose dirt should be pushed and packed into low places to further facilitate drainage and eliminate small depressions. Time and money used in preparing the pond bottom are well spent.

Possibly the most important feature of the pond is the minimum depth. If that depth is too shallow, aquatic vegetation becomes a thief in the night that relieves the fish farmer of many unseen dollars by "stealing" fertility and having many other detrimental effects. Enduring or controlling aquatic plants is expensive. Prevention is the cure, and it can be accomplished, or at least facilitated, by having a minimum water depth of at least 2½ to 3 feet. The maximum depth seems to be much less important, but it is usually held at 4 to 6 feet because of cost and the difficulty of working in deeper water. In hill ponds, the water depth is governed almost entirely by the topography of the area before development, and often exceeds 15 feet.

If the texture of the soil is such that the soil will hold its position well, a drain basin equaling about 10% of the total pond area is a worthwhile feature. A basin near the dam, about 2 feet deeper than the rest of the pond, facilitates the holding and removal of fish when the pond is drained.

Building the Levees

In general, there are three methods of constructing levees. The preferred method involves the use of a bulldozer. Earth within the pond area is pushed to all sides to form earthen banks. The bottom is left smooth and without borrow ditches. Levee material is compacted by the earth-moving equipment (Fig. 2.1).

A second method is similar, except that a dirt scoop or dirt buggy is used to carry the dirt to the levee.

Still another means of erecting levees requires the use of a dragline. Earth is taken from either side of the levee area. Levees constructed in this way are rough on the sides, and additional compaction is required. The borrow ditches that result are less than desirable. However, in the wet, low-lying areas where traction and equipment support are poor, the use of a dragline may be the only feasible method of pond construction.



Fig. 2.1. Bulldozer moving dirt from the future bottom of a dike pond to construct a levee. Levee material must be of good quality clay and free of sticks and vegetation (which, when they decay, channel the water away). *Photo by J. Avault, Jr.*

An important phase in levee construction is the preparation of the base. All plants and humus must be pushed to the outside before the dirt for the levee is moved into position. The levee core must be of good quality clay, free of roots and vegetative matter. Failure to meet this criterion is an invitation for seepage problems to develop at the base of the levee. The outside of the levee can contain construction material of lower quality if necessary.

The crown width of levees should be at least 10 to 12 feet to permit vehicle traffic. The levees should extend at least 2 feet above the water level. Extra material should be added during construction to allow for settling. The sides of the inside levee may slope at rates ranging from 2.5:1 to 4:1, although a slope of 3:1 seems to be the most common. The advantage of a steep slope is that there is less earth in the levee, less land is taken up, and there is less shallow water, making it more difficult for emergent vegetation to become established. The major disadvantage of a steep slope is that the erosion rate is increased. Although riprap (stones and debris) may be placed at the water's edge to reduce washing, the type of earth really determines the amount of erosion and thus dictates the slope of the

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levee. It is important to visit production ponds in a given vicinity to determine the rate of erosion of levees at different slopes, and then select the best slope for the pond.

The outside slope of a completed levee is normally 2:1. Completed levees should be fertilized and seeded with low-growing grasses as soon as possible. Centipede or Bermuda grasses are excellent. Water supply pipes are embedded in the levee top below the frost line.

With proper planning and construction, other ponds can be added next to the first ponds, thereby saving space and construction costs. Such planning allows additional ponds to be built by constructing only two or three levees, rather than four.

Sealing Pond Bottoms

If pond bottoms do not retain water, various approaches can be taken to seal them. It is highly unlikely, however, that such an effort will be economically justified in large-scale fish culture systems. The simplest method involves construction of a clay lens (liner) on the pond bottom. Another method is the placing of special clays, such as bentonite, on the pond bottom. Bentonite swells when wet, thus sealing the porous spaces. Up to 8 pounds of bentonite per square foot are needed in very sandy soils; soil with more clay may require only 2 to 4 pounds per square foot. Some fish producers report that sodium tripolyphosphate yields good results.

Polyvinyl sheets, such as those used to line swimming pools, can be used to seal ponds (Fig. 2.2). The length of sheeting required is equal to the length of the pond plus twice its maximum depth, and the width required is equal to the width of the pond plus twice its maximum depth. An additional 1½ feet all around will allow adequate overlap. The liner should be covered with about 6 inches of soil and the edge buried in a trench around the edge of the pond, above the maximum water level.

Emergency Drains

All ponds must be constructed with provisions for removing rainfall or runoff in excess of that needed to maintain normal water depths. Because dike ponds receive little runoff, standard drain structures are usually adequate. Ponds built in areas subject to heavy rains (such as those associated with tropical storms and hurricanes) may require larger drain structures than ponds in other regions.

Hill ponds require emergency spillways. The design depends on the size and nature of the watershed and the probability of heavy rains and flash floods. Soil Conservation Service personnel from the U.S. Department of Agriculture should be consulted for assistance in determining spillway requirements. A fish-retaining device should be installed on the spillway to prevent loss of fish.

Water Supply

Water is a limiting factor for commercial fish production. If a flow of at least 13 gallons per minute for each surface acre cannot be assured, there is little hope for success. In regions with high evaporation rates or considerable water seepage, the minimum water requirement is greater. Ideally, the availability of fresh water should be 20 to 50 gallons per minute per acre above the minimum maintenance requirement. These minimum volumes

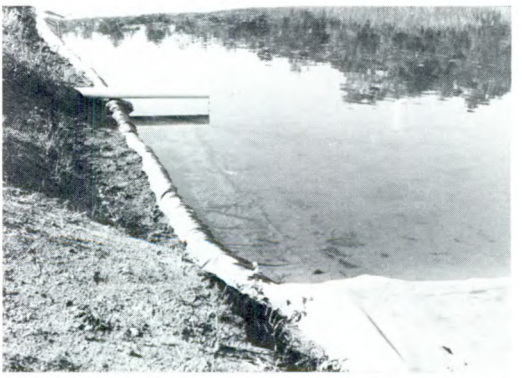


Fig. 2.2. Polyvinyl liners can be used to make a pond watertight. The liner should be covered with about 6 inches of soil, and the edge buried in a trench around the edge of the pond. Liners are expensive and should be used only as a last resort to prevent excessive water seepage. *Photo by Jay V. Huner.*

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should be available during the hot and dry periods of the year.

The preferred source of water is a deep well, provided that sufficient water is available at an affordable energy cost. Spring water may be used where available since little energy cost is involved. Water quality requirements (discussed later) vary with the culture system.

Some channel catfish are cultured in hilly areas where little water is available other than that from surface runoff. Such culture systems are more difficult to manage than the dike-type ponds that have well or surface water supplies. Watershed ponds are often used to supplement farm income and to furnish on-farm food, rather than as a principal source of farm income.

Surface water contained in streams or reservoirs can provide excellent production. However, some surface water may contain wild or trash fish, or their eggs. Many of these trash species are predatory, and all are competitive and may carry disease organisms. Proper use of filters made of gravel and sand, or Saran cloth (National Filter Media Corporation), often eliminates this contamination. Many surface waters contain pesticides and other contaminants that can kill fish or render them unacceptable for consumption. Suitability of the water for fish production must be determined by chemical analyses and bioassays before construction is started.

If surface water is to be used, consideration should be given to the location of the pump intake. The graveling or mudding-in of the intake may be reduced by the use of a sump and a concrete inlet structure. Such a fixture may also serve as a mount for the pump and its power unit. Flood-stage data must be obtained to establish the minimum elevation of this pump fixture.

Water supply lines installed to each pond should be large enough to carry all the available water in the area. This provision is extremely important when rapid filling is required, or when fresh water is needed to correct a fish die-off. A supply of fresh water available in the drain sump is well worth the expense during the harvest period.

Pond Draining

Rapid draining of ponds is of utmost importance when one plans to use the "seine and drain" method for harvesting ponds, especially in hot weather. Most fish are removed by seining, but some escape and must be removed from the drain basin. A slow rate of drawdown at this point often results in fish being killed due to insufficient oxygen or muddy water. Large standpipes are difficult to manipulate and can be a hazard. Pipes 8 to 10 inches in diameter provide fast, safe drawdowns.

Within the levee base, two "anti-seep" collars are essential. These collars are made of concrete and extend outward 12 inches around the pipe. The collars reduce the possibility of water following the drainline out through the levee, and help prevent animals from burrowing along the drainline and causing leaks. The conventional style of standpipe (Fig. 2.3) is inexpensive and simple to construct and operate. It needs only to be lowered to the desired water level, and requires no further attention.



Fig. 2.3. This conventional type of standpipe is easy to build and operate. The fish culturist merely tilts the standpipe to the desired depth; the water stops draining at the selected level with no further attention.

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Fig. 2.4. A hill-type catfish pond constructed by damming a gully. This pond can provide water for crop irrigation, livestock, and recreation, as well as yield substantial quantities of fish for home use. *Photo courtesy of Alabama Cooperative Extension Service.*

A tightly fitted screen over the end of the standpipe during a drawdown prevents the escape of fish. The entire drainage system should be laid on a slope of at least 1 inch per 100 linear feet of pipe. The drainlines should be constructed with few or no turns; if turns are required, a clean-out provision is highly desirable.

Hill Ponds

Typically, hill-type ponds (Fig. 2.4) serve only as supplemental sources of income for two important reasons: pond bottoms are irregular, making harvesting difficult; and water is often in short supply, preventing pond draining. Then, too, because these ponds are usually built for irrigation of crops, watering of livestock, and recreation, there is often not enough acreage to allow the raising of substantial quantities of fish. Skillful pond placement and construction, however, can make harvesting efficient and ensure adequate water supplies in all but the driest of years. A thorough survey of the area with assistance of the Soil Conservation Service may reveal enough practical pond sites to justify a substantial investment in fish culture in hilly areas.

In constructing hill-type ponds, a farmer should keep in mind that the contours can be altered so that a uniform basin is formed when 1 to 3 feet of water is removed, leaving water 4 to 6 feet deep in most of the basin. This is enough to provide water for livestock. The even bottom and constant shape facilitate seining. When a grading seine is used, plenty of water is left to hold undersized fish, even if runoff is the only source of water available to fill the pond. Skillful placement of levees at the upper end of hill-type ponds can effectively control runoff water entering a pond. Careful consideration of available pond sites can permit transfer of water between ponds by gravity flow, or by pumping the water over low areas to nearby ponds.

Water

Because water is the environment in which fish live, an understanding of its physical and chemical qualities is critical to successful fish culture. Most waters contain both dissolved

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and suspended matter. Dissolved substances are normally measured in terms of milligrams per liter. One milligram per liter is equivalent to 1 part per million (ppm), the designation of concentration more familiar to fish farmers, and the one used here.

Suspended Material

Suspended material includes living organisms such as minute phytoplankton (plants) and zooplankton (animals), dead organic matter (detritus), living microbes (bacteria), and inorganic matter (clay and silt particles). Total suspended solids refers to the weight of material suspended in a given amount of water. Some living organisms are important as fish food and as oxygen producers. Zooplankters such as water fleas, copepods, and rotifers are vital foods for all fish fry and some adult fishes. Phytoplankton (e.g., algae and diatoms), however, is indispensable in pond systems because it produces most of the oxygen used by the fish, by photosynthesis. Water with heavy growths of plankton (a "plankton bloom") is colored various shades of brown, green, blue-green, or yellow-green, depending on what species is dominant.

Suspended clay and silt not only muddy the water, but at high levels abrade and damage fish gills. They also interfere with penetration of sunlight necessary to permit photosynthesis by phytoplankton.

Turbidity, a measure of the absorption of light passing through water, is closely related to total suspended solids. Light penetrates only a short distance in highly turbid waters. In contrast to the principally greens and blues of plankton turbidity, silt-clay turbidity is normally light brown or tan, although red clay imparts a reddish cast to water.

Generally, if a Secchi disk (Fig. 2.5) cannot be seen at depths greater than about 12 inches, the water is too turbid. Phytoplankton turbidity is ideal when a Secchi disk lowered into the water disappears from view at a depth of 18 to 24 inches.



Fig. 2.5. The commonly used Secchi disk is about 8 inches in diameter and has alternate black and white quadrants. It is lowered into the water with a graduated cord or chain (sometimes a yardstick or meterstick) attached at its center. The depth at which the disk disappears from view is a convenient measurement of water turbidity.

Gases

The most important gas dissolved in water is oxygen. Its solubility, like that of other gases, varies inversely with temperature and altitude (Table 2.1). For example, water can hold 9.2 ppm of dissolved oxygen (DO) at 68°F but only 7.6 ppm at 86°F. For channel catfish, optimum DO levels are above 5 ppm; values between 3 and 5 ppm are stressful, and concentrations below 2 ppm are often lethal (depending on the size of the fish, water temperature, and other water quality factors).

Fish culturists need to be familiar with the terms biological oxygen demand (BOD) and chemical oxygen demand (COD). The BOD is a measure of the oxygen used by all organisms in a pond, including microbes, plankton, and fish. Microbes (bacteria and fungi) use oxygen to decompose organic matter in water. The COD is a measure of the oxygen needed to oxidize the organic matter in a pond. Be-

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Table 2.1. *Solubility of oxygen (parts per million) in water: relation to temperature, salinity*[a], *and elevation*[b].

Variable	Water temperature (°C and [in parentheses] °F)					
	20(68.0)	22(71.6)	24(75.2)	26(78.8)	28(82.4)	30(86.0)
Salinity (ppt)						
0	9.2	8.8	8.5	8.2	7.9	7.6
5	8.7	8.4	8.1	7.8	7.5	7.3
10	8.3	8.0	7.7	7.4	7.1	6.9
15	7.9	7.6	7.3	7.0	6.8	6.5
20	7.4	7.1	6.9	6.6	6.4	6.1
Altitude (feet)						
0 (sea level)	9.2	8.8	8.5	8.2	7.9	7.6
1000	8.8	8.5	8.2	7.9	7.6	7.4
2000	8.5	8.2	7.9	7.6	7.3	7.1
3000	8.2	7.9	7.6	7.3	7.1	6.8
4000	7.9	7.6	7.3	7.0	6.8	6.5
5000	7.6	7.3	7.0	6.8	6.5	6.3

[a]Data adapted from K. E. Sneed and H. K. Dupree. 1962. An electrical oxygen-temperature meter for fishery biologists. U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries No. 426. 13 pp.
[b]Data adapted from American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1971. Standard methods for the examination of water and wastewater, 13th ed. American Public Health Association, Washington, D.C.

cause fish and other higher living organisms use relatively little of the total oxygen, COD approximates BOD. This relation is important because microbes multiply when the amount of organic matter becomes great, and use up increasing amounts of oxygen, leaving less (sometimes none) for fish and other organisms. In ponds with high phytoplankton turbidity, Secchi disk readings are direct measurements of COD. This relation is used to predict DO depletions in ponds (see Chapter 3).

Most living organisms use oxygen in respiration (metabolism), a process that results in the production of carbon dioxide (CO_2). Plants, including phytoplankton, use CO_2 in photosynthesis. Natural aquatic systems have daily cycles of CO_2 production. All organisms use oxygen throughout the day and night but plants cannot produce it at night because there is no light for photosynthesis. Therefore, DO falls and CO_2 increases at night. During the day, the reverse is true as plants use CO_2 and generate oxygen. The CO_2 content of most natural waters is normally less than 5 ppm, but levels are sometimes as high as 60 ppm in systems with heavy loads of organic matter; concentrations higher than 5 ppm have been shown to be stressful to most freshwater fishes.

If water contains more of a dissolved gas than is normally present at a particular temperature, the water is said to be supersaturated with that gas. Dissolved gases are normally measured in terms of "percent of saturation." Any value greater than the amount of gas the water normally holds at a given temperature constitutes supersaturation. Pond water can become supersaturated with oxygen in late afternoon if phytoplankton is dense. The most common form of supersaturation involves nitrogen. Such supersaturation develops when there is a great deal of turbulence in the water, as occurs below the turbines of a dam or in raceway systems with excessive aeration. Well waters are sometimes supersaturated with nitrogen. Fish absorb the supersaturated nitrogen into their bloodstreams, where it later comes out of solution and produces bubbles. Signs include exophthalmia (popeye) and swollen belly, often followed by death.

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Dissolved Solids

Total dissolved solids constitute the total amount of material, by weight, dissolved in a given amount of water. Much of the material consists of electrically charged molecules, or ions. An ionic substance has an electrical charge with paired positive and negative ions. Several common forms, called salts, include the familiar table salt, chemical fertilizers, and agricultural lime.

The total weight of all dissolved ions in a unit volume of water is termed salinity, which is typically expressed as parts per thousand (ppt or ‰). Fresh water is arbitrarily characterized as having a salinity below 0.5 ppt. Brackish water is in the salinity range of 0.5 to 30 ppt. Most people cannot taste salinity in water until it reaches 4 to 5 ppt. Sea water has a salinity of about 35 ppt. Many freshwater fishes grow poorly or die at salinities greater than 5.0 ppt.

Channel catfish, blue catfish, and white catfish have been cultured in brackish water. Controlled studies have indicated that channel catfish fry and fingerlings grow well in water with salinities up to 9 ppt, and older fish in water with salinities as high as 11 ppt. Upper salinity tolerances for various catfishes are 11 ppt for channel catfish, 12 ppt for blue catfish, and 13 ppt for white catfish. Both channel and blue catfishes spawn at salinities near 2 ppt and eggs can be hatched in water with salinities as high as 8 ppt.

Most prospective fish culturists should be interested in pH, a measure of the positively charged hydrogen (H^+) ions present in water (the hydrogen ion concentration). It is measured on a scale of 0 to 14, in which 0 to 7 is acid, 7 is neutral, and 7 to 14 is basic (or alkaline). Substances such as hydrogen sulfide or carbon dioxide, which release hydrogen ions or cause water to release hydrogen ions, lower pH (i.e., make the water more acid). Substances that complex hydrogen ions, such as carbonate ions and caustic soda (sodium hydroxide), raise pH and make water basic or alkaline. The nightly production of carbon dioxide by plants and animals lowers pH. Conversely, the removal of carbon dioxide during the day raises pH. Most warmwater fishes, including catfishes, prefer pH's of 6 to 9; pH's above 10 or below 5.5 are usually lethal.

The amounts of dissolved ions in fresh water are low. Two measures are of concern to fish culturists. The most important, by far, is alkalinity. It is equivalent to the total concentration of bases (substances that neutralize acids), expressed as parts per million of calcium carbonate. Thus alkalinity is a measure of the ability of water to absorb positively charged hydrogen ions without drastic pH changes. Most alkalinity is made up of bicarbonate ions, although carbonate and hydroxyl ions dominate at high pH's. As a result, total alkalinity can be differentiated into carbonate (or phenolphthalein) alkalinity, and bicarbonate (or methyl orange) alkalinity. Carbonate alkalinity is associated with pH's above 8.3.

Waters with high alkalinities resist pH changes better (i.e., have a higher buffering capacity) than waters with low alkalinities. Bicarbonate and carbonate ions are good buffers; hydroxyl ions are not. Alkalinities of 30 to 150 ppm are preferred in fish culture operations, but good fish crops have been raised in ponds with alkalinities as low as 20 ppm.

The availability of carbon dioxide for phytoplankton production is related to alkalinity. As phytoplankton uses carbon dioxide in photosynthesis, alkalinity increases. Because of this relation, waters with alkalinities below 20 ppm or higher than 250 ppm may become temporarily deficient in carbon dioxide for phytoplankton, because there are either not enough carbonate ions or too many.

Hardness is primarily a measure of the calcium and magnesium in the water, expressed in parts per million of calcium carbonate. Generally, alkalinity and hardness are similar, but it is possible to have low hardness (less than 20 ppm) and high alkalinity (more than 100 ppm). Hardness is not as critical to fish production as alkalinity but it is desirable to have water with a total hardness greater than 20 ppm. The preferred range extends as high as 300 ppm.

Great care must be taken when one is treating fish with chemicals in waters of low alka-

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linity and hardness because the buffering capacity of such waters is low. Alkalinity and hardness can be increased by applying lime (see Chapter 3).

Another dissolved substance that is sometimes a problem is ferrous iron. It is frequently found in well water at concentrations above 3 ppm. Amounts exceeding 0.5 ppm can reduce fish growth and are often lethal to small fish. It is easy to detect the presence of ferrous iron because it reacts with oxygen in the fish-holding vats and ponds to form insoluble ferric iron, a reddish-orange scum. Ferrous iron precipitates and coats the gills of fish, thus suffocating them. Ferrous iron can also be detrimental because its oxidization to ferric iron reduces the amount of oxygen in a fish pond or raceway system.

Fish culturists often encounter three important metabolic compounds in water: ammonia (NH_3), nitrite (NO_2), and hydrogen sulfide (H_2S). These compounds are produced as a result of protein metabolism of the fish or of the decomposition of organic matter such as feces, plankton, or uneaten feed. Ammonia is produced directly by plants, animals, and microbes in aquatic systems. It is subsequently oxidized to nitrite and then to nitrate (NO_3) by bacteria.

Ammonia can be highly toxic in its free (un-ionized) form at concentrations in the range of 0.6 to 2.0 ppm. Ammonia toxicity increases directly with pH and water temperature. At 86°F, the amount of ammonia in the toxic (un-ionized) form is only about 1% at pH 7, but is 45% at pH 9.

Nitrite is formed from the oxidation of ammonia by bacteria. Nitrite concentrations as low as 3 ppm can adversely affect fish growth. In warm weather, nitrite is normally not a problem because bacteria quickly convert it to relatively nontoxic nitrate. However, nitrite often accumulates in colder bottom waters and in oxygen-free (anaerobic) areas of the pond bottom. Regardless of its source and the time of year when it accumulates, nitrite is a serious problem because it complexes with the hemoglobin in fish blood to form methemoglobin. This reaction reduces the oxygen-carrying capacity of the blood. The resulting sign is termed "brown blood" because the blood assumes a chocolate color.

The final ammonia oxidation product, nitrate, is not a direct threat to fish. However, it is a fertilizer and can stimulate excessive growth of phytoplankton that can lead to catastrophic DO depletions and fish die-offs.

Hydrogen sulfide can be a problem in production ponds in which fish are heavily fed. It develops when uneaten feed, feces, and phytoplankton decompose in an oxygen-free environment, primarily in bottom sediments. Concentrations of 1.0 to 1.5 ppm hydrogen sulfide are lethal to channel catfish. Any concentration that can be smelled (it has the distinctive odor of rotten eggs) is excessive and should be avoided. Some well waters contain hydrogen sulfide.

Physical Characteristics

Temperature

Fish growth and activity are directly related to water temperature. Over the range of 32 to 95°F (0 to 35°C), the metabolic rate of catfish doubles for each 18°F (10°C) rise in temperature. Physiologists call this the Q_{10} factor. This Q_{10} factor applies to all cold-blooded organisms in a pond—bacteria, zooplankton, insects, turtles, snakes, and fish.

Most warmwater fishes grow best at temperatures somewhere in the range of 70 to 90°F. Channel catfish do best at 75 to 85°F. The length of their optimal growing season thus equals the number of days when water temperatures exceed 75°F. A growing season of 150 to 210 days is needed to grow 6- to 8-inch channel catfish fingerlings to market sizes of 0.75 to 1.25 pounds.

Water Density and Stratification

As fresh water cools, it becomes denser (heavier), reaching its greatest density at 39°F. As it continues to cool further, its density decreases so that when it freezes and becomes ice, it is lighter than the slightly warmer water

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beneath it; consequently ice floats, and fish ponds rarely freeze to the bottom.

After the ice breaks up in the spring, surface waters in ponds and lakes heat faster than bottom waters. The warmer surface waters are lighter than the colder bottom waters and tend to "float" at the surface. This stratification of water layers normally occurs during warm weather. Temporary stratification (part of a day to several days) occurs routinely in shallow, dike-type ponds, and may stress fish by preventing circulation of oxygenated surface waters to the bottom, forcing the fish to move to less desirable locations in a pond. Permanent stratification (several weeks or longer) is common in the deeper hill-type ponds. Deep areas soon lose all oxygen because no photosynthesis can take place and BOD is usually great. Fish cannot live in such areas until stratification is broken by cooling surface waters and wind-driven currents in the fall.

Heavy cold rains or high winds can stir stratified waters and cause them to "turn over," bringing oxygen-depleted waters to the surface—often with disastrous effects on the fish population. This problem is usually greater in dike than in hill ponds because stratification in dike ponds is less stable.

Transparency and Solar Intensity

Sunlight must penetrate into the water to enable phytoplankton to produce oxygen. The depth to which light penetrates—its transparency—is typically the depth at which a Secchi disk (Fig. 2.5) disappears from view. The amount of sunlight, or solar intensity, also directly affects photosynthesis. Sunlight is reduced on hazy, cloudy, and foggy days and the amount of oxygen produced by phytoplankton decreases. Although DO levels in production ponds are almost invariably low in the early morning during the hottest part of the summer, they normally rise soon after the sun rises; however, cloud, haze, or fog cover can retard or prevent this recovery.

Pesticides

Warmwater fishes are especially vulnerable to poisoning by crop insecticides. More than 50 compounds have been screened and their relative toxicities to channel catfish determined. There are two sources of detailed information: "Handbook of acute toxicity of chemicals to fish and aquatic invertebrates" (1980), by W. W. Johnson and M. T. Finley, U.S. Fish and Wildlife Service, *Resource Publication* 138, available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20240; and "Toxicity of some agricultural chemicals to channel catfish and bluegill" (1979), by T. L. Wellborn, Mississippi Cooperative Extension Service, Extension Wildlife and Fisheries, P.O. Box 5405, Mississippi State, MS 39762 (mimeographed).

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3. POND MANAGEMENT

Jay V. Huner and Harry K. Dupree

Significant advances have been made in the production of food-sized channel catfish during the last 10 years. Production systems changed from a program of annual filling and draining (one crop harvested per year) to that of multiple stocking and multiple harvests, with no annual draining. This program increased the annual harvest to 5,000 or more pounds per acre, as compared with 2,000 to 3,000 pounds per acre at the start of the decade.

This increased production did not come without its problems. Increased production requires more feed, and since only about 50% of the feed is converted into fish flesh, the problems associated with water quality management intensified. The nondraining technique has probably also increased disease and off-flavor problems.

We emphasize here the management of water quality as it relates to feeds and metabolic wastes. Several other aspects of pond management, including the control of vegetation, predators, and competitors are also considered.

Pond Preparation to Facilitate Water Quality Management

Correct pond preparation is essential to fish survival at stocking, and to later water quality management. Time and money spent in this phase reward the fish producer by reducing problems later, and increasing monetary return at harvest.

Pond Pre-filling Preparation

Complete draining and drying of a pond effectively improve later water quality. Organic materials and reduced compounds such as hydrogen sulfide and nitrites are readily oxidized when exposed to the air. This oxidation rate can be accelerated by stirring (disking) the soil and by adding 1,000 to 2,500 pounds of slaked lime per acre. The addition of slaked lime (together with drying) provides the added benefit of killing many infectious organisms and parasites, as well as most predator and competitor fish, tadpoles, and insects. Once the pond bottom is dry, it can be readily worked to eliminate potholes and other depressions that interfere with harvest. At this time it is desirable to carefully inspect the levees for damage by wind, waves, crayfish, and muskrats, and to make whatever repairs are needed. Just before the pond is filled with water, appropriate pre-emergent herbicides can be applied. The types, rates, and methods of application are discussed later.

Filling the Pond

In most culture programs, and especially in the production of fry and fingerlings, the producer must prevent the emergence (or control the quantity) of aquatic vegetation by filling the pond as quickly as possible, and by developing bottom-shading algae. The application of suitable pre-emergent herbicides sometimes simplifies this task. The entrance of wild fish must also be prevented, since many species are predators and all are competitors and can carry parasites and diseases. Contamination is usually no problem when a pond is filled with well or spring water, but surface water supplies usually require filtration through sand and gravel, or screening through Saran cloth.

Two types of filter construction have been used effectively by the fish farming industry.

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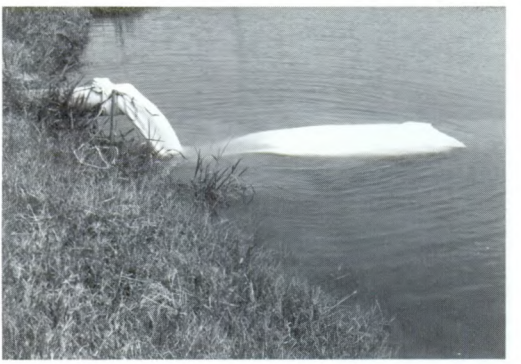


Fig. 3.1. Sock-type filters constructed of fine-mesh cloth remove fish and insects from the inflowing water. Filter life is lengthened when the sock is floated in the pond.



Fig. 3.2. The box-type filter is positioned under the inflow pipe and effectively removes fish and insects from the water supply.

The first, a sock-type filter, is made by sewing two pieces of 3-foot-wide Saran cloth into a cylinder and fitting each end of it with a drawstring closure. Nylon thread and cord must be used to increase durability. The sock is 12 feet long and presents no problems when relift pumps with capacities up to 1,000 gallons per minute are used. The drawstring closures allow easy removal and cleaning. To prevent excessive strain on the material, the farmer should use this filter only on water inlet pipes that discharge near the water surface (Fig. 3.1).

The second filter type is a box filter, which can be installed on the pump inlet or on the pipe outlet (Fig. 3.2). This filter is constructed by securing Saran cloth to the bottom and sides of a wooden box 8 feet long, 3 feet wide, and 2 feet deep. A filter of this size is suitable for water quantities up to 1,000 gallons per minute. The screen bottom is supported by a wooden grid with 1- by 2-foot openings, to prevent excessive stressing and stretching of the Saran cloth. The filter may either be mounted in a fixed position in the pond or equipped with floats that maintain it in a constant position at the surface during periods of changing water levels. If the inlet water line is not too high above the reservoir water level, the floating filter is preferred. In both the fixed and floating arrangements, most of the Saran cloth is below the water surface. Its submergence prolongs the life of the filter because the impact of falling water on the cloth is reduced and direct sunlight is excluded.

Water pumped into a pond usually is deficient in dissolved oxygen. Well water has almost no oxygen, and surface water is rarely saturated. Water must be broken into small droplets to maximize the total surface available for diffusion of oxygen from the atmosphere. Therefore, provisions should be made to bring in water over a baffle or to drop it through a series of three or four boxes with screen bottoms having progressively smaller meshes of ¾ to ⅛ inch.

If quantities of dissolved iron in well water are greater than 3 ppm, it may be necessary to pass the water through a settling pond or a canal before it is used in a pond.

Plankton, Benthos, and Fertilization

Plankton and benthic organisms are indispensable in a properly functioning pond. The organisms are often ignored because they are small and many are microscopic. Chemical and organic fertilizers are used to increase the growth of these organisms.

Plankton

Plankton is an assemblage of minute plants and animals suspended in the water between the surface and bottom. Plant plankton (phytoplankton) is usually much smaller than animal plankton (zooplankton). Phytoplankton species usually complete their life cycles

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in a matter of hours, whereas zooplankton species require 1 to 3 weeks or longer. Heavy densities of plankton (plankton blooms) make water very turbid. From 2,000 to 3,000 pounds of phytoplankton per acre may be present during intense blooms. Healthy phytoplankton blooms take on the color of the dominant plankton group present. Blooms of dead or dying plankton turn gray, and if the kill is complete the water becomes clear or has a black or tea-colored tinge. An earthy, musty odor often is associated with an unhealthy (dying) bloom. A healthy blue-green algal bloom has a blue-green cast; green algae are yellowish-green. Diatoms, especially prevalent in the winter, tend to impart a brownish cast to the water. Phytoflagellates can turn the water red or yellow during bright sunny days, when red and yellow pigments screen the sensitive cells from excessive solar radiation. In early morning such waters usually are brownish.

Blue-green algae are especially prevalent during summer in ponds containing heavily fed catfish. They are especially hardy and can "fix" nitrogen, an essential plant nutrient, giving them a significant growth advantage over other algae. They also thrive in waters with low alkalinities. A common occurrence is the appearance of a surface film that suggests that blue-green paint has been poured on the downwind side of a pond. This film may become fairly thick. Blue-green algae are commonly associated with off-flavor in catfish and with DO depletions.

Zooplankton includes fish food organisms that are vital to fry of all species of fish. Water fleas, fairy shrimp, copepods, and seed shrimp are all minute crustaceans. Rotifers—microscopic animals closely related to roundworms or nematodes—are also important zooplankters. A rich zooplankton bloom yields a brownish color. Many small creatures, about the size of sand grains, can be seen darting about in a jar of water from a pond in which a zooplankton bloom is in progress.

Normally, zooplankters feed on phytoplankters, with a conversion efficiency of about 10%. This is not especially efficient for fingerling production because the time between the filling of fingerling ponds and the stocking of fry is generally too short to allow the development of a good zooplankton bloom. Zooplankton growth can be accelerated in freshly filled ponds by "feeding" the animal organisms various organic manures that they can consume directly (e.g., hay, plant protein meals, and animal wastes). At the same time, phytoplankton blooms occur in response to inorganic fertilizer and reach a level that sustains the zooplankton.

Benthos

The benthos consists of organisms living on or in the bottom sediment. Insect larvae, true worms, clams, and snails are examples of this assemblage of organisms. Less obvious are the microbes, including bacteria and fungi, that are responsible for decomposing organic matter—converting dead plant and animal matter into inorganic nutrients that can be recycled by plants into forms suitable for animals. These animals in turn serve as food and supply many trace elements and essential vitamins for fish. The production of benthic organisms continues on or in the bottom sediments as long as sufficient oxygen is present, and as long as the level of waste compounds is not lethal. However, organic matter can accumulate and become excessive in ponds in which fish are heavily fed. All oxygen in the sediment is then used up in decomposition, and ammonia, carbon dioxide, hydrogen sulfide, soluble ferrous iron, and other noxious compounds accumulate instead of being converted to relatively safe forms. Should this occur—and it commonly does in ponds in which feeding is heavy and which are not left in production for several years without being drained—most benthic organisms and microbial waste converters are adversely affected until conditions improve.

Fertilization

Producers of channel catfish fingerlings, baitfishes, and some hobby fishes often use

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chemical and organic fertilizers to encourage growth of fish food organisms, especially zooplankton. However, producers of food-sized fishes normally do not fertilize their newly filled ponds unless a bloom of phytoplankton is desired to control undesired rooted vegetation. Should an inorganic (chemical) fertilizer be required, any formulation rich in nitrogen and phosphorus (e.g., 16-20-0, N-P-K) can be placed on stationary platforms just below the water surface or in floating devices that permit slow seepage of the nutrients into the water. Some fish producers use liquid formulations if a quick response is desired. Application rates should be about 8 pounds of nitrogen and 10 pounds of phosphate per acre, but the quantity may vary with water quality and temperature. The use of organic matter such as barnyard manure, hay, or soybean meal in conjunction with the chemical fertilizers is recommended. It is sometimes necessary to "seed" a pond by pumping water to it from another pond in which a plankton bloom is in progress.

Organic materials include oilseed and grain by-products, various hays such as Bermuda and alfalfa, green grasses, and animal manures. The quantity used varies, depending on water temperatures and basic pond fertility, but generally 200 to 500 pounds of a mixture of these materials per acre is sufficient. Although organic fertilizers are recommended for production ponds containing fry and small fingerling channel catfish, baitfish, or ornamental (hobby) fish, they must be used cautiously in catfish "grow out" ponds in which fingerlings or yearlings are raised to salable size. Organic materials encourage the growth of blue-green algae, and decomposition of the dead algae by microbes uses up oxygen, which could lead to DO depletions. Organic fertilizers are usually not needed in hill-type ponds that drain pastures, because runoff carries sufficient manure into such ponds.

Phytoplankton blooms help to shade out unwanted rooted aquatic plants. Such plants can fill the water column, reducing living space and covering the bottom, thus reducing the area available for food production and interfering with fish harvest operations. If aquatic plants develop before the bloom, however, fertilizers should not be used because they only encourage further growth of the unwanted plants. Overgrowths of aquatic plants are best controlled by the application of registered herbicides or sometimes by the stocking of plant-eating fish.

Water Temperature

The temperature of the water affects the activity, behavior, feeding, growth, and reproduction of all fishes. Next to oxygen, water temperature may be the single most important factor that affects the welfare of a fish during its life span. Temperature also determines the amount of DO in the water: the higher the temperature, the lower the amount of DO the water can hold. Water has a high heat absorbing capacity; i.e., it can absorb large amounts of heat with little rise in temperature. This characteristic helps prevent sudden changes in water temperature.

The seasons of the year induce a cycle of changes in water through changes in atmospheric temperature. In spring, water temperatures are nearly equal at all depths throughout a pond; consequently, the weight or density of the water is nearly the same from top to bottom. This characteristic permits wind to mix the entire water mass and its nutrients, plankton, metabolic products, and oxygen.

As summer approaches, the surface water warms, becomes lighter in weight, and remains at the surface above the denser, colder water. In shallow ponds the temperatures of layers of water 6 inches apart may differ by as much as 5°F. Circulation of the colder bottom water is restricted due to its greater weight, and the exchange of its gases with those in the atmosphere is prevented. The result is that only water near the surface has direct contact with the atmosphere, and water near the bottom receives no oxygen. Accumulation and decay of feces, dead animals and plants, and wasted fish feed further reduce the DO near the bottom. Respiration of living animals and plants consumes oxygen and reduces

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the DO in upper water layers at night. The higher the temperature, the higher the rate of respiration.

Summer stratification was once believed to be relatively harmless in shallow fish ponds (less than 4 feet deep). Wind usually circulates the water, despite density differences, because of the shallow depths; such ponds rarely stratify for more than a few days. However, because shallow ponds now often remain filled for several years at a time, much more organic matter accumulates on the bottom. Temporary daily stratification in deeper areas may lead to localized DO depletions in bottom waters, or the development of temporary but stressful levels of compounds such as hydrogen sulfide and carbon dioxide.

Summer stratification is an even more serious problem in deeper ponds such as hill ponds because it may last throughout the summer. Fish cannot use bottom waters that are devoid of oxygen, and sudden overturns caused by storms can lead to total fish kills.

Warmwater fishes are stressed when water temperatures exceed 90°F. During especially hot, dry summers, farmers must add enough water to ponds to both compensate for evaporation and dilute and flush away metabolic waste. Although it is expensive and relatively inefficient, well water can be used to reduce pond temperatures.

In fall, water temperatures begin to decline at the surface. The cooled surface water then sinks toward the bottom and eventually a uniform water temperature, like that present in spring, is again temporarily established. Stressful levels of harmful substances may again be circulated throughout the pond. Nitrite poisoning has been recorded in fall when pond waters were freely circulating.

Ice presents management problems. Although it is ordinarily clear, snow may accumulate and prevent sunlight for photosynthesis from passing into the water below; or sometimes ice is opaque due to wind action at the time of freezing, with the same results. Although fish use significantly less oxygen in winter than in summer, they can suffocate, especially in ponds with opaque or snow-covered ice and high densities of fish. At other times, not enough phytoplankton is present to generate the amount of oxygen needed. Ice also prevents the diffusion of oxygen into the water from the air.

Some fish farmers have countered the ice problem by adding warmer well water or scattering rock salt on top of the ice, and others have aerated the water with agitators or compressed air. Farmers with air boats have found them to be especially useful in breaking up ice sheets on ponds. Carbon black or cinders, placed in lines around the edge of the pond, sometimes absorb sufficient heat to partly melt the ice. When fish gather around holes in the ice, low DO levels—and immediate emergency corrective measures—are indicated.

Water Chemistry

The serious culturist must be prepared to measure the following variables: dissolved oxygen, carbon dioxide (CO_2), pH, ammonia (NH_3), nitrite (NO_2), and transparency routinely; and alkalinity, hardness, and hydrogen sulfide as needed.

Dissolved Oxygen

The emphasis on production of market-sized catfish has led to an increase in the number of oxygen-depletion fish kills on fish farms. Heavy stocking, accompanied by heavy feeding of fish in limited volumes of water, results in enrichment. Nevertheless, with good management, DO can be maintained at adequate levels to support the fish despite the progressive increase in fertility caused by their waste products. Adverse weather conditions, coupled with overproduction and poor water quality, may lead to an oxygen loss that kills the entire fish population in a single night (Fig. 3.3). The financial loss may be great, because the fish are usually more than half-grown when a fish kill occurs. Moreover, many diseases are aggravated by chronically low DO. It is important, therefore, that the fish producer understand the factors affecting production and removal of DO in ponds.

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Fig. 3.3. A massive kill of channel catfish in an Arkansas pond caused by overfertility of the water. Excessive feeding and poor water quality management can lead to sudden (overnight) depletion of dissolved oxygen. *Photo by J. Mayo Martin.*

Water in equilibrium with the atmosphere holds 7.6 ppm of DO at 86°F and 9.2 ppm at 68°F (Table 2.1). At these concentrations and temperatures, the water is "saturated," or at 100% DO saturation. Water in fish ponds is seldom 100% saturated with DO because temperatures are constantly changing, and physical, chemical, biochemical, or biological activities continuously use or produce oxygen.

Oxygen in the water comes from several sources. Some is absorbed directly from the air, but most is produced by aquatic plants (primarily phytoplankton) by a process called photosynthesis. The amount of oxygen diffused and absorbed from the overlying air into an undisturbed pond surface is not significant, but wind and wave action increase aeration. The amount of DO is increased by such devices as baffle boards, water sprays, and mechanical agitators, and by the injection of compressed air or oxygen into ponds, holding tanks, or hauling units.

Phytoplankton, which is scattered throughout the water, requires light to carry on photosynthesis and to produce oxygen. The daily process of oxygen production begins slowly at sunrise, increases as the day progresses, and peaks in mid-afternoon. The rate then decreases with the lowering intensity of sunlight and falls to zero at darkness. At night, phytoplankton uses DO for its own respiration.

The intensity of sunlight decreases as it passes downward through water; therefore, the rate of oxygen production decreases progressively with increasing water depth. Suspended microscopic plants and animals, silt, stains, detergent foams, dense mats of floating algae, and debris all reduce light penetration and thus oxygen production. Maximum daily differences in DO, like daily differences in water temperature, are greater just below the surface than at greater depths.

Recent research has quantified the ranges of expected gains and losses of DO caused by different processes in channel catfish production ponds in warm weather. Photosynthesis by phytoplankton is the most important source of DO, and respiration by all plankton is the principal process removing oxygen (Table 3.1). Diffusion assumes its most important role in cold weather, when oxygen levels are usually of no concern.

Heavy plankton blooms are directly correlated with large daily DO changes. Early-morning DO depletions are common occurrences in ponds with dense plankton blooms. Most managers have accepted an early morning DO level of 2.0 ppm as being the critical level below which it should not be allowed to

Table 3.1. *Range of expected gains and losses of dissolved oxygen caused by different processes in catfish ponds with average depths of 3.0 to 4.5 feet at temperatures exceeding 70°F.*

Process	Range (ppm)
Gains	
Photosynthesis by phytoplankton	5–20
Diffusion	1–5
Losses	
Plankton respiration	5–15
Fish respiration	2–6
Respiration by organisms in mud	1–3
Diffusion	1–5

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fall. However, levels below 5 ppm are considered to be stressful for most warmwater fishes, including channel catfish. Normally, DO levels increase rapidly as soon as the sun rises, and fish become active enough to be fed by 9:00 to 10:00 a.m. Channel catfish tend to rise to the surface and gulp air (called piping) at DO levels of 0.5 to 2.0 ppm, depending on their physiological condition and water quality. Channel catfish and other warmwater fishes can also be distressed and even die when DO levels are above 2 ppm, if significant amounts of carbon dioxide are present.

In the absence of meters or kits to monitor DO, a culturist can observe signs that appear several days before catfish begin to pipe or die. A sudden change in the color of the plankton bloom, from a greenish hue to brown or gray, indicates that the phytoplankton has died. Low DO should be suspected when DO-sensitive fish like threadfin shad or tadpoles come to the margin of the pond, or when dark streaks appear in the water. The fish producer may observe that snails are crawling up on emergent plants, and that crayfish are coming to the pond edge. A noticeable reduction in feeding by fish is often associated with low DO, but it is also a sign of disease. Oxygen depletion may often be accompanied by musty odors or the rotten-egg odor of hydrogen sulfide. It should be emphasized again that a culturist who does not have equipment to monitor DO, or has it but does not use it, is not seriously concerned with making a profit.

A Secchi disk (Fig. 2.5) can be helpful in water quality management. This 8-inch disk is lowered into the water to measure light penetration, which is related directly to turbidity. When phytoplankton is the principal source of turbidity, the Secchi disk depth (the depth at which the disk disappears from view as it is lowered into the water) is a measure of phytoplankton density. When phytoplankton is excessive, the only oxygen produced is near the water surface, due to the light-screening effect of the phytoplankton. Generally there is enough oxygen to support fish at depths 2 to 3 times the Secchi disk depth. If the Secchi disk depth is 10 inches, for example, there should be enough oxygen to support channel catfish to depths of 20 to 30 inches. However, researchers have found that in ponds with Secchi disk depths of 4 to 8 inches, DO may fall so low at night or on cloudy days that fish are stressed or die. Risks of DO deficiency are greatly reduced when Secchi disk readings are in the 12- to 24-inch range.

The density of phytoplankton blooms affects the daily DO cycle and the depth distribution of DO. Daily variations in surface DO may be as great as 16 ppm in ponds with heavy phytoplankton blooms (Secchi disk reading, 12 inches or less), whereas they may be as small as 2 ppm in ponds with light phytoplankton concentrations (Secchi disk reading, 24 inches or more). Dissolved oxygen can drop to zero at depths of 3 feet or more in late afternoon in ponds with heavy phytoplankton blooms. Conversely, DO in bottom waters often remains above 4 ppm in ponds with light phytoplankton blooms.

Cloud cover reduces the amount of light available to phytoplankton for photosynthesis. The greater the density of phytoplankton, the greater the likelihood of a DO deficiency resulting from overcast. For example, one can expect the DO in a pond with a Secchi disk reading of 4 inches to be zero at sunrise after 2 days of heavy cloud cover. Conversely, it may take 7 days of heavy cloud cover for this to occur if the Secchi disk reading is 32 inches. The probabilities and density of overcast depend on the local climate. However, managers should use great caution if Secchi disk readings are less than 24 inches and several days of heavy overcast weather have been forecasted.

Fog can result in extensive mortality in high-density catfish ponds. Phytoplankton normally begins to generate oxygen as soon as the sun rises, and DO quickly rises. Heavy fog cover prevents this recovery, however, and DO may fall to lethal levels before the fog dissipates.

There is a direct relation between feeding rates, DO, and other water quality characteristics. The effects that feeding rates of 30, 50, and 70 pounds per acre per day have on early-

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Table 3.2. *Average early-morning dissolved oxygen concentrations and Secchi disk readings in channel catfish ponds with different feeding rates.*

Daily feeding rate (category and pounds per acre)	Early-morning dissolved oxygen (ppm)	Secchi disk reading (inches)
Low (30 lb)	4.7	27
Medium (50 lb)	3.0	18
High (70 lb)	2.0	8

morning DO and Secchi disk readings differ considerably (Table 3.2). When feed use exceeds 70 pounds per acre per day, it is obvious that emergency aeration systems are absolutely essential to the success of high-density fish culture.

Fish do not feed well when DO concentrations continuously remain between 4 and 5 ppm. Daily fluctuations in DO apparently have little effect on feeding and growth if DO during a 24-hour period does not fall below 1 to 2 ppm in the early morning and rises to near saturation within a few hours after sunrise. If DO remains lower than 3 to 4 ppm for prolonged periods, fish cease feeding.

Predicting Low Oxygen

At least three methods—Secchi disk, projections, and chart—have been developed for predicting DO depletions. Such predictions enable the farmer to take corrective action before the depletions actually take place.

Secchi Disk Method

The Secchi disk technique for predicting dissolved oxygen deficiencies in fish production ponds is based on water temperature and Secchi disk depth, both measured in late afternoon. The producer then refers to the appropriate table of standing crop weights (Table 3.3) to determine the minimum allowable Secchi disk reading.

An example may prove useful: If DO in late afternoon is 10 ppm, temperature is 82°F, and the standing crop of fish is 500 pounds per acre, any Secchi disk reading should be safe (Table 3.3). However, should the DO be 8 ppm, any Secchi disk reading less than 7 inches would indicate an unsafe situation.

The Secchi disk method cannot be used successfully in production systems having more than 4,000 pounds of fish per acre, in ponds having substantial amounts of clay or silt turbidity, or in ponds in which water temperature exceeds 90°F.

Projection Method

The projection method (Fig. 3.4) may be used for any pond, and is especially useful for ponds where most of the turbidity comes from suspended silt and clay. It is also satisfactory for use when standing crops of fish exceed 4,000 pounds per acre. Dissolved oxygen is measured at dusk and 2 or 3 hours later. These two values are plotted against time on a graph. A straight line is then projected through the two points. This line is used to estimate the DO at later hours during the night as demonstrated in Fig. 3.4.

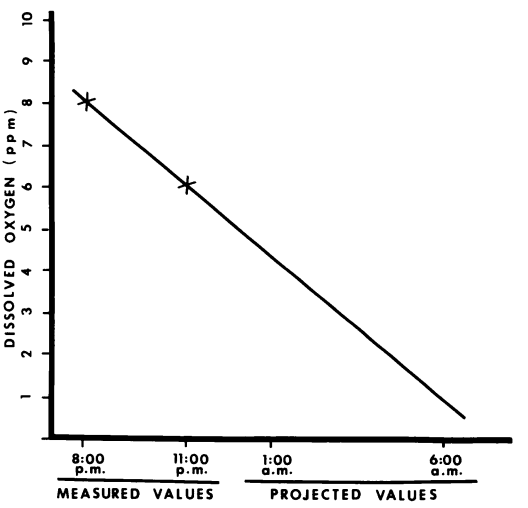


Fig. 3.4. Graphical method for predicting the nighttime decline in dissolved oxygen concentration in fish ponds. Here, dissolved oxygen was 8 ppm at 8:00 p.m. and 6 ppm at 11:00 p.m. The DO concentration projected for 6:00 a.m. was 1 ppm. (Adapted from R. P. Romaire and C. E. Boyd. 1978. Predicting nighttime oxygen depletion in catfish ponds. Alabama Agricultural Experiment Station, Auburn University, Bulletin 505.)

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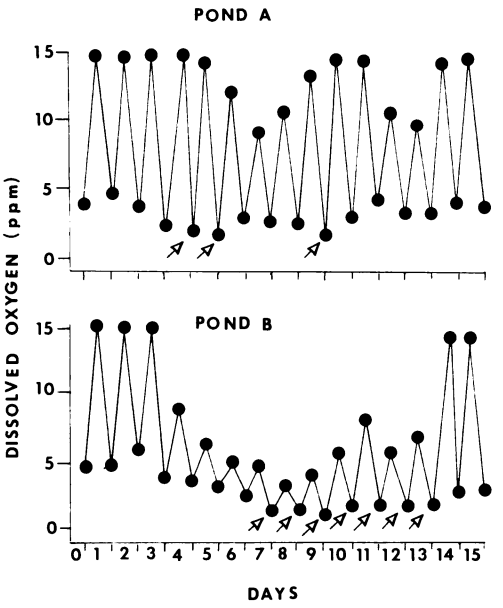


Fig. 3.5. Chart method for predicting the nighttime decline in dissolved oxygen concentration in fish ponds. Oxygen concentrations were measured daily at dawn and dusk for each pond. In pond A, there is a gradual downward trend in dissolved oxygen coupled with wide changes between dusk and dawn. This situation suggests an excessive amount of phytoplankton that, through its respiration, is depleting the oxygen at night. In pond B, there is a downward trend without the wide fluctuations that indicate the death of the plankton. The arrows indicate the mornings on which emergency aeration was required. (Adapted from C. E. Boyd, J. A. Steeby, and E. W. McCoy. 1979. Frequency of low dissolved oxygen concentrations in ponds for commercial culture of channel catfish. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 33:591-599.)

Chart Method

Many commercial fish producers take DO readings at dawn and dusk throughout the summer and chart them separately for each pond (Fig. 3.5). The early-morning readings are carefully watched. Two situations are cause for concern. The first is a gradual downward trend in early morning DO, coupled with wide changes between late afternoon and early morning. After several days, DO depletions may occur in early morning; in this situation, there is a very distinct downward trend without wide daily variations in DO.

In both situations, there is cause for concern. The first combination—low DO readings in the morning and high DO readings in the afternoon, as depicted in Fig. 3.5—suggests an excessive amount of phytoplankton that, through its respiration, is depleting the DO during the night. The second combination—low DO in the late afternoon and even lower values at daylight—indicates the death of phytoplankton.

Cautions About Methods Used to Predict Low Dissolved Oxygen

It is preferable to measure DO several feet from the bank at both ends and near the middle of a pond. If this is not possible, the measurements should be made at the deep end. Temperature and DO must be measured at the surface and roughly ¼, ½, and ¾ of the total depth at the point of measurement. Readings at each depth should be averaged. If more than one site is sampled, the averages for each site should be summed and averaged, and this overall average should be charted. Readings should not be taken beneath a heavy blanket of blue-green algae blown against a downwind shore, or near healthy, rapidly growing rooted aquatics, because readings there are unrepresentative. Careful monitoring of DO is recommended when Secchi disk readings are less than 8 inches. Prediction tables are not applicable for ponds during periods in which massive algal die-offs have occurred.

The methods used to predict DO are only guides. Sudden cold rains can stir a marginal pond and cause lethal DO depletions. Inclement weather, rain, or fog at dawn reduces production of oxygen by phytoplankton and thus slows DO recovery. Disastrous fish kills can result unless the gravity of the situation is quickly recognized and appropriate corrective measures are taken. These methods reduce the effort that a manager must expend on healthy ponds, so that he can concentrate on problem ponds. They cannot, however, replace daily surveys of all ponds.

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Table 3.3. *Critical Secchi disk readings (inches) for earthen ponds containing different standing crop weights of channel catfish. For each standing crop density (pounds per acre), a lower Secchi disk reading than that shown for any combination of temperature and dissolved oxygen concentration taken in late afternoon indicates that dissolved oxygen will fall below 2 ppm before dawn. For combinations of temperature and dissolved oxygen that are designated safe (S), the dissolved oxygen concentration should not drop to 2 ppm regardless of the Secchi disk reading.*[a]

Water temperature in late afternoon		Dissolved oxygen concentration (ppm) in late afternoon										
°C	°F	2	3	4	5	6	7	8	9	10	11	12
		Standing crop 500 pounds per acre										
20	68.0	10	S	S	S	S	S	S	S	S	S	S
22	71.6	23	13	S	S	S	S	S	S	S	S	S
24	75.2	34	23	15	9	S	S	S	S	S	S	S
26	78.8	39	29	21	15	9	S	S	S	S	S	S
28	82.4	39	34	27	21	15	10	7	S	S	S	S
30	86.0	39	36	29	25	20	15	10	7	S	S	S
32	89.6	39	38	33	27	23	19	16	12	9	6	S
		Standing crop 1,000 pounds per acre										
20	68.0	15	S	S	S	S	S	S	S	S	S	S
22	71.6	31	17	9	S	S	S	S	S	S	S	S
24	75.2	39	27	17	10	S	S	S	S	S	S	S
26	78.8	39	34	25	19	13	7	S	S	S	S	S
28	82.4	39	38	29	23	18	13	9	S	S	S	S
30	86.0	39	39	34	27	23	18	14	10	7	S	S
32	89.6	39	39	36	31	26	22	18	15	12	7	S
		Standing crop 1,500 pounds per acre										
20	68.0	19	7	S	S	S	S	S	S	S	S	S
22	71.6	36	19	10	S	S	S	S	S	S	S	S
24	75.2	39	31	21	13	7	S	S	S	S	S	S
26	78.8	39	36	27	21	15	9	S	S	S	S	S
28	82.4	39	39	35	26	21	15	10	7	S	S	S
30	86.0	39	39	37	30	25	21	16	13	9	S	S
32	89.6	39	39	39	34	29	24	21	17	14	10	7
		Standing crop 2,000 pounds per acre										
20	68.0	23	9	S	S	S	S	S	S	S	S	S
22	71.6	39	23	13	S	S	S	S	S	S	S	S
24	75.2	39	35	23	15	9	S	S	S	S	S	S
26	78.8	39	39	31	23	17	10	S	S	S	S	S
28	82.4	39	39	36	29	23	17	13	7	S	S	S
30	86.0	39	39	39	35	27	22	18	14	10	7	S
32	89.6	39	39	39	36	31	26	23	19	15	12	8
		Standing crop 2,500 pounds per acre										
20	68.0	28	10	S	S	S	S	S	S	S	S	S
22	71.6	39	25	15	7	S	S	S	S	S	S	S
24	75.2	39	36	25	17	9	S	S	S	S	S	S
26	78.8	39	39	33	25	18	12	7	S	S	S	S
28	82.4	39	39	38	31	25	19	14	10	S	S	S

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Table 3.3. Continued

Water temperature in late afternoon		Dissolved oxygen concentrations (ppm) in late afternoon										
°C	°F	2	3	4	5	6	7	8	9	10	11	12
30	86.0	39	39	39	36	29	24	19	16	12	7	S
32	89.6	39	39	39	38	33	28	24	21	17	13	10
		Standing crop 3,000 pounds per acre										
20	68.0	31	13	S	S	S	S	S	S	S	S	S
22	71.6	39	27	17	9	S	S	S	S	S	S	S
24	75.2	39	39	27	19	10	S	S	S	S	S	S
26	78.8	39	39	36	27	19	13	9	S	S	S	S
28	82.4	39	39	39	34	26	21	15	10	7	S	S
30	86.0	39	39	39	38	31	25	21	17	13	9	S
32	89.6	39	39	39	39	36	31	26	22	19	15	10
		Standing crop 3,500 pounds per acre										
20	68.0	35	15	S	S	S	S	S	S	S	S	S
22	71.6	39	31	19	9	S	S	S	S	S	S	S
24	75.2	39	39	29	21	13	7	S	S	S	S	S
26	78.8	39	39	38	29	21	15	9	S	S	S	S
28	82.4	39	39	39	36	27	22	17	13	9	S	S
30	86.0	39	39	39	39	34	27	23	19	15	10	7
32	89.6	39	39	39	39	37	31	27	24	20	16	13
		Standing crop 4,000 pounds per acre										
20	68.0	39	19	7	S	S	S	S	S	S	S	S
22	71.6	39	36	21	10	S	S	S	S	S	S	S
24	75.2	39	39	31	23	15	8	S	S	S	S	S
26	78.8	39	39	39	31	23	17	10	S	S	S	S
28	82.4	39	39	39	38	29	23	19	15	10	S	S
30	86.0	39	39	39	39	36	29	25	20	16	12	8
32	89.6	39	39	39	39	39	34	29	25	21	18	14

[a]Modified from R. P. Romaire and C. E. Boyd. 1978. Predicting nighttime oxygen depletion in catfish ponds. Alabama Experiment Station, Auburn University Bulletin 505.

Corrective Action for Low Dissolved Oxygen

Mechanical and chemical methods have been used to increase DO, and phytoplankton populations have been treated with chemicals to increase or decrease DO production. Biological treatments are less exact. Some farmers have stocked plankton-eating exotic fishes such as tilapias and silver carp to prevent excessive growth of phytoplankton or to clean up waste feed; however, quantitative data to support the claims that water quality is improved are still lacking.

Mechanical Devices for Controlling Dissolved Oxygen

Mechanical aeration can involve either slow, continuous stirring of water or rapid, vigorous agitation of water (emergency aeration).

Pond stirring eliminates the daily stratification of the water and mixes the oxygen generated by photosynthesis into the deeper water near bottom. This destratification is especially critical in hill-type ponds where water deeper than about 4 feet may be devoid of oxygen for as long as 6 to 8 weeks during late summer. Energy costs are usually not high because

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the pond-stirring devices are driven at low speed. However, it must be emphasized that pond stirring devices add little oxygen to the water, and merely redistribute that produced by phytoplankton.

The theoretical value of pond stirring devices is clear, especially in deep hill ponds; however, their practical usefulness in terms of energy costs versus production returns has yet to be demonstrated. Stirring devices probably do not benefit old ponds with deep layers of bottom detritus because that material cannot be oxidized sufficiently by the small amounts of oxygen driven to the bottom. However, continuous stirring during hot weather probably prevents the accumulation of organic matter and noxious decomposition products.

Two pond stirring devices that have drawn attention recently are the water fan and the water blender.

The water fan in current use consists of an attic fan blade 4 feet in diameter mounted with the appropriate bearings and supports inside a cube constructed of 2-inch angle iron. Flotation material is attached to the top. The fan is driven by a ¾ horsepower, 1,750 rpm electric motor which, when passed through a 100:1 ratio gear box, turns the fan at about 18 rpm. Often some material must be removed from the back of the fan blade to reduce the load and prevent the motor from overheating. The unit operates by "driving" the oxygenated surface waters into the oxygenless bottom waters. Up to 10 acre-feet of water per day can be moved. Many producers claim that the use of the water fan has virtually eliminated emergency aeration in ponds containing 4,000 or fewer food-sized channel catfish per acre.

The water blender is a small, low-speed paddle-wheel device (not to be confused with the heavy-duty paddle wheels used for emergency aeration). In tests of pond stirring, several blenders have been mounted on floats distributed about a pond, to circulate the water. Trials showed that this type of blender prevents daytime stratification, but it is not yet widely used in the industry. Prices of the units are high when compared with those of other pond stirring devices available.

Several emergency aeration devices are available but not all are useful in all situations. Spray-type (fountain) surface aerators have proved effective in providing emergency aeration, and continuous aeration in ponds smaller than 1 acre. In the operation of these units, a submerged motor turns a propeller that pumps water into the air as a spray. Fish kills in small ponds have been prevented by using units as small as 0.25 kilowatt.

Centrifugal recirculating pumps powered by small electric motors or gasoline or diesel engines are suitable for aerating 1- to 2-acre ponds. With a 4-inch intake hose and a 3-inch discharge hose, pumps of 2 horsepower capacity are capable of delivering 125 gallons per minute with a 50-foot head. The water should be sprayed back over the surface of the pond. The intake hose should not be positioned deeper than 1 foot because it may draw in oxygen-deficient water and compound aeration problems at the surface. Fish are attracted to this oxygenated water, where they can be protected until conditions in the production system improve. In larger systems, the pump size and the number of pump units must be increased.

Impeller-driven lift (relift) and larger centrifugal pumps (Fig. 3.6) used for emergency aeration are usually mounted on wheels and have an extended frame that connects the drive shaft to the power takeoff of a tractor. The aeration equipment is backed into the pond, and water is drawn into the unit and sprayed back into the pond. Commonly used models are capable of moving 1,000 to 5,000 gallons of water per minute over a large area of the pond. If the impeller pump is equipped with a diffusing sprayer, its oxygenating efficiency is almost twice as great as when the unit is used with a straight discharge pipe.

The paddle-wheel aerator (Fig. 3.7), the most commonly used emergency aeration device, consists of large steel paddles welded to two drums attached to a truck axle and differential. The unit is mounted on wheels and is attached to the tractor power takeoff by a drive shaft mounted on an extended frame. Designs and sizes vary considerably. When the

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Fig. 3.6. Impeller lift pump used for emergency aeration. Many of the larger units can move from 1,000 to 5,000 gallons of water per minute and aerate ponds up to 10 acres in surface area. *Photo courtesy of Alabama Cooperative Extension Service.*



Fig. 3.7. Paddle-wheel aerator being used for emergency aeration. Designs and sizes vary considerably but most send up a dome of spray and provide extensive water circulation. *Photo courtesy of Alabama Cooperative Extension Service.*

unit is backed into the pond and the power takeoff is activated, the paddle wheels send up a massive dome of spray and circulate the water extensively. It is important that the unit not be placed in an area with a high buildup of organic matter on the bottom because the agitation of the mud enriched by hydrogen sulfide (black mud with a rotten-egg smell) increases the biological oxygen demand of the water.

In the absence of anything else, outboard motors have been used to produce substantial amounts of current and surface agitation in small ponds. Most specialists believe that the motors should be mounted in a fixed position. Operation of a boat with an outboard motor to stir the water is not believed to be especially effective.

One innovative farmer was able to save the fish in several large ponds during a period of low oxygen by agitating the water surface with a helicopter. This action provided enough wave action and circulation to add appreciable amounts of oxygen to the water.

The relative effectiveness of various emergency aeration devices differs widely (Table 3.4). Emergency aeration devices should be mobile so that they can be placed where they will be most useful. Fish may not be able to swim through oxygen-depleted waters to reach a fixed emergency aeration device.

Research findings and commercial records show that aeration increases catfish production. Commercial-sized ponds often yield over 6,000 pounds per acre with continuous aeration, and research ponds of less than ½ acre have produced up to 12,000 pounds per acre. Several aeration schedules have been used: continuous aeration (24 hours/day), dusk to dawn, and pre-dawn to post sun-up. The fountain-type aerator and the air-lift pump-type aerator are the systems most commonly used. Parasites, diseases, and off-flavor are all serious problems in continuously aerated ponds containing high standing crops of fish.

Use of Chemicals to Control Dissolved Oxygen

Chemicals such as potassium permanganate, phosphate fertilizers, and several forms of calcium have been used to reduce the effect of low DO on fish. In one technique, potassium permanganate is applied at the rate of 4 ppm, followed by one or more applications of 2 ppm until a pink color persists. Potassium permanganate is an oxidizing agent; it does not add appreciable oxygen to the water, although technically very small amounts are

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Table 3.4. *Amounts of oxygen added to pond water by different devices for emergency aeration.*[a]

Type of device and function	Oxygen added (pounds)[b]	Relative efficiency (percent)
Paddle wheel		
Paddle-wheel aerator	68	100
Sprayer		
Crisafulli pump that sprays in-pond water	44	64
Fountain		
Otterbine aerator (3.7 kilowatts)	21	31
Otterbine aerator (2.2 kilowatts)	16	23
Air-o-lator aerator (0.25 kilowatt)	6	8
Circulation or transfer		
Crisafulli pump that transfers oxygenated water from an adjacent pond	27	39
Crisafulli pump that circulates in-pond water	17	24
Rainmaster pump that transfers oxygenated water from an adjacent pond	8	12
Rainmaster pump that circulates in-pond water	15	22

[a]Adapted from C. E. Boyd and C. S. Tucker. 1979. Emergency aeration of fish ponds. Transactions of the American Fisheries Society 108:299–306.

[b]Actual increases in dissolved oxygen content cannot be predicted for all pond situations because of differences in pond sizes, water depths, and area affected by the device. An estimate can be made on the basis that 2.7 pounds of oxygen increases the dissolved oxygen content of 1 acre-foot of water by 1 ppm.

generated by chemical reactions in the water. Its purpose is to oxidize the organic materials and the reduced chemicals such as nitrites and sulfides, thus lowering the demand for DO in the pond. Although it oxidizes organic matter whose decay uses up oxygen, its long-term effect on DO is controversial. Some research has shown that treatments with potassium permanganate have lengthened the time required for DO to return to normal. However, the major problem with the use of potassium permanganate is its high cost. Consequently, the judicious application of fresh water, use of emergency aeration devices, and (above all) the adjustment of feeding allowances during periods of inclement weather are the preferred ways of managing DO.

Potassium permanganate is sometimes the technique of choice, but the probability of an overdose is always present. A simple, precise test is available to determine the potassium permanganate demand of water. First, the manager dissolves 1.0 g of potassium permanganate in 1 liter of distilled water to prepare a potassium permanganate stock solution. Next, about 5 gallons of water from the pond that is to be treated are measured out in successive 1-liter volumes, and poured into each of 10 clean glass jars. Then 1, 2, 3, 4, 5, 6, 7, 8, or 9 milliliters (mL or cc) of the potassium permanganate stock solution are added to nine of the jars. (Thus, jar 1 contains 1 ppm potassium permanganate, jar 2 contains 2 ppm, and so on.) Jar 10, which is not treated with potassium permanganate, serves as the control. The water and chemical are thoroughly mixed in each of the nine jars.

After about 15 minutes the color retention is evaluated in each of the jars of treated pond water. The jar of water having the faintest pink color represents the potassium permanganate demand. In the example given in Table 3.5, the BOD is about 3 ppm potassium permanganate.

To treat the pond, one must add the quantity of potassium permanganate that will satisfy the BOD, plus a residual amount. For example, if a pond has a volume of 22.7 acre-

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Table 3.5. *Determination of the potassium permanganate demand of pond water. Pond water is treated with different amounts of potassium permanganate; the smallest amount that will impart a light pink color to the water after 15 minutes (here jar no. 3) is considered to be the potassium permanganate demand of the water.*

Jar number	Concentration of potassium permanganate added (ppm)	Color after 15 minutes
1	1	None
2	2	None
3	3	Light pink
4	4	Darker pink
5	5	Darker pink
6	6	Light red
7	7	Red
8	8	Dark red
9	9	Very dark red
10	0 (control)	None

feet, the potassium permanganate (BOD) demand is 3 ppm, and the desired residual level of potassium permanganate is 2 ppm, the manager must add 5 ppm potassium permanganate (BOD plus residual level desired) to the pond. This treatment requires the following calculation:

Potassium permanganate to be added = 5 (ppm desired) × 2.72 × 22.7 (acre-feet of water) = 308 pounds

(The value 2.72 represents the pounds of any chemical that, when dissolved in 1 acre-foot of water, yield 1 ppm.)

Some specialists recommend triple superphosphate at the rate of 50 pounds per surface acre, or liquid phosphate at the rate of 20 pounds P_2O_5 per surface acre to stimulate the growth of phytoplankton. The phytoplankton then produces oxygen for the fish by photosynthesis.

Several forms of calcium, including slaked lime (calcium hydroxide) and burnt lime (calcium oxide), have been applied to ponds with low DO. These lime forms tend to buffer the water from wide pH fluctuations, and remove the carbon dioxide, which is usually high when DO is low. The available DO is used more efficiently when CO_2 is low. Since 0.84 ppm calcium hydroxide removes 1 ppm CO_2, 21 ppm calcium hydroxide are required to remove 25 ppm CO_2.

Chemical Treatment of Phytoplankton to Regulate Dissolved Oxygen

It is impossible to discuss DO without including phytoplankton. As noted earlier, phytoplankton blooms can become dense enough to cause DO depletions. In addition, there is often a correlation between thick scums or heavy blooms of blue-green algae and off-flavor in fish. Thus managers are concerned with reducing phytoplankton levels. This is especially difficult to do at high stocking and feeding rates because plant nutrients are constantly being released into the water, making it an ideal environment for phytoplankton growth.

Algicides are sometimes used to control phytoplankton. Copper sulfate kills most species at concentrations of 0.1 to 0.5 ppm in waters with total alkalinities between 20 and 50 ppm. Concentrations of 1.0 ppm or more may be required in water with alkalinities higher than 100 ppm. Copper sulfate may be applied by dissolving it in water and distributing it over the pond surface, by direct application on the water surface if a powder formulation is used, by placing it in a burlap bag and towing it behind a boat until it dissolves, or by placing fine-mesh nylon bags of copper sulfate in the pond so that the chemical gradually dissolves. Copper sulfate can be sprinkled on local areas to spot-treat phytoplankton scums that drift to the downwind shores of ponds.

Phytoplankton killed by copper sulfate decomposes rapidly, and this decomposition may result in low DO. Because copper sulfate has no appreciable residual toxicity, phytoplankton resumes growth soon after treatment. Fish are susceptible to copper sulfate, and may be killed in waters with alkalinities less than 20 ppm by applications of 0.5 to 1.0 ppm copper sulfate.

Synthetic algicides such as Dichlone[x] and

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Table 3.6. *Chemicals registered for fishery use.*[a]

Fishery use and chemical	Application rate (A = acre)	Category of fish (F = food fish; N = nonfood fish only)
Algicides		
Copper sulfate	0.25–4 ppm[b]	F
Dichlone	0.055 ppm	N
Algicide and herbicide		
Diquat	5.4 ppm in water for submerged weeds; 3 lb/A for floating weeds	F
Simazine	1.4–6.8 lb/A	F
Herbicide		
Casoron	7–15 lb/A	N
Copper (from basic copper carbonate)	14 lb/A	F
2,4-D	6–40 lb/A	F[c]
Endothall	6.8–9.5 lb/A	F
Fenac	15–19.5 lb/A	N
Silvex	Granular 40 lb/A	N
	Liquid 6 lb/A for submerged weeds; 8 lb/A for emergent weeds	N
Xylene	100 gal/A	N
Bactericides		
Furanace	0.05–0.1 ppm for an indefinite period; 1 ppm for 5–10 minutes	N
Sulfamerazine	10 g/100 lb fish per day for 14 days in feed	F
Terramycin	2.5–3.75 g/100 lb fish per day for 10 days in feed	F
Parasiticides		
Formalin	25 ppm in ponds; up to 250 ppm for 1 hour in tanks	F
Masoten	0.25 ppm	N
Acetic acid		[d]
Anesthetics		
MS-222	15–66 ppm for 6–48 hours for sedation; 50–330 ppm for 1–40 minutes for anesthesia	F
	Carbon dioxide	[d]
	Sodium bicarbonate	[d]
Disinfectants and sterilants		
Calcium hypochlorite	200 ppm for 1 hour	F
Lime	1,338 lb/A burnt lime	F[d]
	1,784 lb/A slaked lime	F[d]
Toxicants		
Antimycin	5–10 ppb	N
Rotenone	1–5 ppm	N

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Table 3.6. Continued

Fishery use and chemical	Application rate (A = acre)	Category of fish (F = food fish; N = nonfood fish only)
General uses		
Fluorescein sodium	0.1 ppm to check water flows or dilution	F
Potassium permanganate	2 ppm as an oxidizer or detoxifier	F
Rhodamine B	20 ppb to check water flows or dilution	F
Salt (table or sodium chloride)	0.5–3% as a hauling aid	F[d]

[a]From R. A. Schnick, F. P. Meyer, and H. D. Van Meter. 1979. Announcement of compounds registered for fishery uses. Progressive Fish-Culturist 41(1):36–37.
[b]Rate depends on water chemistry.
[c]For use only by Federal, State, or other public agencies.
[d]Declared "Generally Regarded as Safe" (GRAS) by U.S. Food and Drug Administration.

Simazine (Table 3.6) are sometimes used to kill phytoplankton. These algicides are toxic to algae, have a long residual action, and are not damaging to fish at the recommended concentrations used to kill phytoplankton. However, extensive mortality of phytoplankton after the use of synthetic algicides can result in DO depletion. Some fish culturists have attempted to thin phytoplankton blooms by making small, periodic applications of synthetic algicides to ponds in which fish are being heavily fed. However, recent research has shown that this practice may cause prolonged periods of low DO and significantly reduced fish yields.

Certainly, removal of phytoplankton-rich water and its replacement with fresh water temporarily dilutes the remaining phytoplankton. However, phytoplankton can grow to predilution levels in 24 to 96 hours if sufficient plant nutrients are available—which is generally the case when feeding of fish is heavy.

Other Water Chemistry Considerations

Water quality factors such as pH, CO_2, alkalinity, hardness, hydrogen sulfide, ammonia, and nitrite are important in aquaculture. Generally these factors are interrelated. For example, pH values are high when CO_2 concentrations are low, as during periods of high photosynthesis; this combination in turn increases the toxicity of ammonia.

Alkalinity, hardness, and pH can generally be raised by the addition of agricultural lime, preferably in the form of calcium carbonate, to a pond. The local representative of the Cooperative Extension Service Office or U.S. Soil Conservation Service can assist farmers in calculating the lime requirements for ponds. Ponds requiring lime generally have hardness or total alkalinity concentrations below 20 ppm and soil pH below 6.5. Calcium carbonate should be used in ponds rather than calcium hydroxide (slaked lime) and calcium oxide (burnt lime or quicklime) because the hydroxide and oxide are both caustic and can increase the water alkalinity to lethal levels. Liming is pointless in ponds with rapid exchange rates (e.g., some hill ponds with large watersheds) because the chemicals are quickly carried away.

If fish are well fed, production can be good in ponds with soft, poorly buffered waters, even though pH values are often above 9 during periods of intense photosynthesis. However, the proportion of ammonia present as

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un-ionized toxic ammonia is greatly increased in water with a pH value of 9 to 10. Either gypsum or alum can be added to lower pH in ponds. Dilution and pond aeration can reduce dangerously high ammonia levels.

Ammonia in the un-ionized form (NH_3) can be toxic to channel catfish at concentrations of 0.4 to 3.1 ppm in 96 hours. Lower concentrations can depress growth rates.

The principal source of ammonia in catfish production ponds is protein, a major constituent in feeds. When 9,000 pounds of feed per acre are fed in a growing season, as in a typical intensive production system, about 450 pounds of ammonia nitrogen are released to the pond water. This ammonia quickly comes to a pH- and temperature-dependent equilibrium with the ionized (less toxic) ammonia. Upon entering the water, the ammonia may be volatilized into the air, oxidized to nitrate, or taken up by higher aquatic plants, phytoplankton, and bacteria. Under normal conditions, most of the nitrogen is locked up in the tissues of phytoplankton. This continual uptake of ammonia and its oxidation products by phytoplankton serves to keep the concentration of total ammonia ($NH_3 + NH_4^+$) low and un-ionized ammonia (NH_3) at sublethal concentrations.

We briefly discuss here three factors that can upset the equilibrium of nitrogen metabolism in ponds and result in high concentrations of un-ionized ammonia: natural phytoplankton mortalities, disease treatments, and high afternoon pH.

Natural phytoplankton mortalities. — Certain phytoplankton, especially blue-green algae, can come to dominate pond phytoplankton communities. When these algae suddenly die, rapid decomposition can release considerable amounts of ammonia. Increased carbon dioxide usually decreases pH, and this decrease favors the formation of the relatively nontoxic ionized form of ammonia. However, the increase in total ammonia concentrations following these events can raise un-ionized ammonia concentrations to toxic levels.

Disease treatments with certain chemicals. — Potassium permanganate and copper sulfate are often-used pond treatments for external bacteria and protozoal diseases. Both chemicals are toxic to phytoplankton. When applied as a disease treatment, the chemicals may kill a major portion of the phytoplankton, with the same results as those that accompany natural phytoplankton mortalities. Treatment with these chemicals can also adversely affect nitrifying bacteria and inhibit the oxidation of ammonia to nitrate.

High afternoon pH. — When feeding rates are highest, in summer, more nitrogen as a waste product from metabolism is added to ponds than can be rapidly taken up by phytoplankton. Production of all forms of nitrogen increases as the growing season progresses, and under normal conditions this is the period of highest total ammonia concentrations. Also, the high photosynthesis rates cause wide day-to-night fluctuations in the pH of pond water. The combination of increased total ammonia levels and high pH in late afternoon results in temporary high levels of un-ionized ammonia.

In the typical intensive production system, phytoplankters in the surface waters fall to the pond bottom when they die. Some decomposition occurs, with the formation of ammonia. Bacteria in the presence of oxygen then convert (oxidize) the ammonia to the intermediate nitrite, and then to nitrate. Nitrite is considerably more toxic than ammonia, whereas nitrate is relatively nontoxic to fish. Because bottom waters become anaerobic or nearly so during summer, nitrite accumulates in the pond bottom sediments, reaching especially high levels at the bottoms of stratified hill ponds. Nitrite also accumulates in the water column in winter, when bacterial activity is reduced by low temperatures. Both these conditions also can produce toxic levels of nitrite throughout a pond when the water is mixed during spring and fall overturns.

Nitrite enters the blood of fish through the gills and combines with the hemoglobin to form methemoglobin. This compound imparts a brown color to the blood and results in the toxic condition known as "brown blood." This condition can be prevented if there are at least three parts of chloride for each part of nitrite in the water. The usual

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procedure is to analyze the water for nitrite (in parts per million), multiply by 3, and then subtract the water chlorides (in parts per million). A zero or negative value indicates that no additional chlorides are needed. Chloride sources and the amounts that yield 1 ppm chloride per acre-foot follow: sodium chloride, 4.5 pounds; anhydrous calcium chloride, 4.3 pounds; and dihydrous calcium chloride, 5.6 pounds.

Nitrite concentrations can also be reduced by adding fresh water to dilute the chemical.

Hydrogen sulfide also accumulates in oxygen-poor or oxygen-free bottom sediments, such as those in feeding areas with high concentrations of organic matter. Accumulations of hydrogen sulfide can be identified by the presence of black sediments with a rotten-egg smell. Concentrations are highest in summer and lowest in winter.

Exposure of fish to hydrogen sulfide is reduced if fish are harvested in areas with little organic accumulation; i.e., at locations where the bottom is hard and the water is relatively deep. Less sediment is then disturbed to release hydrogen sulfide, and any of the hydrogen sulfide released from the bottom muds is diluted. If such a harvesting area is not available, however, fish should be moved immediately from muddy water to fresh, deep water, or a pump should be used to direct a flow of fresh water into the landing area.

Two pond treatments can reduce the effects of hydrogen sulfide. The application of lime, especially in areas where the pH of the soil and water is low, may reduce the toxicity of hydrogen sulfide by raising the pH. Also, potassium permanganate can be applied to the pond during harvesting to oxidize the hydrogen sulfide in the water.

Fish that have been exposed to hydrogen sulfide should not be transported immediately after capture because a fatal blood acidosis may result. Two precautions should be taken: (1) physical exertion of the fish should be kept to a minimum, and (2) fish should be held for several hours—preferably overnight—in cool water before being transported. When transporting fish that have been exposed to hydrogen sulfide at harvest, or if metabolic hydrogen sulfide buildup is anticipated during transport, one should use supplemental oxygen and the fish should be transported at as low a temperature as is practical, to reduce the metabolic rate.

Off-flavor

Off-flavor is one of the most serious problems in intensive catfish culture. Catfish flesh has been described as having "musty-earthy," "fecal," "chemical," or "stale-rancid" off-flavor. The most common off-flavor is the musty-earthy. It is associated with several species of blue-green algae and with filamentous or rod-shaped bacteria called actinomycetes. These organisms produce a compound called geosmin, which is absorbed by the fish.

Fish may be off-flavor in ponds rich in organic matter (Fig. 3.8) and plant nutrients. The off-flavor usually increases in intensity when standing stocks of fish and feeding rates are both highest, in late summer. However, inasmuch as some ponds in their first year of production also have off-flavor fish, the problem is not due totally to an accumulation of organic matter from feeding. Then too, the off-flavor can be just as serious in pasture or watershed ponds (with low feeding allowances but with high inputs of manure) as in ponds with extremely high allowances of manufactured feed.

Fish farmers are justifiably concerned with the off-flavor problem, since sales are prevented and the fish may grow to an uneconomical size before off-flavor is lost. Normally such a condition clears up in a month or so if feeding rates are reduced, or if environmental conditions improve. Pond flushing seems to help, too. This is no consolation, however, to farmers who are ready to market a crop or who need to partly harvest a heavily stocked pond.

Clay (inorganic) turbidity reduces light penetration in ponds and seems to reduce off-flavor problems by reducing the amount of algae in ponds. Paddle-wheel aerators may help by increasing the clay turbidity, but no specific recommendations are yet available.

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Fig. 3.8. Masses of green algae that appear in nutrient-rich ponds contribute to off-flavor and interfere with fish harvest. *Photo by Jay V. Huner.*

Some farmers have used algicides to reduce algae, with the hope that the reduction would alleviate the off-flavor problem. Unfortunately, these same algae produce the oxygen needed to keep the fish alive.

A farmer should be aware that fish can absorb off-flavors from rancid feed, and from fuel and oil lying on the bottoms of boats or left in containers used to move fish. Fish quickly acquire many of the tastes and smells of the water. This problem is particularly significant because the fish retain these off-flavors after they are killed and processed.

Pesticides

Fish production facilities should not be built in areas where residual pesticides are present in the soils, or where the water supply is contaminated. However, ponds and other fish-production facilities are often built in areas where other crops are produced, on which insecticides, pesticides, herbicides, and other agricultural chemicals are used. Also, chemicals must often be used in various aspects of fish production. Production sites and farming practices that were not harmful to fish when the facility was constructed may be adversely affected by agricultural chemicals later.

Because of changing agricultural practices, the presence and effects of pesticides must be monitored. Sources of pesticide contamination include surface runoff, back-filling from drainage ditches, surface waters pumped into the pond, water from shallow wells, and aerial drift from spraying of nearby fields (Fig. 3.9). Ponds supplied by surface runoff should never be located below agricultural fields or orchards that are likely to be treated with pesticides. Streams, rivers, and bayous used as water sources must be monitored closely for the presence of sick or dying organisms, and water should never be used when they are present. Water from shallow wells should be analyzed periodically for the presence of harmful pesticides.

Several common-sense precautions can reduce pesticide kills of fish. Label instructions should be read carefully before any

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Fig. 3.9. It is dangerous to spray insecticides near fish ponds. Some chemicals are very toxic to fish, and can reach the pond by wind drift or runoff. *Photo by J. Mayo Martin.*

chemical is used. Also, the farmer who is not sure of the correct method of applying chemicals to fields close to fish ponds should contact the chemical company representative or the County Cooperative Extension Service Office for specific information. Some general suggestions are given here to reduce potential chemical toxicity problems in commercial and recreational ponds.

(1) When chemical applications are made by either ground or aerial equipment in the immediate vicinity of fish ponds, it is recommended that no more than 3 gallons of spray per acre be applied with aerial equipment and no more than 6 gallons of spray per acre with ground equipment. It is also recommended that low pressure be used (maximum, 25 pounds per square inch for aircraft and 40 for ground equipment) in conjunction with nozzles that produce large spray droplets.

(2) Chemical applications in the vicinity of fish ponds should be delayed until the wind is blowing away from the fish pond. For aerial application, it is recommended that applicators avoid spraying too close to the downwind side of fish ponds to avoid the spreading of chemicals into the pond by the vortex roll. Also, as a special precaution, flying with the left wing next to the fish pond should be avoided because the vortex roll is much greater from the left wing than from the right wing.

(3) It is recommended that farmers use chemicals that are least detrimental to fish when making applications in the immediate vicinity of ponds.

(4) Fields should be scouted and chemicals used only when necessary and at the minimum recommended rate required to obtain effective pest control.

(5) Wherever practical, crops that require little or no chemical insect control should be grown in the immediate vicinity of fish ponds (e.g., soybeans or rice).

(6) Applicators should check their equipment regularly and ensure that there are no leaks, and that hoses, fittings, and equipment are in good operating condition.

(7) Aerial applicators, empty or loaded, should not fly over fish ponds, nor should they ferry chemicals upwind in the immediate vicinity of fish ponds.

(8) Chemicals should be used only as directed on the label; and as a special precaution to avoid poor emulsification, chemicals should be premixed with water in a holding tank immediately before the aircraft is loaded.

(9) Chemical applicators should use any other good operating practices that reduce or alleviate drift.

(10) It is highly desirable for all persons or agencies involved in the application of chemicals to carry adequate liability insurance for their own protection, in case of spills or other accidents.

Aquatic Vegetation Control

The presence of dense vascular vegetation in ponds drastically reduces the production of most fish, although small amounts can be beneficial in the production of some sport species. Vegetation uses nutrients from the soil and the water that could be used in the production of plankton, and limits the access of the fish to food organisms produced on and in the pond bottom soils. Extensive vegetation interferes with feeding of prepared rations, and may contribute to lowered water quality if the fish cannot reach the feed that settles in the vegetation. Vascular vegetation, like phytoplankton, competes with the fish for

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Fig. 3.10. Dense aquatic vegetation makes ponds unmanageable and reduces production. Furthermore, the plants may die and cause fish losses from oxygen deficiencies. *Photo by Jay V. Huner.*

oxygen at night. Seining is severely hampered by vegetation, and may interfere with pond draining by clogging the screens and drains, and by trapping fish (Fig. 3.10).

The prime consideration in the control of aquatic vegetation is prevention. The ponds should be constructed with the smallest possible area of shallow water (less than 3 feet deep). Vegetation generally begins growing along the shoreline and progresses toward deeper water. A good bloom of plankton shades the bottom, and thus retards vegetative growth. This bloom can be encouraged by fertilization, as previously discussed.

Mechanical removal (pulling, cutting, raking) is expensive, time-consuming, and not particularly effective except when the vegetation is confined to a small area.

Herbicides are currently the most efficient method of controlling undesired weeds. When the vegetation has not yet appeared, preemergent application is the method of choice, since the problem of oxygen demand by decaying vegetation is avoided. When the vegetation is already present, control should be carried out gradually with partial treatments and in consideration of weather conditions, so that no oxygen deficiency results. It is important to read the label before using any chemical. All chemicals used in ponds must be registered by the Food and Drug Administration for such use. Caution must be observed in the release of water containing chemicals into receiving streams, or the use of this water in irrigation.

Biological control is desirable because it converts a problem into salable food fish. A high-value plant-eating fish would be ideal for this kind of biological control. A number of species have been considered for this purpose, including grass carp, Israeli carp, and tilapias. Experiments have indicated that the numbers of Israeli carp and tilapias needed to control plants effectively are so large that the fish would compete for space and interfere with the production of other, more desirable species.

The grass carp (sometimes called white amur) is known to feed actively on aquatic plants. Arkansas farmers routinely stock 10 to 40 grass carp per acre to control vegetation. However, the species is not widely used elsewhere because it is an exotic from Asia, and cannot legally be used in many States. Also, small fingerlings can grow to a weight of several pounds in a season; harvesters can be injured when these large fish leap over nets, and small fish may be killed when the larger grass carp thrash about in the seine.

The identification of plants is necessary before treatment because the species governs the choice of herbicide. Several publications listed in Chapter 21 should be helpful. Botanists in nearby colleges and universities, technical assistance personnel of the Federal and State governments, and the Cooperative Extension Service Office may assist in identification.

Aquatic vegetation is generally divided into four large groups: algae, and submergent, emergent, and marginal (nearshore) plants.

Algae consist of lower forms of plant life; most species are without roots. In this group are the filamentous algae (straight and branched), chara or muskgrass (often confused with higher plants, which they resemble), and planktonic algae (generally desirable in the food chain).

Submergent plants are rooted and remain entirely beneath the surface of the water. Some of the more common ones are hornwort

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(*Ceratophyllum*) and the various species of pondweeds (*Potamogeton*) and naiads (*Najas*).

Emergent plants are rooted in the pond bottom and rise above the surface of the water. True floating plants have leaves on the surface of the water and roots hanging free in the water. The waterlilies (*Nymphaea*), lotus (*Nelumbo*), cowlilies (*Nuphar*), and watershield (*Brasenia*) are examples of plants rooted to the pond bottom and having leaves floating on the surface of the water or extending above the water. Duckweeds (*Lemna*), ducksmeat (*Spirodella*), and watermeal (*Wolffia*) are among the true floating weeds. Most are minute plants (small leaves) with a root hanging down into the water below the leaves.

Marginal plants grow in very shallow water or wet soil along the edge of the pond. Cattails (*Typha*), spikerushes (*Eleocharis*), rushes (*Juncus*), and flatsedges (*Cyperus*) represent this group.

We have summarized the compounds registered for aquatic vegetation control and for other uses in fisheries in Table 3.6. The fish farmer must remember that herbicides are often specific for particular plants, and should always read the label to make sure that a registered chemical is being used.

Control of Competitors

Some fish compete with other fish for living space and food. Some competitors, such as the sunfishes and bullheads, may become large enough to prey on the smaller fish that are being cultured for sale or for use in fishery management (Fig. 3.11). It is usually not economical to grow a mixture of production fish and wild fish. If the water source contains wild fish, it must be filtered through Saran cloth, fine-mesh screen, or gravel (as discussed earlier). Predator species such as largemouth bass are sometimes stocked to control undesired wild fish. This practice is not useful, however, in ponds that are not drained annually because the bass may become large enough to feed on production fish the following spring.



Fig. 3.11. Wild fish compete for space and food in commercial production ponds, and thereby reduce profits. The sunfishes and shad shown here take up space, and the sunfishes not only prey on the smaller fish being cultured but also eat the feed that more profitably should go to the farmed fish. *Photo courtesy of J. Avault, Jr.*

Bullfrogs prey on small catfish and baitfishes, and tadpoles compete for space and food, especially in fingerling ponds. Adult frogs are easily caught at night and can provide supplemental income. Eggs can be killed by applying a few crystals of copper sulfate to the egg masses.

Green turtles, which normally do not prey on healthy fish but eat large amounts of catfish feed, can be easily trapped.

Chemicals can be used to control wild fish (Table 3.6). The two principal ones, rotenone[x] and Antimycin A[x] (sold as Fintrol), are not now registered for use with food fish but can be applied when ponds are drained after food fish have been removed.

Rotenone[x] is relatively inexpensive and moderately effective, except for bullheads and mosquitofish. It should be applied at a rate of 0.5 to 2.0 ppm. A higher concentration may be required for some fish species, or when the water is cold. Its chief disadvantage is that it may require up to 2 weeks to lose its toxicity in warm water, and even longer in cold water. However, potassium permanganate detoxifies rotenone.

Antimycin A[x] is a selective poison that can be used to eliminate scaled fish in the presence of catfish. Because this chemical varies in activity in relation to water chemistry and

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temperature, the instructions on the label should be closely followed, or expert advice sought.

Hydrated lime applied at 150 pounds per acre is an effective fish toxicant when scattered over water-filled depressions and low spots in a drained pond. When the entire pond bottom is treated, the standard application rate is 1,000 pounds per acre. Because the material is very caustic, the applicator should take appropriate precautions.

Control of Predators

Predators must be controlled in fish production systems. Often cultured fish and other aquatic animals are not as wary as wild ones. A few predators can often capture and eat enough cultured animals to make the production system unprofitable. Control of these predators often depends on the ingenuity of the aquaculturist. Since a special license or permit is often required before some nuisance animals can be killed or removed, the fish farmer should consult with the appropriate State and Federal conservation authorities before beginning a control program.

Filling a pond just before the stocking of eggs or fry may not eliminate predators, but the damage is usually reduced because the fish eggs soon hatch and the fry quickly become large enough to avoid many of the predators.

Predator fish, as a whole, cause more production losses than all of the other predator animals combined. Many fish species not generally considered predatory usually consume smaller fish and cultured aquatic animals if given the opportunity. (The green sunfish is an excellent example.) These predators can usually be eliminated by draining and disinfecting the pond, and screening and filtering the water supply. The fish producer must also carefully inspect the fish to be stocked, to avoid introducing unwanted fish.

Crayfish and snails are sometimes serious problems in catfish fingerling ponds and minnow ponds. They may prey on eggs and sac fry and eat prepared feed. Crayfish can injure small fish in seines. Snails can be killed before the eggs or fry are stocked by covering the pond bottom with water 1 inch deep and applying 10 ppm copper sulfate, followed the next day by 500 pounds per acre of finely ground agricultural limestone. Crayfish are often controlled by drying the pond and treating depressions with calcium hypochlorite (HTH). Stocking 10 to 15 channel catfish, 6 to 8 inches long, in a catfish fry pond can significantly reduce crayfish populations if the crayfish are small when the catfish are stocked.

Reptiles such as snapping turtles, alligators (Fig. 3.12), and water snakes (Fig. 3.13) eat many fish, often catching them while the fish are feeding. They are more common in ponds near wetland areas than elsewhere. Normally they are a problem only during summer. Snapping turtles can be trapped or shot. Snakes can be controlled by keeping the grassy banks and surrounding areas closely mowed and free of debris (Fig. 3.14). Gill nets can sometimes be used to entangle snakes and turtles. Alligators present a problem because they are a protected species. The only legal remedy is capture and transfer.

Most water birds are protected by Federal or State law. Kingfishers, herons, grebes, egrets, mergansers, cormorants, anhingas, pelicans, and diving ducks are predators of fingerling catfish and minnows, and pose a serious problem if present in large numbers. Fireworks and other noise- and light-producing devices are of only limited value in keeping these predators out of ponds.

Otters can often cause serious problems in fish ponds, especially in winter (Fig. 3.15). During cold weather, otters may have difficulty in finding food in natural waters. Fish predation by otters normally coincides with local trapping seasons, thus offering the fish farmer a legal control method.

Control of Other Noxious Animals

Burrowing aquatic rodents such as muskrats, nutria, and beaver can seriously damage levees (Fig. 3.16). Farmers would do well to

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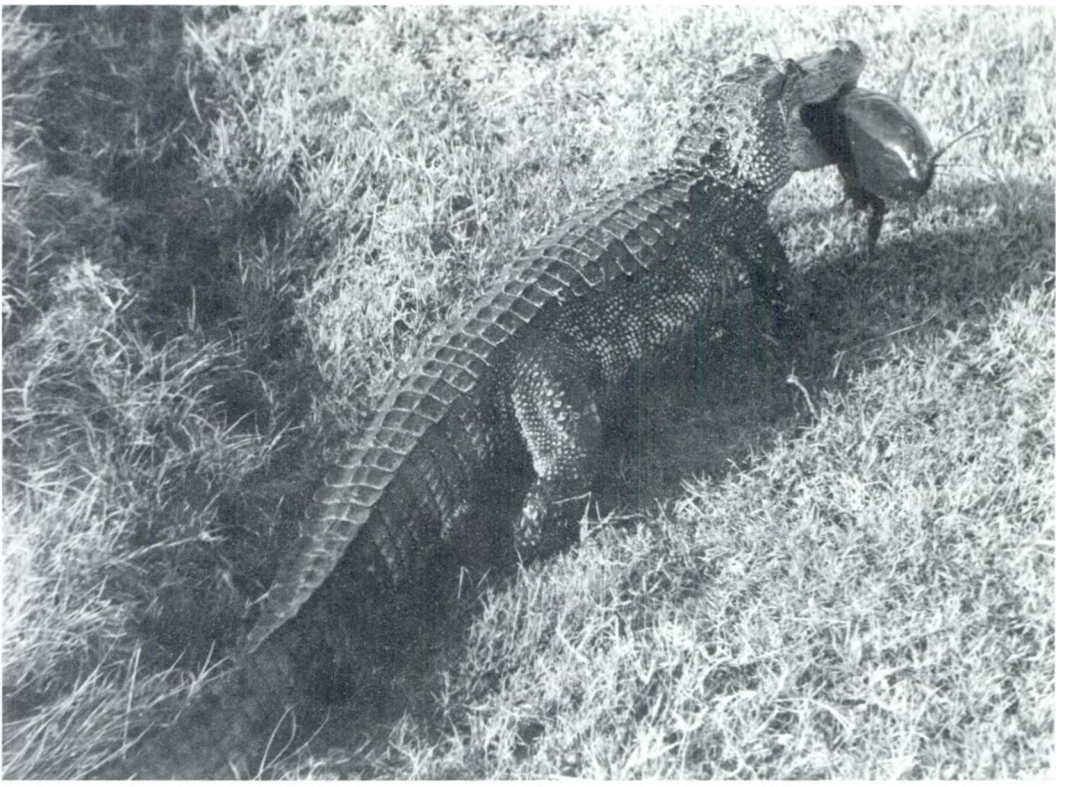


Fig. 3.12. Alligator carrying a brood catfish from a pond. Channel catfish are especially vulnerable to alligators and other predators when the fish are near the surface feeding on floating feed. *Photo courtesy of Louisiana Department of Wildlife and Fisheries.*

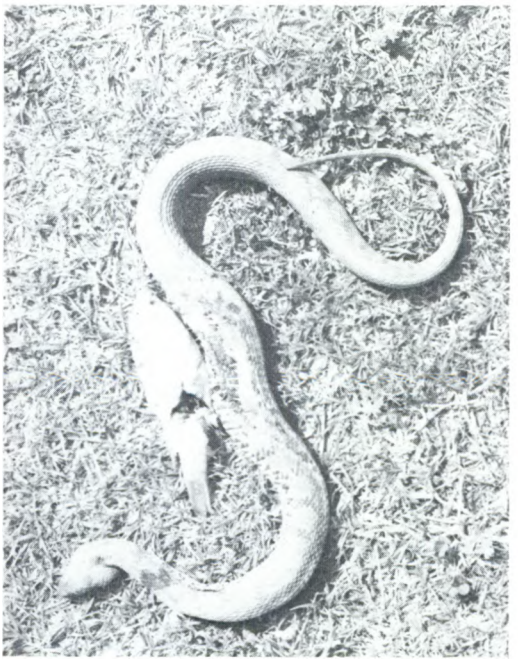


Fig. 3.13. Water snakes of all sizes eat fish, and prefer to feed on easily captured farmed fish. During summer a water snake may eat 6 to 10 fish a day. The gizzard shad shown was removed from the stomach of this snake. *Photo courtesy of J. Avault, Jr.*

Fig. 3.14. Lush growth of aquatic vegetation may provide shelter for water snakes when they are resting. Small fish also venture near shore to feed and become easy prey for snakes. Mowing and chemical control of the vegetation eliminates most snake problems.



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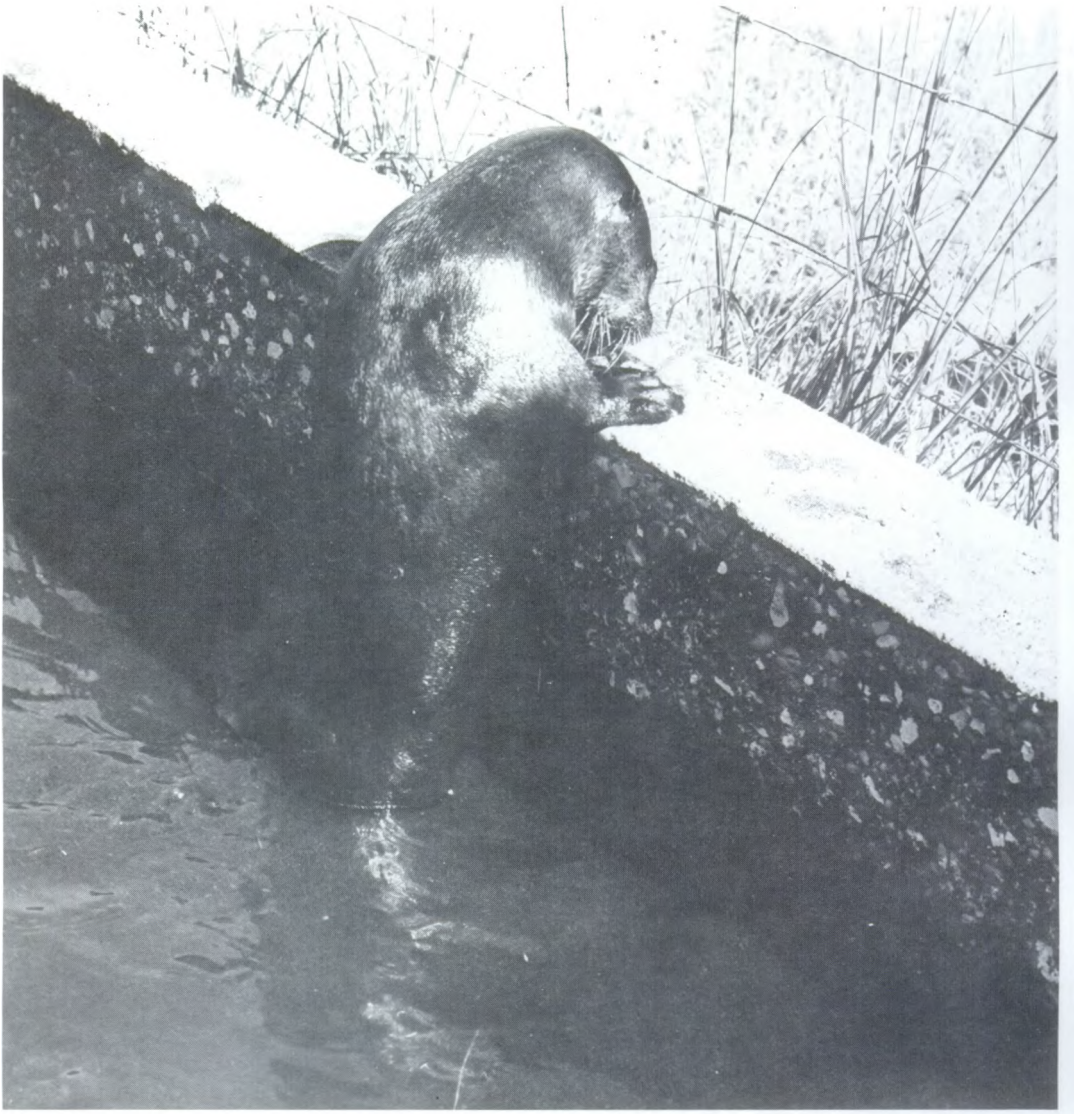


Fig. 3.15. Otters are excellent swimmers and have little difficulty in catching cultured fish. The animals are very intelligent and ingenious, making fences of little value. Often trapping is the only remedy for a marauding otter. *Photo courtesy of D. W. Pfitzer.*



Fig. 3.16. Burrowing aquatic rodents such as muskrats and nutria can cause extensive levee damage. The animals can be controlled by keeping the levees free of excess vegetation and by trapping. *Photo courtesy of J. Avault, Jr.*

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keep banks and levees free of debris and grass that can provide shelter for these animals. The farmer should ensure that the pond area, including drainage ditches, is intensively trapped during the regular trapping season. Trapping at other times of year usually requires special permits.

Muskrats can sometimes be controlled with poison baits. Baits treated with zinc phosphide can be used. Alternatively, anticoagulant poisons used for rat control can be mixed with grain, molasses, and paraffin. Fish farmers should check with State wildlife and fishery extension personnel or State conservation officers for further instructions.

Poachers and vandals present problems to many fish farmers. Adequate attention must be given to maintenance of fences and "no trespassing" signs. Routine surveillance of ponds and close communication with local law enforcement officers are extremely helpful. Several States have severe laws that discourage the stealing of fish. If persons are suspected to be stealing fish, or are trespassing after dark, it is more prudent to summon enforcement officers than to personally accost the intruders.

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4. METHODS AND ECONOMICS OF CHANNEL CATFISH PRODUCTION, AND TECHNIQUES FOR THE CULTURE OF FLATHEAD CATFISH AND OTHER CATFISHES

Jay V. Huner and Harry K. Dupree

Catfishes have been cultured in the United States for more than 50 years. State and Federal hatcheries were the first producers, and the fish raised were used for stocking public waters to provide recreational fishing. In the 1950's, commercial fish farmers began producing catfishes for food and for stocking fee-fishing waters.

In recent years commercial interests have become increasingly involved in sport fishing by operating fee-fishing ponds, and by selling catfish to State and Federal agencies for recreational programs and resource enhancement. Thus fish farmers are becoming progressively more active in producing and selling all species of catfishes—including those that traditionally have been cultured only by government agencies. By far the most widely produced species is the channel catfish. Other species are the flathead, blue, and white catfishes, and the brown, yellow, and black bullheads.

The channel catfish adapts readily to the commonly used intensive production systems—ponds, raceways, and cages—and eats a wide variety of manufactured and natural foods. It is the species about which the most is known, and which we discuss in greatest detail here. Most of the fish are produced for food because of their excellent table qualities and wide human acceptance. This species is also widely used in fee-fishing ponds and for public recreation.

The flathead catfish is an extremely important predator species in the management of certain large reservoirs, lakes, and rivers. In some areas it also contributes significantly to recreational and commercial fishing. Populations of flathead catfish were severely reduced in some waters in the 1950's by illegal capture. The species is particularly sensitive to electrofishing. Management biologists have tried to reestablish the species throughout its former range as a predator species to control rough fish such as gizzard shad and common carp. In addition to production in State and Federal hatcheries, some flathead catfish are raised by private aquaculturists. Fingerlings are sold to governmental fish management groups and to private pond owners. Production of flathead catfish in intensive culture for food has not been profitable because the cost of feeding this predator species is too high and the level of production currently being obtained is too low.

We offer later some techniques that can be used for the production of small fingerling flathead catfish and a limited number of larger fish for management purposes. Methodology is similar or identical to that used in the propagation of channel catfish, except for the techniques of feeding the fry and brood fish.

The blue catfish is sometimes confused with the channel catfish. Both species have forked tails and are similar in appearance. They can be distinguished, however, by the shape and structure of the anal fin: in blue catfish this fin has a straight margin and 30 to 36 supporting rays (Fig. 4.1); in channel catfish it has a rounded margin and 24 to 29 rays (Fig. 4.2).

The blue catfish attains a larger size than the channel catfish, and the dress-out percentage is higher: 60 to 62%, as compared with

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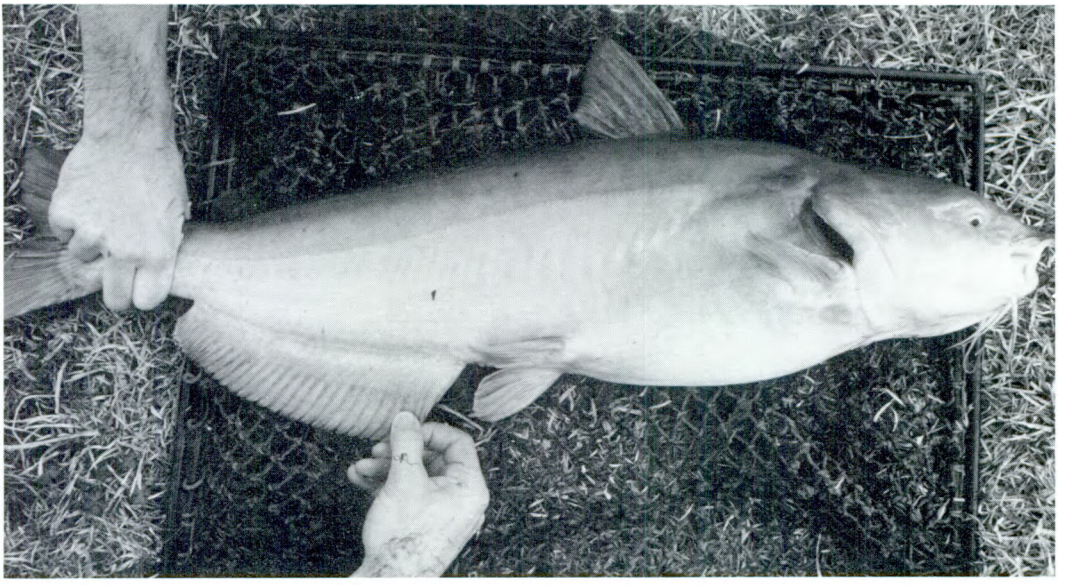


Fig. 4.1. Blue catfish—especially the larger ones—are effective predators, and thus are important in the management of large reservoirs, lakes, and rivers. They are, however, inferior to the channel catfish as a farmed species. *Photo courtesy of R. O. Smitherman.*



Fig. 4.2. The channel catfish can be distinguished from other catfishes by its deeply forked tail, rounded anal fin, and the conspicuous, patternless black spots on the sides.

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58 to 60% for the channel catfish. However, at sizes up to 1 pound, the blue catfish often grows slower than the channel catfish, and converts food less efficiently. It is also much more difficult to propagate because egg-taking is complicated by the large size of the brood fish (20 to 60 pounds), and the fry and fingerlings are much more susceptible to infectious diseases and handling injuries. This species appears to have only limited value in commercial pond aquaculture, but it does have potential as a large predator in lake and river management.

The white catfish (Fig. 4.3) was determined in the 1960's to be inferior to the channel catfish in most aquacultural programs. Few fish producers are now culturing this species. Extensive testing and commercial production during the 1960's showed that, although growth of the fish was initially rapid, growth and feed conversion efficiency decreased rapidly after the fish reached weights greater than ½ pound. Dress-out percentage was less than 55 (due principally to the large head), but the flesh quality was comparable with that of channel catfish and blue catfish. The white catfish is the most hardy of the catfishes and tolerates well the crowding, adverse water conditions, and high water temperatures inherent in intensive aquaculture in the South. This species is desirable in combination stocking with channel catfish in recreational fishing waters.

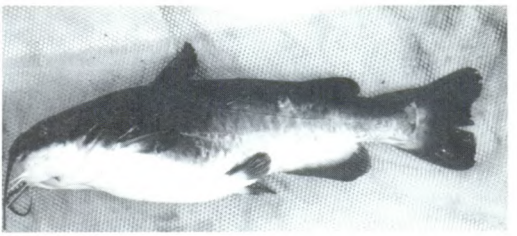


Fig. 4.3. A white catfish of the 1-pound size suitable for processing. These fish grow rapidly to ½ pound, but their growth rate and dress-out percentage declines rapidly at the larger sizes, reducing their value for food production. The species is desirable in recreational fishing waters because it tolerates crowding and adverse water conditions characteristic of fee-fishing ponds.

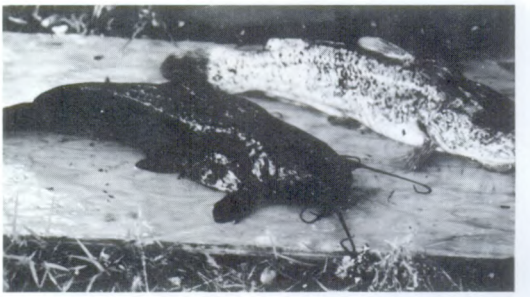


Fig. 4.4. Brown bullheads (two color variants shown here) and yellow and black bullheads have been tested in aquaculture. The brown bullhead is the most promising of the three, but even it is far less suitable than the channel catfish for intensive production.

Bullheads have received only limited attention in aquaculture. In general, they are more susceptible to disease, but more tolerant of adverse water conditions, than are channel catfish. Although the brown bullhead (Fig. 4.4) appears to offer the greatest potential for culture, prices paid for all bullheads are generally low, and consumer demand is limited. Inasmuch as the economics of producing bullheads and channel catfish are essentially identical, there is no clear advantage favoring the production of bullheads. Production for recreational purposes may be warranted in areas where water quality or other environmental constraints limit the production of channel, blue, or white catfishes.

Recently some interest has been expressed in the culture of channel catfish × blue catfish hybrids. Preliminary studies suggest that hybrids are easier to catch than either parent, both with seines and with hook and line. This characteristic has obvious management implications in harvesting fish from hill ponds that are hard to seine, and in stocking fee-fishing ponds. Several studies have shown that the growth rate of hybrids may exceed that of the parent species by about 30% and that the dress-out percentage is higher than that of channel catfish. Some observations indicate also that the hybrid has a higher tolerance of adverse water quality conditions. However, the hybrids are not easy to produce nor are they now readily available at competitive prices.

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Techniques for the propagation of blue catfish, white catfish, and bullheads (and with a few exceptions, flathead catfish) are essentially identical with those for channel catfish. We describe detailed techniques here for the production of channel catfish, nearly all of which can be directly applied to the production of all of the catfishes.

Culture of Channel Catfish

Channel catfish stocks are divided into five basic groups: brood fish, fry, fingerlings, yearlings or "stockers," and food fish. Brood fish are adult spawners kept as a source of seed stock. Fry are newly hatched fish shorter than 1 inch. Fingerlings are typically young of the year, 1 to 8 inches long. Yearlings are held for about a year until they reach food-fish size (usually exceeding 12 inches in length and 0.75 pound in weight). The average weights of channel catfish 3 to 25 inches long, by ½-inch intervals, are shown in Table 4.1.

The typical sequence of events in channel catfish culture follows: Brood fish are spawned in late spring or early summer of year 1. Fry are stocked into production ponds and are grown to fingerling size for stocking in the early spring of year 2. These yearlings are harvested as food fish in late summer or fall of year 2 or during winter or early spring of year 3. Culture of fish of sizes suitable for fillets or steaks (2 to 5 pounds) ordinarily requires 1 to 2 additional years. The time from egg to human consumption may thus be as short as 15 months or as long as 48 months. We describe here the fundamentals of each phase of channel catfish culture.

Table 4.1. *Length–weight relation of channel catfish fed formulated feeds. Nonfed fish may weigh as much as 10% less.*[a]

Total length (inches)	Average weight (pounds)	Total length (inches)	Average weight (pounds)
3.0	0.008	14.5	1.07
3.5	0.013	15.0	1.19
4.0	0.020	15.5	1.32
4.5	0.029	16.0	1.46
5.0	0.040	16.5	1.60
5.5	0.053	17.0	1.76
6.0	0.070	17.5	1.92
6.5	0.090	18.0	2.10
7.0	0.112	18.5	2.28
7.5	0.138	19.0	2.48
8.0	0.170	19.5	2.69
8.5	0.206	20.0	2.91
9.0	0.245	20.5	3.13
9.5	0.289	21.0	3.38
10.0	0.339	21.5	3.63
10.5	0.394	22.0	3.90
11.0	0.444	22.5	4.19
11.5	0.523	23.0	4.48
12.0	0.597	23.5	4.79
12.5	0.678	24.0	5.11
13.0	0.765	24.5	5.45
13.5	0.860	25.0	5.80
14.0	0.962		

[a]Adapted from B. A. Simco and F. B. Cross. 1966. Factors affecting the growth and production of channel catfish, *Ictalurus punctatus*. University of Kansas Museum of Natural History Miscellaneous Publication 17(4):191–256.

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Selection and Care of Brood Stock

Source of Brood Stock

The channel catfish is native to streams and lakes of the eastern United States and southern Canada. Originally, brood stock was obtained from natural waters; now, however, the species has been domesticated for nearly 50 years, and most brood stock is hatchery raised. Catfish brought into the hatchery from the wild do not usually make good brood stock, although fish taken from natural waters shortly before the spawning season usually spawn if they are treated with hormones.

Determination of Sex

Sex of brood fish must be determined so that females and males can be stocked in equal numbers or in such other commonly used female to male ratios as 2:1 or 3:2. Some producers who use pens keep the sexes in separate ponds and pair them at spawning time.

The female can be recognized during the breeding season by the folds of skin on each side of the urinary and genital openings, which are raised and divided by a groove. The female usually has the smaller head and mouth. The male has a wider head, thickened lips, and more pronounced development of the head muscles, and is usually darker than the female during the spawning season. Occasionally, when the sex of the fish is not readily apparent, the culturist may apply other techniques to determine sex. For example, the tip of a broom straw thrust forward from the anal fin toward the genital opening is stopped by the papilla of a male but penetrates the genital pore of a female.

Selection of Brood Stock

Larger and older catfish usually spawn earlier in the season than smaller ones and produce fewer eggs per pound of body weight. Culturists prefer brood fish weighing 2 to 10 pounds, although catfish may be mature when they weigh as little as ¾ pound. Fish heavier than 10 pounds are difficult to handle. Channel catfish brood stock can usually be reliably spawned at 3 years of age.

In the selection of brood stock, females should be examined to ensure that abdominal fullness reflects the size of the gonads, rather than the amount of food in the stomach and intestine. The best characteristic indicative of good spawning condition in the female is a well-rounded abdomen, the fullness of which extends posteriorly past the pelvis to the genital orifice. The ovaries when felt through the body wall should be palpable and soft, and the genitals should be enlarged and pink (not bloody). Less attention needs to be given to selection of the male. However, the testes are usually well developed in males with prominent secondary sex characteristics such as a heavily muscled head that is wider than the body, dark pigmentation under the jaw, and a large, protruding genital papilla. Such males can be used to spawn two or three females during the season, whereas those with poorly developed secondary sex characteristics may not adequately fertilize more than one lot of eggs. Fish with abnormally shaped fins, spinal deformities, or other defects should be culled from the brood stock.

Pairing

Correct pairing of fish, which is particularly essential in pen spawning, depends on the skill of the culturist in sexing and selecting the fish. The male and female spawned in a pen should be of about equal size. If they are not, the female should be the larger of the pair. Sex determination is slightly less important in pond spawning.

Males and females often fight during the spawning season, and males constantly fight each other. Their bites are often deep enough to break the skin, and the resulting wounds may become infected. Fish sometimes die from severe bites. Consequently, special care must be taken to pair fish correctly in pens. If the female, in particular, is not ready to spawn, the male fights with her, and in the confinement of a small pen may inflict enough damage in 15 to 20 minutes to kill her. In larger spawning pens, the condition of the female is not as important, because she can often avoid the attacking male. Even so, it is not uncommon to see bite marks on the female in a pen. When fish reproduce in

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ponds, they pair when they are ready to spawn, and fighting is not a serious problem except when the males are competing for spawning sites. Only the pond method should be used if the fish are in marginal spawning condition.

Care and Handling

Since brood channel catfish sometimes fight savagely, it is inadvisable to hold them longer than necessary in close quarters such as a trough or truck tank. They can be safely transported long distances during the spawning season, however, if they are tranquilized or if each fish is placed in a separate muslin bag or other container.

Immediately after the spawning season, the brood fish may be restocked in holding ponds at the rate of 600 to 1,000 pounds per acre. Although the brood fish are more easily frightened than fingerlings or food-sized fish, 90 to 95% of the fish held in small ponds learn to come for feed within a week. However, when brood fish are held in large ponds, 25 or 30% may never come for feed, and consequently will be in poor condition and unsuitable for spawning during the next spawning season. It is desirable to divide the brood fish among several ponds to lessen the possibility of total loss due to an epizootic or oxygen deficiency. Some hatchery managers distribute the adult catfish throughout their total pond system during summer. The scattered fish then need only limited feed because large amounts of natural food are usually available. Since crayfish, if available, predominate in the diet, this practice has the added advantage of being a method of crayfish control. When the ponds are drained in fall and winter, the catfish from several ponds are returned to a single pond and fed commercial feeds until time for spawning. The feeding of brood stock is important because diet quality and quantity largely govern the number and size of eggs, spawning time, and general health.

Feeding rate and diet quality depend largely on water temperature and standing crop. Brood fish should be fed 2 to 3% of their body weight either daily or on alternate days when water temperature is above 55°F; during periods of generally cold weather they should be fed only on the warmer days. During winter, brood catfish prefer cut fish and organ meats, or diets high in animal protein, over cereal-base feeds. Meat diets can be readily digested by the fish, and it is generally accepted that fresh or frozen meat or fish should be included in the diet of brood stock. The addition of forage fish to brood stock holding ponds may meet this need.

Spawning Season, Methods of Artificial Spawning, and Mechanical Hatching of Eggs

Spawning Season

The beginning and duration of the spawning season for channel catfish vary from year to year and among localities. The season may start as early as April in the deep South and end as late as August in the northern States. In any given locality, it may be as short as 2 weeks or as long as 4 months.

Temperature is the critical factor affecting spawning. Spawning activity begins soon after water temperatures remain consistently above 70°F, and drops off sharply at temperatures below 70°F or above 85°F. Sudden drops in temperature below 70°F or increases above 85°F cause fish to abandon nests. Knowledgeable farmers have adequate pumping capacity to raise or lower water temperatures at will, if necessary.

In June and early July, fish in pens or ponds occasionally spawn for a few days and then stop. If the water level is rapidly raised several inches (e.g., by pumping), spawning sometimes resumes immediately. Some farmers inject brood females with human chorionic gonadotropin or fish pituitary before transferring them to a spawning pond or pen.

Spawning can be advanced about 2 weeks by stocking the brood fish into the warmer water of small, shallow earthen ponds; or it can sometimes be delayed by as much as 20 to 30 days by keeping the sexes separated. Spawning may also be delayed by holding the fish in water at temperatures of 62 to 65°F

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during May, June, and July. A farmer who needs late hatches of fish can use small adults obtained from streams in late July or August, or use precocious 2-year-old pond fish that are sexually mature. Since it is usually difficult to induce such fish to spawn naturally, they should be injected with hormones.

Female catfish do not release all their eggs at one time, as females of many other fish species do. Instead, the female positions herself close to the male and releases a few to as many as several hundred eggs. Simultaneously, the male releases milt to fertilize the eggs. The eggs fall to the bottom into a mound, held together by an adhesive material. After a few minutes to an hour, the female again ovulates and the procedure is repeated. The spawning may be completed in an hour or require as long as 20 hours.

Use of Hormones

The hormone injection dosage and procedure are the same, whether fish are bred in ponds or pens. The female is injected intraperitoneally—the needle is inserted through the muscle at the base of the pelvic fin into the body cavity—with human chorionic gonadotropin at the rate of 500 to 800 international units per pound of body weight (Fig. 4.5). Acetone-dried carp pituitary can also be injected intraperitoneally at the rate of 2 mg per pound of body weight. Both types of hormone are suspended in distilled water. The quantity of water should not exceed 1 mL for each 5 pounds of weight of the female fish. An 18-gauge needle must be used to inject the pituitary suspension because a smaller needle often becomes clogged with suspended tissues. The female can be reinjected at 48-hour intervals. Usually the female ovulates within 16 hours after the first or second injection; a third is seldom needed if the brood fish is in good condition, but fourth or even fifth injections may be required if the fish is in marginal condition. Whether these additional injections are given is usually based on economic considerations—on whether the eggs, if obtained, would be worth the cost of the hormone.

The number of eggs can be roughly estimated by weighing the egg mass. Individual masses weigh from ⅓ to more than 6 pounds, depending on the size of the female and the development of the ovaries. The accuracy of estimates of egg numbers based on weight vary because the amount of water in the egg mass, as in a sponge, changes with the size and shape of the mass and to some extent with its age. More water drains from older spawns than from younger ones, and eggs decrease in weight slightly as they near hatching.

Numbers of fry can be estimated rather accurately by counting a volumetrically measured sample of yolk-sac fry and applying this count to the total volume of fry at hand. A simple technique is to siphon the sample of fry into a graduated cylinder (Fig. 4.6) or measuring cup. Gravimetric estimates may also be made; the numbers of yolk-sac fry per fluid ounce range from 750 to 1,800 and average about 1,000.

Methods of Spawning

The three basic methods of artificial spawning of channel catfish, in order of their popularity, are open pond, pen in pond, and aquarium. The aquarium method is now little used; details of this method were treated in the *Second Report to the Fish Farmers,* and are not repeated here.

Pond method of spawning. Only a pond and spawning containers are required for the pond method of spawning, and no demands are placed on the farmer for critically selecting, sexing, and pairing the brood stock. The fish in the pond continue to feed and develop sexually until they pair and spawn. If the brood fish are of marginal quality, spawns are more likely to be produced by the pond method than by the pen method.

Ten-gallon milk cans and small drums are popular spawning containers. *Under no circumstances should a spawning device be made from a container that held PCB's, or other potentially harmful chemicals.* Ordinarily it is not necessary to provide a spawning receptacle for each pair of fish, because not all fish spawn at the same time. Most culturists allow two or three receptacles for each four

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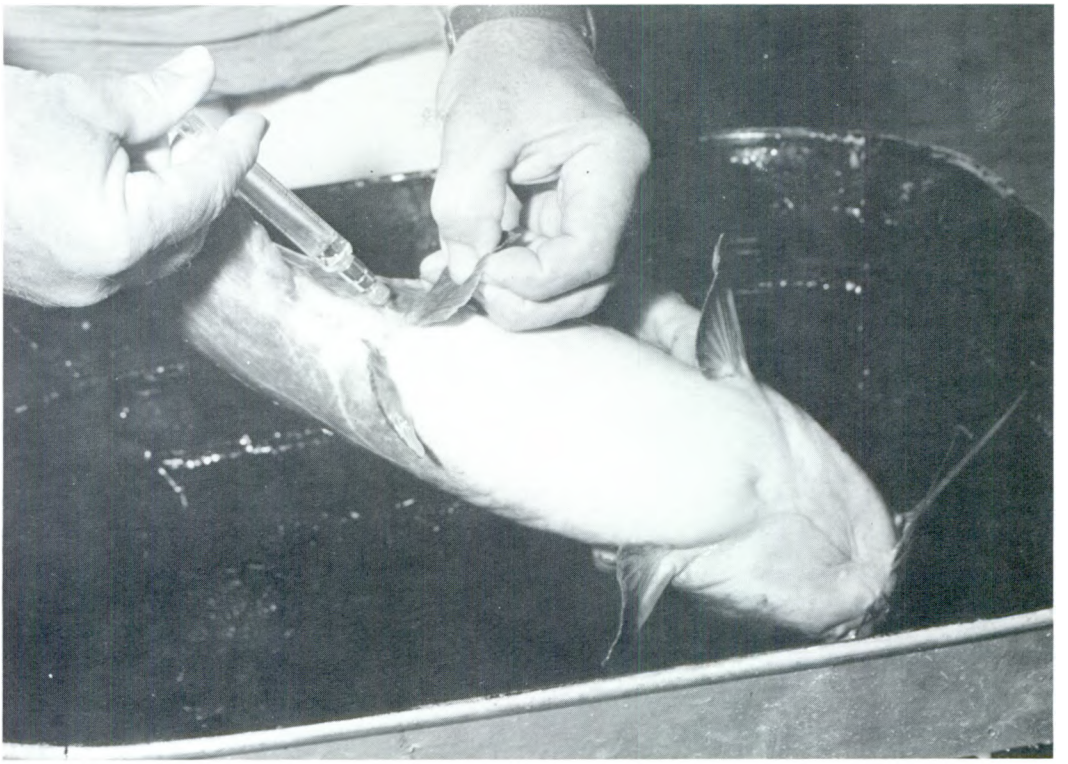


Fig. 4.5. An intraperitoneal injection of 800 international units of human chorionic gonadotropin or 2 milligrams of fish pituitary per pound of body weight induces spawning in female channel catfish. Some fish require two or more injections on alternate days.

pairs of fish. Usually they place the can or drum with the open end toward the center of the pond. Channel catfish have spawned in containers in water as shallow as 6 inches and as deep as 5 feet. The receptacles can be most easily inspected if they are in water no deeper than arm's length. It is desirable to mark the location of each container with a float or stake.

Frequency of examination of spawning containers depends on the number of brood fish in the pond and the rate at which spawning is progressing. Caution should be used, because an attacking male can bite severely. In checking a container, the culturist should gently raise it to the surface. If the water is not clear, the container can be slowly tilted and partly emptied (often the male is then frightened away, but soon returns when the container is replaced) so that the bottom can be viewed for the presence of eggs or fry (Fig. 4.7).



Fig. 4.6. Channel catfish fry can be siphoned into a graduated measuring cylinder and the numbers closely estimated. Note that the fry swim to the bottom and thus facilitate the measurement of volume. *Photo courtesy of E. Thune.*

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Fig. 4.7. A spawning container can be inspected for eggs or fry by carefully raising it to the water surface with the open end tilted slightly downward. The location is marked with a stake. *Photo courtesy of J. Avault, Jr.*

Females that weigh 1 to 4 pounds and are in good condition produce about 4,000 eggs per pound of body weight; larger fish usually yield about 3,000 per pound. Fish in poor condition produce fewer eggs or do not spawn.

After the spawning act is completed, the male drives the female away and cares for the eggs during the incubation period. He assumes a position over the egg mass, moving his pelvic fins alternately in a continuous beat. He usually faces in the same direction (toward the open end of the container), but occasionally circles away from the eggs and returns. The most striking activity of the male is the vigorous shaking of his body as he presses the eggs with the side of his pelvic fins and moves the entire egg mass. Seemingly this act helps aerate the developing eggs, especially those deep inside the mass, but it may also serve to move the embryos within the eggs.

As an alternative to incubation in the pond, the spawn may be removed from the container and hatched in an artificial system. Good incubation and hatching are obtained at some hatcheries by the paddle-wheel method (described later), which simulates the male's agitation of the eggs. Removal of the eggs has several advantages: it prevents or reduces the spread of diseases and parasites from adults to young, provides protection from predation, and may increase the percentage of eggs hatched.

The number of days required for eggs to hatch varies with water temperature. The incubation period ranges from 10 days at 70°F to 5 days at 85°F. At temperatures above 85°F, the embryos develop rapidly but many deformed fry are produced. At temperatures below 70°F, the eggs develop slowly and may die due to the growth of fungus.

When the eggs are hatched in the pond, the fry are often removed and restocked in specially prepared fry culture ponds. To remove fry from a spawning receptacle, the culturist first frightens the male away and then lifts the spawning container to the water surface and pours off part of the water (Fig. 4.7). The remaining water, with the fry, is then emptied into a floating tub already containing water 1 to 2 inches deep. Numbers of fry should be estimated volumetrically (Fig. 4.6), and the fry then moved to either a rearing trough or a pond.

If the fry are to be left in the pond, the brood stock should be removed with a large-mesh seine (1-inch mesh or larger, bar measure). Periodic seining with a small-mesh seine provides a rough estimate of the numbers and rate of growth of fingerlings.

Pen method of spawning. Spawning pens about 10 feet long and 5 feet wide are commonly used by Federal and State hatcheries and by a few commercial hatcheries. The pens are constructed of wood and wire fencing (Fig. 4.8), or of concrete blocks. They may be enclosed on four sides, or the bank of the pond may be used as one side. The sides should be embedded in the pond bottom and should extend at least 12 inches above the water surface to prevent escape of the fish. Water in the pen should be 2 to 3 feet deep.

Location of the spawning receptacle in the pen is not critical, but generally it is placed in the center of the pen, with the opening facing the middle of the pond. The receptacle should be staked down. Ten-gallon milk cans,

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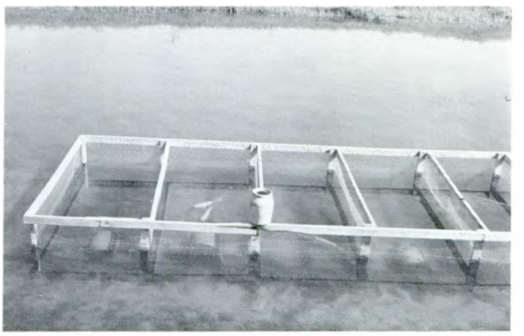


Fig. 4.8. Spawning pens are constructed of wire and lumber, or concrete blocks. Inside dimensions of 5 × 10 feet and water 2 to 3 feet deep provide adequate space for the spawning container and the fish (albino channel catfish shown here).



Fig. 4.9. Catfish hatching troughs are typically 20 to 36 inches wide, 10 to 20 feet long, and 10 inches deep. Spawns are placed in wire baskets attached to the tops of the troughs. Paddles attached to a center shaft rotated by a motor agitate the eggs. *Photo courtesy of J. Avault, Jr.*

100-pound grease drums, and earthenware crocks are commonly used containers. After the parent fish spawn, they may be removed and a new pair of fish placed in the pen. Alternatively, the female may be removed as soon as an egg mass is found, and the male then left to hatch the eggs.

The pen method has several advantages: (1) it provides close control over the time of breeding, because spawning may be delayed by separating females from males, or hastened by using hormones; (2) it allows selected individuals to be paired; (3) it facilitates removal of spent fish to a separate pond where they can be given special care; and (4) the pen protects the spawning pair from intruding fish. To succeed with the pen method, the culturist must be able to judge the condition of the fish well enough to be able to pair the right fish at the right time.

Mechanical Hatching of Eggs

All hatching devices must provide sufficient agitation to supply the entire egg mass with oxygenated water of suitable temperature. Although hatching jars have been used for incubating catfish eggs, they generally yield poor results.

When eggs are hatched in troughs (Fig. 4.9), they are agitated with paddles driven by an electric motor or a water wheel. The agitation should be sufficient to move the whole spawn, but not enough to throw eggs out of the holding baskets. If well water is used, it must be aerated and of suitable temperature and quality. Water suitable for rearing channel catfish fry, or for holding bait minnows, is usually adequate for egg hatching. Water containing dissolved iron or hydrogen sulfide is not suitable. The presence of dissolved iron can be easily detected by a rust-like scum or reddish-colored water in the trough, and hydrogen sulfide is detected by the rotten-egg smell of the water. Gravity-flow water should be used if available, because such a water delivery system reduces the possibility of failure.

Trough hatching systems may be constructed from a variety of materials. Aluminum is commonly used, but wood, fiberglass, or steel serves equally well. Typical hatching troughs are 20 to 36 inches wide, 10 to 20 feet long, and 10 inches deep. Some producers use steel pipes 30 inches in diameter that have been split lengthwise and closed at the ends. A divider can be placed at mid-length to strengthen the tank or to separate spawns of different ages. In each section, 1- to 2-inch collars and nipples serve as drain or overflow structures.

Agitation paddles are attached to a steel shaft or pipe that is supported by pillow bearings and extends the full length of the hatching trough. Paddles are constructed of aluminum or galvanized tin and are spaced to allow spawn baskets between each set of paddles.

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The paddles are commonly 4 inches wide and long enough to dip well below the bottom of the baskets as they turn. The pitch of the paddles is adjusted as required to ensure vigorous movement of spawns in the baskets.

The shaft is fitted with a pulley at one end and is belt- or chain-driven by an electric motor (frequently ½ horsepower). A gravity-powered water wheel can be used where power outages frequently occur. The preferred shaft speed is 30 rpm. Combinations of pulley sizes or a variable-speed gear box can be used to provide the desired speed.

Spawn baskets are usually 18 to 34 inches long, 12 inches wide, and 4 inches deep, and constructed of ¼-inch hardware cloth. Each basket is divided into four to six equal sections and fitted with wire hooks so that it can be positioned at the proper depth in the trough.

Hatcheries must have a standby source of emergency electricity in the event of a power failure. An emergency water storage tank can supply water by gravity flow, but only for a period of time determined by the flow rate and tank capacity.

For egg incubation, temperatures below 70°F and above 85°F should be avoided. Temperatures of 78 to 82°F are considered ideal. Extremes above or below this range adversely affect development and may result in deformity or mortality. In the 78 to 82°F range, the eggs hatch in about 8 days. Eggs are very sensitive to sudden temperature changes, and must be tempered gradually if temperature differences exceed 5°F. Provisions for aerating eggs must be made during the tempering process.

In hatcheries, well water is piped directly into the hatchery or indirectly through a fish-free pond. In the indirect "pond" method, the water is warmed and contaminants such as dissolved iron, hydrogen sulfide, and carbon dioxide are eliminated. Most culturists heat the water to 78°F or cool it with well water to that temperature before it enters the troughs.

A flow of well-aerated water at the rate of about 2.5 gallons per minute should be provided for each typical hatching trough. It is important that spawns in each section of the trough be of the same age; the mixing of spawns of different ages may prevent the use of prophylactic treatments and results in the stocking of fry of different ages.

Table 4.2. *Stages of channel catfish egg development at 78°F, as observed with the unaided eye. (For each increase of 2°F above 78°F, subtract 1 day from incubation time; for each 2°F decrease below 78°F, add 1 day to incubation time.)*

Distinctive feature	Age (days)
No internal pulsation	1
Pulsation visible	2
Bloody streak visible	3
Entire egg bloody in appearance	4
Eyes visible	5
Eyes prominent; embryo turns in shell	6
Embryo complete; no bloody streak present	7
Embryo begins to break from shell	8

Color of the egg mass is an important indicator of the condition and stage of development of channel catfish eggs. During normal development, the yellow egg mass turns pink and then red as the embryo develops and establishes its blood supply. Unfertilized or dead eggs turn white and enlarge. Information on the stages of development of channel catfish eggs, which enables the culturist to predict the remaining time required before hatching begins, is given in Table 4.2.

To remove fry from the hatching trough, the culturist simply siphons them from the trough with a hose into a washtub or pail. They should be counted volumetrically as described earlier (Fig. 4.6).

The only compound now approved for the prevention and control of fungus on catfish eggs is betadine, an iodide. However, farmers are advised to practice good hygiene, and sterilize the tanks before and after use. Maintaining incubation temperatures of 78 to 82°F and ample water exchange allows for a normal rate of development and hatching before fungus growth becomes a problem. A water heater (and sometimes a water cooler or source of cold well water) allows the aqua-

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culturist to regulate water temperature. We recommend discarding or hatching separately any egg masses that are already diseased.

Culture of Fry and Fingerlings

At the time of hatching, the fry settle to the bottom; they have a conspicuous yolk sac, and are called sac fry or yolk-sac fry. These fry can either be stocked into rearing troughs or moved directly to a specially prepared rearing pond. In troughs they are held until they have absorbed their yolk sacs and have developed a grayish color. These fish, now called swim-up fry, rise to the surface to seek food.

Trough Method

While the swim-up fry are in the troughs, it is mandatory that suitable formulations and allowances of feed be offered. Channel catfish eat a variety of feeds, including commercial dry formulations, organ meats such as beef liver, and live organisms such as brine shrimp. Feeding frequency and food particle size are important considerations. Young fry should be fed every 2 to 4 hours around the clock, and older ones at least four times daily.

Troughs for fry have various dimensions, but commonly are 8 to 12 feet long, 15 to 30 inches wide, and 8 to 10 inches deep. They may be made of fiber glass, wood, aluminum, or stainless steel. Galvanized steel should be avoided. Water should enter at the head of the trough at the rate of 1 to 5 gallons per minute, and drain at the lower end through a screened standpipe. Usually no more than 25,000 sac fry should be stocked per 1 gallon per minute of water exchange. A screened agitator, or air stones, may be used to supplement the oxygen supply.

Once the fry have begun to feed well, the culturist has several options: stocking them directly into a pond, where they are grown to salable size; waiting until the fry are about ¾ inch long before they are stocked into a pond; or dividing the fry among more troughs and growing them to still larger sizes before they are transferred to ponds. The use of troughs to raise fry to fingerling sizes offers good control over culture conditions; however, it is labor and energy intensive, and the fish become especially susceptible to partial loss due to disease, and to total loss due to power failures. As a result, few culturists raise fry to a size much longer than ¾ inch before transferring them to ponds to grow to a size suitable for stocking into still other ponds, for development to food-fish size.

Pond Method

Before fry rearing ponds are stocked, they should be dried and the depressions and wet spots treated with slaked (hydrated) lime to kill competitor and predator fish, as well as parasites. If soil tests indicate the need, agricultural lime should be applied while the pond is dry.

At this time any depressions that are likely to interfere with harvesting the fingerlings should be filled, and any holes through the levees that would allow contamination from adjacent ponds must be repaired. Screens should cover the inlet water supply pipe to prevent the entrance of fish predators, and the outlet pipe to prevent the escape of catfish fry and fingerlings.

Just before the ponds are filled, it is also desirable to apply herbicides to prevent the emergence of rooted aquatic plants, and to add nutrients to stimulate the growth of phytoplankton and zooplankton. Phytoplankton shades the pond bottom and thus retards the growth of vegetation. Zooplankton (e.g., copepods and daphnids) is an excellent food for young catfish. Many types and forms of nutrients have been successfully used. One good combination consists of three constituents (per acre of water): 100 to 200 pounds of 20–20–0 (N–P–K) inorganic (chemical) fertilizer; 200 to 500 pounds of organic materials such as cottonseed meal, alfalfa meals, and manures; and two to five bales of hay (Fig. 4.10).

Fry stocked at 30,000 per acre in June should reach an average length of 6 to 8 inches in October; those stocked at 140,000 per acre reach only 3 to 4 inches in the same period (Table 4.3).

As an alternate to a single stocking and single harvest program, a fingerling producer

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Fig. 4.10. Hay and other types of plant vegetation are often used as organic fertilizers in channel catfish fingerling ponds. The addition of chemical fertilizers and oilseed protein meals supports the growth of daphnids and copepods, which are eaten by small catfish. *Photo courtesy of J. Avault, Jr.*



Fig. 4.11. In harvesting channel catfish fingerlings, the fish are seined, netted, and placed into tubs as shown here, and transferred to another pond or to the fish holding facility. It is important not to stress the fish by overcrowding them or exposing them to extreme changes in temperature. *Photo courtesy of Arkansas Game and Fish Commission.*

may plan to make multiple harvests from a pond (Fig. 4.11). If so, as many as a million swim-up fry per acre are stocked and fingerlings are harvested monthly. Up to half of the fry might be harvested within a month, at a length of ¾ to 1 inch. The number removed each month has a direct effect on growth of the ones that remain. Generally, when growth of the fish declines or ceases, it is essential to remove some of them so that the rest will continue to be in good physiological condition, and not readily susceptible to infectious diseases.

When swim-up or advanced fry are stocked in a pond, they must be fed several times a day along the edge of each pond. Because they are so small, they should not be fed on the basis of a percentage of their body weight. Rather, 10 to 25 pounds of feed per acre should be offered daily, divided into two or

Table 4.3. *Stocking guide for production of channel catfish fingerlings during a 120-day growing season.*[a]

Number of fry stocked per acre	Length at harvest (inches)	Production (pounds per acre)[b]
10,000	7–10	1,600–4,700
15,000	6–8	1,000–2,500
30,000	6–8	1,800–4,700
50,000	5–7	1,600–4,500
73,000	4–6	2,100–4,500
95,000	3–5	1,050–3,000
100,000–120,000	3–5	1,300–4,000
140,000	3–4	1,500–3,100
500,000	2	1,000–2,000

[a]Adapted from data supplied by J. Chappel, Farm Fresh Fish Corporation, Lake Village, Arkansas; and J. J. Giudice, U.S. Fish and Wildlife Service, Fish Farming Field Station, Jackson, Mississippi. (unpublished)
[b]Range depends on fish survival rates.

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three feedings. As the fish grow larger, the pellet size can be increased and the feeding rate adjusted to the standing crop weight.

Production of Food-sized Fish

Channel catfish are cultured to food size in extensive and intensive production facilities. In extensive production, which is commonly carried out in hill-type ponds with no supplemental water supplies, strip-mining pits, irrigation reservoirs, or marginally managed ponds, the yield is generally less than 1,000 pounds per acre. In intensive production, which is done in earthen dike-type ponds and well-managed hill ponds, as well as in cages, pens, raceways, and silos, the annual harvest usually exceeds 2,500 pounds per acre.

Extensive Production Facilities and Culture

Extensive production facilities provide from several hundred to about 2,000 pounds of channel catfish per acre per year. Although the unit harvest is small in comparison with that for some intensive production systems, the total harvest can be rather large because the acreages are often large. Areas of irrigation reservoirs are usually 500 to several thousand acres, and strip-mining pits of several hundred acres are common. Since fish production is secondary, the cost of water and facility maintenance is not considered, and thus the cost of fish production is usually low. Hill ponds are usually smaller, but they may also produce fish profitably since their primary use is generally for erosion control and livestock watering.

Several levels of management can be considered. The lowest level consists of maintaining through periodic restocking a population of 50 to 200 fish per acre. The fish are not fed, and the water is not fertilized. Fish are generally harvested by trapping or by hook and line. Anticipated annual production is between 50 and 200 pounds of fish per acre, depending on the natural soil fertility.

The next level of management is the stocking of 200 to 500 fingerling channel catfish per acre each year. Generally these fish are not offered supplemental feed but instead the waters are enriched with chemical fertilizers or animal manures. Fertilization recommendations for farm ponds are applicable, and can be secured from the County Cooperative Agricultural Extension Service. Fish are usually harvested by trapping and hook and line, and the annual yield is typically 300 to 600 pounds.

Higher production generally requires supplemental feeding. At production levels less than 2,000 pounds per acre, feed conversion values are commonly as good as 0.8 to 1.5 (i.e., 0.8 to 1.5 pounds of dry catfish feed yield 1 pound of catfish flesh) because the fish eat considerable amounts of natural food to supplement the manufactured feed. The farmer takes advantage of this natural food and offers the fish the supplemental commercial feed at the rate of 1 to 2% of the standing crop weight. Fish are usually harvested by trapping, hook and line, or draining of the pond or reservoir. However, the high cost of energy for pumping has virtually eliminated the annual draining of ponds, except for those that can be readily refilled by rainfall or groundwater seepage.

Feed requirements in extensively managed production systems depend primarily on stocking levels and the amount of natural food available. Generally, the manager stocks 500 to 2,500 fish per acre. These stocked fish must be large enough to escape predation from other fish that are invariably present. The manager counts and weighs the fish to be stocked. Feed is offered at the rate of 1 to 3% of the weight of the standing crop per day during the period when the water temperature exceeds 70°F. The high feeding rate results in fast growth. At intervals of 2 to 4 weeks, a sample of fish is obtained by hook and line, seining, or trapping; a new standing crop value is estimated; and a new daily feed allowance is calculated. It might, for example, be calculated as follows: If 1-ounce fingerlings are stocked at a rate of 1,000 fish per acre, the standing crop equals stocking rate (1,000) $\times$ average weight (1 ounce) = (1,000 $\times$ 1) $\div$ 16 (ounces per pound), or 63 pounds. The feed allowance equals the

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standing crop (63 pounds) × feeding rate (0.03, or 3% of body weight), or about 2 pounds per acre per day.

Many management variables are apparent to the enterprising fish producer who uses extensive fish-production facilities. It is important to capitalize on the advantages inherent in his production system, such as the natural food and alternate water use. Although the monetary gross income is less in extensive than in intensive production, the overall profit can be significant and can provide a substantial supplemental income to the farmer or landowner.

Intensive Production Facilities and Culture

Intensive production facilities include the earthen ponds where production exceeds 2,000 pounds per acre per year, and containers where the standing crop exceeds 1 pound per cubic foot of water. Almost all commercial catfish production takes place in either dike-type or well managed hill-type earthen ponds.

Techniques for intensive production of channel catfish in ponds. Channel catfish in intensive production normally require 15 to 18 months to reach harvest sizes of ¾ to 1¼ pounds, and an additional 1 to 2 years to reach fillet or steak size of 2 to 5 pounds.

There is no single recommended stocking rate for channel catfish grown for food. Rates may vary from 1,500 fingerlings per acre in irregular, hard-to-seine hill ponds in Alabama to 4,000 or more in easy-to-seine dike ponds such as those in the delta area of Mississippi.

Harvest size of the fish is determined to a great extent by the stocking rate. Fewer fish can be stocked when the harvest size desired is 2½ pounds than when it is ¾ to 1¼ pounds. However, regardless of stocking density, growth is not uniform. A sizable proportion of the 6- to 8-inch fingerlings (yearlings) stocked in March reach ¾ to 1¼ pounds by July. These larger fish compete with the smaller fish and slow their growth. Thus production can be increased by cropping the larger fish so that the smaller fish remaining have more space. Several such harvests must be made when stocking numbers and standing crop weights are high, if maximum production is to be attained. This management strategy is practiced in such areas as Mississippi, Arkansas, and Alabama, and provides most of the channel catfish currently produced in the United States.

Fingerlings 6 to 8 inches long, stocked at the rate of 3,000 per acre, reach a weight of about 1¼ pounds in a 180- to 210-day growing season. Carrying these fish over the winter produces fish in the 1½- to 2-pound class by late spring or early summer of the next year. Fish farmers in central Arkansas and in Oklahoma and Texas cater to fee-fishing, live hauling, and local consumer markets that demand the larger fish.

In the past decade, many catfish farmers have ceased draining their ponds annually. Rather, the ponds are periodically restocked to replace the fish that have been harvested. Some farmers stock two sizes of fingerlings at the same time: 6- to 8-inch fish and 2- to 3-inch fish (Fig. 4.12). The larger fish are harvested during the ensuing fall. The smaller fingerlings grow to lengths of 6 to 8 inches during the growing season, and 2- to 3-inch fingerlings are then again stocked into the pond. Unfortunately, inventories are especially difficult to maintain for such ponds.

Research results now available support the contention that a stocking rate of about 10,000 fingerlings per acre maximizes the production of a pond system with current technology. This level of production should be approached only with caution by experienced farmers, and avoided by novices. Feeds are fed in the maximum amounts that can be assimilated by the pond system, up to the amount that will be eaten by the fish. A fixed percentage rate is usually not applicable. The feed allowance varies, depending on water temperature, amount of water exchange, and whether supplemental aeration is being used. Generally the feed allowances are 75 to 150 pounds per acre per day, the amounts required to support biomasses of 3,000 to 5,000 pounds of fish per acre. Partial harvesting is also required periodically throughout the year to ensure maximum production.

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Fig. 4.12. Channel catfish fingerlings are usually graded to 1-inch groups for stocking into intensive production ponds. One technique is to stock both 6- to 8-inch and 2- to 3-inch fish. The larger fish then grow to harvestable size and the smaller fish grow to the 6- to 8-inch length by fall. The farmer needs only to restock the smaller fish each fall to perpetuate the production scheme.

Research findings on channel catfish physiology and behavior can assist the farmer in producing higher quality fish. Seasonal changes affect the body composition of channel catfish. This information is especially important when fish are being selectively harvested throughout the year. A recent study by the U.S. Fish and Wildlife Service showed that dressed weight as a percent of total weight was highest (59) for both sexes in September and lowest (52 for males and 50 for females) in November (Table 4.4). This difference of 7 to 9 percentage points was not solely a function of gonad development but apparently also included an accumulation of smaller differences in the weights of other tissues. The seasonal variation in dress-out weight results in a considerable difference in the price of fish to the

Table 4.4. *Seasonal variations in body characteristics and composition of intensively cultured channel catfish.*[a]

Month	Standard length[b] (cm)	Weight (g)	Dress-out percent[c]		Gonadosomatic index[d]		Lipsomatic index (%)	Hepatosomatic index (%)	Liver		Muscle	
			Males	Females	Males	Females			Lipid (%)	Water (%)	Lipid (%)	Water (%)
Jan	27.1	304	56.6	56.3	0.11	0.54	1.89	2.15	1.60	24.6	3.62	27.1
May	29.3	400	52.9	54.9	0.14	2.03	1.35	2.05	2.14	22.7	3.07	24.8
Jul	32.9	576	54.9	55.7	0.21	3.31	1.83	1.81	3.27	24.2	2.31	28.7
Aug	33.5	602	57.9	58.4	0.18	0.32	1.94	1.70	3.28	23.0	2.00	22.8
Sep	33.9	624	59.4	59.3	0.22	0.44	2.13	1.45	2.24	26.4	1.52	21.9
Oct	35.0	690	54.4	54.0	0.33	1.78	1.37	1.86	1.80	25.2	1.83	21.5
Nov	35.0	710	52.2	50.2	0.25	2.80	1.19	1.93	1.75	24.5	1.47	21.8
Jan	36.8	824	56.9	56.3	0.26	2.91	0.97	2.17	1.77	25.6	2.41	23.4

[a]Adapted from N. C. Parker. 1982. Seasonal changes in body composition of channel catfish. Pages 34–35 *in* Proceedings of the Fourth Annual Research Workshop, Catfish Farmers of America, Biloxi, Mississippi, 17–19 January 1982.
[b]Length from end of snout to base of the caudal fin (where a groove forms when the tail is bent upward) as measured on a measuring board.
[c]Percent of body weight: (weight of dressed fish/weight of intact fish) × 100.
[d]Percent of body weight contributed by gonads: (weight of testes or ovaries/weight of intact fish) × 100.

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retailer and consumer. Body fat content was especially high from July to September. This observation is of concern because compounds producing off-flavors in fish accumulate in body fat, and off-flavor problems thus tend to peak during these same months.

Information on channel catfish distribution patterns should enable a fish farmer to improve culture practices such as feeding, spawning, disease treatment, harvesting, and pond reclamation. Feeding rates decline markedly in cold weather but total consumption increases if feed is supplied where fish are concentrated. Spawning containers can be placed closer to the brood fish; in at least one study, this practice increased the number of spawns. It is also much easier and less costly to treat fish for disease in a small volume of water where they are concentrated than to treat an entire pond. Furthermore, harvest effort can be reduced if the farmer knows where the fish are located.

In a useful and informative study by a group of researchers in Oklahoma, floating markers were attached to channel catfish in a pond equipped with demand feeders, so that movements of the fish could be monitored throughout the year. Fish in one pond were in four length categories (18, 14, 12, and 10 inches), and those in another pond were of more uniform size (12 to 14 inches). There were three clearly defined behavior patterns: (1) occupancy of home areas; (2) a daily trip to the feeder; and (3) feeding. When fish were not in their home areas, they were moving back and forth to the feeder along specific routes or swimways. The pond bottom in home areas and swimways was hard and free of silt but the rest of the bottom was covered with a layer of soft silt and mud. In ponds stocked with similar-sized fish, home areas were fewer and larger, and swimways were fewer but wider, than in the ponds stocked with mixed-sized fish. Distribution was seasonal. Home areas and swimways were in shallow water in fall and spring, but in deeper water during winter and summer.

Swimways to the feeding area were direct in summer. Some were also direct in spring and fall, but swimways near the edge of the pond were more heavily used. This choice of swimways seemed to be a response to the higher temperature in shallow water. There was little movement in winter and no swimways were formed. Fish were relatively inactive at temperatures below 55°F.

The information from this Oklahoma study should prove useful to pond managers, but it should be noted that winter water temperatures are much lower there than in central Mississippi and western Alabama. Therefore, activity patterns may not be restricted as much as they were in the Oklahoma study, or for as long a period. Farmers in warmer areas might do well to mark some fish and observe their behavior, especially in cold weather, when feed and medicaments must be precisely placed.

Beginning catfish farmers need to collect information on growth rates of their fish; experienced farmers generally know what to expect. The anticipated standing crops of channel catfish stocked in ponds as 5-inch fingerlings at rates of 2,000, 3,000, and 4,000 per acre near Auburn, Alabama, are given in Table 4.5. Since various factors affect growth rates, this information is approximate and

Table 4.5. *Expected monthly standing crop (pounds per acre) of channel catfish for ponds (Auburn, Alabama) stocked at three rates with 5-inch channel catfish fingerlings on 1 March. Fish fed at 3% of body weight, 7 days per week.*[a]

Month (1st day)	Stocking rate (number of fingerlings per acre)		
	2,000	3,000	4,000
March	74	111	148
April	119	173	227
May	195	278	357
June	326	453	571
July	535	726	898
August	895	1,184	1,436
September	1,495	1,930	2,295
October	2,300	2,970	3,401

[a]Department of Fisheries and Allied Aquaculture, Auburn University, Alabama. (unpublished)

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may not apply to other areas—particularly those with a colder or warmer climate than that in the mid-South.

Production of channel catfish in cages and pens. Cages and pens provide commercial fish producers, resource managers, or even fish hobbyists with the opportunity to use strip mines, gravel pits, lakes, and large reservoirs that cannot be seined, drained, or otherwise readily harvested. Cages and pens allow for the production of several, often noncompatible, species at the same time. For example, channel catfish can be grown in cages and largemouth bass or other large predator species can be left free in the open water, or trout can be cultured during winter in cages placed in catfish ponds (Fig. 4.13).



Fig. 4.13. Floating net pens used for the production of trout in winter and channel catfish in summer. Pens vary in size but typically are 40 feet long, 20 feet wide, and 15 feet deep. Feed is transported to the pens in a boat or sometimes scattered from a floating walkway.

Cages are constructed of metal or treated wood and covered with treated nylon netting, vinyl-coated welded wire, galvanized hardware cloth, or plastic hardware cloth. They are commonly about 4 feet long, 3 feet wide, and 3 feet deep. Pen sizes vary, but units used successfully by the Arkansas Game and Fish Commission are 40 feet long, 20 feet wide, and 15 feet deep. Pens usually have no frame support, and are fabricated from treated nylon netting. Plastic flotation materials are used to maintain the level of both cages and pens in the water.

Cages and pens are usually stocked with channel catfish 7 to 8 inches long, at a density of 8 to 9 per cubic foot. Only good quality fish, free of infectious diseases and parasites should be stocked. Extreme care must be exercised in the transport and stocking of the fish to ensure high survival and rapid growth. A nutritionally complete floating feed, 35 to 38% protein, is required for good production of catfish in cages and pens. A medicated feed should be offered for the first 10 to 14 days after stocking to reduce losses from stress and disease. A good rule when feeding is to offer the amount of feed that the fish will eat in 10 minutes. The fish should be fed at least 6 days each week.

The fish should be observed for signs of distress or disease. These observations are important during the feeding period. If feeding activity lessens, the water should be analyzed for dissolved oxygen and other key chemical characteristics, and the fish inspected for signs of nutritional deficiencies and infectious diseases. If dissolved oxygen in the cages and pens falls below 1.5 ppm, emergency aeration should be started, and fresh water added if available.

Although channel catfish can be produced commercially in cages and pens, the technique has a number of disadvantages. The body of water must be at least 5 acres in area if such production is to be commercially feasible. (A smaller pond could be used for producing a few fish for personal use.) The cost of constructing cages is relatively high, partly because durable, strong, and rust-resistant materials are expensive. A hole in the wire, or destruction of the cage by wind or waves, can result in the loss of the fish. The nutritionally complete, floating fish feed usually required is more expensive than the type of feed used in pond culture. Aeration equipment is often necessary because oxygen requirements are higher for confined fish than for fish in open ponds. Incidence of infectious diseases and parasites may be increased because the fish are stressed by crowding. It is often more difficult to apply chemical treatments and to harvest fish in cages than in

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Fig. 4.14. Circular tanks provide excellent facilities for research studies with feeds or selective breeding. Facilities of this type are unsatisfactory for commercial production because of the high cost of pumping water. *Photo by Southeastern Fish Cultural Laboratory.*

ponds. An overlooked but often economically destructive element is vandalism, when the fish are stolen or the cages destroyed. A producer should not expect to produce more than 1,500 pounds of fish per acre per year by cage culture unless there is a significant inflow of fresh water, or aeration devices are used.

Production of channel catfish in containers. In container culture systems, different types of production facilities are used. Linear raceways, circular raceways, tanks (Fig. 4.14), and vats are common examples of equipment used to produce catfish and other warmwater fishes. These facilities are similar in operation in that water of good quality is continually added to supply oxygen and to dilute or flush out the uneaten feed, feces, and metabolic wastes that are detrimental to fish. These production systems are also similar in that everything needed by the fish must be supplied by the manager from outside sources.

Water used in container systems can come from springs, wells, or surface sources. The availability of adequate amounts of water of suitable quality at an affordable price is a major hindrance to the development of this system of culture. Spring water is often too cool for good production, and well water is often both too cool and too expensive (because of pumping costs) for use. Surface water, such as that from streams and large reservoirs, may be expensive to pump or may contain pesticides and disease organisms. Often legal and environmental constraints prevent the use of these waters.

In some container production systems, water reuse techniques have been used. Several techniques that have been devised and

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tested have different degrees of biological and economic feasibility. Many are energy intensive, and thus costs are prohibitive. All of these systems require pumping. The simplest method involves oxidation and settling out (in a large pond or reservoir) the waste materials in the water from the production system. Plants such as hyacinths and animals such as mussels, which can filter nutrients from the water, are often used to increase the efficiency of the water cleanup. Aerators, separators, and filters used in sewage treatment are uneconomical in this type of operation. As in all types of aquaculture, the fish producer should determine the cost of water cleanup before constructing the facilities.

Heated water from electric power generation plants has been proposed for aquaculture in winter. This heated water has been used in several research and commercial container systems. The systems work, but the deficiencies are great. For instance, most cooling water effluent contains toxic antifouling chemicals and metals. Also, power plants sometimes shut down unexpectedly in cold weather, and the entire fish crop may be lost; and often the effluent water is too hot in summer, necessitating an alternate water supply.

At some sites, good quality geothermal water is available for warmwater aquaculture. However, legal constraints (water laws) can limit the use of water from these sources.

Container culture systems require the feeding of high quality, nutritionally complete feeds. In contrast to pond culture systems, the water supply usually provides no supplemental protein or vitamins.

Production of channel catfish in raceways. Raceways are of two general types, linear and circular. They may be made of concrete, stone, treated lumber, earth, or a combination of these materials. For example, a raceway may have concrete side walls and bottom, concrete side walls and gravel bottom, treated lumber side walls and gravel bottom, or (if soil stability permits) earthen sides and bottom (Fig. 4.15). Selection of the material must be based on construction economics, but potential disease, excess seepage, and durability must all be considered.

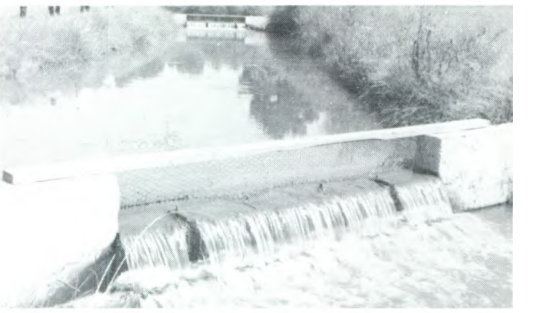


Fig. 4.15. Earthen raceways can be used to produce channel catfish, provided that sufficient low-cost water near 82°F is available to carry away waste and to provide adequate dissolved oxygen. However, such water is not available in most areas where channel catfish are produced. *Photo courtesy of K. O. Allen.*

Many linear raceway designs are in use. One commercial facility has concrete units 20 feet wide by 96 feet long, divided into 12-foot sections. Water depth is about 2.5 feet at the shallow end and 3 feet at the deep end. Water temperatures of 80 to 83°F are maintained year-round by mixing geothermal water at 90 to 95°F with cooler spring water. All water transfer is by gravity, and no mechanical aeration is used. The raceways are constructed to provide "splash" aeration every 12 feet along their length. Production of fish per 12-foot section is 5,000 pounds with a water flow of 1,000 gallons per minute or 10,000 pounds with a flow of 2,000 gallons per minute (total carrying capacity, 10 pounds per cubic foot).

A commercial earthen raceway facility that involved an oxidation pond in a recirculation system was moderately successful. The raceways were 100 feet long and were supplied with reused water from an adjacent oxidation pond. Production was 0.5 pound per cubic foot at an exchange rate of 500 gallons per minute and 4 ppm dissolved oxygen. However, the pumping cost related to water reuse made this system unprofitable.

Circular raceway systems are rather limited. In one commercial system, channel catfish were cultured in a series of units of 7,000, 12,000, and 36,000 gallons supplied with blended geothermal hot water and cool well

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water to provide a constant 84°F. Liquid oxygen was used to increase the carrying capacity of the system. The units were arranged in a series in which each 7,000-gallon unit was initially stocked with 200,000 channel catfish about 2½ inches long. Stocking density was about 0.4 pound per gallon. It required 4 to 5 weeks for the fish to reach a density of 0.8 pound per gallon, the optimum carrying capacity.

The production strategy was to grade the fish at the sizes of 4, 6, 8, and 10 inches to separate out the faster growing fish, and then to restock them in progressively larger tanks. At a constant water temperature of 84°F, the 2-inch fingerlings reached weights of 1¼ to 1¾ pounds in only 9 months.

Vats and tanks in channel catfish production. Although vats and tanks can be used to culture food-sized catfish, they appear to have little commercial application. Some research groups use tanks and vats equipped with once-through water supplies, or recirculating water supplies, to maintain test fish. The once-through water systems are usually supplied with activated charcoal dechlorination equipment, an aeration system to provide oxygen and eliminate nitrogen, and a device for controlling water temperature.

Some innovative recirculating systems incorporate hydroponic tanks. Vegetables grown in these tanks extract waste products and provide useful crops. Tomatoes, cucumbers, and lettuce have done well in such tanks. However, the economics of this system are as yet unproven.

Recirculating water systems are more complex than the flow-through systems. The ratio of biological filter to tank volume, and the supplemental oxygen requirement, are high because both biological and chemical oxygen demands are high. The researcher must pay particular attention to the buildup of metabolic products in the water.

Culture of Channel Catfish and Flathead Catfish Compared

As we mentioned earlier, many aspects of the culture of flathead catfish are similar or identical to those for channel catfish. However, there are several key differences, a knowledge of which is essential for successful production of flathead catfish. The flathead is a predator with a strong preference for live fish, and it has a voracious appetite. The fish at all sizes are extremely cannibalistic. However, techniques are available to the culturist for monitoring the brood fish and producing small fingerlings and a limited number of larger fish suitable for fishery management purposes.

Selection and Care of the Brood Stock

The brood fish can be cultured at the hatchery or captured from natural waters. Little domestication of flathead catfish stocks has been attempted. Inasmuch as at least 3 years are required to produce brood fish, it is nearly always more economical to collect them from the wild. These fish can be obtained by trapping, hook and line, or electrofishing. Capture of flathead catfish by hook and line or by trapping is often permitted in State waters after the appropriate commercial fishing permits, or sometimes sport fishing licenses, are obtained. Most States have stringent laws prohibiting electrofishing, and thus capture by this method is usually limited to governmental agencies. However, electrofishing should be used only as a last resort because of the extreme sensitivity of the species to electricity. Brood fish captured at the normal spawning time may be taken directly to the hatchery to spawn. These fish can also be saved for brood fish for future spawning.

Larger and older flathead catfish usually spawn earlier in the season than do smaller ones, and produce fewer eggs per pound of body weight. Culturists prefer 5- to 20-pound brood fish, although flathead catfish may mature when they weigh as little as 2 pounds. Fish heavier than 10 pounds are difficult to handle (Fig. 4.16).

Care must be taken not to injure the brood fish. Placing each fish in a muslin bag before putting it in a transport tank is recommended. Addition of 1 to 2% table salt, 2 to 5 ppm

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Fig. 4.16. This male flathead catfish (estimated weight, 40 pounds) is difficult to handle, and its transport requires an oversized tub. However, this is an excellent quality brood animal because of its overall good condition and prominent secondary sex characteristics, including a heavily muscled head wider than the body and dark pigmentation under the jaw. *Photo by Southeastern Fish Cultural Laboratory.*

Furacin,[x] and 15 to 30 ppm quinaldine[x] to the water in the transport unit is often beneficial.

Brood fish can be produced in a hatchery by stocking 100 to 200 large fingerlings per acre and providing large amounts of forage fish for their food. At least 1,000 pounds of forage fish each year must be made available for each 100 pounds (standing crop) of flathead catfish. Forage fish should be added frequently throughout the year. Almost any fish small enough to be swallowed are suitable.

Methods of Spawning and Hatching

There are three methods of spawning flathead catfish—open pond, pen, and vat. The pond and pen methods of spawning are identical with those for channel catfish previously described.

The pond method is preferred when the brood fish are of marginal quality, and only a few spawns are required. The disadvantage of the method is that the spawns are obtained over a long period; each hatch, when obtained, requires the same round-the-clock attention if good survival and growth of the fry are to be obtained.

The pen method somewhat overcomes the disadvantages of the pond method, especially if hormone inducement is employed so that the fry obtained are of equal age. However, inspecting the spawning containers is time-consuming and troublesome.

The method of choice for spawning flathead catfish is the vat method (in which concrete fish-holding vats are used), coupled with hormone assistance. Usually the egg or fry requirements are less for flathead catfish than for channel catfish, and the space in vats is usually adequate. In vats the fish can be continually observed, can be easily netted and reinjected with hormones, and the spawn can be quickly observed and easily removed for mechanical hatching.

Concrete holding (or shipping) vats are usually 3 to 8 feet wide, 10 to 50 feet long, and 2 to 3 feet deep. Sturdy dividers can be installed so that several pairs of fish can be kept separated and spawned in the same vat. Spawning areas required by the larger pairs of catfish are usually about 50 square feet. Water depth is not critical, but 18 inches is usually sufficient for the activities of the fish, and this depth enables the hatcheryman to inspect the vat for spawn. The vat must be covered to prevent the fish from jumping out. Sufficient water exchange and aeration must be provided to maintain dissolved oxygen above 5 ppm. Water temperatures should be between 70 and 83°F. Often heated water must be blended with cold water to maintain temperatures in this range.

The brood fish should be seined at about the time that channel catfish are naturally spawning in ponds. The female should be inspected to ensure that it is gravid and that the genital vent is pink (not bloody). The males should be inspected for obvious secondary sexual characteristics. Enough females should be selected to provide the eggs needed to meet the requirements for fry and fingerlings. Gravid females of good quality generally produce 2,000 to 3,000 eggs per pound of body weight, and most good quality females spawn. Most of the eggs hatch. Thus, if 200,000 fry are desired, about 100 pounds of females should be sufficient. (A cautious producer might add 25 pounds for a safety margin.)

Hormone assistance is essential for spawning flathead catfish in vats. The procedure

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previously described for channel catfish—intraperitoneal injection of human chorionic gonadotropin or fish pituitary—is applicable to flathead catfish.

A spawning receptacle is not usually placed in a vat. The fish usually deposit the eggs on the bottom, along one wall or in a corner. The eggs can be left for the male to care for, or they can be removed from the vat and hatched in a mechanical hatching device. Artificial hatching is the preferred method. The technique is identical to that described for channel catfish.

It is important that spawns hatched together be of the same age. Otherwise the mixing of spawns of different ages may prevent the use of prophylactic treatments and will result in the stocking of fry of different ages. The stocking of flathead catfish of different ages (and thus different sizes) leads to cannibalism and is therefore to be avoided.

Color of the egg mass is an important indicator of the condition and stage of development of flathead catfish eggs. Under normal development, the yellow egg mass turns pink to red as the embryo develops and establishes its blood supply. Unfertilized or dead eggs turn white and enlarge. The appearance of flathead catfish eggs and newly hatched fry at different stages of development is described in Table 4.6.

Restocking of Brood Fish

Since brooding flathead catfish sometimes fight savagely, it is inadvisable to hold them longer than necessary in close quarters such as a trough or truck tank. They can be safely transported long distances during the spawning season, however, if they are tranquilized or if each fish is placed in a separate muslin bag or other container.

Immediately after spawning the brood fish can be returned to the wild or restocked in holding ponds at the rate of 100 to 300 pounds per acre. The size of the fish must not be so different that the larger fish can eat

Table 4.6. *Development of flathead catfish eggs and sac fry at 77 to 80°F.*[a]

Age (days)	Appearance or state
0	Newly spawned.
1	No internal pulsation. Egg cream-colored with prominent yolk; about 0.2 inch in diameter.
2	Internal pulsation visible.
3	Movement more vigorous. Tip of tail touches head. Vertebral column distinct; brain visible as a darker expansion of spinal column. Circulatory system developing over yolk mass.
4	Embryo turning more vigorously, 90 to 180° at each movement. Eyes and circulatory system visible. Yolk mass reduced in size.
5	Movement of embryo active. Dorsal aorta (prominent upper blood vessel) visible. Noticeable heartbeat. Barbels and eyes prominent. Yolk mass decreasing.
6	Movement active. Network of blood vessels on yolk increasing. Head structure more prominent.
7	Embryo moving freely within shell. Opercular movement visible. Entire body becoming reddish. Yolk size decreasing.
8	Fry hatch, move actively. Total length about 0.43 inch.
9	Body of fry gray and gradually darkening; fry moving about energetically.
10	Head of fry almost black. Yolk sac still prominent. Movement active and continuous for extended periods.
11	Body of fish continues to darken. Total length, 0.59 inch.
12	Yolk sac still present, but greatly reduced in size. Color of fry grayish black. Duration of movement increasing.

[a]Adapted from J. R. Snow. 1959. Notes on the propagation of the flathead catfish, *Pilodictis olivaris* (Rafinesque). Progressive Fish-Culturist 21:75–80.

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the smaller ones. Forage fish must be immediately provided as a food source, because flathead catfish will not eat prepared diets. It is desirable to maintain at least 2 pounds of forage fish for each pound of brood fish. Thus, frequent restocking of forage is required. The culturist must be prepared to feed at least 1,000 pounds of forage for each 100 pounds of brood fish maintained each year.

Because the cost of providing forage fish is high, the culturist should determine the production requirements in advance and then maintain only the number of brood fish required to meet those needs.

Good water quality is essential in flathead catfish brood fish ponds. Because no fertilizers are required and plankton blooms seldom develop, rooted vegetation tends to grow in these ponds and must be controlled. In some hatcheries an appropriate herbicide is used and in others the vegetation is controlled by biological methods. Common carp are sometimes useful, since they tend to roil the water and make it opaque.

Culture of Fry and Fingerlings

At the time of hatching, the fry (which have a conspicuous yolk sac) settle to the bottom. They can either be moved directly to a specially prepared rearing pond, or stocked into rearing troughs and held until they have absorbed the yolk sac and developed a grayish color. At this stage, the fish swim to the surface as swim-up fry to seek food.

The trough method is the technique of choice for the culture of flathead catfish fry and fingerlings to a length of 1½ to 2½ inches. The fish are generally released into ponds, lakes, or rivers at this size. Although the pond method of culture is usually unprofitable for the commercial farmer and impractical for the resource manager, we also briefly describe this technique.

Trough Method

Troughs suitable for fry are identical to those used for channel catfish. Water should enter at the head of the trough at the rate of 1 to 5 gallons per minute, and drain at the lower end through an overflow pipe. A trough screen is usually used because the connective tissue and uneaten feed quickly close a simple standpipe screen. Water of the quality mandatory for all fish culture is required; it should be saturated with oxygen and lack carbon dioxide, hydrogen sulfide, and iron. A water temperature of 80 to 85°F is required for rapid growth. Thus, in most practical situations, heated well water or water from a fish-free, unfertilized pond is desirable. Since the standing crop is necessarily rather heavy in the troughs, supplemental aeration from one or more agitators is recommended. These agitators are generally covered with wire screen to exclude the fry.

To remove the fry from the hatching trough, the culturist simply siphons them from the trough with a hose into a washtub or pail, and estimates their numbers volumetrically as described for channel catfish (Fig. 4.6). Numbers of yolk-sac fry per fluid ounce range from 750 to 1,200 and average about 800. These fry are stocked into rearing troughs at the rate of 1,500 to 2,000 per cubic foot. During the next 5 to 7 days the fry subsist on yolk.

At about day 5 to 7, the fry have absorbed the yolk and begin seeking food. It is essential that food be offered at this time. Fry not receiving food within a few hours after they begin seeking it usually do not feed later, and soon die.

Flathead catfish fry can be fed live organisms, including brine shrimp and zooplankton. Boiled egg yolk can also be pulverized and interspersed into the water near feeding fry. Any of these foods are usually satisfactory, provided that they are available to the fish continuously, and in liberal amounts. The food must be fresh, and living food must be moving.

In government hatcheries, as well as in commercial production facilities, results have been improved by feeding fresh or canned meat diets. These feeds can be prepared in large amounts and though they are not inexpensive, they cost less than brine shrimp and zooplank-

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Table 4.7. *Content, preparation, and storage of artificial feed for flathead catfish fry.*[a]

Ingredient	Amount: Weight (g) (for 450 g or about 1 lb)	Amount: Percent
Fresh beef liver Canned salmon Canned sardines Canned meat-based pet foods Frozen marine fish Shrimp	240 total[b]	53
Marine fish oil	9	1.8
Water	200[c]	44
Vitamin mixture	5[d]	1
Carboxymethyl cellulose	1[e]	0.2

[a]Feed is prepared by placing 240 g—about ½ pound—of a meat ingredient (or a combination of meat ingredients that total 240 g), and 200 mL—about ½ pint—of water into a household-type food blender. The meat and water should be blended for 1 to 2 minutes until a milk shake consistency is attained, followed by the addition of the vitamins and oil. (An antibiotic may be added if required.) The binder, carboxymethyl cellulose, is poured into the vortex of the feed mixture and mixed. The operator is cautioned to turn off the unit as soon as overloading is observed—usually within 15 seconds—to prevent damage to the blender motor.

[b]Any combination of bracketed ingredients can be used that total 240 g or 53%.

[c]Larger or smaller amounts of water can be added to attain a milk shake consistency.

[d]Vitamin fortification mixture available from ICN Nutritional Biochemicals, P.O. Box 28050, Cleveland, Ohio 44128; or quantities listed in "Nutrient requirements of warmwater fishes," National Academy of Sciences, Washington, D.C., 1977.

[e]Carboxymethyl cellulose sodium salt. Available from ICN Nutritional Biochemicals.

ton. The feed can be prepared as shown in Table 4.7, refrigerated or frozen, and fed directly to the fish.

The quantities of ingredients listed in Table 4.7 are the amounts suitable for a household-size food blender. Larger quantities can be prepared in a commercial food-service blender. The meat ingredients are placed in the blender, and sufficient water is added to provide the consistency of a milk shake. The marine fish oil and the vitamin mixture are then added and blended into the mixture. With the blender operating, the carboxymethyl cellulose is slowly poured into the vortex of the mixture. Since the mixture quickly thickens, the technician must turn off the unit when motor loading is observed, to avoid damaging the unit.

The prepared feed may be poured into cups of suitable size and stored in a refrigerator for 1 or 2 days, or frozen for 30 days; frozen feed can be placed in the refergerator compartment overnight to be fed the following day. Paper cups used for the serving of soft drinks or iced tea (available at most grocery outlets), covered with aluminum foil, provide excellent low-priced containers for storage of the feed.

Initially the feed, thickened with carboxymethyl cellulose, can be smeared in thin layers on glass sheets or aluminum plates. The sheets or plates are set on edge, near the fish. Alternatively, the feed can be smeared on one side of a board and the inverted board floated over the feeding area. The fish then "graze" on this material. It is important that these sheets or plates be removed and replaced with freshly prepared (or freezer stored) feeding plates or boards every half hour. For best results this replacement must be continued for 24 hours each day.

Within about 6 days, the fry start to feed on the same feed placed on the bottom near the feeding plates, and after 2 weeks the use of plates or boards can be discontinued.

The hatchery facilities must be kept clean. There is considerable connective tissue and oil in the feed ingredients. Also, it is essential to offer feed in excess to ensure that the fish are fed to satiation. These meat-based feeds quickly spoil in the 80 to 85°F water in which the fish are cultured. Best results are obtained when the uneaten water-leached feeds are siphoned from the tanks before fresh feed is offered.

Growth of flathead catfish fry depends greatly on the feed allowance and water temperature. However, aquaculturists should be able to produce fish 1½ inches long in 30 days, and 2½ inches long in 45 days. It is difficult to produce larger fish because cannibalistic behavior develops at about this time. Thus, the culturist must plan to sell or stock the fish at about this stage.

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It is essential to maintain a dense standing crop of flathead catfish fry in troughs. A standing crop of 3 pounds per cubic foot is not unusual, and fish have been held at even heavier densities. Oxygen levels are maintained by water exchange and by supplemental aeration, rather than by thinning the population. It is not unusual to exchange water at the rate of 20 gallons per minute in rearing troughs 10 feet long and 16 inches wide.

When the standing crop level of 3 to 4 pounds per cubic foot of water is attained, it is desirable to grade out the larger fish because they are likely to begin feeding on the smaller ones. A significant loss in production can occur in only 1 week in the presence of just a few oversized cannibals. It is difficult to stock or store the oversized individuals because usually only one can be placed in a container. It may be prudent to release these cannibals at nearby stocking sites or use them to fill small-sale orders.

If possible, the culturist should avoid splitting a tank group into two or more tanks. It is difficult to attain sufficient fish density to prevent the development of territorial behavior, which results in fighting and mortality.

The culturist must not provide minnows or sunfish as supplemental feed because this supplementation accelerates the development of cannibalism.

At the end of the culture period, the fish must be immediately transported and stocked. They must not be placed in fish holding tanks before they are shipped, as is commonly done with other fishes. Since a 24- to 48-hour intestinal cleanout is not recommended, the culturist should plan to carry light loads of fish so that the extra water will dilute the waste products.

Pond Method

Some culturists stock the fry directly into earthen ponds for growth to large fingerling size. However, the return is disappointedly low; a yield of only 20 to 50 fish per acre is common. Some culturists provide additional havens by scattering tin cans or other food containers over the bottom (Fig. 4.17), or by disking or plowing the bottom. Even when these techniques are used, however, the return is low.



Fig. 4.17. Metal cans such as those used for beverages and canned goods, or larger tiles and buckets, provide havens for individual flathead catfish fingerlings. Some culturists plow the pond bottom to provide depressions in which the fish can hide.

In instances where only a few large flathead catfish fingerlings are needed, some culturists have stocked them in their other production ponds. Again the return is low and the manager must decide whether the few flathead catfish produced are worth the loss of the other fish that they eat.

It is important at harvest time to rapidly drain the pond and recover the fish for immediate sale or distribution. Since the fish may be hiding in the containers and in depressions, a close inspection of the entire pond bottom is usually required.

Improving Strains of Channel Catfish

Substantial gains have been made in agricultural production through selective breeding and hybridization. Improved stocks of swine, poultry, and cattle are available to farmers worldwide. In fish farming, most fish stocks being cultured are only "domesticated" in the sense that they have undergone nondirected selection for culture traits that increase survival, such as tolerance to adverse water conditions and resistance to disease. Several species, primarily the rainbow trout, koi carp, goldfish, tropical aquarium fishes, and the common carp, have undergone some

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selective breeding for production or for ornamental traits.

All channel catfish now being cultured have been "domesticated" for intensive production on commercial fish farms and in governmental fish hatcheries. This does not mean that further improvement cannot be made in feed conversion efficiency, growth rate, and dress-out percentage. Techniques used to accomplish these goals include strain evaluation, selective breeding, cross breeding, and hybridization. Strain evaluation involves determining the characteristics of various fish strains so that the appropriate strain can be matched with each production system. Long-term selective breeding enhances desired characteristics, thus developing a high-performance fish for each production system and geographical area. Short-term crossbreeding involves mating unrelated strains of the same species to enhance production or survival characteristics, or to avoid inbreeding. Hybridization involves the crossing of different species such as blue catfish and channel catfish to enhance desirable production or survival characteristics found in these species.

It is unfortunate that the commercial channel catfish industry has not been provided with the selectively improved seed stocks being used in other fields of agriculture. Breeding programs require substantial commitments in personnel, funds, and facilities that have not been available to catfish geneticists. A complicating factor lies in the biology of the fish: it is difficult to observe because it lives in water and it usually requires roughly 3 years to produce a new generation.

Selective Breeding

Despite these impediments, some selection studies emphasizing channel catfish are in progress. These studies have led to several recommendations to the catfish industry (which follow) for producing better fish—primarily by the avoidance of inbreeding and the careful selection of brood stock.

(1) *Avoidance of inbreeding.*—Inbreeding is caused by mating closely related individuals, which results in depressed growth and reduced survival. The selection of the largest individuals in a pond for brood fish may result in brother–sister matings, since these fish may have been the product of a single spawn. Keeping the same brood fish for 4 to 10 years, with replacement brood fish coming from progeny produced on the same farm, may result in father–daughter and mother–son matings. Brood fish purchased from another producer may also contain the same narrow genetic base. Inbreeding can be avoided or eliminated by applying the following techniques:

(a) *Enrichment of bloodlines.*—The addition of unrelated stock may be effective in correcting deterioration in quality of brood stock common to inbreeding and disorderly selection. The need to enrich bloodlines might be suspected if a high percentage of deformed progeny, low hatchability of eggs, low survival of fry, or poor growth becomes evident.

(b) *Crossbreeding of unrelated stocks.*—Stocks originating from different river systems and different commercial lines are usually unrelated, and combining them may yield a desired combination of traits, especially in resistance to disease. If a hatchery stock shows susceptibility to disease (e.g., to channel catfish virus disease), crossbreeding should be tried. Branding enables the fish farmer to keep two or more stocks at the same facility at the same time (Fig. 4.18). These stocks may then be outbred to correct the negative effects of inbreeding and to produce fingerlings of uniform performance year after year.

(2) *Selection of brood fish.*—It should be possible to improve the performance of channel catfish by selecting the largest fish and saving these for breeding. However, several cautions must be noted and several pitfalls avoided. The fish must be of identical age in the pond. When fish are of unequal age, the oldest are usually the largest, and if they came from a single spawn, these largest fish would be brothers and sisters. They should be sexed to ensure a roughly equal number of males and females. Inasmuch as males usually are

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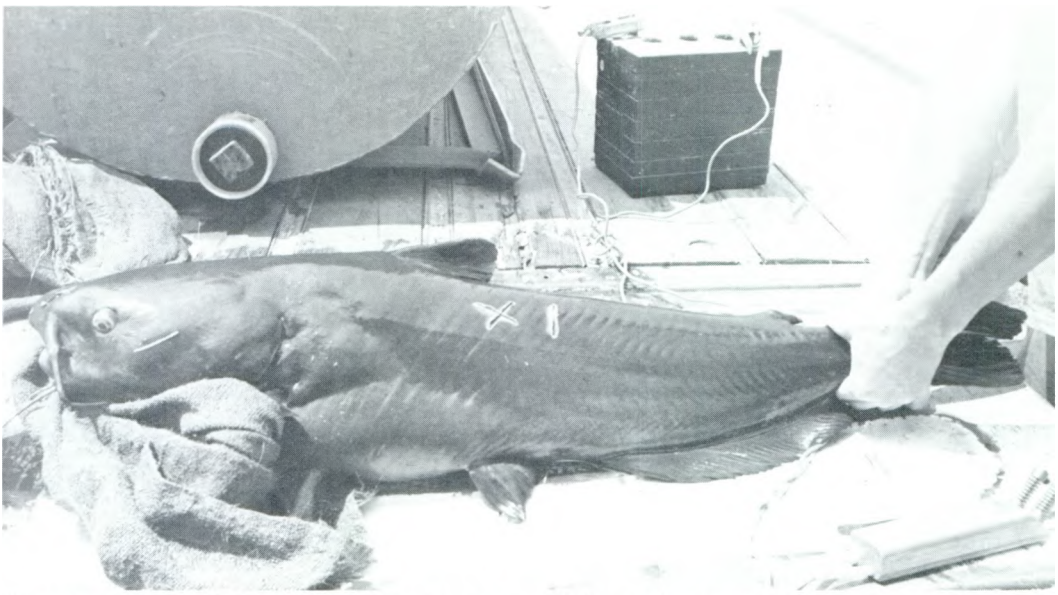


Fig. 4.18. Catfish heat-branded for identification. Other symbols and other marking locations increase the number of groups or individuals that can then be identified and separated. *Photo by J. Avault, Jr.*

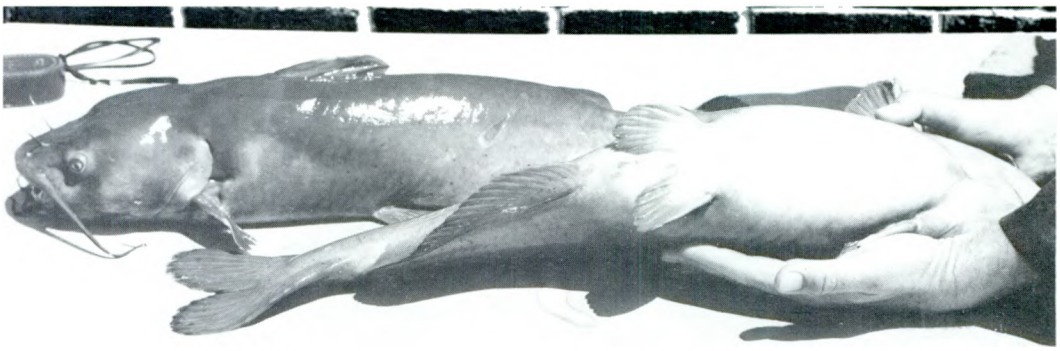


Fig. 4.19. Channel catfish brood fish may be selected for egg production and good body conformation. The muscular head is characteristic of the male, and the distended abdomen and well-developed genital organ is characteristic of the gravid female. Brood fish with deformities should be discarded.

larger than females of equal age, the producer could be saving all or nearly all males for brood fish. Consequently, the males and females should be selected separately (Fig. 4.19). That is, the largest males and the largest females should be selected—not just the largest fish. These selections should be made when the fish are 18 to 24 months old, and have reached marketable size.

Hybridization

The offspring of two different species may possess hybrid vigor, such as fast growth, high dress-out percentage, good tolerance to adverse water conditions, and increased resistance to disease. Hybrid crosses have been produced among channel catfish, blue catfish, white catfish, flathead catfish, brown bull-

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heads, black bullheads, and yellow bullheads. Other crosses have resulted from pairing a hybrid to a species not used to produce the hybrid (out-crossing) and the crossing of the hybrid with one of the parental species (back-crossing).

Some hybrid crosses can be obtained by pairing the fish in pens or aquaria, and encouraging of spawning through special handling, use of hormones, and alterations of the environment. Other hybrid crosses have been obtained by fertilizing the hormone-induced ovulated eggs with surgically excised testicular tissue. Either method complicates fingerling production when compared with the techniques used to produce true species.

Some crosses—specifically the channel catfish × blue catfish hybrid—grow faster than either parent species. Such hybrids have not yet been field tested in production ponds, nor are they available commercially. The major limitation to the use of this hybrid in commercial aquaculture appears to be the lack of sufficient seed stock at an affordable price.

Economics of Channel Catfish Culture

Markets

The high demand for channel catfish has resulted in a profitable industry for all facets of production and marketing. Growth of the industry has been rapid. The number of acres of water devoted to the commercial production of channel catfish in the United States was 400 in 1960 and 73,840 in 1982. Sales of fish basically have kept pace with the increasing acreage going into catfish production. A recent report of the U.S. Department of Agriculture[1] stated that "Domestic production of farm-raised catfish processed during February 1982 totaled a monthly record of 7.85 million pounds (3,560 metric tons) round weight (live weight), up 62 percent from February 1981, and 44 percent from January 1982."

However, no one should enter the business without identifying the market or markets for his product. Marketing is in itself a complicated subject that involves much more than the act of changing ownership of a product (selling). If an operation is to be profitable, marketing may also include harvesting, grading, transporting, processing, packaging, storing, wholesaling, retailing, and advertising.

Catfish farmers have traditionally sold their fish to six principal buyers: (1) processing plants, (2) live-fish haulers, (3) local stores and restaurants, (4) local retail outlets, (5) civic, church, and other fund-raising groups, and (6) fee-fishing operations (Table 4.8). Variations are possible—for example, farmers may own catfish specialty restaurants or fee-fishing lakes that become the principal outlet for their own fish.

Table 4.8. *Producer sales of food-sized channel catfish in the United States in 1981.*[a]

Outlet	Quantity (thousands of pounds)	Percent of total
Processors	71,800	81
Live haulers	5,921	7
Consumers	2,704	3
Fee and sport fishing	1,951	2
Other producers	1,812	2
Government agencies	49	Tr
Others	3,874	4
Total	88,111	

[a]From U.S. Department of Agriculture. 1982. Aquaculture outlook and situation. U.S. Department of Agriculture Economic Research Service AS-3.

Processing Plants

Processing plants dress and package fish for appropriate markets. Generally, dressing includes skinning, eviscerating, and beheading (Fig. 4.20). Some fish are steaked or filleted. The fish are sold in "ice pack" or frozen. The major processing plants are in the fish-producing areas of Mississippi and Alabama, but small plants are located in all the

[1]U.S. Department of Agriculture. 1982. Aquaculture outlook and situation. U.S. Department of Agriculture Economic Research Service AS-3.

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Fig. 4.20. A band saw is used to behead channel catfish in a modern processing plant. About 40% of the live weight is lost in preparing the fish for sale. *Photo courtesy of Alabama Cooperative Extension Service.*



Fig. 4.21. Restaurants provide a sales outlet for many pounds of delicious catfish. *Photo courtesy of National Marine Fisheries Service.*

States in which fish are produced. Plants often employ specialty harvesting crews and can provide trucks for hauling. The minimum load is between 8,000 and 10,000 pounds live weight. Arrangements usually must be made in advance with the plant to accept, harvest, and transport the fish. Because of the rather common problem of off-flavor, the fish must be taste-tested before they are accepted by the processor.

Live-fish Haulers

Live-fish haulers purchase fish from the producer and transport them to the owner of fee-fishing lakes. The hauler only transports fish—he does not harvest or grade them. Most haulers do not accept orders for small numbers of fish. The fish must be in excellent condition, so that they will survive the trip and begin feeding in the fee-fishing lake. Live-fish haulers often pay above-market prices to obtain good quality fish but they purchase them only during a 4- to 5-month period (mid-April to mid-September). Therefore, the farmer must adjust production and harvesting schedules to meet the needs and schedule of the hauler. The producer often must overwinter fish to meet this market.

Local Stores and Restaurants

Many stores and restaurants have a continuous need for relatively small amounts of catfish (Fig. 4.21). The amounts are too small to make it feasible for large processors to supply them, but this market can be significant to a local producer. These markets can be among the best for catfish farmers located in areas remote from processing plants. Local stores and restaurants usually want fish weekly, throughout the year. Therefore, a farmer must be able to harvest fish weekly by seining or trapping. A major problem is that many stores and restaurants accept only dressed fish; consequently, the catfish farmer must be willing to hand-process the fish.

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Local Retail Sales

In some areas, local citizens enjoy eating fresh catfish frequently. The producer can often expand this market into surrounding towns and counties. The fish can be live or dressed, and purchased on the farm or delivered. Another approach is to harvest fish once (or a few times) a year and advertise by local radio and newspaper that fish will be available on a certain date. Depending on location, area population, size of the catfish operation, the number and size of other catfish operations in the area, and other factors, this marketing method ranges from excellent to poor.

Fee Fishing

Fee fishing is a modified recreational fishing program. A person pays a fee for the privilege of entering the site and trying to catch fish and usually pays an additional charge for the fish caught. The angler usually keeps the fish (Fig. 4.22). Some operators of fee-fishing lakes dress the fish for a modest charge.

Fish for fee-fishing lakes may be purchased from a producer. Some producers operate their own fee-fishing pond. Ponds may be open all year, or only on certain days of the week or only during certain periods. However, a representative of the fee-pond operator must be present whenever the pond is open for fishing.

Distribution of Markets

The strength of the various markets changes from time to time. In the early days of catfish farming, live hauling and fee fishing made up a substantial portion of the market. In local areas, this remains true. However, with the establishment of a well-managed processing industry in Mississippi, Alabama, and Arkansas, the portion of the production going into processed fish sales has increased tremendously. In late 1982, six major catfish processors handled more than 50% of the catfish raised in the United States. The quantity of fish going into live-haul and fee-fishing operations has not decreased; these operations still account for a significant amount of business in States such as Texas and Missouri, which are well away from the highly competitive markets of the mid-South.

Costs of Catfish Farming

Once prospective fish farmers are relatively certain that a good market is available for the fish, they must determine the actual costs and projected returns. Few lending institutions will consider the funding of a fish farming operation unless detailed data are provided.

Catfish farming and most of the other established fish farming industries can be profitable even in times of financial instability. That instability, however, soon makes obsolete any financial data that we can include here; however, since resources and relative costs tend to remain constant through time, we offer limited current financial information. Table 4.9 provides estimated investment requirements for channel catfish production in three farm situations—163, 323, and 643 acres in the delta area of Mississippi—as of January 1980. Annual ownership (or fixed) costs and annual operating (or variable) costs are presented in Tables 4.10 and 4.11 for the same operation. Table 4.12 presents costs and returns per surface acre of water for the three farm situations in 1982. Experienced management, and a relatively heavy stocking rate of 4,000 fingerlings per acre, are assumed. Net returns are attractive, and are indicative of the reason for the marked expansion of the channel catfish industry in Mississippi and adjacent States.

The economic information on catfish culture from Mississippi assumes that most of the owner's income is derived from aquaculture. This is not possible in many areas where, for example, topography prevents extensive pond construction, water is scarce, or markets are limited; however, the smaller fish culture operations can successfully supplement farm income, especially in areas such as Alabama and Texas.

Agents of the Alabama Cooperative Extension Service have made several economic studies on the hill-pond system. They assumed that fish farming would be a supplemental

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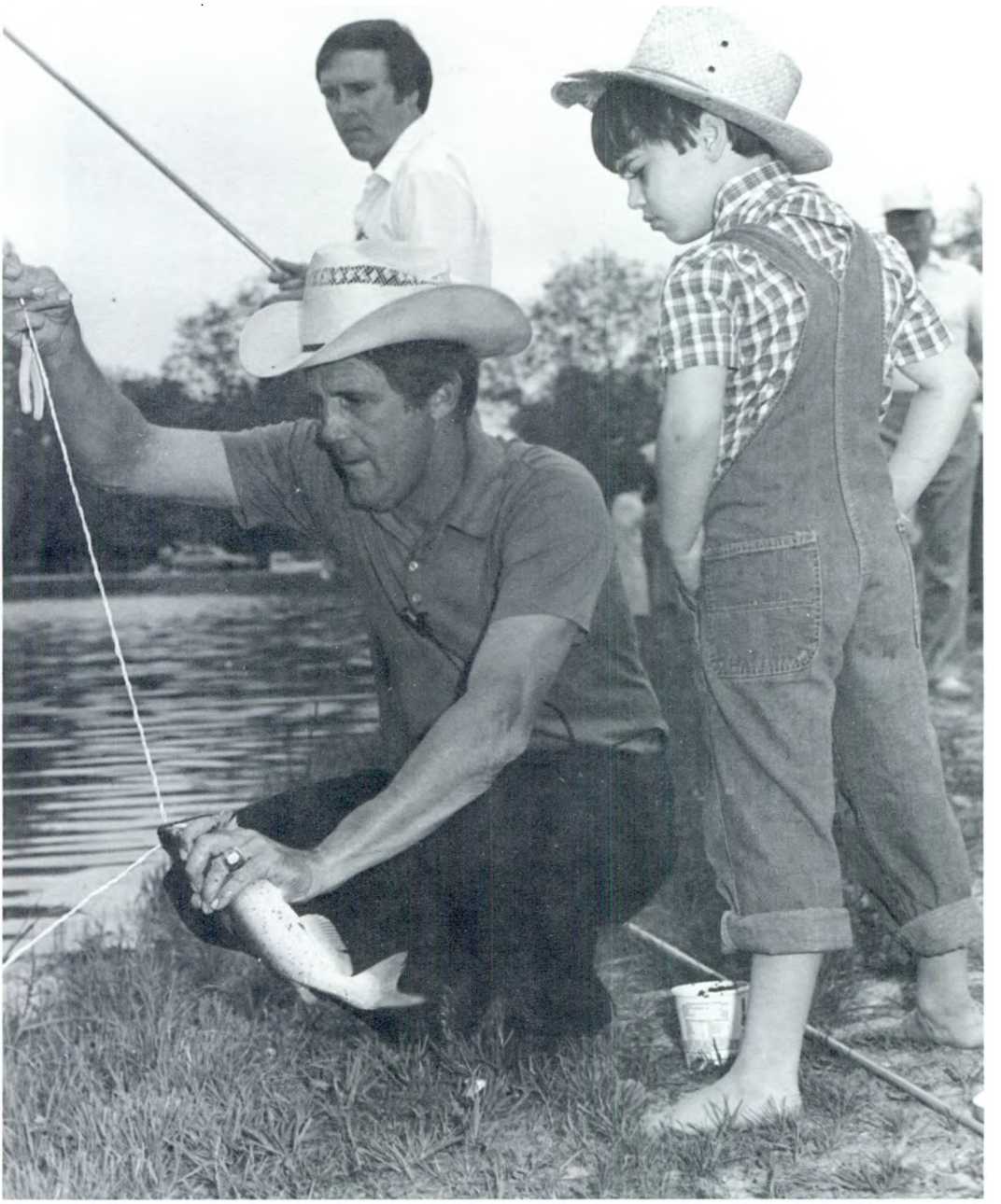


Fig. 4.22. Young angler watches as his catch is placed on a stringer at a fee-fishing operation. *Photo courtesy of Alabama Cooperative Extension Service.*

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Table 4.9. *Estimated investment requirements for catfish production at farms of three different sizes in Mississippi, 1980.*[a]

Item	Farm area (acres)		
	163	323	643
Land	$163,000	$324,000	$ 643,000
Pond construction (20 acres each)	87,414	165,863	330,534
Earth moving	(62,546)	(117,626)	(235,588)
Drainage structures	(11,040)	(22,080)	(44,160)
Gravel	(12,895)	(24,539)	(47,557)
Vegetative cover	(993)	(1,618)	(3,229)
Water supply (wells, drainage pipes)	37,640	75,280	150,560
Feeding (feeder and bulk storage)	10,740	14,940	25,680
Disease, parasite, and weed control	3,708	3,708	3,708
Harvesting	14,008	14,008	14,008
Miscellaneous equipment	115,047	143,373	209,992
Tractors, 90–100 hp	(61,940)	(86,716)	(136,268)
Truck, 1½ ton	(10,875)	(10,875)	(10,875)
Truck, ½ ton	(7,000)	(7,000)	(14,000)
Service building, 18 × 42 ft	(16,000)	(16,000)	(16,000)
High lift pumps, 16-inch diameter	(10,647)	(14,196)	(21,294)
Side mount mower, 6 ft	(2,900)	(2,900)	(5,800)
Farm shop equipment	(4,800)	(4,800)	(4,800)
Fiberglass transport tank	(460)	(460)	(460)
Waders	(425)	(425)	(425)
Total	$431,557	$740,172	$1,377,412
Investment per surface acre of water (141.6, 285.8, and 572.9 acres, respectively)	$ 3,048	$ 2,590	$ 2,404
Investment per acre of land	$ 2,648	$ 2,292	$ 2,142

[a]From J. E. Waldrop and R. D. Smith. 1980. An economic analysis of producing farm-raised catfish for food in Mississippi. A January 1980 update. Department of Agricultural Economics Research Report 103, Mississippi State University, Mississippi State.

rather than a primary source of income; that ponds were already present (no construction costs); and that existing farm labor and equipment were used in catfish production. The authors examined the costs and returns for ponds of various sizes (1, 2.5, 5, 10, and 20 acres) stocked with 2,500, 3,500, or 4,500 catfish fingerlings per acre. They showed that small ponds produce far less profit than larger ones (Table 4.13), because the basic costs of getting into the business are relatively much higher at low production levels than at higher ones. It is unlikely that this disparity will change unless technological breakthroughs permit much higher production of marketable fish per unit volume of water. Polyculture systems (discussed later) offer that potential, but markets for most of the fishes that can be produced in polyculture systems have not been established.

Fixed and variable costs differ greatly from region to region. Application of Alabama costs in Texas or Oklahoma will lead to erroneous economic projections. However, fixed and variable cost categories are common to all pond culture systems.

Production of channel catfish in cages may be extremely profitable if the limitations discussed earlier can be eliminated. A sample budget for a cage-culture operation in Oklahoma is presented in Table 4.14. The major production expenses are for fingerlings and feed, and the major fixed expense is for cages. Cost of the pond, lake, river, strip-mining pit,

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Table 4.10. *Estimated annual ownership costs for catfish production facilities and equipment of farms of three sizes in Mississippi, 1980.*[a]

Item	Farm area (acres)		
	163	323	643
Annual ownership costs			
Depreciation[b]			
Ponds	$ 4,371	$ 8,293	$ 16,527
Water supply (wells and discharge pipe)	3,496	6,992	13,984
Feeding (feeder and storage)	1,039	1,459	2,498
Harvesting equipment	1,995	1,995	1,995
Disease, parasite, and weed control equipment	324	324	324
Miscellaneous equipment	11,317	13,737	19,694
Interest on investment[c]			
Land	16,300	32,300	64,300
Pond construction (drainage structures, gravel, and vegetative cover)	4,371	8,293	16,527
Water supply (wells and discharge pipe)	2,258	4,517	9,034
Feeding equipment (feeder and storage)	644	896	1,552
Equipment for controlling diseases, parasites, and weeds	222	222	222
Chemicals on hand	116	116	116
Harvesting equipment	840	840	840
Miscellaneous equipment	6,902	8,602	12,175
Taxes and insurance	3,072	3,953	5,872
Total	$57,267	$92,539	$165,660

[a]Adapted from J. E. Waldrop and R. O. Smith. 1980. An economic analysis of producing pond-raised catfish for food in Mississippi. January 1980 update. Department of Agriculture Economics Research Report 103, Mississippi State University, Mississippi State.
[b]Computed by the straight-line method, with zero salvage value for depreciable items.
[c]Charges at the rate of 10% on total land cost, pond construction, and chemicals on hand, and 12% on one-half of the investment in depreciable items.

or reservoir is not normally considered, since fish production is secondary to the main function of the production system.

In Mississippi a microcomputer program has been developed to provide information required by managers of catfish production farms to make decisions. This program computes daily feeding rates by pond, and projects number of feeding days to harvest. The operator may select specific feeding rates (as percent of estimated body weight), and fixed food conversion values, or select specific food conversion values with fixed feeding rates. Assumptions for feeding rates and food conversion values are based on the best available data, but operators are encouraged to monitor ponds closely so that adjustments can be made when needed. The program stores information daily on dissolved oxygen (morning and afternoon, top and bottom), nitrite concentrations, phytoplankton blooms (Secchi disk readings), and water temperatures. Fish of five ages (batches) in each pond can be handled and a total of 100 ponds can be accommodated. The program produces "firm" summaries when desired, and projects both the estimated harvest date for various batches of fish and the total amount of feed that must be supplied through various harvest dates. Information on this computer program is available from the Mississippi Cooperative Extension Service, Mississippi State University, Mississippi State, MS 39762.

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Table 4.11. *Estimated annual operating costs for channel catfish production at farms of three sizes in Mississippi, 1980.*[a]

Item	Farm area (acres)		
	163	323	643
Repairs and maintenance			
Vegetative cover	$ 712	$ 1,235	$ 2,464
Water supply (wells and discharge pipe)	1,129	2,258	4,517
Fuel			
Pumping	16,720	32,720	66,009
Power, transportation, feeding, harvest, etc.	8,071	13,380	26,095
Chemicals	2,467	4,960	8,977
Fingerlings	45,312	91,456	183,328
Feed (35% protein, floating)	152,080	306,986	614,112
Labor			
Management	24,000	24,000	38,400
Hired labor (full time)	23,335	30,335	37,335
Hired labor (part time)	2,121	4,224	9,331
Interest on operating capital[b]	11,412	20,918	40,234
Total	$296,724	$543,566	$1,046,117

[a]From J. E. Waldrop and R. O. Smith. 1980. An economic analysis of producing pond-raised catfish for food in Mississippi. January 1980 update. Department of Agriculture Economics Research Report 103, Mississippi State University, Mississippi State.
[b]Charged at 12% for 4 months.

Table 4.12. *Estimated costs and returns per acre for channel catfish produced by experienced growers on farms of three sizes in Mississippi, 1982. Assumptions made are a fingerling stocking rate of 4,500 per acre, 20-acre ponds, and production of 5,344 pounds per acre.*[a]

Item	Farm area (acres)		
	163	323	643
Income			
Catfish (5,344 lb @ $0.56)	$2,992	$2,992	$2,992
Catfish (5,344 lb @ $0.62)	3,313	3,313	3,313
Catfish (5,344 lb @ $0.70)	3,741	3,741	3,741
Direct expenses			
Feed (1.85:1 feed conversion ratio and $300 per ton)	1,490	1,490	1,490
Fingerlings (4,500 @ $0.075 each)	337	337	337
Electricity (pumping)	86	86	86
Fuel	76	72	74
Chemicals	31	31	30
Repairs and maintenance	85	66	55
Management (salary)	202	100	80
Labor	196	126	78
Liability insurance	13	9	6
Interest on operating capital (19% for 4 months)	161	148	142
Harvesting and hauling costs	214	214	214
Total	$2,891	$2,679	$2,592

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Table 4.12. Continued

Item	Farm area (acres) 163	323	643
Field expenses			
Depreciation	$ 233	$ 198	$ 180
Interest on investment	401	365	350
Taxes and insurance	22	14	11
Total	$ 656	$ 577	$ 541
Total expenses	$3,547	$3,256	$3,133
Net returns per acre			
At $0.56 per pound	$ -554	$ -263	$ -140
At $0.62 per pound	-234	57	180
At $0.70 per pound	194	485	608

[a]Adapted from R. J. Martin. 1982. Estimated costs and returns from farm-raised catfish. Pages 8 and 9 *in* For fish farmers. Cooperative Extension Service, Mississippi State University, Reference 82-4.

Table 4.13. *Estimated costs and returns from hill-type catfish production systems of various sizes and stocked at different rates in Alabama, 1980.*[a]

System		Variable costs[c]		Total costs			
Area of pond (acres)	Stocking rate[b] (number per acre)	Total	Per pound of fish (cents)	Total	Per pound of fish (cents)	Net return[d] Total	Per acre
1	2,500	$ 1,265	50.6	$ 1,466	58.6	$ 159	$159
1	3,500	1,811	51.7	2,254	64.4	21	21
1	4,500	2,365	52.6	2,809	62.4	116	116
2.5	2,500	3,150	50.4	3,468	55.5	595	238
2.5	3,500	4,386	50.1	4,967	56.8	721	288
2.5	4,500	5,750	51.1	6,370	56.6	942	377
5	2,500	6,259	50.1	6,670	53.4	1,455	291
5	3,500	8,749	50.0	9,442	54.0	1,933	387
5	4,500	11,401	50.7	12,186	54.2	2,439	488
10	2,500	12,561	50.2	13,607	54.4	2,643	264
10	3,500	17,447	49.8	18,867	53.9	3,883	388
10	4,500	22,958	51.0	24,591	54.6	4,659	466
20	2,500	23,776	47.6	25,249	50.5	7,251	363
20	3,500	32,807	46.9	34,886	49.8	10,614	531
20	4,500	43,106	47.9	45,329	50.4	13,171	659

[a]Adapted from J. Crews, J. Flynn, and J. Jensen. 1981. Budgeting for Alabama catfish producers. Alabama Cooperative Extension Service, Natural Resources Series, Auburn University, Alabama.
[b]Channel catfish 5 to 7 inches long (1 oz) were stocked in all ponds on about 1 April 1981.
[c]Variable costs are cost expenses directly related to production, and include fingerlings, feed, hired labor, chemicals, fuel, equipment repair, and interest on operating capital.
[d]Total net return equals gross return minus total costs. Gross returns were calculated on the basis that the number of fish stocked weighed 1 pound at harvest (November 1981) and sold for $0.65 per pound.

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Table 4.14. *Sample budget for a channel catfish cage-culture operation, 1979.*[a]

Item	Amount	
	Per cage	Per acre
Estimated sales		
375 lb per cage @ $0.80 per lb	$300.00	$1,200.00
Estimated production expenses		
Fingerlings (325 per cage @ $0.12 each[b])	39.00	156.00
Fish feed (550 lbs @ $0.20 per lb[b])	110.00	440.00
Chemicals	3.00	12.00
Equipment repair, maintenance, and fuel	3.00	12.00
Labor	20.00	80.00
Interest on operating funds @ 9% for 9 months	11.81	47.24
Total direct production costs	186.81	747.24
Annual fixed costs and capital requirements		
Land ($300 amortized @ 9% for 25 years)	7.64	30.56
Equipment ($500 each amortized @ 9% fr 5 years)	6.43	25.72
Cages ($40 each amortized @ 9% for 3 years)	15.80	63.20
Total fixed costs	29.87	119.48
Total annual costs	216.68	866.72
Net return to management	83.32	333.28

[a]Adapted from C. M. Collins. 1979. Catfish cage culture—Fingerlings to food fish. Publication No. 13 of The Kerr Foundations, Inc., Poteau, Oklahoma.
[b]Costs of fingerlings and feed may vary with quantities purchased.

Processing

Some farmers process at least part of their crop; for catfish, processing includes killing, skinning (Figs. 4.23, 4.24), eviscerating, and beheading. The dressed fish can be sold either whole or converted into steaks (Fig. 4.25) or fillets. Dressed fish heavier than 1½ pounds are usually steaked or filleted.

In small operations, fish often are processed entirely by hand; however, processing machinery (such as a band saw and skinning machine) is available if the size of the operation justifies its use. Fillets must be prepared entirely by hand, as filleting machines for channel catfish have not yet been perfected. Farmers who process their own fish must be aware of, and in compliance with, local sanitary codes.

A processor must be innovative. People of different geographic regions invariably have strong preferences toward specific sizes or processed forms of fish. It may not always be economical or practical to accommodate these preferences. Thus the farmer must be prepared to convince his customers that some other product form is just as desirable.

Waste Disposal

Catfish processing wastes—heads, viscera, and skins—have been a liability to most catfish processing operations. Traditional disposal methods have included trucking wastes to rendering plants and landfills, or spreading them over agricultural lands. Besides the sanitary problems associated with these disposal methods, there is the added problem of spines, which can puncture tires on farm vehicles and machinery if wastes are spread over fields.

Disposal of wastes is especially costly for major processing plants—so costly, in fact, that at least two plants have built conventional dry rendering units to treat wastes and produce by-products, including high-grade fish oil and high-protein fish meal. Some of the waste is included in feeds for domestic pets.

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Fig. 4.23. A skinning machine removes much of the drudgery of dressing channel catfish. A high-speed rotating knife positioned in the table bed efficiently removes the skin. *Photo courtesy of Alabama Cooperative Extension Service.*

Fig. 4.24. In small-scale processing plants, hand labor and pliers are used to skin channel catfish. *Photo courtesy of Alabama Cooperative Extension Service.*





Fig. 4.25. A band saw is used to cut dressed channel catfish into steaks (cross sections) ½ to 1 inch thick. Steaks provide a good market outlet for fish weighing 2 pounds or more. *Photo by J. Avault, Jr.*

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Table 4.15. *Approximate composition of raw wastes from catfish processing and two experimental by-products—fish meal and concentrated silage.*[a]

Waste or by-product	Weight (pounds)	Proximate analysis (%)			
		Moisture	Fat	Protein	Ash
Raw processing wastes[b]	100	66	12	16	6
Fish meal[c]	26	8	8	58	25
Concentrated silage	28	52	6	39	3

[a]Southern Regional Research Center, U.S. Department of Agriculture, New Orleans, Louisiana. (unpublished)
[b]Raw wastes composed of 70% heads, 20% viscera, and 10% skins.
[c]Ground bones added to concentrated silage, then dried.

A relatively new method for processing catfish wastes involves preparation of fish silage. Catfish wastes are ground up, heated, and treated with formic acid so that the skin and flesh are liquefied. The silage is poured through a screen to remove bones. Centrifuging removes much of the oil. The silage is then concentrated in a vacuum evaporator at 95°F.

The silage process has several advantages over conventional rendering methods. Because lower temperatures are used in processing silage, the quality of the oil and protein by-products should be higher than those from conventional rendering processes, and because concentrated silage contains no bone, it can be dried to a meal by-product containing about 80% protein.

The typical products of the basic silage process consist of 15% bone, 9% oil, 48.3% water, and 27.7% concentrated silage. The proximate analyses of products made from catfish when the fish silage process is used are summarized in Table 4.15.

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5. PRODUCTION METHODS FOR BAITFISH: GOLDEN SHINERS AND FATHEAD MINNOWS

Jay V. Huner and Harry K. Dupree

Commercial production of several minnow species for use as bait in sport fishing is worth more than $100 million at the fish farm level, and the acreage devoted to minnow farming almost equals that used for channel catfish farming. Production at well-managed minnow farms ranges from 300 to 1,000 pounds (average, 500 pounds) per acre per year. We review here some of the more pertinent information on bait minnow production practices.[1]

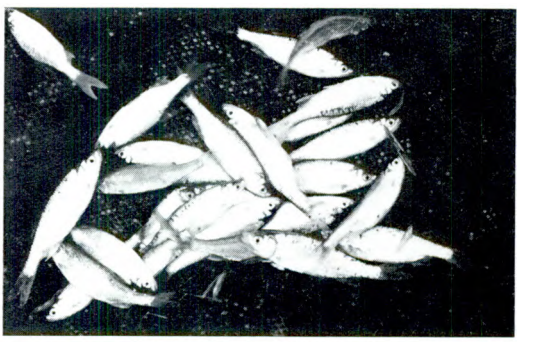


Fig. 5.1. The golden shiner is the most popular baitfish among fishermen in the southern States. It is a desirable commercial species because it can be produced intensively in managed ponds. *Photo by J. Avault, Jr.*

Species Selection

At least 20 species of fish have been raised commercially for bait. We consider here the physical aspects and biological requirements of the two most popular species cultured in the southern States—the golden shiner and the fathead minnow.

Golden Shiner

The bright, flashing appearance of the golden shiner (Fig. 5.1) has made it the most popular baitfish among anglers. Its body is deep and compressed laterally and covered with large gold- or silver-colored scales that are rather loosely attached. The characteristic downward curve of the lateral line follows the ventral body contour. The golden shiner prefers lakes but is commonly found in shallow water of large streams throughout the central and eastern United States.

A strain of the golden shiner that has orange or red fins occurs in limited areas of the South. This strain has an exceedingly "nervous" temperament and is difficult to keep in confinement. Its habit of leaping out of bait containers is especially disconcerting to anglers. This strain should be avoided when brood stock is selected.

Female golden shiners grow faster and become larger than males. In the South, this species becomes sexually mature at the age of 1 year and a length of about 2.5 inches. Some fish have been known to live for 8 years and attain a length of over 10 inches. The recent (1963) discovery of the ovarian protozoan *Plistophora ovariae* in golden shiners has caused baitfish culturists to select their brood stock with special care. Because severity of the infection increases with the age of the females,

[1]This chapter is based largely on a 1981 publication by J. J. Giudice, D. L. Gray, and J. M. Martin, entitled "Manual for bait minnow culture in the south" (Bulletin EC 550, U.S. Fish and Wildlife Service and the University of Arkansas Cooperative Extension Service), which provides detailed information on cultural practices, including spawning, rearing, harvesting, and transporting.

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it is best to select brood stock each year from the yearling population to lessen the impact of this parasite. Other parasites to be avoided in selecting brood stock are the Asian tapeworm (*Bothriocephalus opsarichthydis*) and the anchor parasite (*Lernaea cyprinacea*).

Another factor to consider is "domesticity," which is characteristic of some golden shiner brood stocks that have been cultured for many generations. The use of these domesticated brood fish greatly facilitates handling. Wild stock should be avoided.

Golden shiners start spawning in the South when water temperatures reach 70°F (usually in May) and continue spawning through June. Eggs are emitted indiscriminately in areas covered with vegetation. Some females lay as many as 10,000 eggs. Living plants seem to be preferred spawning substrates, but if they are not available, the fish spawn on detritus or plant roots. Eggs are adhesive and cling to the surface of plants, debris, and rocks; they hatch in 4 to 8 days at water temperatures of 75 to 80°F. No protection or care is given to eggs or fry by the adults.

The golden shiner is omnivorous and eats any plants and animals that are small enough for it to ingest. Artificial food is readily accepted.

Golden shiners are delicate and easily damaged, and are particularly sensitive to handling in hot weather.

Fathead Minnow

A cylindrical body, small scales, and dull color distinguish the fathead minnow; it seldom exceeds a length of 3 inches (Fig. 5.2).

Males grow larger than females. This characteristic may create a problem when a mechanical grader is used to select brood stock, because grading for large fish may result in a preponderance of males. Many anglers have come to know this fish as the blackhead minnow due to its appearance during the spawning season. Breeding males assume a very dark color about the head and may have dark vertical bars on the body. Numerous horn-like projections called breeding tubercles develop on the heads of adult



Fig. 5.2. Fathead minnows have a cylindrical body, small scales, and a dull color. Breeding tubercles develop on the heads of adult males during the breeding season. The rule (right background) is 6 inches long.

males during the breeding season. A fleshy pad that develops on the back just behind the head is used in preparing the nest site and caring for the eggs.

Sexual maturity is reached at the age of 1 year. Spawning begins when the temperature of the water nears 65°F and resumes during cool periods in summer and sometimes briefly in fall. A single female lays 200 to 500 eggs. After the eggs are fertilized, the male picks them up in its mouth and attaches them to the underside of any object in shallow water. This process is repeated until a nest is completed. A male may use eggs from several females to complete the nest, which he then guards until the fry emerge (usually in 5 or 6 days).

Like the golden shiner, the fathead minnow feeds on most aquatic organisms small enough to be eaten, and readily accepts artificial feed.

The fathead minnow can be handled (with care) during warm weather and is therefore a popular baitfish. It has one serious disadvantage in that many adult males die after spawning.

Culture of Minnows

Golden Shiners

Golden shiners are conventionally produced by three methods: wild or free spawning

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method, egg transfer, and fry transfer. Regardless of the method used, high quality water is essential during the cultural period, and especially during the spawning season. When the fish are spawning, pond enrichment should be closely controlled because heavy plankton blooms inhibit reproduction. If availability of natural foods appears to be a problem, the offering of manufactured feeds is recommended. Excessive blooms can be controlled by flushing with fresh water.

In the wild or free spawning method, a common practice is to lower the water level in the brood pond during early spring and permit grass to grow along the shoreline; intermittent rows of rye grass are sometimes planted on the exposed portion of the pond bottom. When the ponds are refilled, the grass provides spawning substrate. Aquatic plants also make excellent spawning substrates. If plants are lacking or scarce, hay or straw can be placed in shallow areas. Such material should be anchored so that it will not drift as a result of wave action. Spawning mats made of Spanish moss can also be used. These mats are constructed by sandwiching Spanish moss between woven wire (Fig. 5.3). Steel-welded wire (2- by 4-inch mesh) is folded so that the dimensions of each mat are about 20 by 48 inches. Selected wires are usually removed from the top side, making the mesh size 4 by 4 inches. Hognose rings are used to hold the top and bottom section of woven wire together.

For ponds containing suitable natural vegetation or artificial spawning material, brood fish are introduced at the rate of 20 to 40 pounds of ungraded fish per acre.

If spawning activity diminishes before the normal season is over, it may be increased by rapidly raising the water level of the pond. Adding large quantities of cool water to a small narrow pond, such as a semi-raceway, can extend the spawning season. Shiners can also be induced to spawn by chemically shocking them with 4 ppm potassium permanganate[x]. This is done by spraying the dissolved chemical over the water surface, or by placing the crystals in a nylon cloth bag towed behind a motor-powered boat.



Fig. 5.3. Newly spawned golden shiner eggs on a mat that was constructed by sandwiching Spanish moss between woven wire. *Photo by J. Mayo Martin.*

Egg laying and hatching, and growing of fish to marketable size, can occur in the same pond. Preferably the adults should not be left in the pond with the young of the year. They should be removed and stored in another pond for use as future brood stock or sold for bait. If left with the young, parasite-laden brood fish transmit the infestation to their offspring.

In the egg transfer method, the brood fish are kept in ponds at a stocking density of 400 to 500 pounds per acre. It is vital that the pond be kept completely free of any natural vegetation to prevent permature egg deposition. Leaves and roots of marginal plants must also be prevented from growing in the water along the shoreline.

When the fish are ready to spawn, mats are placed in the pond. If necessary, the pond level may be raised quickly to stimulate spawning. The spawning mats are positioned in shallow water with one side of the mat at the edge of the pond. It is important that shiner mats be placed 1 inch below and parallel with the pond water surface. Several mats should be placed in groups in an end-to-end arrangement along the shoreline. The number of mats placed in the brood stock pond depends on the spawning action of the

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fish. Only as many mats should be put out as the fish can fill with eggs in a relatively short period. One should avoid providing too many mats because it is important that the fish use the spawning mats efficiently. As spawning activity continues, the full mats should be removed and replaced with empty mats to prevent overloading with eggs. The mats should not be left in the pond until the eggs become so abundant that they touch one another. The presence of excessive numbers of eggs on a mat encourages the growth of saprophytic fungi, which may spread over the developing eggs and kill them.

When the mats are covered with eggs, they should be moved to rearing ponds for hatching. Estimating the number of egg-laden mats that should be used per acre is a difficult task and requires considerable experience. Depending on the number of eggs per mat, the number of mats stocked per acre in golden shiner ponds may vary from 50 to 75. Mats should be removed, washed, and stored when hatching is completed.

In the fry transfer method, the fry produced by either of the methods described are trapped and counted, and then transferred to rearing ponds. Fry to be transferred are produced in hatching ponds that have been purposely overstocked with eggs. Lift-traps and short seines constructed of fine-mesh netting are used to remove fry from areas that have been baited. Fry should be transferred early in the day or during cloudy weather, when the water is cool. Golden shiners are generally transferred when they reach a length of about ¾ inch.

Numbers of fry can be determined, and rigid control can be exercised over the number of fry stocked per acre in rearing ponds. Fry can be counted relatively easily by first counting the number of fry in 1 ounce (liquid measure), and multiplying by the number of ounces of fry transferred. A bucket graduated in quarts (32 liquid ounces = 1 quart) is used to transfer fry. For example, if by count there are 200 fry per ounce, the volume of fry needed to yield a stocking of 200,000 is 31¼ quarts.

Stocking densities for golden shiner fry depend on such factors as how soon salable fish are needed, size of fish desired, the intensity of pond management, and the length of the growing season. Usually stocking rates range from 50,000 to 200,000 fry per acre.

The fry transfer method provides uniform production and optimal use of all pond areas. Pond space is conserved early in the growing season so that small fish left from the previous year may be grown to market size before the ponds are needed for the current year's crop.

Fathead Minnow

Cultural methods for fathead minnows differ from those of golden shiners because their spawning habits differ greatly. The culture of fathead minnows is restricted to either the free spawning or fry transfer method.

In the free spawning method, the brood fish are stocked at the rate of 500 to 2,000 fish per acre. A sex ratio of 1 male to 5 females is desirable. Spawning materials include rocks, bricks, and lumber. Although large ponds can be stocked by the free spawning method, they tend to become overpopulated, resulting in stunted populations.

The fry transfer method is the favorite method of producers and is generally used in small, specially prepared hatching ponds. Spawning ponds are stocked with 20,000 to 25,000 brood fish per acre. As in the free spawning method, a sex ratio of five females per male is preferred. Rocks, pieces of tile, bricks, or boards can be used to supplement existing spawning sites. Some producers staple pieces of old lumber (cut in 4- by 12-inch sections) to a wire stretched parallel to shore in shallow water. Boards are spaced about 12 inches apart (Fig. 5.4).

Fathead minnow fry are captured, counted, and handled in the same way as previously described for golden shiners. The fry are restocked at the rate of 50,000 to 300,000 fish per acre. The choice of stocking densities is based on the same considerations as those mentioned for golden shiners.

It would be difficult or impossible to suggest which of these methods is best suited for a specific operation. The method that is ideal for one hatchery may be inadequate for an-

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Fig. 5.4. Eggs of fathead minnows laid on the underside of a board (here inverted). These boards are attached to a wire stretched parallel to the shore in shallow water. *Photo by J. Mayo Martin.*

other. Often a combination of two or more methods is advisable.

Feeds

Natural Food

Success in raising baitfish fry depends on the management of natural food so that it is available when the fry are ready to eat. Natural food is produced as a result of the application of organic or inorganic fertilizer. Fertilization establishes a bloom of plant and animal plankton, which is the natural food. The bloom also shades out aquatic weeds. It should be dense enough so that a Secchi disk (or an aluminum plate on a stick) lowered into the water disappears from view at a depth of about 10 inches. If the pond begins to clear, more fertilizer should be applied. If the water in a nearby pond contains a suitable bloom, it can be used to seed a clear pond. Besides providing a start for a bloom, water pumped over the levee is more desirable and less expensive than water pumped from a well. The water should be carefully screened to prevent the introduction of fish, and water transfer should of course not be considered if the fish in the adjoining pond are infected with diseases or parasites.

Establishing and maintaining a plankton bloom in early spring is sometimes difficult. If the plankton dies after cold weather, or if aquatic weeds competing for nutrients prevent a bloom from developing, the young fish may starve or become vulnerable to disease.

Nutrients that encourage the growth of plankton blooms include liming compounds and organic and chemical fertilizers. Before or while the pond is filling, finely ground limestone is added if soil analyses indicate the need. The amount would be near the amount customarily recommended for field crops in the area. Producers generally use inorganic fertilizer on large minnow farms, but ponds on smaller farms can be fertilized better, and at less expense, with a combination of organic and inorganic fertilizer. Some organic materials to consider are barnyard or poultry manures, dried hay, and plant by-products high in nitrogen (such as cottonseed or soybean meals). Manures are applied at rates of 400 to 1,000 pounds per surface acre, in combination with 100 pounds of an inorganic fertilizer, such as 16-20-0 or 10-20-0 (N-P-K). Nitrate of soda or superphosphate is used in acid soils, and ammonium phosphate in alkaline soils. Some researchers and producers are using liquid fertilizers to good advantage. When these fertilizers are sprayed on the water surface, more of the phosphorus remains available for pond organisms instead of being bound in the bottom soil. When inorganic fertilizer is used alone, about 200 pounds of 16-20-0 (N-P-K) per application per acre are required to produce a bloom.

Starter Feed

It is generally accepted that production of minnows can be doubled by artificial feeding. The fry of golden shiners and fathead minnows require a starter feed.

Minnow starter feeds are normally higher in protein than feeds used for larger minnows and tend to be more complete in nutrients, especially vitamins. The starter feed for bait-

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Table 5.1. *Percent composition of diets for golden shiners and fathead minnows developed at the Fish Farming Experimental Station, compared with diets widely used in the baitfish industry (starter feed) or developed at Auburn University (grower feed).*

Ingredient	Fish Farming Experimental Station (%)	Industry (starter feed) or Auburn University (grower feed) (%)
	Starter feeds for minnows	
Soybean flour	30.0	10.0
Fish flour or feather flour	18.7	11.5
Dried skim milk	18.7	10.0
Rice bran	20.0	
Distillers' solubles	10.0	10.0
Bone meal	1.3	
Mineralized salt	1.0	2.5
Oat flour or ground wheat		45.0
Gluten meal		10.0
Vitamin premix[a]	0.3	1.0
	Grower feeds for minnows	
Meat scraps	15.0	
Fish meal	10.0	10.0
Feather meal or poultry by-product meal	10.0	7.5
Blood flour		5.0
Soybean meal	10.0	10.0
Cottonseed meal	15.0	
Wheat middlings	13.0	46.5
Dried skim milk		5.0
Alfalfa meal	2.0	13.5
Rice bran	22.0	
Vitamins and minerals[a]	3.0	2.5

[a]Vitamin and mineral requirements published by National Research Council. 1977. Nutrient requirements of warmwater fishes. National Academy of Sciences, Washington, D.C.

fish species should be ground as fine as flour; double grinding may be required. Fry feed is made into a slurry and is fed on all sides of the pond to help ensure that all fish receive food.

The formula shown in Table 5.1 was developed and field-tested at the Fish Farming Experimental Station, with excellent results.

If the bloom is lost in the rearing ponds while the fish are still fry, it is essential that supplemental feed be offered. Fish should be fed every 2 hours for several days. Feed should be placed along the entire perimeter of the pond to increase availability and encourage feeding. Initially the fish are overfed, but the uneaten feed serves as organic fertilizer that produces natural organisms.

"Grower" Feed

After 3 weeks, the fish are converted to a diet of "grower" feed. This ration is more coarsely ground and has a lower protein content. It can be fed dry by broadcasting from one side of the pond, downwind.

Commercially formulated grower feeds for golden shiners and fathead minnows are similar. Two minnow feeds developed and tested at Auburn University and the Fish Farming Experimental Station are shown in Table 5.1.

When a feed formulation is to be used as meal, animal fat should be added to hold the nutrients and keep the feed afloat; for pelleted feed, no fat is added.

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Recent research at the Fish Farming Experimental Station indicated that heat-treated full fat soybeans are a promising ingredient for minnow diets. The soybeans are heat-treated for 4 minutes at 375 to 400°F to destroy growth inhibitors. Whole soybeans contain 38% protein and 18% fat. The fats add essential fatty acids to the diet and serve as an energy source. No additional fat is needed to make the feed float.

Feeding Practices

Golden Shiners

Golden shiners eat varying amounts of food, depending on their size, the amount of natural food in the pond, and pond water quality.

In extensive production, the water is fertilized until a plankton bloom develops that results in a Secchi disk reading of 8 to 9 inches. This bloom should be maintained until the fish reach a length of about 1 inch and before the weather becomes hot. The density of the bloom should then be reduced (by adding fresh water and reducing the amount of added fertilizer) until the Secchi disk reading is about 14 inches. This reading should be maintained throughout the summer.

In intensive production, the fry are offered a feed similar to those described earlier. If the fry come to the surface and eat when a small amount of feed is thrown into the pond, they can be fed normally. Ponds should be checked at the downwind edge 2 hours after feeding to determine whether the feed has been eaten. If feed remains, the amount fed should be reduced because leftover feed otherwise decays, and may lower water quality. When shiners stop feeding, the problem is usually low oxygen, pesticide contamination, disease, weather conditions, or the presence of a dense natural plankton bloom that meets their food requirements.

If faster growth is desired, shiners can be fed more than once a day. As shiners grow, the amount of feed is increased every few days. Golden shiners in heavily stocked ponds with an adequate water supply can be fed at least 40 pounds of feed per acre of pond per day, and production of 600 to 800 pounds per acre can be expected.

If the feed formula is changed, the old and new mixture should be blended together for a few days. Golden shiners can detect ingredient changes and sometimes reject new formulas.

Fathead Minnows

Fathead minnows are raised in both extensive and intensive culture operations. Each culture method requires different feeding techniques. In extensive production, the technique is the same as that described for golden shiners.

In intensive production, the young fish are fed starter feed in fertilized ponds that contain up to 25,000 brood fish. To ensure that the young fish are getting adequate amounts of feed, some producers offer starter feed to the fry and grower feed to the brood fish. The fry are then transferred from the brood pond to the recently filled, fertilized ponds and fed starter feed along the entire perimeter of the pond until they are about ¾ inch long. The ration is then changed to pelleted grower feed. To ensure that the minnows accept the new ration, the culturist blends four parts of pellets with one part starter feed. This blend should be continued until it is determined by observation that the minnows are eating the pellets. The minnows cannot swallow the pellets whole, but nibble on them until they are consumed. The amount of food eaten is determined by placing the feed in small piles near the shore on all sides of the pond, and rechecking the piles after 2 hours, to see whether all the feed has been eaten. If feed remains, the amount fed is reduced. Production per acre ranges from 350 to 1,200 pounds, but usually is 500 to 800 pounds.

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6. PRODUCTION METHODS FOR GOLDFISH, COMMON CARP, AND BUFFALOES

Jay V. Huner and Harry K. Dupree

Goldfish, common carp, and buffaloes have similar life cycles and environmental requirements. Each species spawns readily in earthen ponds and lays adhesive eggs that can be easily collected on spawning mats. Because propagation of these species is so similar, we combine them in this discussion of their culture.

The goldfish, a member of the minnow family, is a native of Asia. No detailed description is needed here because the colorful ornamental varieties are familiar to most people. Colors include the traditional gold and red, but range from white to black. Fancy varieties feature multiple colors, telescoping eyes, and multilobed fantails. Recognized varieties include common, calico, shubunkin, comet, veiltail, fantail (Fig. 6.1), and black moor (veiltail moor).

Goldfish are popular ornamental fishes but many are used for fish bait, especially on trotlines. Different fishermen prefer different colors—red, gold, olive, or bronze.

In recent years, large numbers of 1- to 2-inch goldfish have been sold for feeding to aquarium fishes. Tropical fish enthusiasts offer them to carnivorous species such as oscars. This still-growing market has rejuvenated the American goldfish industry.

Common carp have been cultured for centuries in Europe and Asia. This member of the minnow family was brought to North America in the late 1800's because of its popularity as a food and sport fish in the Old World. It has been generally treated as a pest or ignored in the United States—although one variety, the mirror carp, has been raised for trotline bait in some areas. Most objections to common carp as a food fish can be traced to the annoying intermuscular Y-shaped bones in the flesh. It is extremely likely, however, that the common carp will become important in United States aquaculture because it is an ideal species for culture, and (popular opinions to the contrary notwithstanding) an excellent food fish.



Fig. 6.1. Goldfish are members of the minnow family and are native to Asia. Colors are not limited to the traditional gold and red but include most colors of the spectrum. *Photo by Brenda Rodgers Moore.*

Buffaloes are native North American fishes belonging to the sucker family. They resemble the common carp and share so many environmental requirements that they do not coexist well in the same waters. Buffaloes are popular food fishes in the south-central United States despite the presence of the annoying intermuscular Y-bones also found in common carp. In fact, warmwater food fish culture can be traced to Arkansas in the 1950's, where buffaloes were propagated in managed fish ponds. They were later superseded by channel catfish but, at low stocking densities, are still good companion species with channel catfish, and interest in their culture is again high.

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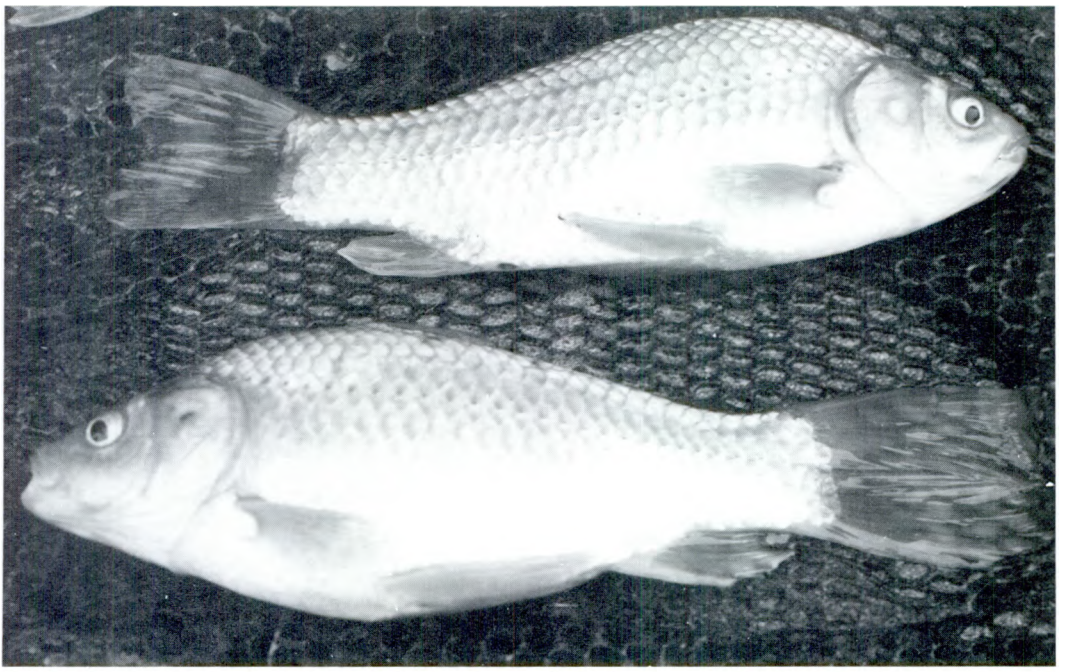


Fig. 6.2. Brood goldfish should be selected from fast-growing, disease-free, and well-proportioned stocks. Good spawns can be obtained from yearlings weighing 4 to 8 ounces. *Photo by J. Avault, Jr.*

Selection and Maintenance of Brood Fish

Brood fish should be selected from fast-growing, disease-free, and well-proportioned fish. Fish of known age that were reared in ponds or reservoirs are best because they are usually of uniform age, size, and condition. Brood fish should be caught and handled in small numbers to avoid overexcitement and injury. It is advantageous to cover transfer tubs with cloth or burlap while handling the fish, as they soon calm down in a darkened tub.

Goldfish rarely exceed 2 pounds in weight, but brood fish can be spawned in 1 year, when they weigh 4 to 8 ounces (Fig. 6.2). Buffaloes and common carp may weigh 40 to 50 pounds. Fish of 3 to 8 pounds and at least 3 years old (for buffaloes) or 2 years old (for carp) are recommended for brood stock because they can be easily handled and transported, and are usually satisfactory sources of spawn.

By careful selection of brood stock, growers of goldfish can readily control the color and shape of their fish to meet market demand. If a bronze color is preferred, brood stock should be selected accordingly. For 100% bronze-color offspring, the brood stock male should be the bronze shubunkin variety—a hybrid that can be obtained from a producer of fancy goldfish. If an increase in the number of red fish is desired, early-coloring fingerlings should be selected from the rearing ponds for potential brood stock. Body contour may similarly be improved. Although odd-shaped, heavy, thick-bodied fish are preferred by hobbyists, a slim-bodied variety is preferred for bait. Undesirable brood fish should be removed before spawning occurs.

A great deal of genetic selection practiced with the common carp has led to the development of several distinct varieties. The most spectacular variety is the ornamental koi carp developed in Japan. Koi carp have a wide range of color patterns that can include red, orange, white, blue, yellow, and black. Some individual fish have been sold for more than $20,000. In Europe, selection has resulted in several varieties of common carp that are

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Fig. 6.3. The mirror (or Israeli) carp, a true-breeding strain of common carp, has a row of scales along the back and a few scales scattered on other parts of its body. It has been selectively bred for fast growth and improved food quality by Israeli geneticists. *Photo by J. Avault, Jr.*

characterized by fast growth and high meat production. Four distinct European varieties of common carp are distinguished on the basis of their scale patterns (listed here in order of decreasing number of scales): scale (fully scaled) carp, mirror (or Israeli) carp (Fig. 6.3), line (or Zeil) carp, and leather (scaleless) carp.

The scale carp differs from the original common carp in body shape. The common carp—the one with which most Americans are familiar—is elongate and has an almost circular cross section. In the scale carp, the contour of the top of the body rises steeply behind the head, which is much smaller than the height of the body. The height-to-length ratio of the common carp is typically 1:3.2, whereas that of the scale carp is 1:2.8. The mirror, line, and leather carps have height-to-length ratios similar to that of the scale carp.

The mirror carp has a row of scales along the back and a few usually large scales scattered on other parts of its body. The line carp has a continuous row of scales along the lateral line, and may also have parallel lines of scales along the back and belly. The leather carp is without (or almost without) scales.

The mirror carp breeds true, but the line and leather varieties do not. Line or leather carp can produce offspring from a single batch of eggs that include fully scaled fish, mirror carp, line carp, and leather carp. High mortality and much deformation is typical among the offspring of leather carp.

Three species of buffaloes occur in the United States—the smallmouth, bigmouth, and black. The following characteristics differentiate the species: the smallmouth buffalo has a compressed body, elevated back, pointed nose, and turned-down mouth; the bigmouth buffalo has an elliptical, robust body, blunt nose, and turned-up mouth; and the black buffalo has an elliptical, robust body, pointed nose, and a turned-down mouth. All three species thrive in rivers, where the smallmouth buffalo predominates, the bigmouth ranks second, and the black buffalo ranks third. Usually only the bigmouth buffalo is found in northern lakes, whereas the other two species (the black predominating), occur in southern lakes. In commercial production, the bigmouth buffalo is the preferred species.

Hybrid buffaloes have become popular for culture, especially in polyculture with channel catfish, because some crosses grow much faster than pure-strain fish. The best cross in both laboratory and field tests has proved to be that between the female bigmouth buffalo and the male black buffalo. At the end of the second year of life, the hybrid is one-third heavier than a fish with single-species parents.

Brood fish of each species—goldfish, common carp, or buffalo—should be held in wintering or holding ponds after spawning. A well-fertilized 1-acre pond 3½ to 6 feet deep easily accommodates 400 to 600 pounds of brood fish without supplemental feeding. Overcrowding may cause fish to lose weight, become diseased and infested with parasites, and die. Satisfactory spawning cannot be expected unless the fish are in good physical condition.

Goldfish, common carp, and buffaloes that are sexually mature can be easily sexed at or near spawning time. The vent of the female is larger, redder, and more protruding than that of the male. Slight pressure near the vent of the male produces a small amount of white milt. At spawning time, female buffaloes feel relatively smooth, whereas males feel like

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sandpaper because they have numerous breeding tubercles on their scales and fins. The presence of serrations on the pectoral spines of the male goldfish, which are absent in the female, make it possible to identify the sexes throughout the year.

Pond Method of Spawning

Spawning ponds should be stocked when water temperatures rise to and remain above 60°F for goldfish and 65°F for common carp and buffaloes. Ponds may be of various areas, but the 1-acre size is ideal. Spawning ponds should be dry during winter and refilled with well water just before the brood fish are introduced.

Fertilizers should be applied when the brood pond is filled to ensure the presence of a plankton bloom when the eggs hatch. Chemical fertilizer (16-20-0, N-P-K) at the rate of 100 pounds per surface acre, and organic fertilizers such as chicken or sheep manure, alfalfa meal, or soybean meal at 200 to 300 pounds per surface acre, should provide nutrients for the desired food organisms. Applications should be repeated as required, to maintain the plankton bloom.

Eggs may be left in the spawning pond (the wild or free spawning method) or moved to other ponds (the egg transfer method). For goldfish, stocking rates should be 40 to 80 pounds (100 to 200 fish) of brood fish per acre for the free spawning technique or 800 to 1,000 pounds per acre for the egg transfer method. If carp or buffalo fry are to be raised to large fingerling size in the spawning pond, only 2 or 3 pairs of adult fish are needed per acre, but if small fingerlings are to be transferred to rearing ponds, 8 to 10 pairs of brood fish can be stocked per acre. Only one species of buffalo should be stocked unless hybrids are desired.

In wild spawning, the water in the spawning pond is typically lowered before stocking, and rye grass is planted in intermittent rows below the normal waterline. When the pond is refilled, the grass provides spawning sites. If plant growth is scarce or absent, hay or straw, or spawning mats made of Spanish moss or synthetic fiber, can be anchored (to prevent drifting) along the shore in shallow water.

When the egg transfer method is to be used, all vegetation must be removed from the pond to prevent deposition of eggs that cannot be readily recovered. Spawning mats used to collect eggs are ready for transfer when they are uniformly covered with eggs; they should not be left in ponds until the eggs become so abundant that they touch one another. Excessive numbers of eggs on a mat encourage the growth of saprophytic fungi, which may smother developing eggs. When mats are covered with eggs, they can be moved to rearing ponds for hatching. The eggs must remain wet in transit. Estimating the number of mats to use per acre is difficult and requires much experience. If too few or too many fry are produced, advanced fry may have to be transferred between ponds.

Fry are usually transferred from ponds that have been intentionally overstocked. Goldfish are usually transferred when they reach lengths of ¾ inch, and carp and buffaloes when they reach 1½ inches. Lift traps and short seines constructed of fine-mesh netting are used to capture the fry in baited areas.

When fry are stocked, predaceous insect control is vital. Each week 2 to 4 gallons of diesel fuel (to which low-grade motor oil has been added at the rate of 1 pint per gallon) should be applied per surface acre. Oil and diesel fuel suffocate air-breathing insects. Applications should be continued until fry reach lengths of ¾ inch for goldfish or 1 to 1¼ inches for carp and buffaloes.

Stocking densities for fingerling goldfish, carp, and buffaloes depend on how soon salable fish are needed, size of fish desired, the level of intensity of pond management, and the length of the growing season. Stocking densities for goldfish range from 25,000 to 1 million per acre. For carp and buffaloes, 1½-inch fingerlings removed from a fry production pond reach lengths of 7 to 8 inches in the same season if stocked at 2,000 per acre, or 4 inches if stocked at 10,000 per acre.

Spawning often begins within 24 hours after

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brood fish are stocked, and eggs hatch in 72 to 96 hours at water temperatures of 66 to 75°F. Fry may be seen swimming in schools along the shoreline 7 to 10 days after spawning is complete.

When the fry are observed, supplemental feed in the form of flour-fine meal should be provided at rates of about 2 to 3 pounds per acre per day. Minnow feeds are excellent if particle size is small enough. Generally, this feeding practice applies equally to goldfish, carp, and buffaloes; however, because carp and buffaloes grow faster and become larger, closer attention must be paid to particle size.

Goldfish can be fed extensively with natural food produced by heavy fertilization, or intensively with fertilization and feed. Fertilized ponds produce 900 to 1,000 pounds per acre. Fertilizer, feed, and good fish cultural practices can produce yields of 3,000 pounds or more of goldfish per acre. A plankton bloom dense enough to yield Secchi disk readings of 5 to 7 inches is preferred before hot weather begins. After the water temperature exceeds 80°F and the fish are longer than 1 inch, the water should be clear enough to increase the Secchi disk reading to 10 inches. Clarity is increased either by pumping in fresh water or by allowing the bloom to recede (by discontinuing fertilization). Fertilizer is then added, as needed, to maintain this bloom level.

In intensive culture, feed is added along with the fertilizer. Fish production in fertilized ponds may be increased by the supplemental feeding of minnow production feeds. Goldfish production can be increased to more than 1 million fry per surface acre by fortifying the basic golden shiner starter feed formula (Table 5.1) with 5 to 10% commercial egg yolk in place of some other ingredient such as feather meal. Multiple daily feedings also increase fry survival.

After the fish are feeding well and are almost 1 inch long, starter meal is gradually changed to "grower" pellets. Four parts of starter meal should be mixed with 1 part pellets and fed until the fingerlings are eating the pellets; they can then be converted entirely to pellets.

The feeding of goldfish, carp, and buffaloes requires good management, especially when high standing crops are being fed large amounts of feed. If oxygen depletion is to be avoided, the feed allowance must be reduced when dissolved oxygen is low, if the air temperature is 95°F or higher, or if the sky is overcast.

Artificial Method of Spawning

Goldfish, common carp, and buffaloes are easily spawned artificially. The eggs and milt can be collected without difficulty. Although this practice is not especially common for goldfish because of their small size, or for carp because they spawn so readily, it is a useful method for producing hybrid buffaloes.

When water temperatures reach 65 to 70°F, which is the usual spawning temperature, adult fish are transferred from ponds to holding tanks. The females can be injected intraperitoneally at the rate of 800 international units of human chorionic gonadotropin per pound of fish or with fish pituitary at the rate of 2 mg per pound. The males can be injected with 0.5 mg fish pituitary.

The fish usually ovulate 16 to 18 hours after injection; consequently, females should be injected during the afternoon so that eggs can be collected the following morning. If ovulation has not occurred by afternoon, the injections should be repeated and the fish returned to the holding tank.

The appearance of a few eggs in the tank is an indication that ovulation is imminent. Females should be carefully netted and slight pressure applied to the abdomen. If eggs flow freely, the fish can be stripped as follows: Grasp the caudal peduncle (fleshy part of the tail) with the left hand and tuck the head and body under the right arm, holding the female in an upright position. Wipe water from the body of the fish with a cloth and gently apply pressure to the abdomen by stroking it with the right hand. Collect the eggs in a dry porcelain pan. When no more eggs can be taken, place the fish in a tank for return to the brood pond. Next, grasp a male in the same way, wipe the body, and strip milt into the pan containing the eggs. Mix the eggs and milt by stir-

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ring them slowly with a large feather (e.g., a wing feather from a turkey). After 3 minutes, begin slowly adding water. Stir the eggs continuously while the water is being added. Then pour off the water to remove blood and ovarian fluids and tissue, and again add water. Some culturists add laundry starch, kaolin, or fine clay to the water during the entire washing process. The particles of starch, kaolin, or clay adhere to the sticky surface of the hardening eggs and make them non-adhesive. Many concentrations have been used—2 ounces per gallon of water being very popular—and adjustments may be made to meet individual requirements. Regardless of the technique used, rapid and continuous stirring of the eggs for as long as 2 hours is essential to retard clumping.

Water-hardened eggs are transferred to standard McDonald hatching jars (or equivalent) supplied with well-aerated water at 65 to 75°F. Two quarts of eggs are usually placed in each jar. Care should be taken to ensure that the flow is sufficient to slowly roll all eggs in the jar. Eggs that are not agitated sufficiently, or which clump, soon die and develop fungal growths that endanger survival of the rest of the eggs in the jar.

Hatching should occur in 72 to 96 hours at 65 to 75°F. Buffalo fry leave the jar soon after hatching; they should be collected in a rearing trough or in small floating boxes with bottoms or walls of Saran cloth (60 meshes per inch). If boxes are used, fry must be periodically transferred to a rearing trough. Drains from rearing troughs should also be covered with Saran cloth to prevent the loss of fry.

Feed should be offered ad libitum 72 hours after the fish hatch, and regular feeding should begin at 96 hours. Finely ground trout feed, finely ground commercial catfish or minnow feed, or pulverized yolks from eggs boiled for 15 minutes are all acceptable as beginning feeds. The egg yolk appears most desirable as initial feed because it yields a cloudy suspension of very small particles when it is crushed between the fingers in a small amount of water. Boiled yolks can be frozen and stored until needed.

Fry should be fed several times throughout each day and night until they are 5 to 10 days old. They can then be transferred to the specially prepared rearing ponds described earlier.

If jar culture is not possible, freshly fertilized eggs can be scattered over mats of Spanish moss, artificial fiber, or cedar boughs while they are still adhesive and before they have become water-hardened. After 2 hours (for water hardening), the egg-laden mats can be transferred to freshly filled rearing ponds for hatching. Some goldfish producers have transported eggs and milt to the pond in separate containers, combined the eggs and milt, and then added the water to initiate fertilization. The eggs can then be scattered before clumping begins, on brush, grass, and other structures in the prepared pond.

Production of Food-sized Fish

Goldfish are raised for food in the Orient but not in the United States. Common carp are the most important freshwater food fish in Europe and Asia but are almost invariably raised in polyculture with other fishes of low trophic levels. Culture of common carp for food is extremely limited in the United States. In Europe and Asia, 1,000 to 3,000 large fingerling carp are stocked per acre to produce fish weighing 1 to 3 pounds in a typical growing season. If carp are to be stocked with channel catfish, rates should be 50 to 125 large fingerlings per acre to ensure that large 3- to 5-pound fish are produced. However, they should not be put into ponds that are not drained annually because their abundant offspring will create difficult management problems. Another consideration is their use of feed: common carp readily eat pellets and probably compete directly with channel catfish for feed. (This is not a problem with buffaloes, which rarely eat pelleted catfish feed.)

Buffaloes are not usually grown in monoculture because their value does not justify the effort (Fig. 6.4). Common polyculture combinations are channel catfish, bigmouth buffaloes, and largemouth bass; channel catfish, bigmouth buffaloes, and minnows; or channel

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Fig. 6.4. Buffaloes are not usually grown in monoculture because their value is relatively low. Bigmouth buffaloes grow rapidly from the ½-pound stocking size to the 5-pound market size in a single season.

catfish and bigmouth buffaloes. Buffaloes are stocked at the rate of 50 to 125 fingerlings per acre. Hybrid buffaloes are preferred because they normally do not spawn if held for a second year. The bigmouth buffalo and its hybrid grow from about the ½-pound stocking size to the 5-pound harvest size in a single season. Largemouth bass stocked at the rate of 20 to 50 per acre usually eliminate most buffalo fry when non-hybrid fish are stocked.

Small, labor-intensive fish farms that involve hand sorting and weekly sales of small lots of fish to local markets are ideally suited to polyculture of buffaloes. Large-scale fish culture operations may use large-mesh gill nets or seines to selectively harvest buffaloes. At harvest size, buffaloes are large, midwater fish that swim actively during the day and can be caught in gill nets, while smaller catfish swim beneath or through them. This technique will not, however, prevent the need to "throw buffaloes over the net" when smaller mesh catfish seines are used to selectively harvest the smaller ¾- to 2-pound catfish in the ponds. The manager must decide whether the effort is justified.

Buffaloes have been successfully cultured for up to 2 years in ponds with salinities ranging from 2 to 11 parts per thousand (ppt), with a normal range of 3 to 7 ppt. They have spawned at salinities near 2 ppt.

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7. PRODUCTION METHODS FOR CHINESE CARPS

Harry K. Dupree and Jay V. Huner

Grass carp, silver carp, and bighead carp have been cultured for food in China for several thousand years, and in Asia and some European countries for lesser periods. The grass carp (Fig. 7.1) was introduced into the United States in 1963, and the silver carp and the bighead carp (Fig. 7.2) somewhat later. Considerable information exists for the production and management of these fishes for food throughout the world, and interest in production for food has increased in the United States. However, prior interest in the grass carp here has been centered on its use as a vegetation control animal, and the silver carp has been investigated principally as a nutrient removal species in sewage and animal waste lagoons. We include here a summary of some techniques and procedures that have been shown to be practical for the large-scale production of these fishes in the United

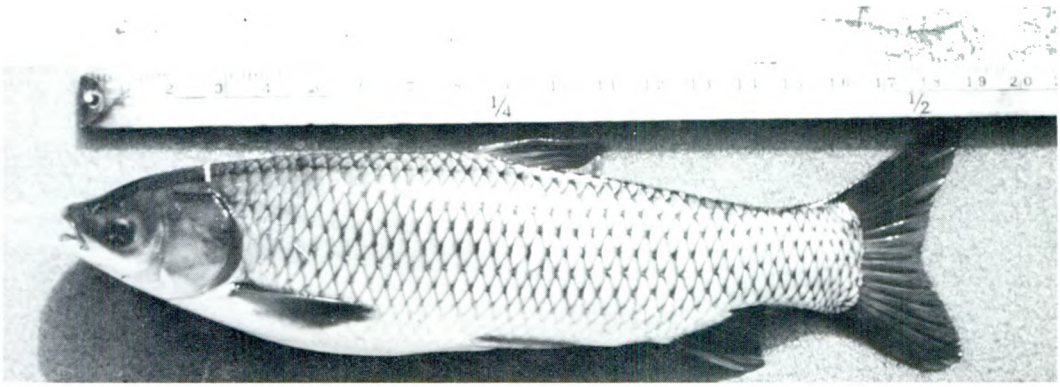


Fig. 7.1. The grass carp was introduced into the United States in 1963 to be used in biological weed control. It has long been a popular food fish in Asia and Europe, and its acceptance as a food animal is increasing in the United States.



Fig. 7.2. The bighead carp is an excellent food animal, and highly prized by Asians in the United States. It is well suited for culture in combinations with other fishes such as the grass carp, silver carp, and common carp. Its acceptance by consumers in the United States is rapidly increasing.

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States. Some techniques routinely used in other countries that we believe would be useful and beneficial are included.

Grass, silver, and bighead carps do not spawn in still water such as that in ponds. Much controversy has surrounded their importation because many people fear that they will become established in natural waters, displacing native species and possibly disrupting natural ecosystems, as the common carp is believed to have done. As a result, most States have outlawed these exotics. Thus anyone contemplating their culture must first become acquainted with local restrictions.

Production of Seed Stocks

Brood Fish

Grass carp, silver carp, and bighead carp for potential brood stock should be selected at 1 to 2 years of age and stocked in brood fish ponds. Ponds suitable for channel catfish brood fish are adequate for the Chinese carps. Generally these ponds are from 1 to 10 acres in area and have adequate water supplies. Female grass carp and bighead carp mature at about age IV, and the silver carp (both sexes), male grass carp, and male bighead carp at about age III.

The different species of brood fish can be stocked alone, or some species can be stocked together. Males and females are generally stocked at the ratio of 1:1 or 3:2. Many stocking combinations are possible (Table 7.1).

Mature brood fish that have been spawned can be held for use the following year. Generally, these fish are stocked on the basis of standing crop weight rather than by numbers. The males and females are generally stocked at the ratio of 1:1 or 3:2. A typical restocking schedule is shown in Table 7.1.

Water management practices recommended for channel catfish production ponds must be observed. It is important to maintain dissolved oxygen levels above 5 ppm, and to prevent the buildup of detrimental water quality characteristics.

Spawning of Brood Fish

In mid-April to mid-May in the southern United States, the brood fish should be seined and inspected. Since common carp spawn at about the same time as the Chinese carps, they can be observed as an indicator of readiness. The female fish should have a distended, flaccid abdomen as compared with that of the males. A pinkish area around the egg vent indicates that a fish is ready to ovulate. The male grass carp should have protuberances on the head and operculum (pearl organs) when ripe. Milt usually can be easily expressed from the vent of all mature male carp during the breeding season.

When the seined brood fish appear ready to spawn, fish that will be spawned immediately should be taken from the net and each put into a muslin or porous cloth bag, placed in water in a transport unit, and carried to the spawning shed. Water in the transport unit must be aerated and the fish must be protected from rapid changes in water temperature. It may be necessary to anesthetize the fish during transport to prevent them from injuring themselves.

Brood fish should be stocked in separate tanks. Most tanks in holding sheds or shipping sheds have been shown to be adequate, provided that the water has sufficient dissolved oxygen and that the water temperature can be held near 77°F. The tanks must be covered to keep the fish from jumping out.

Good quality water is essential for maintaining brood fish, hatching eggs, and culturing larvae and fry. Water obtained from wells is often preferred because it is usually free of pesticides and disease organisms. However, it may contain dissolved iron, carbon dioxide, and hydrogen sulfide, and is often too cold. Aeration and filtration of the water usually remove most detrimental water quality factors, and passing the water through a water heater and mixer warms the water to the desired 77°F. However, it is essential to vigorously agitate the water before use with brood fish, eggs, or fry, in order to "beat out" the excess nitrogen and saturate the water with oxygen. A head trough positioned above the

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Table 7.1. *Suggested stocking rates and feeding methods for Chinese carps: rearing of brood stock (fish stocked at 1 to 2 years of age, and maintained until mature at 3 to 4 years of age) and maintenance of brood fish after spawning.*

Brood stock program		
Rearing (species, minimum weight at stocking [in parentheses], and number stocked per acre)	Maintenance (species, and number of pounds of brood fish stocked per acre)	Feed or fertilization
Single species Grass carp (½ lb), 60–80	Grass carp, 500–800	A catfish-type supplemental or nutritional complete floating feed (32 to 36% protein) should be offered at the rate of 2 to 3% of the standing crop of grass carp. During cold weather feeding allowances should be reduced to the amount that is eaten within 30 minutes.
Species combination Grass carp (½ lb), 40–60 + Bighead carp (⅓–½ lb), 30–40	Grass carp, 400–600 + Bighead carp, 200–300	
Silver carp (⅓–½ lb), 40–60 + Bighead carp (⅓–½ lb), 30–40	Silver carp, 300–500 + Bighead carp, 200–300	Chemical fertilizers or manure should be applied to develop a plankton bloom. The bloom should be maintained at a density that yields a Secchi disk reading of 18 inches. During winter, a minnow meal feed or oilseed protein meal should be offered at the rate of 5 to 10 pounds per acre whenever the water temperature exceeds 55°F.

hatching containers and equipped with mechanical agitators can serve as a water reservoir, distribution system, and aerator tank.

A number of hormone injection schedules have been used for Chinese carps, and most are satisfactory. The injection protocol shown in Table 7.2 was modified from that used by the Arkansas Fish and Game Commission.

Egg Taking

About 10 hours after the 24-hour hormone injection, the females should be netted and inspected. When slight pressure is applied to the abdomen of a fish that is ready to ovulate, the eggs flow rapidly. If few or no eggs are obtained, the fish should be returned to the vat and examined again after another hour.

Table 7.2. *Injection sequence for spawning Chinese carps: amount of hormone to be injected per pound of fish at different intervals.*[a]

	Hormone and hours of injection		
	HCG		Dry pituitary
Sex	0 hours	12 hours	24 hours
Female	100 IU	850 IU	1.0 mg
Male	0	0	0.1 mg

[a]The required amount (International Units [IU]) of human chorionic gonadotropin (HCG) is dissolved in saline and injected with an 18- or 22-gauge needle. The fish pituitary is pulverized, mixed with saline, and injected with an 18-gauge needle. All injections are made intraperitoneally. Females generally ovulate within 10–12 hours after the 24-hour injection with pituitary. The 24-hour injection can be varied by 6 to 8 hours among different fish so that all fish do not ovulate at the same time.

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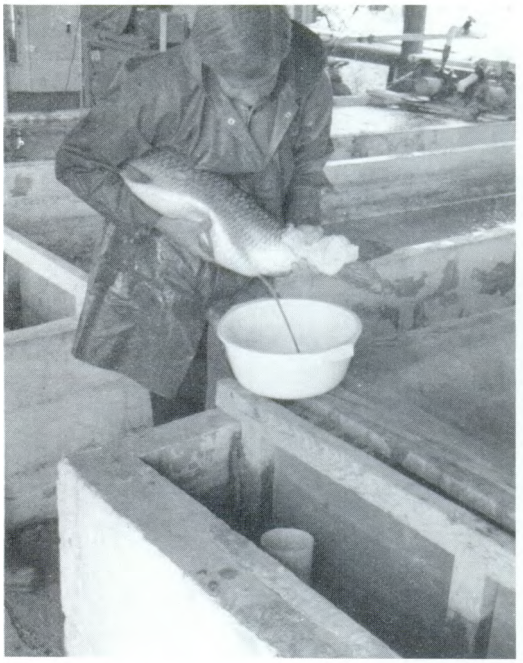


Fig. 7.3. Stripping eggs from a grass carp that ripened after hormone injection. A soft towel is used to dry the fish, and also to aid in holding it.

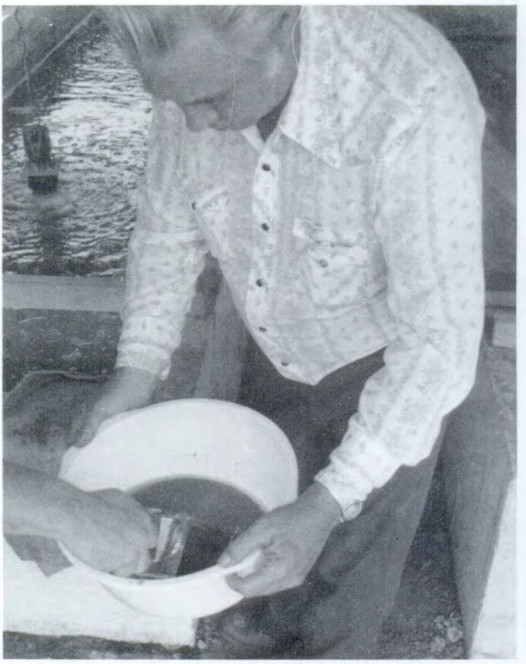


Fig. 7.4. In the dry method of fertilization, after the eggs and milt are combined, water is slowly added to activate the milt. Constant stirring of the eggs, milt, and water usually ensures a high fertilization rate.

When the eggs flow rapidly, place a finger over the vent. Wrap the fish in a towel or place its head in a sack (Fig. 7.3). Dry the fish around the vent. Then, holding the tail slightly lower than the head, remove the finger and allow the eggs to extrude into a wash pan. Apply additional pressure to eliminate the remaining eggs. Keep all water out of the egg-collecting pan.

Next, remove two males and press the abdomen to ensure that milt is flowing. Dry the fish and press the abdomen to obtain enough milt to cover the eggs. Stir the mixture of eggs and milt with a feather, paint brush, or even with a dry finger. Then slowly add water and mix further. Repeat until the water volume is twice the egg volume (Fig. 7.4). Continue stirring for about 3 minutes. Then decant and replace the water. Repeat this process 3 or 4 times.

After about 10 minutes, the eggs are water-hardened. At this stage a 1-quart volume contains 225,000 to 250,000 eggs.

Hatching

Eggs of Chinese carps can be hatched in a variety of devices. For small quantities of eggs, the glass or plastic McDonald hatching jars used by the trout industry are adequate. Larger quantities can be hatched in fiber glass containers. Some producers have used catfish rearing troughs equipped with a lawn sprinkler, or circular fiber glass cattle-watering troughs equipped with underwater nozzles. Essentially, all that is necessary is to provide sufficient water exchange to maintain adequate DO and flush out waste metabolites, and sufficient agitation to move the eggs. This movement ensures that there are no dead-water areas in the hatching container where the eggs might suffocate. The outlet must be screened to prevent the loss of the eggs and fry through the hatching tank overflow. Before hatching begins, a screen of ⅛-inch mesh is suitable, and requires less maintenance than a smaller mesh screen.

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As mentioned previously, the water supply for the hatching containers can be a well or pond. The water should be well oxygenated and the excess gasses beaten out. Dissolved iron, carbon dioxide, and hydrogen sulfide must be removed if present, and a different water supply would be preferred if these chemicals are present in large amounts. The water can be heated or cooled to provide a temperature near 77°F.

The eggs normally hatch after about 20 hours of incubation. The water flow should be increased to flush away the egg waste and shells. Care must be taken to prevent the loss of the fry; Saran cloth screening is recommended. The fry can be held in the hatching tanks or removed to other tanks and kept for about 5 days before they are stocked.

Culture of the Young

Fry

Ponds suitable for the culture of Chinese carps are similar to those used to culture channel catfish fry, bait minnows, and striped bass. In the culture of all these fishes, it is essential to drain and dry the pond, and to disinfect any wet spots and puddles with hydrated or burnt lime. (Care should be taken because these forms of lime are caustic.) From 1 to 2 weeks before the fry are stocked, the pond should be filled with well water or filtered surface water. The surface water must be free of pesticides, and the filter medium should be sand and gravel or Saran cloth, either of which removes all fish and predaceous organisms. Any mixture of organic materials and chemical fertilizers that enhances the growth of zooplankton can be applied at the time of the filling. A mixture that we have used consists of 200 to 300 pounds of chemical fertilizers such as 20-20-0 (N-P-K) or the equivalent amount in a liquid formulation, 200 to 300 pounds of alfalfa leaf meal, and six to eight bales of high-protein hay per acre. Some workers have used 100 to 200 pounds of a high-protein oilseed meal, such as cottonseed meal, with good results. Waste from swine, poultry, or cattle can be applied at the rate of 100 to 300 pounds per acre. Because different ponds respond differently to fertilization, the fish culturist must experiment to find the best mixture for each pond.

Research has shown that survival of the fry is increased if the predaceous insects and other organisms in the pond are killed before the fish are stocked; either 0.5 ppm methyl parathion[x] or 10 ounces Baytex[x] should be applied per acre-foot. Diesel fuel applied at the rate of 4 gallons per surface acre kills air-breathing insects and can be used after ponds are stocked with carp fry.

Chinese carps are stocked initially in monoculture. The fry can be stocked at the rate of 100,000 to 500,000 per acre. It is best to stock them in the early morning to reduce temperature shock. The vat water temperature can be gradually raised or lowered to that of the pond. The fry can be poured or drained from the hatching device into tubs and immediately transported to the ponds. Netting of the delicate fry should be avoided if possible. If the fry are to be transported a considerable distance, it may be necessary to place them in oxygenated plastic bags.

At first the fish will feed primarily on zooplankton and other animal organisms. However, supplemental feed can be offered. Meals used in bait minnow farming, scattered on the water surface, are usually adequate until the fish are 3 to 4 inches long. The growth of the fish must be observed. When growth rates diminish, either more supplemental feed must be offered or density must be reduced by transferring some of the fish to other ponds. Water quality must be observed when the fish are fed. In most areas the producer should be especially cautious when more than 30 pounds of feed per acre are offered.

Fingerlings

Fingerling grass carp, bighead carp, and silver carp can be produced in monoculture, or grass carp and bighead carp, or grass carp and silver carp (Fig. 7.5) can be produced in polyculture. The date of sale and the desired size

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Fig. 7.5. The silver carp is cultured in combination with grass carp, bighead carp, and several other food fish species. It is receiving considerable interest in the United States for nutrient removal in sewage and animal waste lagoons. *Photo by J. Avault, Jr.*

at sale dictate the specifics of the production program. For example, relatively large numbers of fish can be stocked when only small fish are needed late in the growing season, but fewer fish must be stocked when the demand is for large fish early in the production period.

Production information is limited in the United States to the grass carp. However, observations thus far show that much of the culture information available from China can be used here. Some of the Chinese information on stocking and production of carps is given in Tables 7.3 and 7.4.

Feeding and management techniques used depend on whether the fish are being produced alone or in polyculture. Polyculture species could also include some native United States fishes such as catfishes or black basses. Various stocking combinations have been tried by commercial fish producers and by researchers, but for the most part no conclusive findings or recommendations are available. The suggestions given here have been obtained from the literature and from fish producers, and modified on the basis of our knowledge of the culture of other fishes.

Grass carp fingerlings and food-sized fish feed exclusively on aquatic plants in nature. However, the fish in managed systems feed on floating pelleted fish feeds and terrestrial grasses such as millet and Bermuda grass.

Table 7.3. *Monoculture of fingerling Chinese carps.*[a]

Species, and length (inches) at stocking	Stocking rate (number per acre)	Length at harvest (inches)	Production period (days)
Grass carp			
1	120,000	2	20
2	24,000	2½	20
2	35,000	5	150[b]
Bighead carp			
1	100,000	2½	30
2½	30,000	5	30
1	100,000	4	150[c]
Silver carp			
1	120,000	2½	20
1	120,000	4	50
2½	5,000	5	30
4	6,000	8	40
1	180,000	8	150[c]

[a]Sources: (1) Artificial propagation of grass carp, silver carp, and bighead carp in China: Nursing fry culture of adult fish and technique about prevention and treatment of fish's disease. Edited by Fisheries Research Institute of Shanghi. Peoples Republic of China. December 1978. (2) Pond fish culture in China. Edited by Pearl River Fisheries Research Institute, China National Bureau of Aquatic Products, Guangzhou, Peoples Republic of China. February 1980.

[b]September–January.

[c]July–November.

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Table 7.4. *Polyculture of fingerling Chinese carps. For all combinations, production period is July to January, and average length of fish at stocking is 3 inches for grass carp and 2 inches for bighead carp and silver carp.*[a]

Combination and species	Stocking rate (no./acre)	Length at harvest (inches)
Combination 1		
Grass carp	18,000	6
+ bighead carp	90,000	3
Grass carp	20,000	6
+ bighead carp	12,000	7
Combination 2		
Grass carp	30,000	6
+ silver carp	150,000	3
Grass carp	20,000	6
+ silver carp	18,000	7

[a]Summarized from Chinese fishery literature. See text for discussion. Specific references are given in Table 7.3 (footnote).

These plants can be fed green (freshly cut) at rates up to 200 pounds per acre daily. Some producers have fed smaller amounts of green forage to supplement a diet of pelleted feed.

Most grass carp producers are now feeding pelleted feed. Growth responses have been good to offerings of a 36% protein floating feed formulated for intensive catfish production. When small fishes first begin feeding, it may be necessary to offer floating meals formulated for minnows. Feeds are usually offered at the rate of 3 to 4% of the weight of the standing crop of fish, scattered from the upwind side of the pond. Initially the fish appear to feed best near sundown. During winter the fish should be offered feed only on the warmer days.

Bighead carp feed on detritus and zooplankton in the natural environment. In managed environments, however, they feed on baitfish feeds and sinking channel catfish feeds. Fertilizers, plant materials, and animal wastes that result in the collection of pond bottom detritus can be used to indirectly support the growth of bighead carp. The nutrient content of these materials varies, and thus the amounts to be used cannot be standardized. It would appear that the maximum amounts of feed, fertilizers, and organic or animal wastes that could be applied without significantly reducing water quality would be the correct amount for maximum fish production.

Silver carp feed on plankton in the natural and managed environment. Chemical fertilizers and organic and animal wastes that stimulate plankton production probably provide the best conditions for growth. Plankton production varies with nutrient source and natural pond fertility. Thus the production system should be managed for maximum plankton production but without significant reduction in water quality.

In polyculture systems consisting of grass carp stocked in combination with silver carp or bighead carp, the production system should be managed for grass carp, as already described. The uneaten feed, and other organic materials, provide detritus for bighead carp or nutrients for the phytoplankton that is eaten by silver carp.

Production of Large Fish

Polyculture and Monoculture

Fingerlings are generally cultured to subadults and adults in polyculture because this technique maximizes pond use and profit.

The Chinese practice extensive polyculture, using grass, silver, and bighead carps in combination with several other carps, including the black carp, mud carp, and common carp. Other species such as mullets, tilapias, and snakeheads (fish similar to the bowfin of North America) may be added in certain situations. Neither the mud carp nor black carp is known to be present in the United States. All species benefit from the addition of chemical and organic fertilizers that enhance the growth of food organisms. Details of stocking combinations of subadult and adult grass, silver, and bighead carps are shown in Table 7.5. Annual yields of 2,000 to 5,000 pounds per acre are common.

Feeding of these fishes is identical with that described previously for the production of the

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Table 7.5. *Production of Chinese carps in polyculture.*[a]

Life stage and species	Stocking rate (number per acre)	Weight at stocking (pounds)	Weight at harvest (pounds)	Production period (days)
Subadults				
Grass carp	900–1,500	0.2–0.3	0.5–1.1	60–180
Bighead carp	420	0.4–0.5	1.1	40
Silver carp	120–200	0.1	0.5–1.3	90–180
Adults				
Grass carp	250–500	0.5–1.1	2.9–3.3	60–180
Bighead carp	130	1.1	2.2–3.3	40
Silver carp	120–240	0.5–1.3	1.5–2.2	90–180

[a]Summarized from Chinese fishery literature. See text for discussion. Specific references are given in Table 7.3 (footnote).

grass carp. That is, the feed allowances should be based on the weight of the standing crop of grass carp. If water quality declines due to possible overfeeding, the amount of feed offered can be reduced, or the amount of pond flushing increased.

In Israel, silver carp and bighead carp have become useful components of the domestic fish culture industry. Stocking rates are 100 to 300 fish per acre. The increased fish production and apparent improvement of water quality have encouraged this culture practice. Another Israeli practice involves the use of "sanitary" fish. Many ponds used primarily to culture other species are stocked with combinations of 400 silver carp, 200 common carp, and up to 40 grass carp per acre. The silver carp added to the stocking combination are believed to prevent blooms of blue-green algae and to stabilize phytoplankton communities, resulting in fewer off-flavor problems. Common carp stir up the bottom, making the water opaque and thus reduce the amount of filamentous algae on the bottom. The grass carp eat the vascular plants.

Some observations on the monoculture of grass carp in the United States suggest that production techniques for the intensive production of channel catfish apply to the monoculture of grass carp. It appears that standing crops of grass carp can reach at least 2,000 pounds per acre, and that crops of 1,000 to 1,200 pounds per acre are easily attainable when commercial feeds are offered. Thus, if the grass carp producer wishes to produce fish that are 8 inches long and weigh about ⅓ pound each, he might stock 3,000 advanced fingerlings per acre to reach the projected standing crop of 1,000 pounds per acre. Other stocking levels and production schemes are possible; an ingenious fish farmer should be able to devise a workable program for a particular farm.



Fig. 7.6. Harvesting grass carp by seining. The jumping fish (e.g., center and left center in photo) are difficult to keep in the net.

Harvesting

Seining, handling, and transporting are more difficult for the Chinese carps—especially the grass carp—than for some other warmwater fishes (Fig. 7.6). Because grass

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carp are prone to jump over a seine, the seine must be held up manually, or some other method must be devised to keep the fish inside the net. Some workers use floats to hold the cork line 1 to 2 feet above the water. Others use a floating seine inside the main seine. The simplest method is for workers to physically hold the net above the water. However, this method is labor-intensive (and therefore costly), and the workers may be injured by the jumping fish.

It is important to restrain the fish when they are being handled. Self-induced injuries, some of which are fatal, are common. The fish can be placed individually in porous bags (muslin or netting) to restrain them, and can be anesthetized to reduce their activity in the transport tubs and tanks and in the holding shed.

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8. PRODUCTION METHODS FOR STRIPED BASS

Nick C. Parker and James G. Geiger

The striped bass, and more recently the hybrid of white bass and striped bass, have become important recreational and management fishes in the Nation's large reservoirs and rivers. Historically, natural populations of striped bass were found only along the Atlantic Coast and from Florida to the Mississippi River on the Gulf Coast. These populations were essentially decimated before the turn of the century due to commercial exploitation and environmental degradation. In 1954, however, landlocked striped bass were reported to have spawned in the Santee-Cooper Reservoir, South Carolina. The discovery of this reproducing landlocked freshwater population stimulated interest in striped bass as a freshwater sport fish and as a large predator for the control of gizzard shad.

Striped bass weighing 125 pounds have been reported, but 40- to 60-pound fish are still considered trophies (Fig. 8.1). Hybrid striped bass may weigh up to 25 pounds. Trophy fish are generally caught with casting or spinning gear and natural or artificial baits. Because the smaller 1- to 2-pound striped bass (Fig. 8.2) and hybrids are highly sought for table fare, a few commercial producers have investigated their commercial culture for the food fish market. Hybrid bass are much hardier and faster growing than striped bass in the first several years of life but their life span is only about 8 to 10 years.

The striped bass is normally anadromous and spends most of its life along the coast in nearshore salt water and in brackish estuaries. Normally it comes into fresh water only during the spawning season. However, striped bass and hybrids have been stocked in freshwater reservoirs and rivers throughout the Nation. Successful sport fisheries have been established in all the southeastern States, in several midwestern States, and in California, Oregon, and Nevada.



Fig. 8.1. Striped bass are highly sought by sportsmen. This 45-pound trophy gave these fishermen an exciting battle—and a subject for many hours of conversation. *Photo courtesy of South Carolina Wildlife and Marine Resources Department.*

Successfully reproducing populations of striped bass are generally limited to areas with streams or rivers that have a flow sufficient to keep the eggs in suspension for 60 hours (until they hatch), to prevent them from settling to the bottom and dying. However, some areas without suitable flowing streams or rivers provide brood fish that are artificially spawned. Eggs are collected from these fish and the fry are reared in managed facilities.

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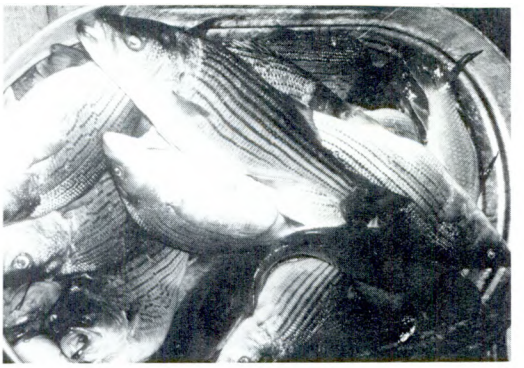


Fig. 8.2. Cultured striped bass of the 1- to 2-pound size are well accepted by the consumer as table fare. *Photo by D. Bishop.*

Fingerlings are then stocked to maintain the population. This type of operation is of particular interest in the present discussion.

Collection and Preparation of Brood Fish

Availability of fingerlings for fishery management depends largely on collecting brood fish that can be spawned, handling the fish carefully to avoid injury, and using spawning techniques that result in good egg and milt production. Poor management techniques and procedures involving the brood fish can result in a total failure.

Collection of Brood Fish

Gravid brood fish are normally taken during their spawning migration, when water temperatures are 58 to 72°F. These fish need not be from reproducing and self-sustaining populations, but can be from populations established and maintained by the periodic stocking of fry or fingerlings. Striped bass have been cultured to maturity and spawned at only a few research or hatchery facilities, and the artificial propagation of brood fish does not now appear promising. Wild brood fish are less expensive and more productive than cultured ones. However, since wild populations are generally found only in public waters, regulations restricting the taking of the fish may constrain the commercial production of striped bass.

Striped bass are captured by electrofishing, netting, or hook and line as they move upstream to spawn. They may be particularly plentiful below dams, which stop their upstream migration. Females mature sexually at age IV or V, and continue to spawn annually throughout their lives. Males are usually sexually mature at age II or III. Reproductively suitable males usually have free-flowing milt, or the milt can be easily expressed by applying a gentle stripping pressure along the abdomen toward the urogenital vent. A suitable gravid female has a deeper body than the males, and a fully rounded abdomen.

Injecting the Brood Fish

Immediately after brood fish are captured they should be separated by sex and evaluated for spawning potential. The fish selected should be injected intramuscularly with human chorionic gonadotropin at the rate of 125 to 150 international units per pound of body weight before they are transferred to the transport unit. Survival of striped bass during transportation in a hauling tank is improved if the water contains 0.5 to 1% table salt (NaCl), 5 ppm (active ingredient) nitrofurazone (Furacin)[x], and either 25 ppm tricaine methanesulfonate (MS-222) or 2.5 ppm quinaldine[x]. Dissolved oxygen must be maintained above 5 ppm by using agitators, aerators, or pure oxygen. The fish must not be crowded—no more than two or three 15-pound fish in an 80-gallon unit—in the hauling tanks, and the water temperature should not exceed 72°F during transport.

At the hatchery, the fish should be kept separate by sexes and stocked in linear concrete holding tanks or circular fiberglass tanks. They must not be crowded. The fish can be maintained with aerated flow-through water at 68 to 72°F, or in static aerated water. In the static system the salt, bacteriostatic, and anesthetizing treatments recommended for hauling tanks can be maintained. Brood fish should not be handled or disturbed more than is absolutely necessary. Even gentle handling

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is stressful, and excessive handling increases mortality and reduces the production of viable eggs.

Preparing the Brood Fish for Spawning

Fish nearing ripeness when they are injected with hormones can usually be spawned within 15 to 60 hours. Multiple injections are not used because they do not induce unready fish to ovulate. Hormone injections exceeding 125 to 150 international units per pound of body weight may also induce premature ovulation. Fish that do not spawn within 72 hours probably will not spawn and should be released.

For fish that are to be artificially ovulated and stripped, the females must be netted, anesthetized, and then catheterized to obtain an egg sample 20 to 24 hours after the hormone injection (Fig. 8.3). A sample is collected by inserting a glass tube into the oviduct to remove a small number of eggs. The stage of egg development is determined by microscopic examination. Immature eggs are opaque and granular. The eggs begin to clear about 15 hours before ovulation. At the time of ovulation the eggs appear as two smooth, transparent spheres, one inside the other. At ovulation the eggs are expelled from the ovary and pass into the abdominal cavity; they can then be freely expressed from the genital pore. Eggs retained in the abdominal cavity for 30 minutes or more begin to deteriorate. These overripe eggs can be microscopically identified by the appearance of an outside cloudy ring, which forms as the chorion begins to deteriorate. Usually viability is preserved if the eggs are stripped from the fish less than 30 minutes after ovulation.

Collection and Incubation of the Eggs

Injected brood fish can be individually stripped and the eggs and milt combined, or the injected brood fish can be paired, stocked into circular fiber glass tanks, and allowed to spawn naturally. Tank spawning is less stressful and less labor-intensive than artificial stripping, and most brood fish survive the handling. Tank-spawned fish can thus be released into the natural waters from which they were taken and once again become potential brood or trophy fish.



Fig. 8.3. Striped bass eggs must be examined to determine the stage of development. A few eggs are collected for microscopic examination by inserting a small-diameter glass tube into the oviduct. *Photo by R. E. Stevens.*

Tank Spawning

Tank spawning requires much less manpower than is required for stripping fish; however, this method is unsuitable for the production of hybrid striped bass. Two male and one female striped bass are usually placed in a tank 6 to 8 feet in diameter. The center drain of the tank is fitted with 60-mesh Saran cloth to contain the eggs and fry. A perforated air line or a piece of porous plastic is placed around the bottom of the screen, providing a "bubble curtain" that keeps the eggs and larval fish off the screen. The tank should be checked frequently and the brood fish removed after they have spawned. The fertilized eggs are left in the tank to hatch. A slow circular water flow keeps the eggs and fry in suspension and prevents heaping and suffocation. Volumetric samples can be used to estimate the number of eggs and the number of fry produced. Fry can be easily removed by siphoning. A siphon placed next to the tank wall near the surface removes fry as they congregate around the edge of the tank.

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Obtaining Eggs and Milt

About 15 hours after egg clearing is first observed, the female should be carefully netted and the abdomen stroked to determine if ovulation has occurred. The abdomen feels soft and flaccid in an ovulated fish, rather than firm as in a non-ovulated fish. The fish can be sedated by spraying the gills with an anesthetizing solution containing 1 g/L quinaldine[x] or 10 g/L MS-222. The fish must not be oversedated, lest it be killed. The fish should be wrapped in a damp towel to facilitate handling, but the vent should be kept uncovered. If the head of the fish is covered, it is less excitable and easier to handle.

The male white bass (used in the production of the striped bass × white bass hybrid) is injected, handled, and anesthetized much as the female striped bass. Either the dry or wet fertilization technique can be used to produce striped bass hybrids. In the dry technique, the urogenital areas of both sexes are wiped to remove free water. The oviduct of the female is positioned over a pre-weighed pan or bowl with the tail somewhat lower than the head. The abdomen is stroked and pressed in a motion that strips out the eggs into the container. The spent female is then held for later release, or discarded. The male striped bass (or male white bass if hybrids are desired) is also dried and positioned above the egg pan. The milt is obtained by pressing and stroking the abdomen in the direction of the vent (Fig. 8.4). Usually milt is obtained from two or three males. (Like the spent females, the spent males are held for later release to their natural waters or discarded.) The eggs and milt are gently mixed and water is added to activate the milt. Water is normally added four to six times during the course of a 3-minute period, during which the water and eggs are continuously stirred, until the total volume of water is twice the egg volume. The water is decanted, and the process is repeated a second and third time to remove excess milt, as well as blood, ovarian fluid, and extraneous tissue debris. Wet fertilization is similar to dry fertilization, except that the eggs and milt are stripped directly into a pan of water.



Fig. 8.4. Milt for fertilizing the eggs is obtained by stroking and pressing the abdomen in the direction of the vent. *Photo by G. Drew.*

The fertilized and washed eggs can be weighed to obtain an estimate of their number. Striped bass eggs are very small— 25,000 weigh only about 1 ounce. Depending on size, a female striped bass may produce 0.5 to 4 million eggs.

Incubation of the Eggs

Fertilized and washed eggs are placed in plastic or glass McDonald hatching jars to incubate. The recommended stocking rate is 100,000 eggs per jar, although eggs stocked at twice this rate have been successfully hatched. The stocking number can be estimated volumetrically; 100 mL of the fertilized and washed eggs before water-hardening equal 90,000 to 100,000 eggs. The egg volume is measured when the incoming water is turned off, and after the eggs have settled to the bottom of the jar.

Maintaining an adequate water exchange is the most critical aspect of jar culture. The eggs must be gently moved or rolled by the incoming water but not flushed from the jar. The water temperature should be between 65 and 68°F, and dissolved oxygen near saturation at both the inlet pipe and the overflow lip. Gasses such as nitrogen and carbon dioxide must not exceed 100% saturation. There must be no measurable hydrogen sulfide gas or dissolved iron in the water. Striped bass eggs hatch in about 48 hours at 65 to 68°F. In general, about 50% of the eggs hatch.

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Culture of Larvae, Fry, and Fingerlings

Transporting Larval Fish

Striped bass and their hybrids are much hardier when they are 1 or 2 days old than when they are 3 to 5 days old. If fish are to be moved, they should be transported as soon as possible after hatching. At this age the fish quickly adjust to changes in water quality that they are unable to tolerate as 3- to 5-day-olds. Fry can be shipped in plastic bags within Styrofoam boxes (capacity, 2 ft^3) at the rate of 100,000 to 150,000 fry per box if shipping time is less than 8 hours. For longer shipping times, this number should be reduced to about 50,000 or less. Double plastic bags are recommended; they should be filled with oxygen and tightly sealed with rubber bands. Fry should be kept cool and protected from sunlight. (Further details are given in Chapter 13.)

At the receiving station, striped bass are usually moved to indoor tanks and held until they are about 10 days old. The plastic bags, removed from the Styrofoam boxes under subdued lighting, should be floated in the receiving water for thermal equilibration. Once the fry have been thermally acclimated, the bags should be opened and the fry immediately released. Fish may go into shock and die if exposed to direct sunlight or if the shipping bags are opened and mechanically aerated. Carbon dioxide and ammonia increase in direct proportion to the time and number of fish in the bag. If the bags are opened and the water is aerated, the carbon dioxide is driven off and pH increases. This rise increases the toxicity of ammonia and can quickly kill the fry while they are still in the shipping bag.

Feeding Larval Fish

Striped bass begin feeding when about 5 days old and the yolk sac is usually absorbed by day 7. If food particles of the preferred size and concentration are not available at the time fish seek to feed, they may never feed. Many attempts have been made to feed larval fish artificial feeds and frozen or dried natural diets. Striped bass offered live nauplii of brine shrimp (*Artemia*) as the starter feed have consistently had higher rates of survival and have grown faster than have fry offered other feeds. Because striped bass seek food continuously, 24 hours a day, abundant food should be present at all times. Dead fry and organic debris should be removed from the tank frequently to prevent bacterial and fungal growth. Striped bass can be transferred to ponds 10 days after hatching.

Pond Method for Rearing Fingerlings

Pond culture is the preferred method for producing fingerling striped bass and hybrids. This technique is dependent on the production of zooplankton for food, and protection of the larval fish from predation. Details of the procedures used to meet those needs are described here.

Pond Preparation

Earthen ponds of any size may be used to rear larval striped bass or hybrids; however, ponds of ¼ to 1 acre are used by most Federal and State fish hatcheries. Ponds are usually left fallow during winter. Sometimes, however, a cover crop of rye grass, hay, or wheat is grown. This cover crop can then be mowed and sun-cured before the pond is filled. Other culturists dry and then disk the pond bottom to aerate the nutrient-rich bottom layers and increase organic decomposition. In smaller ponds, old mats of aquatic vegetation can either be removed by hand or burned. Removing aquatic or terrestrial vegetation before the pond is filled seems to reduce the amounts of filamentous algae and higher aquatic plants that develop and later hinder or complicate the harvest. Agricultural lime may be applied before the pond is filled to increase water hardness and the buffering capacity of the water in ponds, especially in areas where the incoming waters are soft and the soil is relatively acidic.

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Pond Filling

Ponds should be filled and fertilized 10 to 14 days before the fish are stocked. The time of stocking may vary, depending on whether water is taken from wells or from surface sources. Streams and other surface water sources may be rich in phytoplankton and zooplankton and can immediately provide adequate forage for striped bass. Surface water should be filtered through 40-mesh Saran cloth to remove fish and predaceous invertebrates.

Pond Fertilization

The object of fertilization is to provide all necessary nutrients for the growth and reproduction of a dense zooplankton population in the rearing pond. Growth and survival of striped bass fry have been shown to be proportional to the composition and density of zooplankton organisms in the rearing pond. The major zooplankton groups in rearing ponds are rotifers, cladocerans, and copepods. Cladocerans and copepods compose most of the preferred forage of striped bass fry. In addition, both of these crustacean zooplankters have high reproductive rates and can measurably add to the zooplankton population within about 2 weeks if adequate food such as bacteria, algae, fungi, protozoans, and small detrital particles are available. The fertilization program should be devised with this information in mind.

Organic fertilizers such as the various hays, alfalfa pellets, oilseed meals (soybean, peanut, and cottonseed), meat scraps, and animal manures have been used in striped bass rearing ponds. The types and quantities of organic fertilizers depend on availability and cost. The application rates are best determined under each individual situation; however, about 500 to 1,000 pounds of ground hay or 100 to 500 pounds of oilseed meal, meat scraps, or animal manures per acre have been used with differing degrees of success. There seems to be some advantage in using ground hays and the various oilseed meals—possibly because they decompose rapidly. Organic fertilizers can be applied either at one time or at weekly intervals during the period in which the small fish are being cultured.

Inorganic or chemical nitrogen and phosphorus fertilizers are frequently used in combination with organic fertilizers. There is seldom a need to include potassium in the formulation. These inorganic fertilizers can be in granular, powdered, or liquid form. Inorganic fertilizers result in relatively rapid development of phytoplankton blooms. These blooms then support the growth and reproduction of zooplankton. However, inorganic fertilizers must be used with caution because they may support excessive phytoplankton production, which may result in high pH and low dissolved oxygen. These adverse water quality factors are particularly detrimental to both striped bass and hybrids.

Aquatic Insect Control

Research has shown that predaceous aquatic insects can be eliminated from a pond by applying methyl parathion[x] at the rate of 0.5 ppm, or 10 ounces of Baytex[x] per acre-foot of water. These compounds should be applied no later than 7 days before the fry are to be stocked, and no sooner than 21 days after the fry have been stocked. Any compound that kills predaceous insects also kills zooplankton, which is the principal food of striped bass fry. This time interval is the least disruptive to the food supply, since the 7-day interval before the fry are stocked gives the zooplankton population time to recover. The food organisms eaten by striped bass 21 days after stocking are little harmed by the chemicals.

Air-breathing predaceous insects can also be killed by applying 4 gallons of diesel fuel per surface acre. Bubbling air through the diesel fuel for 24 hours before applying it to the pond drives off most of the volatile hydrocarbon compounds that are highly toxic to the zooplankton and to striped bass. This aerated fuel can be applied immediately before the striped bass fry are stocked, and at 3-day intervals thereafter until the fry are too large and too fast to be seriously threatened by predaceous insects.

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Aquatic Vegetation Control

Several aquatic herbicides are used to control undesirable filamentous algae and higher aquatic plants. The principal differences between them generally lie in the time required for them to elicit a response. Karmex (Diuron)® is a dimethyl urea herbicide that is very effective when used at recommended levels. However, it kills aquatic vegetation rapidly, and may cause dissolved oxygen depletion. Diquat is a dipyridylium-ion type herbicide. Like Karmex®, it also acts rapidly. Aquazine (Simazine) is a triazine herbicide that seems to act more slowly than Karmex® and Diquat. All chemical herbicides may adversely affect zooplankton. It is desirable that they be applied either before the pond is filled and stocked, or at least 3 weeks after it is stocked.

The recommended herbicides and application rates may vary locally. We suggest that local, State, and Federal agencies be asked for their recommendations, based on the results of their observations and tests. Each compound must be applied in accordance with the manufacturer's instructions, as stated on the approved label.

Stocking

Usually 5- to 10-day-old fry are stocked into rearing ponds to produce phase I (1- to 2-inch) fingerlings. The typical stocking rate is about 100,000 fry per acre. In some southeastern States, stocking rates of 300,000 or more fry per acre have been used with moderate success. Because striped bass fry are sensitive to light and heat, they should be stocked by direct release, after temperature acclimation, either during the night or at dawn. Numbers of larval striped bass are usually estimated by volumetric techniques—i.e., by counting fry in a known volume of water and extrapolating the results to the total volume. If larvae are to be in transport longer than 10 minutes, they should be placed in plastic bags charged with oxygen. Striped bass should be stocked only after adequate zooplankton populations have been established in the rearing ponds.

Water Quality

Suitable water quality must be maintained, especially when organic and inorganic fertilization is moderate to heavy. Dissolved oxygen should be routinely maintained above 4 ppm; if it drops lower than 3 ppm, fresh aerated well water should be added. Emergency aeration devices that produce strong currents and vigorously agitate the water are not recommended. Total hardness and pH can be improved by adding agricultural lime, as required, to increase the buffering capacity of the water and neutralize acidic soil-water interactions. High pH can be reduced by using chemical herbicides to decrease phytoplankton production, by decreasing fertilizer applications, or by adding fresh water to the ponds. Temperature in rearing ponds should be between 65 and 90°F. However, the lower temperatures in this range retard the growth of striped bass, phytoplankton, and zooplankton, and temperatures of 90°F or higher can decrease growth and reproduction of zooplankton.

Supplemental Feeding

Supplemental feeding can increase the total food supply and extend the availability of zooplankton forms. Many culturists offer a dry type of feed, starting at 21 days post-stocking. The feed should be a nutritionally complete formulation with 40 to 50% protein. The particle size should be near size 0 (420 to 595 micrometers) initially and increased to size 1 (595 to 841 micrometers) as the fish increase in size. A starter diet for catfish or trout fry is suitable as a first feed for pond-reared striped bass. The feeding allowance should not exceed 10 pounds per acre per day unless suitable water quality can be maintained by dilution and aeration. Supplemental feeding may increase survival of fish that have either exhausted their natural forage, or that are to be kept in the culture pond longer than 35 to 40 days.

Harvesting

Phase I fingerlings (1 to 2 inches long) are harvested after 35 to 40 days of pond culture

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(Fig. 8.5). After the fish have depleted the zooplankton, they begin to seek other prey. The larger fish are often cannibalistic, and can quickly lower the survival rate of fish produced in the pond by preying on the smaller fish. It is important that fish be harvested before they exhaust their food. The preferred harvesting methods include glass V-traps, catch basins, and seining; of these, glass V-traps appear to be most effective when properly used because stress and later disease problems of the harvested fish seem to be reduced. Catch basins can be used to concentrate the fish as the pond is drained. However, this method is slow and the fish can be subjected to water quality extremes that reduce survival and fitness. Seining can be used to herd fish toward catch basins or glass V-traps. Any abrasion or penetration of the protective mucous coat of the fry usually results in death of the fish due to bacterial and fungal infections. At harvest, the number of fish required to weigh 1 pound is usually 1,000 to 2,000; however, this number can be as low as 150 to 200. Survival has ranged from 0 to almost 100%, but 25% is common.



Fig. 8.5. Early fingerlings (1 to 2 inches long) are harvested after 35 to 40 days of pond culture. These fish are sometimes restocked in ponds to grow larger before they are released into public waters. *Photo courtesy of Tennessee Wildlife Resources Agency.*

Counting and Grading

Production is usually expressed as pounds of fish per acre. Numbers of fish harvested can be estimated by counting fish in several half-pound subsamples, obtaining an average number, and extrapolating. If phase I fingerlings are kept in troughs or tanks longer than a few days, it is advisable to grade out the larger fish to reduce cannibalism. Fish held in troughs and tanks should be fed a dry pelleted feed of an acceptable particle size at the rate of about 6% body weight per day. (Particle sizes suitable for fish of different lengths are given in a later chapter [Table 11.7].)

Transportation and Release

Phase I fingerlings can best be transported by using a combination of 1% salt (NaCl) and a bacteriostat such as Furacin[x] (5 ppm active ingredient). Hauling densities should not exceed ¼ to ½ pound of fish per gallon of water. Aeration by agitation or direct application of gaseous oxygen may be advisable, depending on hauling distances. Striped bass and hybrids 1 to 2 inches long are normally released into reservoirs and lakes as soon as possible after they are removed from the pond. Water from the lake should be pumped into the transport tank for about 1 hour to thermally acclimate the fish. Release from the tank through slide gates is preferable to dip-netting the fish from the tank. Fish should be released into deep, opaque water to reduce their exposure to predation. Multiple release sites are preferred.

Production of Advanced Fingerlings

Advanced striped bass fingerlings are produced by restocking early fingerlings (1 to 2 inches long) into ponds at the rate of about 10,000 to 25,000 per acre. The fish should be graded (Fig. 8.6) before restocking to reduce cannibalism. Fingerlings can be fed extruded pellet (floating) feeds at the rate of about 4 to 6% of body weight per day. For more intensive culture, when forage fish are not available, the pelleted feed should be nutritionally complete and contain about 38% protein.

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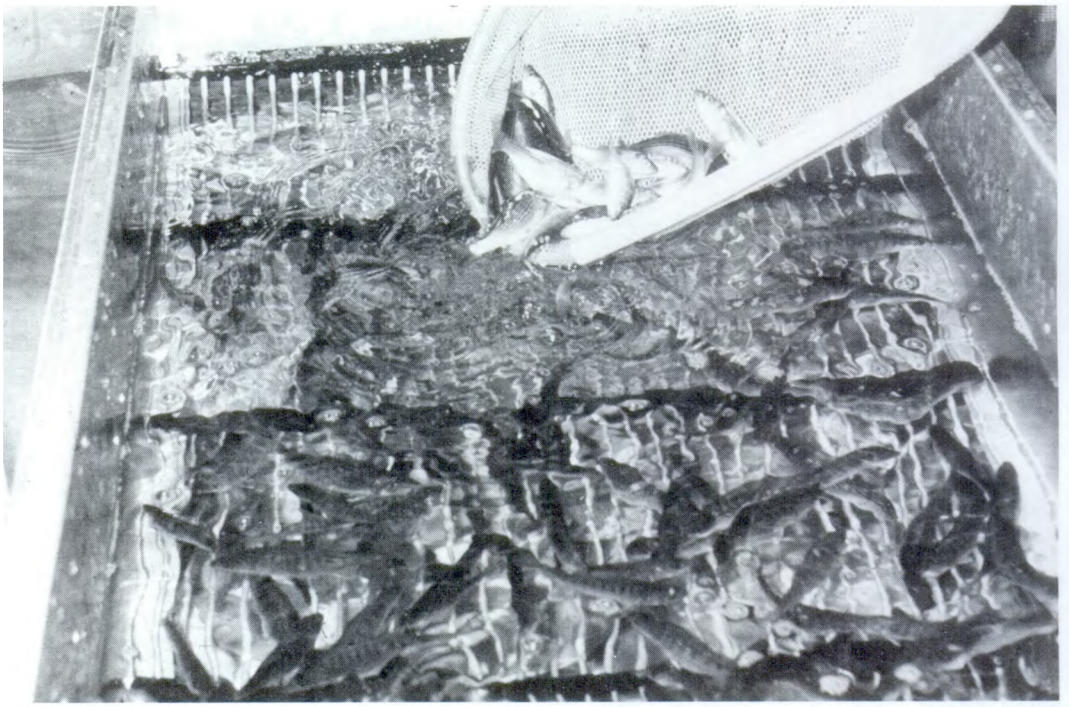


Fig. 8.6. Early striped bass fingerlings must be graded before they are restocked, to reduce cannibalism. The bar grader is well suited for this purpose. *Photo by R. E. Stevens.*

Once striped bass start feeding on forage fish, they usually cease feeding, or feed only reluctantly, on pelleted feeds. Advanced striped bass with a count of 10 to 15 per pound (about 6 to 7 inches long) can be produced in 5 to 6 months.

Closed Culture Methods

Researchers have investigated the use of closed or recirculating systems (Fig. 8.7) for culture, as opposed to the open or pond method. We stress that the closed system is undeveloped, and still only at the research level; because of its potential usefulness, however, we briefly discuss it here.

All closed systems include about the same components, although their arrangement may vary, depending on the types of filters used. In operation, the water from culture tanks carrying dissolved wastes and some particulate matter drains by gravity to a settling basin, where the particulate matter is removed partly by sedimentation and partly by flotation. The clarified water then passes through a biofilter, where the dissolved waste materials, especially ammonia, are acted upon by bacteria growing on the filter substrate. The bacteria convert the highly toxic ammonia to less toxic nitrates. The water is then aerated and returned to the fish production chamber. Daily replacement of 5 to 10% of the water volume prevents the accumulation of nitrates and other metabolic waste. In theory and in practice, the water reuse systems used in striped bass study programs differ little from systems used for channel catfish and other warmwater animals.

The limiting factor in the culture of striped bass fry in closed (recirculating) systems, in open (flow-through) systems, or in pond systems is the same. Striped bass require small living organisms during their initial growth period. Currently, these organisms must be

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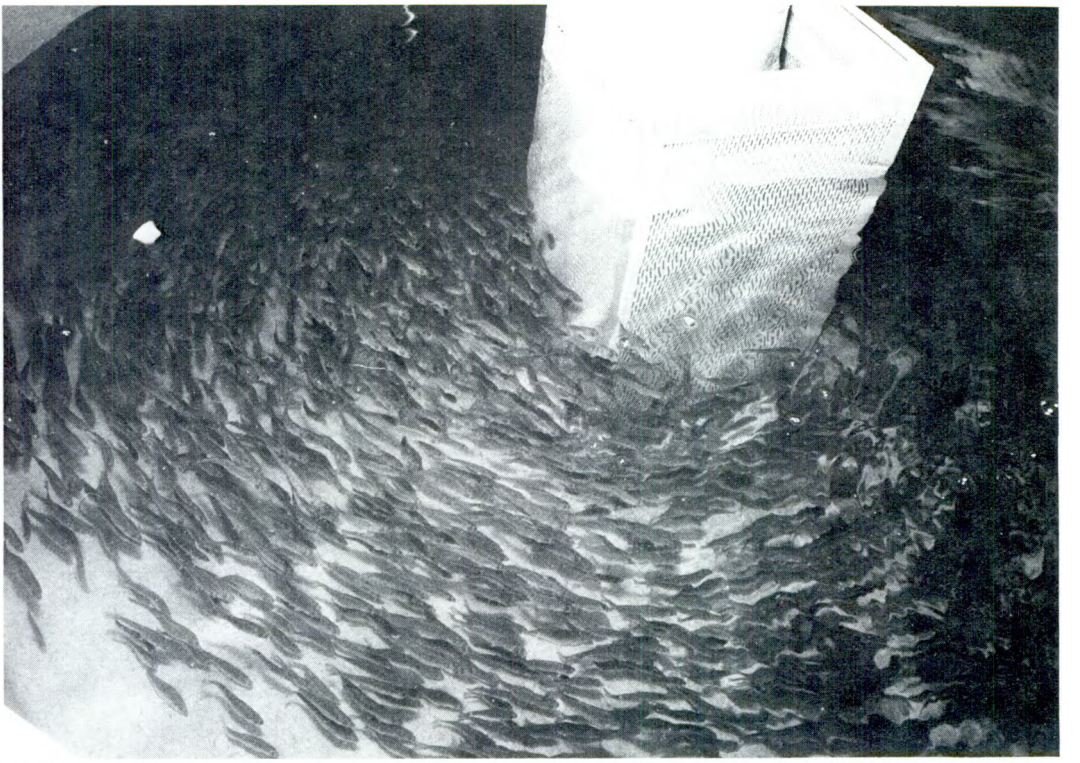


Fig. 8.7. Advanced fingerling striped bass, about 3 inches long, are being cultured in this recirculating system. This technique is still in a research phase, and is not yet used in commercial production. *Photo by W. Lewis.*

provided from indoor intensively managed cultures or from outdoor semi-controlled ponds. The use of formulated or artificial foods has met with only limited success.

Thus, the production of striped bass in closed systems must be evaluated on the basis of economics. Closed systems are energy intensive and subject to mechanical failure, and production of food for the fish is expensive and time-consuming.

Diseases and Disease Treatment

Infectious diseases pose few problems in the culture of striped bass, even though many disease agents of the species are known. The few disease problems that do occur vary greatly from one cultural facility to another. Most of the variation in disease among hatcheries is accounted for by differences in intensity of culture, phase of culture, water quality (dissolved oxygen, total hardness and alkalinity, temperature, and salinity), and management.

Striped bass are sensitive to many of the chemicals and drugs used in management. Because striped bass are cultured in ponds and usually involve low standing crops of fish, the cost of treatment is often prohibitive. Some managers have found that it is often more economical to drain out a production system containing diseased fish, eliminate the problem through sterilization, and refill and restock. For others the fish may have sufficient value to justify treatment.

Table 8.1 provides a summary of the more important infectious disease organisms and the treatments used by culturists to control them. Before any chemical is used, the label should be checked for the percent of active ingredient, and the required amount of chemical carefully calculated. We also recommend that a chemical be tested on a small number of fish held in the water from the pond to be treated, before the entire pond is treated.

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Table 8.1. *Infectious disease organisms of striped bass and the treatment chemicals and rates used by striped bass culturists.*[a,b]

Bacteria

Flexibacter columnaris, Aeromonas spp., *Pseudomonas* spp., *Vibrio* spp.

Acriflavine[x] (trypaflavine)

In a water treatment, applied at a concentration of 5 to 10 ppm (19 to 38 mg/gal; 0.67 to 1.3 oz/1,000 gal; 5 to 10 oz/1,000 ft^3) for 1 hour or longer. Longer treatments may kill fry. As a preventative it has been used at 2 ppm.

Combiotic[x] (penicillin plus streptomycin)

In a water treatment, applied at 10 to 15 ppm (1.3 to 2 oz/1,000 gal) for up to 24 hours, on fry and fingerings, or at 25 ppm (3.3 oz/1,000 gal) for up to 2 hours on fingerlings.

Copper sulfate ($CuSO_4$)

In a water treatment, applied for 1 hour or longer to fish larger than fry. The effective concentration is dependent on the total alkalinity of the water. As a general rule, 0.75 ppm $CuSO_4$ may be used for each 100 ppm total alkalinity of the water. At alkalinities above 250 ppm, the effectiveness of $CuSO_4$ may be limited. In salt water it has been used at 0.5 ppm (1.35 lb/acre-foot or 0.5 oz/1,000 ft^3). The snow or powder formulations are preferred because of their rapid solubility. Low dissolved oxygen levels may result from the use of copper sulfate because it kills algae and plants and the resulting decay of organic matter consumes oxygen.

Diquat

Active ingredient, 25%. In a water treatment, applied at the rate of 1 to 2 ppm (0.5 to 1 oz/1,000 gal or 4 to 8 oz/1,000 ft^3) for extended periods on fish larger than fry. More Diquat may be needed if the organic load in the water is heavy. The treatment can be applied to fry but it should be discontinued at the first sign of stress.

Furacin[x] (nitrofurazone)

In a water treatment, applied at 5 ppm (active ingredient) for 1 hour or continuously. The application rate is 0.9 lb/1,000 gal (6.8 lb/1,000 ft^3) for the 4.59% formulation, or 0.45 lb/1,000 gal (3.4 lb/1,000 ft^3) for the 9.2% formulation.

Furanace[x] (nifurpirinol, P-7138)

In a water treatment, applied at a concentration of 1 ppm active ingredient for 8 hours.

Potassium permanganate ($KMnO_4$)

In a water treatment, applied at 2 to 3 ppm (0.27 to 0.39 oz/1,000 gal or 2 to 3 oz/1,000 ft^3) for an indefinite period for all sizes of fish other than fry. The treatment should be discontinued for fry at the first sign of distress, or at the end of 1 hour. To obtain an effective treatment in organically rich waters, one must use just enough chemical to maintain a light pinkish color in the water for about 12 hours. This can be done by applying 2 ppm (5.4 lb/acre-foot or 2 oz/1,000 ft^3) at a time, until the desired color persists. If the color fades or turns brown after application, but before the 12-hour period, another 5.4 lb/acre-foot can be added. The powder form is most easily dispersed. Because $KMnO_4$ kills algae, dissolved oxygen problems may occur if it is used in hot weather.

Salt (sodium chloride)

In a water treatment, applied at the rate of 0.3 to 1% (25 to 83 lb/1,000 gal) for all sizes of fish. Salt may be applied in combination with other treatments and often results in better control.

Terramycin (oxytetracycline)

In a water treatment, applied at 10 to 20 ppm (12.2 to 24.3 oz TM_{50}/1,000 gal) for at least 1 hour. (TM_{50} is water-soluble Terramycin containing 11% active ingredient.) In feed the TM_{50} is added at a rate of 2 to 2.7 lb/100 lb feed, and the feed is offered to the fish at the rate of 3% body weight per day for 10 to 14 days. If the fish are not actively feeding, the proportion of medication in the feed can be increased to ensure that the fish receive the recommended amount of drug.

External fungi

Saprolegnia, Achyla, and other forms

Copper sulfate ($CuSO_4$)

See rates given for bacteria. More than one repeated treatment may be necessary.

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Potassium permanganate ($KMnO_4$)

See rates given for bacteria. More than one repeated treatment may be necessary.

External protozoans

Ambiphrya, Chilodonella, Cryptobia (*Bodomonas, Colponema*-complex), *Ichtyobodo* (*Costia*), *Ichthyophthirius* (Ich), Trichodinids.

Copper sulfate ($CuSO_4$)

See rates given for bacteria.

Potassium permanganate ($KMnO_4$)

See rates given for bacteria.

Salt (sodium chloride)

See rates given for bacteria.

Formalin (commercial formaldehyde-37%)

In a water treatment, applied at 150 ppm (1.2 pints/1,000 gal) for up to 1 hour on fingerlings. Before such treatment is used, a rapid flush system should be set up for use if fish show signs of stress early and, as a further precaution, fish should not be fed for at least 24 hours before treatment begins. Other factors to take into consideration are the need for abundant aeration during treatment, the fact that stress is more likely to develop when fish are crowded during treatment or when debilitated, and that in soft acid waters the treatment is more toxic. If the culturist is unsure, it is suggested that the treatment level be lowered to 50 to 100 ppm for 30 minutes to 1 hour.

Epistylids

Salt (sodium chloride)

In a water treatment, applied at 1.5% for 3 hours.

Amyloodinium (*Oodinium*)

Copper sulfate ($CuSO_4$)

See rate given for use in salt water for bacteria.

Quinacrine hydrochloride

In a water treatment, applied at 15–20 ppm for 2 hours. One or two additional treatments are advised for the next day or two. To increase the effectiveness of treatment, fish are put into a fresh or low salt water bath until they show strong signs of stress. They are then returned to the salt water and the chemical treatment begins.

Trichophrya

Copper sulfate ($CuSO_4$)

See rates given for bacteria.

Trematodes

Monogenea: *Dactylogyrus, Gyrodactylus* spp.

Formalin (commercial formaldehyde-37%)

See rates given for external protozoans.

Potassium permanganate ($KMnO_4$)

See rates given for bacteria.

Masoten[x] (Dylox)

Active ingredient, 80%. In a water treatment, applied at 0.5 ppm (0.6 oz/1,000 ft^3 or 1.7 lbs/acre-foot) when water temperature is lower than 85°F. Masoten is generally ineffective at water temperatures above 85°F and should not be used at pH levels above 8.5. The use of Masoten with fry should also be avoided because the chemical kills zooplankton and thus may cause starvation.

Digenea: *Clinostomum complanatum* (yellow grub)

Snail and bird control

No chemical treatment is available for controlling the yellow grub directly. Snails or birds that serve as intermediate hosts can perhaps be kept out of the ponds. When the fish are removed, copper sulfate at 10 ppm (27 lb/acre-foot) kills most snails in a water treatment. In a drained pond, 10 ppm available chlorine (1.9 oz HTH/1,000 gal or 1.6 pints household bleach/1,000 gal), applied to the potholes and on the moist soil, is effective. Complete draining, drying, and disking is the best method of snail control. The species of birds that are known to harbor fish

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pathogens are protected by law, and State and Federal agencies should be consulted before any action is taken. Devices for frightening the birds may help, and pond-side perches such as trees can be removed to prevent bird droppings (which may contain parasites) from reaching the ponds.

Nematodes

Goezia

No effective treatment.

Crustaceans

Ergasilus spp.

Formalin (commercial formaldehyde-37%)

See rates given for external protozoans.

Masoten[x] (Dylox)

See rates given for trematodes (monogenea).

Salt (sodium chloride)

See rates given for bacteria.

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[a]In the United States, fish that are intended for human or animal food can be treated with drugs and chemicals only in accordance with current regulations of the U.S. Food and Drug Administration, U.S. Environmental Protection Agency, U.S. Department of Agriculture, and State and local agencies. Furthermore, the status of drugs and chemicals is always subject to change due to research findings or regulatory agency rulings. Therefore the user should always read and carefully follow the instructions on the label. References to drugs and chemicals whose usefulness has been demonstrated by fish culturists appear throughout this report. Compounds that have not been approved for use with food fish, or whose use for the purpose being discussed is restricted, are marked by the superscript symbol x (e.g., Furacin[x] is an excellent bacteriostat); compounds that have been approved for the indicated use bear no superscript. The use of trade names does not imply U.S. Government endorsement of commercial products.

[b]List prepared by Andrew J. Mitchell.

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9. PROPAGATION OF BLACK BASS, SUNFISHES, TILAPIAS, EELS, AND HOBBY FISHES

Harry K. Dupree and Jay V. Huner

Propagation of largemouth and smallmouth bass and many species of sunfish has been practiced extensively by Federal and State hatcheries for many years, and more recently by private fish farmers. Private operators alone are involved in the production of tilapias, eels, and the hobby fishes, except for a few university- and government-supported research and development programs.

Many of the culture techniques described here were developed over a period of 50 to 60 years and have survived the test of time. Several techniques—especially those pertaining to eels and tilapias—were adapted from practices used in foreign countries. Private aquarists have been almost solely responsible for the development of the hobby fish program into a major industry.

We have attempted here to describe the techniques considered best or those most often practiced for the culture of these fishes.

Black Bass

Black bass are highly sought by anglers, and fishery biologists and resource managers use them to help control the composition of fish populations. The sizes and numbers of these fish used varies among the different user groups. The highest prices are paid for catchable-size fish that go into fee-fishing ponds, and relatively good prices are paid for yearlings suitable for corrective stocking of private ponds. Probably the lowest prices are paid for the fry suitable for the initial stocking of farm ponds or reservoirs. Since the production of black basses is expensive and labor-intensive, the prospective fish producer should assess the potential market before he begins raising the fish.

The two species of black bass that are typically cultured are largemouth bass and smallmouth bass. Two strains of largemouth bass are commonly cultured—the northern strain, which is native to North America east of the Rocky Mountains, and the Florida strain, which is native to southern Georgia and Florida. Although the Florida strain can be differentiated morphologically from the northern strain, the two strains readily interbreed. Two other black basses are the redeye bass and spotted bass. However, these species are not now widely produced in aquaculture.

Brood Fish Stocking and Care

Successful production of black bass, like the production of all fish, begins with good care of the brood fish. Ponds 0.5 to 3 acres in area are usually suitable. These ponds should be free of rooted vegetation, and have depth and bottom characteristics that facilitate seining when the brood fish are to be recaptured. An individual water supply is desirable so that good quality water can be maintained.

Bass culturists are in general agreement that female brood fish should outnumber the males. A good ratio appears to be two males to three females, although a still larger proportion of females can yield good results. Because the sex ratio is not highly critical, the culturist can usually obtain satisfactory results by stocking fish of undetermined sex.

The number of brood fish stocked varies greatly, depending largely on the size of the fish. Excellent results are obtained with about

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40 fish weighing 3 to 4 pounds, or about 70 fish weighing ¾ to 2 pounds. Two-year-old fish are ideal, but 1-year-olds are adequate if they weigh ¾ pound or more. The health and condition of the brood stock is more important than the size of the fish. (Old bass are usually not as productive as younger fish.)

Bass brood stock should be fed forage fish throughout the year, but forage should be excluded from spawning ponds. Ideally, about 600 pounds of forage should be made available for each 100 pounds of brood bass.

Some of the forage fish that have been used are golden shiners, fathead minnows, tilapias, bluegills and other sunfishes, common carp, and goldfish. Of these, golden shiners and fathead minnows are widely preferred primarily because the other species have certain disadvantages: tilapias, although satisfactory from the standpoint of production potential, die in winter, and many States restrict their use because they are exotics; production potential for bluegills and other sunfishes is low, and they are not preferred by bass; common carp grow so rapidly that they soon become too large for bass to swallow; and goldfish (including those of the fantail variety, which can be captured more easily by bass) often carry the anchor parasite *Lernaea*.

Spawning Ponds and Spawning

When the bass are ready to spawn, they should be moved to specially prepared ponds to ensure a good recovery of fry. These ponds can range from 0.5 to 3 acres in area, although larger ponds can be used. The pond bottom should be firm and the water depth should be between 1 and 3 feet for easy wading. The pond should have been dried and any wet spots and potholes treated with hydrated lime to kill wild fish and fish parasites. An appropriate pre-emergent herbicide can be applied at this time. The pond should be filled with well water, or with water filtered through gravel or Saran cloth, to exclude wild fish. The ponds are filled about 2 weeks before they are stocked.

Spawning ponds must be prepared differently for smallmouth bass than for largemouth bass. Before smallmouth bass ponds are filled, low heaps of gravel should be placed a short distance from shore in areas where the water will be 2 to 3 feet deep after the pond is filled. These gravel mounds, sometimes placed on black plastic sheets (Fig. 9.1), serve as nesting sites. This procedure is usually unnecessary in largemouth bass ponds, but is recommended for old ponds with soft mud bottoms. Usually bass spawning ponds are not fertilized and contain no forage fish. Air-breathing predaceous insects may be killed by applying 4 gallons of diesel fuel to the water surface every 3 days after spawning starts.

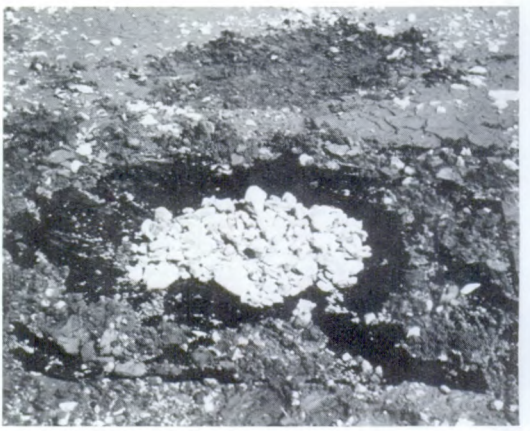


Fig. 9.1. Smallmouth bass require gravel as a spawning surface, in contrast with largemouth bass, which can spawn on almost any hard surface. Placing the stones on a black plastic sheet makes it much easier for the fish culturist to locate the nest and to recover the fry. *Photo by J. Anderson.*

Black bass spawn once a year, normally in spring; however, spawning may be delayed well into summer. Bass seldom spawn at temperatures less than 64°F, and 68 to 70°F is the most favorable range. As in the rest of the sunfish family, the male builds the nest and guards the eggs and fry. The nest of the smallmouth bass is more elaborate than that of the largemouth bass, which is sometimes so inconspicuous that it is difficult to find. After the nest is built, a male and female spawn while side by side, facing in the same direction. Two or more females sometimes spawn with a single male in the same nest.

The eggs hatch in 1 to 2 weeks, depending on water temperature. The male guards the

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nonswimming yolk-sac fry while they remain on the nest, as well as the larger fry after the yolk sac is absorbed and the fry swim freely in schools.

Fry, Fingerlings, and Yearlings

The technique used to capture fry for transfer to growing ponds is different for largemouth bass than for smallmouth bass. Largemouth bass fry usually stay in compact schools for as long as 1 month after hatching, and two or more schools may merge to form a larger school. Schools of advanced fry are often seined with a bobbinet seine, usually less than 10 feet long. If seining is done in windy weather, the pond surface is sometimes covered with fish oil to calm the water surface so that the schools of fry can be seen. Other fish culturists trap largemouth bass fry near shore with a V-trap having a lead running from the bank to the center of the V in the trap.

Many fish culturists prefer to transfer largemouth bass fry when they are about ½ to ¾ inch long, because they are then easy to count and handle. However, many are transferred at a smaller size; fry can be transferred at any time after they rise from a nest.

Smallmouth bass fry are usually captured by imprisoning the fry before they leave the nest. A cylindrical frame 3 feet in diameter and about 40 inches deep, covered with plastic or aluminum window screen, is placed over each nest before the fry leave it (Fig. 9.2). Since the fry usually hover near the nest for only a short time after hatching, and then scatter, they are difficult to catch if they are not contained by a cylinder. After they rise from the nest, they are merely dipped from the cylinder.

The fry of largemouth bass or smallmouth bass captured by netting the schooled fish or by dipping them from holding cylinders are sometimes transferred directly to recreational fishing ponds, but usually to specially prepared fingerling or yearling production ponds. The preparation consists of drying the ponds, treating the wet spots with hydrated lime to kill wild fish and parasites, and applying a suitable pre-emergent herbicide to the pond bottom to inhibit growth of vegetation. Detailed methodology is presented in Chapter 3.

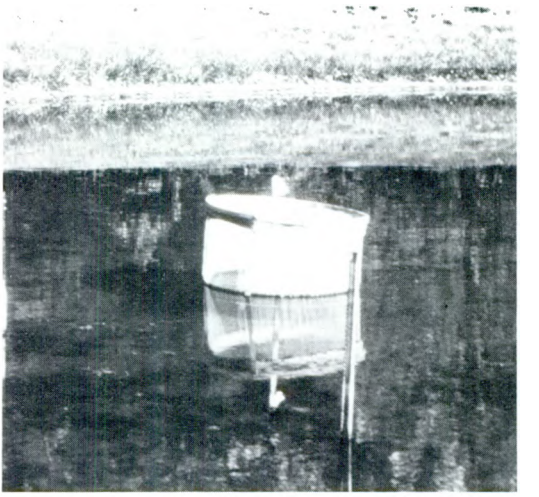


Fig. 9.2. Fabric-covered circular hoop retainers are placed over smallmouth bass nests to protect the fry from predators and to prevent their dispersal and facilitate collection. *Photo by J. Anderson.*

When the pond is filled, well water or water filtered through Saran cloth or gravel must be used to exclude wild fish. Chemical and organic fertilizers, including hay, grasses, animal manures, oilseed protein meals, and other locally available products can be applied to stimulate the production of zooplankton for use by the bass fry. Some fish culturists grow rye grass on the dry pond bottom. When the pond is flooded, the grass dies and decays. However, the culturist must monitor the water quality and take corrective measures to prevent the decaying rye grass from depleting the dissolved oxygen in the pond. Many combinations of these fertilizers and techniques can be used but it is best to ask other producers, or State or Federal hatchery personnel, what enrichment program is best in a given area. Before the bass fry are stocked, predaceous insects and other fry-eating organisms may be eliminated from the pond water by applying either 0.5 ppm methyl parathion[x] or 10 ounces Baytex[x] per acre-foot to kill insects with gills, and 4 gallons of diesel fuel per surface acre to kill air-breathing insects. Because recovery periods differ between locations, it

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is prudent to confer with fish farmers or hatchery personnel, in the area concerned, about the proper time to apply the pre-stocking treatments.

Numbers of bass fry are estimated in various ways. One method consists of counting a known number (usually 1,000) into a tub containing water 1 to 3 inches deep and then placing fry in other tubs until the density appears to be the same as that in the tub containing the known number. It is helpful to use tubs with the bottoms painted white or silver. Large white enamel pans may also be used.

A specially prepared pond should be completely stocked in a single day, to ensure early uniformity of growth, and thus reduce cannibalism. There is little agreement among culturists about the number of bass fry to stock per acre; generally about 15,000 to 40,000 give good results. State and Federal hatcheries may stock as many as 50,000 to 75,000 per acre but the fish they produce for stocking lakes in early summer are only 1½ to 2 inches long.

Other than maintaining the water levels and the zooplankton bloom, there is little that the fish culturist can do during the first few weeks after the bass fry are stocked. However, the fish tend to grow at unequal rates, and cannibalism becomes a problem, especially after the fish are 1½ to 2 inches long, and the zooplankton becomes depleted. For this reason, State and Federal hatcheries usually stock smallmouth bass fingerlings at a small size.

In pond culture, it is important that the large, fastest-growing fish be taken out of a pond before cannibalism begins. Some fish culturists drain the pond and grade the fish. Others use a seine with meshes that allow small bass to pass through but retain the larger ones, and still others seine the fish and pond-grade them with a box grader. None of these pond-grading techniques are always successful; a few large cannibals are often left in the pond.

Since bass fingerlings normally require forage, some fish culturists provide it by transferring fathead minnows from a separate pond. Another method is to stock about 10,000 closely graded 1½-inch bass per acre into a fathead minnow pond that was prepared by stocking 2,000 adult fathead minnows during the preceding month. Additional minnows may have to be added if the forage supply becomes depleted, to reduce cannibalism.

Artificial feed can also be used to raise bass. Training fingerlings to accept this food is a problem, since live organisms compose the natural food of bass. Patience and hours of careful attention may be required. The use of mechanical or demand feeders removes some of the tedium of this task.

Recent studies have shown that some special strains of bass fingerlings may be more easily trained than others to accept feed. The best temperature for training is near 80°F for largemouth bass, and somewhat lower for smallmouth bass. Small fish are removed from ponds and placed in holding tanks. Fish are graded to separate out the larger individuals, which are usually cannibals. Semi-moist, stabilized diets are offered five times daily. After a week or so, the obviously non-feeding fish are separated and stocked together. These nonfeeders are then offered artificial feeds and many begin to feed. Altogether, as many as 80% of all fish can be trained to eat artificial feed in this way. Small largemouth bass that are reluctant to take artificial feeds can be trained with carp eggs. Although carp eggs are more expensive and troublesome to feed than commercially available artificial diets, they may be cost-effective in areas where they are readily available. Trained fingerlings are then stocked in small earthen rearing ponds at rates of 5,000 to 20,000 per acre. These fish are gradually weaned from eating carp eggs or moist feed to the eating of floating (extruded) fish feeds of the types generally formulated for trout.

Some channel catfish producers have been successful in rearing yearling-sized bass by stocking the fry or fingerlings directly into catfish production ponds. Survival is usually low, however, and there is no assurance that any of the fry will survive predation. However, little work or expense is involved. Many farmers report that 100 to 200 pounds of 0.5- to 1-pound bass can be produced per acre by this method. A further benefit is that the bass

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eat wild forage fish that compete with catfish for feed.

Sunfishes

Crappies, bluegills, and redear sunfish (Fig. 9.3)—all members of the sunfish family Centrachidae—are widely cultured for stocking recreational ponds. Various hybrids of bluegills, redear sunfish, and green sunfish are also popular.

Pure-strain sunfishes spawn readily and are easy to produce. Most species hybridize spontaneously in nature and in hatchery ponds. Basic production practices are the same, whether pure-strain fish or hybrids are cultured.

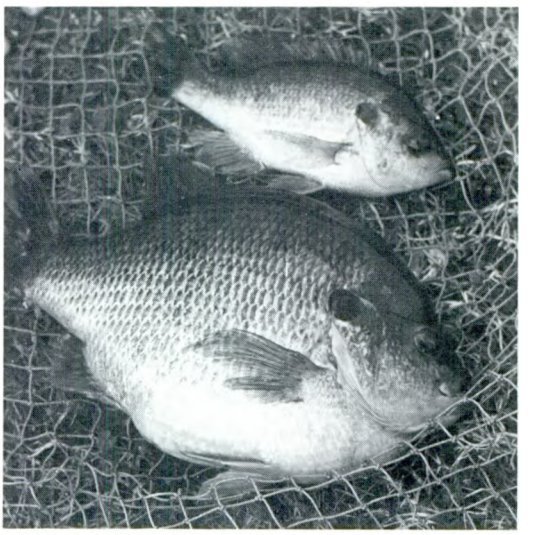


Fig. 9.3. Redear sunfish are popular sport fishes. Fish of the 1-pound size, such as the larger one shown here, are occasionally caught, but its 5-inch companion is more common. *Photo courtesy of Arkansas Game and Fish Commission.*

Pond Preparation, Stocking, and Care of Brood Fish

Because the various species of sunfish interbreed readily, it is important that ponds not be contaminated by wild sunfish. Therefore water from surface sources must be filtered, or water from deep wells used. Ponds should be dried thoroughly before the spring spawning season begins. Depressions in the pond bottom should be treated with hydrated lime, rotenone, or other toxicants, lest some unwanted fish survive in holes or crayfish burrows. This aspect cannot be overemphasized. Some 2- to 3-inch sunfish—and especially green sunfish—can be fully mature and spawn readily, thus producing many unwanted hybrids.

Ponds less than 1 acre in area are preferred by most hatchery managers. Maximum and minimum water depths of 48 and 18 inches provide for vegetation control and ease of harvest. The application of a suitable herbicide and provisions for an appropriate fertilization program usually control the growth of unwanted rooted aquatic vegetation and produce zooplankton and other fish-food organisms. Because these fertilization recommendations differ from State to State, prospective sunfish producers should consult with personnel at nearby State or Federal hatcheries.

Brood fish should be offered a pelleted feed to supplement the available natural feed when a standing crop of more than 200 pounds per acre is maintained. An extruded (floating) feed formulated for catfish is adequate. The pellets should range from ⅛ to ¼ inch in diameter. Amounts fed vary directly with water temperature: when temperature exceeds 70°F, feed should be offered five to seven times per week, at a rate of 3% of the estimated weight (standing crop) of brood fish; at temperatures of 55 to 70°F, the fish should be fed on alternate days at a rate of 1 to 2% of estimated body weight; and when water temperature is lower than about 55°F, no feeding is required.

In most production systems where fingerlings of the 1½- to 2-inch stocking size are desired, brood fish should be stocked at the rate of 40 pairs per acre. If larger brood fish are used, or if the pond is especially unproductive, a stocking rate of 30 or fewer pairs per acre is recommended. Brood fish of the size preferred for stocking weigh 5 to 10 ounces each; the best stocking ratio for males and females is 1:1.

Spawning activity starts near 70°F for green sunfish, 75°F for redear sunfish, and 80°F for

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bluegills. Such activity becomes obvious when the males begin digging out saucer-shaped nests near the pond edges. When desired, spawning can be delayed in two ways. Sexes may be kept separate until spawning is desired, or cold well water can be circulated through holding ponds to keep temperatures below those needed for spawning. Spawning is retarded in bluegills at temperatures below 75°F and in redear sunfish and green sunfish at temperatures below 70°F.

Sexing of the brood fish is especially critical when hybrids are to be produced. Several methods are used, and their success depends on the skill of the aquaculturist, condition of the fish, and the time of year. As the spawning period nears, males in good condition take on distinctive, often brilliant spawning colors. It is usually easy to express milk-colored milt from the vent. In females in good condition, the abdomen is much fuller and rounder than in the male. A second method for verifying sex is to probe for eggs. This is time-consuming but useful when hybrids are being produced. A capillary tube 5 to 10 cm long and 1.1 to 1.2 mm in diameter is used as a probe. It is gently inserted through the urogenital opening into the urogenital sinus. At this point, the tip of the capillary tube is angled slightly back toward the tail and also slightly to one side. When light, gentle pressure is then exerted, the tube passes through the oviduct and into the ovary. The upper end of the capillary tube is sealed with the finger to hold the eggs in the tube as it is removed. If no eggs are retrieved, the fish is rejected as a brood female. This procedure takes practice, and should not be attempted with prize brood stock in late spring.

The fish are stressed during the sexing process. Other injuries may result from scale loss and from probing and pressing. It is desirable to treat the fish in a 5- to 10-ppm solution of nitrofurazone[x] for 2 hours before stocking them into the ponds. The fish should be transported in a 0.5% salt solution, but only for a period that does not exceed 2 hours.

Fry should be seen in 2 to 3 weeks after the brood fish are stocked. The fingerlings should reach a length of 1 inch in 30 to 40 days and 1½ to 2 inches in 40 to 60 days. Growth depends on the availability of food and population density. Normally, about 125,000 fingerling sunfish per acre can be produced.

Hybridization

The subject of hybrid sunfish is controversial. Claims by private growers are sometimes difficult to substantiate. A hybrid that performs well in one area may perform poorly in another. The problem seems to involve identification of parent species, and contamination of spawning ponds with sunfish of the wrong species or sex. Sunfish hybridize so readily that pure-strain fish may be hard to select, even though they appear to be pure.

The best hybrids for sport fishing studied to date have been female green sunfish crossed with either male bluegills or male redear sunfish (here termed bluegill hybrids and redear sunfish hybrids). Both hybrids grow rapidly and are easy to catch with hook and line. The bluegill hybrid is recommended when fish are to be fed, and the redear sunfish hybrid when the fish are not to be fed (because it does not feed as well as the bluegill hybrid on pelleted feeds). Since the bluegill hybrid prefers shallower water than the redear sunfish hybrid, the two are sometimes stocked together.

Feeding

The original stocking strategy for recreational fishing ponds called for stocking predators, primarily largemouth bass, to control overpopulation and resultant stunting of sunfishes. Costs were reduced by fertilizing ponds with inexpensive inorganic fertilizers.

Feeding can also overcome stunting problems. However, it requires time, effort, and money. These demands should be considered closely before a feeding program is begun. A vigorous fertilization program, coupled with selective removal of small sunfish with seines or poisons, or by stocking bass, may result in the production of larger fish with less expenditure of time and money. Culturists considering a feeding program should note the following guidelines.

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Pelleted feeds ⅛ to ¼ inch in diameter should be used for sunfishes. The ⅛-inch pellets should be in both floating and sinking forms; this size is best for ponds with many small fish. The ¼-inch pellets should be of the floating type for fish longer than 4 inches. Normally, sunfishes should be fed at water temperatures between 65 and 90°F, although (as in brood fish) feeding may begin when temperatures reach 55°F in spring. Feeding should be on alternate days at water temperatures below 70°F, and daily at higher temperatures. Consistency in terms of time of day is important in training sunfish to take feed. Quantity of feed depends on feeding activity of fish. Typically one should feed the amount that the fish eat in about 30 minutes, but no more than 20 pounds of total feed per acre per day. The use of demand feeders (see Chapter 11) might be considered. Usually two feeders per acre are adequate. Most sunfishes do not eat artificial feed that has fallen to the bottom.

Several different feeders can be used successfully in sunfish ponds. One especially good design for feeding both floating and sinking pellets consists of a plastic ring with a plastic tray suspended beneath it. The ring is about 2 feet in diameter and confines the floating pellets. The plastic tray is about 2 feet square and is suspended under the ring. It is positioned at a 25° angle and at a depth of 1 to 2 feet. The tray, attached to the ring by four lines, retains pellets that sink through the ring. A stake driven into the pond bottom and attached by a cord to the feeder keeps it from drifting with the wind. Larger fish tend to feed at the surface but not at middepths, whereas small fish tend to shy away from feeding at the surface but readily feed at the 1- to 2-foot depths of the suspended tray.

Platform feeders may also be used. A platform feeder should contain a plywood tray about 2 feet square and 2 inches deep secured at a 25° angle to four support posts. The tray should be at a water depth of 1½ to 2 feet. If floating feeds are to be used in combination with sinking feeds, a floating ring should also be attached by lines to the platform.

Automatic feeders can be used, but this type of unit dispenses feed, irrespective of whether the fish are feeding. Demand feeders overcome this problem, but they have the limitation of forcing the owner or manager to check on the fish daily. This daily observation is vital if problems such as oxygen depletions and disease losses are to be kept in check.

Tilapias

Tilapias constitute a large group of food fishes widely distributed in mainly the tropical and subtropical areas of the world. They were originally introduced into the United States for biological vegetation control, in place of chemical and mechanical control methods. They are still useful in this aspect of pond management. They are also being produced in limited numbers as a commercial food animal and as a sport species. Considerable interest is being shown in the use of tilapias in domestic and animal waste lagoons as living "sumps" that remove and concentrate plant nutrients before the waste waters are released to the environment. Some aquaculturists use tilapias both as feed for brood fish and carnivorous fishes and for the control of unwanted aquatic vegetation.

Other biologists and managers, however, see tilapias as a threat to the environment and the native fishes. There is some support for this view in the deep South where the prolific tilapias spawn year-round and quickly dominate lake systems. Although they are not carnivorous, they are very aggressive, especially when nesting and raising young. This aggressiveness leads to physical disruption of spawning sites and spawning patterns of many sunfishes, as well as largemouth bass. Inasmuch as largemouth bass are the predators that ordinarily check forage fish numbers, such lakes are quickly overpopulated by tilapias. Stunting normally follows, and sport fishing rapidly declines.

Tilapias have disrupted native fish populations in power plant cooling reservoirs in more northerly regions through central Texas into Oklahoma. Normally they die in winter at

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Fig. 9.4. Tilapias being cultured in raceways supplied with heated water from a coal-fired power plant near Charleston, South Carolina.

these latitudes, but they survive in the warm water being discharged from power plants. These populations have been exploited by commercial interests (Fig. 9.4), but they are unstable. If a power plant has only one hot water discharge, and it must be shut down at any time during the winter, all of the tilapias die.

On the positive side, tilapias cannot establish sustaining populations in most of the United States because they die during winter. This characteristic eliminates the problem of eradicating them before they can cause the ecological damage sometimes seen at southern latitudes.

Commercial Culture

Before obtaining brood fish and developing a production program, the aquaculturist must determine the legality and requirements for culturing tilapias in the State concerned. Some States have no restrictions, but others have strict rules and regulations that prohibit even the ownership of tilapias. Other States require a permit. Some States require filter facilities and other protection devices that prevent the cultured fish from escaping into open waters. Information about the possession and cultural requirements can be obtained from appropriate State agencies (see Chapter 20).

Fish farmers are interested in tilapias because of the low cost of their production. As a group, tilapias are very hardy and thrive under adverse conditions that kill most native fishes. They grow and reproduce in waters warmer than 90°F, and tolerate early-morning DO levels below 1 ppm for extended periods. They have few diseases and parasites. Although they are basically freshwater fishes, most of the species can live in brackish water and some adapt readily to sea water.

All tilapias occupy low trophic levels, eating phytoplankton, zooplankton, decaying organic matter, and benthic organisms (e.g., worms, insect larvae, clams, and snails), depending on species. Thus almost any supplemental feeds are acceptable; they have included such diverse materials as animal manures, municipal sewage, rice bran, bean mash, grain dust, cottonseed meal, and vegetable scraps. Most species eat feeds formulated for catfish, goldfish, minnows, and other farmed fishes.

Annual production can exceed 10,000 pounds per acre in the tropics and, depending on management strategy, can approach that amount in the subtropics. The flesh is white and flavorful. Tilapias grow well when cultured with other popular commercial pond fishes such as channel catfish and buffaloes. They have also been successfully cultured with freshwater prawns in Texas.

One of the major problems in the culture of tilapias for food in the United States is that they become lethargic and stop feeding when the water temperature falls below 60°F, and die at water temperatures of 45 to 55°F (depending on the species). This restriction reduces the length of the growing season to 4 to 7 months, depending on the latitude.

The innovative fish farmer can manage this sensitivity to cool water in a number of ways. The best method is to use a groundwater source warmer than 70°F, and preferably between 80 and 90°F. Water in the 70°F range can be used to overwinter tilapia, and the warmer water, if available in sufficient quantities, can be used to grow tilapia to food size. Self-flowing wells are desirable wherever they are available; however, producers should

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Fig. 9.5. The blue tilapia resembles our native sunfishes and is well accepted by consumers. These 1½-pound males can be prepared as eye-appealing fillets. This species is the most cold-tolerant of the tilapias and readily accepts artificial feeds. *Photo by Jay V. Huner.*

evaluate the economics of pumping water from other wells before they undertake it.

As an alternative the fish farmer can overwinter brood stock and fingerlings in heated indoor facilities. Tilapias tolerate high densities and much abuse, making their overwintering more of a nuisance than a serious problem. Then too, adults of most species spawn almost immediately in brood ponds when temperatures rise above 68 to 72°F.

Choice of Species or Hybrids

The choice of the tilapia species to be cultured depends on the needs of the buyer and production requirements. Some species control vegetation better than others, and some—especially those that grow to the larger sizes—are usually preferred for food markets. Two species that have been popular with aquaculturists and that are readily available are the redbelly tilapia and the blue tilapia.

The redbelly tilapia is a nest-guarding species. It is primarily a vegetarian and is an excellent vegetation control animal that is widely used to control weeds in western irrigation systems. The blue tilapia, a mouthbrooder, is an excellent food fish (Fig. 9.5). It is the most cold-tolerant of the tilapias, thrives in brackish water, and readily accepts artificial feeds. The Mozambique tilapia, another mouthbrooder, thrives in full-strength sea water. It quickly overcrowds its environment but good crops can be produced even in fresh water by careful managers.

Other species of tilapia sometimes raised in the United States are the mouthbrooders *Tilapia nilotica* and *T. hornorum* and the

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vegetation-nesting species *T. melanopleura.* Many other species occur in Africa and the Near East, some of which are almost certain to show potential as candidates for aquaculture.

Normal color patterns of tilapias are blue, green, or black, often with red highlights. Golden and red mutants, now being propagated commercially, often are more readily salable than are naturally colored ones.

Hybrids of the mouthbrooding tilapias already mentioned may be all or nearly all males. Many of the hybrids grow larger and faster than either parent, and unwanted reproduction may not be a problem. The most popular hybrid cross is the female *Tilapia nilotica* × male *T. hornorum.* This cross produces all-male offspring that grow exceptionally fast, reaching weights of ½ to 1 pound in 100 to 150 growing days. A major problem with this cross is that the female *T. nilotica* does not produce large numbers of young.

Another cross that produces all male or nearly all male offspring is the female *Tilapia mossambica* (Mozambique tilapia) × male *T. hornorum.* It produces far more offspring per female than the hybrid *T. nilotica* × *T. hornorum,* but does not grow as fast.

Hybridization can be complicated. Both crosses of *Tilapia aurea* × *T. mossambica* produce offspring that are routinely 70% male. Second generation crosses of the offspring are about 90% males, a significant increase; however, the problems involved with identifying and managing the different generations of offspring are great.

Another problem with hybrid crosses arises from the fact that tilapias hybridize so readily that there is some question about the existence of pure species in the United States. If a cross fails to produce the desired results, the identity of the parents should be questioned.

Stocking Rates, Polyculture, and Control of Overproduction

The best fingerlings to stock in ponds and raceways or cages have proved to be all-male hybrids, followed by all males of a single species. Alternatively, high-density culture of mixed sexes shows considerable promise.

Stocking rates depend largely on the management strategy. A stocking rate of 10,000 fingerling tilapias per acre is appropriate when organic manures are used. Higher stocking rates, 20,000 or more per acre, are used when the fish are fed pelleted feeds. The fish grow to weights of ½ to 1 pound in 150 to 200 days if water quality is adequate, and if little or no competition occurs from the progeny. As many as 10 to 15 pounds of tilapias can be produced per cubic foot of water in a raceway or cage system.

Polyculture of tilapias with food-sized channel catfish has been only partly successful. The tilapias compete with catfish for the pelleted feed, and mixed-sex tilapias stocked in catfish ponds to control algae usually reproduce and become overcrowded. This problem becomes even more severe when 500 to 1,000 pounds per acre of these subsalable tilapias die in catfish production ponds during the first cold weather of fall. All-male populations of tilapia are not generally obtainable.

Some channel catfish culturists stock several pairs of tilapias per acre in ponds with brood channel catfish. These tilapias and their offspring control filamentous algae and submerged vegetation. Small tilapias are eaten by the brood catfish during the summer, and especially during fall, when the water temperature declines to the 40 to 50°F range. Production of tilapias is an excellent way to add animal protein to the diet of brood catfish.

Another major problem in managing most tilapia species is overreproduction and resultant crowding. The available food and living space soon becomes inadequate to grow all the potential offspring to a usable size. A number of strategies that have been used to solve the overpopulation problem are listed here. (1) Tilapia fry and fingerlings are harvested periodically to reduce competition. This approach is effective in small ponds if labor is readily available. (2) Sexes may be separated after a period of growth, since the males grow significantly faster than the females. This sort-

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ing can be done visually, or the 35 to 40% of the fry that are largest can be graded out and restocked; the other 60 to 65% of the fish, mostly females, are discarded. (3) Different species are frequently crossed to produce all or nearly all male hybrids. (4) Adult tilapias can be grown in cages or pens suspended off the bottom. When spawning occurs, the eggs are lost through the cage mesh, fall to the bottom, and die. (5) Tilapias can be cultured at high densities in ponds or raceways. The crowding effect prevents spawning but does not affect growth. (6) Predaceous fish such as largemouth bass, bowfins, and even crappies can be stocked as fingerlings or adults in tilapia ponds. They then eat young tilapias, controlling their numbers. Predators should not be large enough, however, to prey on the tilapias that were originally stocked. (7) Sex reversal is being tried with some success. In this technique, tilapia fry are fed feeds containing male sex hormones so that all become males. (8) Sexually immature fish can be stocked. These can be fed and grown to a harvestable size before they become sexually mature.

Eels

The commercial production of food-sized eels and the capture of elvers (small eels) for export has created considerable interest among aquaculturists in the United States. Eel is considered a gourmet food in Japan, Taiwan, and most European countries and commands high prices. Unfortunately, the demands and prices for food eels and elvers are highly unpredictable, often being phenomenally high in one year and catastrophically low the next. American eel culturists have been left at the mercy of the unpredictable overseas markets because there are virtually no domestic sales in North America. The lack of markets has greatly hampered the development of eel culture in the United States.

The American eel is a snake-like fish that has a continuous dorsal, caudal (tail), and anal fin and appears to be scaleless (the scales are small and embedded). It sometimes reaches a length of about 5 feet and a weight of 15 pounds but usually does not exceed 2 pounds. The American eel is often confused with salamanders, such as the sirens. However, sirens have external gills and small forelegs.

Eels have a complicated life cycle. Anguillid eels spawn in the sea and mature in fresh or brackish waters. The American eel spawns in the Atlantic Ocean, but the exact location of its spawning site is still unknown. Its cousin, the European eel, spawns in the vicinity of the Sargasso Sea near Bermuda. It takes at least a year of travel for the semi-transparent, leaf-like larvae of the American eel to reach freshwater streams along the eastern coast of North America. Upon reaching the coast, the larvae metamorphose into worm-like elvers. The 2- to 3-inch elvers are also semi-transparent and have about the diameter of a pencil lead when they begin to ascend streams and rivers. It takes 3,000 to 4,000 elvers to weigh 1 pound. Male eels remain in estuarine areas but females travel many miles upstream. Females mature in 5 to 20 years, turn a silvery color, stop eating, and return to the sea to spawn, never to be seen again.

The transparent elvers are called glass eels and can be netted or trapped in large numbers near waterfalls and culverts in spring, when they migrate upstream from the sea. This is the only way that large numbers of eels can be obtained for seed stock in eel culture. Since eels have not yet been artificially spawned and cultured, the eel culturist must depend on the whims of nature for seed stock —as well as contend with objections of conservationists and eel fishermen, who hold that the removal of glass eels depletes wild stocks.

Culture techniques used in the United States are similar to those used in Japan and Taiwan. Japanese eel culturists stock the 2-inch elvers or glass eels in tanks 16 feet in diameter by 2 feet deep at the rate of about 14 ounces (2,500 to 3,500 elvers) per square yard. They are kept in the tanks until they are about 3 inches long and then restocked at the rate of 3.5 ounces per square yard into concrete tanks that are 30 to 100 square yards in area and 3 feet deep. They are kept in these tanks

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until they reach a length of about 6 inches. These elvers are next transferred to 0.05-acre earthen ponds, where they are held until they are 8 inches long. These fingerlings are stocked at the rate of 1,000 to 15,000 per acre in "grow-out" ponds of 0.1 to 4.5 acres in area. Eels should reach 2 ounces in the first year, and the desired market weight of 5 to 7 ounces in the second year. One pound of glass eels should produce 400 pounds of market-sized eels.

In the United States, about 10 pounds of 2-inch glass eels caught in spring are stocked in 250-gallon tanks equipped with aeration and filtration devices. These elvers are trained to eat prepared feeds and are then restocked in ponds at rates of 10,000 to 15,000 per acre later in spring when water temperature reaches 68°F. A harvest of 3,000 to 6,000 pounds per acre can be expected in 14 to 16 months from the time that the glass eels are secured.

Maintenance of water quality is a major consideration in eel farming, as it is in all types of aquaculture. Ponds that contain several thousand pounds of eels require just as much attention as ponds containing equivalent weights of channel catfish. Techniques for water quality maintenance in channel catfish ponds apply equally to eel ponds. Asian eel farmers normally use small paddle wheels to aerate their ponds, and similar techniques are recommended for eel culturists in the United States.

Feeding of eels constitutes a special problem. In nature, the diet of eels is similar to that of channel catfish. Unfortunately, eels do not readily accept commercial pelleted feeds formulated for channel catfish.

In the Far East, trash fish are commonly used as feed. The fish are first boiled to soften the skin and flesh, and then suspended in the pond by a string that passes through their eye sockets. After the flesh has been eaten, the skeletal remains can then be easily removed. Chopped fish can also be fed, but water quality reduction and transfer of disease can create management problems.

The preferred method in both Japan and the United States is the offering of artificial feeds, which glass eels must be trained to eat.



Fig. 9.6. Eels are usually fed a starch-bound, dough-like feed, which is placed in a partly submerged wire basket under a protective sunshade.

Traditionally, the starting diet has been a thickened paste containing three ingredients: deboned and blended fish, 86.5%; earthworms, 12.0%; and table salt, 1.5%.

This starting diet is fed for the first month, after which it is usually replaced with a dough-like feed composed of dry ingredients mixed with water. A typical elver diet consists of 75% fish (mostly menhaden), 25% alpha corn starch, and a vitamin pre-mix. Antibiotics can be added in the feed mixture.

The feed ball is placed in a partly submerged wire basked positioned under a sunshade (Fig. 9.6). The eels are attracted to the protection of the sunshade and are in the vicinity when the feed is added. They slither through the wire mesh to reach the feed.

Eels are subject to many diseases and parasites, and thus require close attention. Whenever eels at any life stage are handled, prophylactic treatments are essential. Eels are also cannibalistic and should be periodically graded to reduce unnecessary losses.

Eels are generally harvested with traps. Feeding trays are frequently constructed to serve as traps. The trays are quickly raised to the surface and the larger eels that cannot pass through the mesh are retained. Eels can also be seined.

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Eels are usually transported alive to the consumer. Most transportation units consist of buckets or trays in which the eels are kept moist and cool. If the eels are covered with water, the water must be well aerated, and waste metabolites must be removed.

What is the prognosis for eel culture in the United States? Without stable supplies of elvers and market outlets, eel culture represents a risky venture. Yet, enterprising fish farmers may find that eels provide a good supplement to farm income in areas where seed eels can be obtained and where ethnic food markets and bait markets are close at hand. Eel culture technology is satisfactorily advanced.

Hobby Fishes

Most species of hobby fish (also called tropical fish or aquarium fish) occur naturally in tropical or semitropical fresh water, brackish water, or salt water. The group includes representatives of several families, and over 100 species of small, colorful, and unique fishes.

Hobby fish are either domestically produced or imported. Most of the domestically bred fish are cultured at the more than 300 farms located near Tampa in central Florida. However, hobby fish are also raised in most of the other States; most culturists specialize in the production of the varieties that are most colorful and easy to propagate. All operations, regardless of location, are limited by available space, cost of labor, and the cost of heating water during winter. Even in southern Florida's warm, semitropical climate, winter temperatures reduce production for a 2- to 4-month period in a warm-winter year, and virtually stop it in a cold-winter year. The retail value of hobby fishes produced in the United States is estimated to exceed $200 million annually.

Tanks, vats, and earthen ponds are used to culture hobby fish. A typical farm may propagate 20 to 30 or more species or varieties, each of which requires separate accommodations. Ponds of the sizes usually used are 20 by 80 feet or 80 by 100 feet, and number from 100 to 200 at many farms (Fig. 9.7). Ponds are generally excavated below the water table and the dirt removed is used to build up the levees. The freeboard of the levee is 3 to 5 feet, and the maximum water depth of the ponds is usually about 5 feet. The ponds have no drains or overflow pipes. Water must be pumped out when the ponds are to be drained. Farms are equipped with a water discharge sump where the particulate matter and fishes are removed by settling and filtration before the water is released to the environment. Some pond sites are equipped with electrical outlets to facilitate the use of aeration and agitation equipment.

Other hobby fishes are imported from throughout the world. They are typically received by a wholesaler who acclimates, reconditions, or finishes rearing them for a time before shipping them to the ultimate retailer. Imported hobby fish are usually colorful and unique, and difficult to propagate. The retail value of hobby fish imported into the United States in the early 1980's was estimated to be $500 million annually by the Florida Tropical Fish Growers Association.

Important families of hobby fish include livebearers and egg layers with a variety of spawning habits (Table 9.1). A typical text for the home aquarist lists 50 to 100 different species, not to mention popular mutants or hybrids of various species.

The livebearers are fairly easy to propagate, but they hybridize so readily that great care must be taken to keep the individual species and strains separate. As a group, they are not as prolific as the egg layers. Livebearers can be propagated in earthen ponds. A producer may stock as many as 400 or as few as 25 brood fish in a pond. It is sometimes desirable to place all the brood fish in one pond, and net or trap the offspring and remove them to other ponds. However, specific hybrids of livebearers are usually bred in tanks or vats, and the fry are later transferred to earthen ponds for further growth. One problem in the propagation of livebearers is that the most popular and most profitable varieties are recessive hybrids. Fewer than 25% of the

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Table 9.1. *Representative popular tropical fishes: families, breeding habits, and species.*

Poeciliidae (livebearers)
These fish often eat the living young they bear and need to be separated from them by using spawning cages or by providing cover for the young. This group includes the mosquitofish, which is common throughout the United States.
Poecilia latipinna—sailfin molly
P. reticulata—guppy
Xiphophorous helleri—swordtail
X. maculatus—platy

Cyprinidae (carps and minnows)
Some of these egg layers scatter eggs in gravel; others scatter them among fine-leaved or broad-leaved aquatic plants, depending on species. Parents do not care for the young and should be removed after spawning has ended. All Chinese carps belong to this family, as do common carp and koi carp.
Brachydanio rerio—zebra danio
Puntus everetti—clown barb
Rasbora (rasboras)

Cyprinodontidae (killifishes)
Eggs laid by these fishes adhere to plants or gravel. Parents do not care for young and should be removed from tank after spawning. The fish are very aggressive. This group includes the killifishes found throughout North America, some of which are important baitfishes.
Aphyosemion coeruleum—blue gularis

Characidae (characins)
Egg layers with varied breeding habits. Typically, adhesive eggs are scattered among thick plants. Parents eat the eggs if they are not removed after they are laid. Some species have very exacting water quality requirements and will not spawn if the requirements are not met.
Carnegiella marthae—black-winged hatchetfish
Copeina gukttata—red-spotted copeina
Gymnocorymbus ternetzi—black tetra
Hemigrammus erythrozonus—glow-light tetra

Cichlidae (cichlids)
The cichlids include the mouthbrooding tilapias. Some species build nests on the bottom or in crevices or natural cavities. Still others lay adhesive eggs that adhere to flat surfaces on rocks or vegetation. Parents guard eggs and young. The discus fish "feeds" newly hatched young with secretions in surface mucus. Some species are piscivorous.
Symphysodon discus—discus fish
Cichlasoma meeki—firemouth cichlid
Pterophyllum scalare—angelfish

Anabantidae (gouramies)
Labyrinth fishes with air chambers in their heads. They require atmospheric oxygen and drown if denied access to the surface. The males of the more popular species build bubble nests at the surface for egg incubation and guard eggs and fry. Males of some species must be removed from the tanks, however, because they eat the fry.
Betta splendens—Siamese fighting fish
Trichogaster trichopterus—blue gourami

Callichthyidae (Corydoras catfishes)
Breeding pairs of species from this family "join" belly to belly, as eggs are extruded into a pocket created by the female's ventral fins, where they are fertilized. The female then deposits them on plants and the process is repeated until all eggs are laid. Parents normally ignore the offspring.
Corydoras aneneus—bronze catfish

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Fig. 9.7. This earthen pond for the production of hobby fish measures 20 × 100 feet and has a 3-foot freeboard. It has no drain. Usually only one species is cultured in each pond. *Photo courtesy of T. F. H. Publishers.*

hybrids in a pond may be marketable, and thus extensive selection and culling are usually required.

The egg layers are generally difficult to propagate because their breeding requirements can be very exacting. Some species deposit adhesive eggs on vegetation, rocks, tiles, and other surfaces. Other species lay their eggs in small nests that look like depressions in the pond or container bottom. Some species build floating bubble nests in which the embryos develop and hatch. A few popular species are mouthbrooders that gather the fertilized eggs in their mouths and carry them until they hatch.

A few species of egg layers can be propagated in earthen ponds. Mats of Spanish moss may be used as a substrate for species that lay adhesive eggs on plants or rocks. However, the preferred method for propagating egg layers is inducing them to spawn in tanks or vats. Breeding pairs are stocked into 10- to 30-gallon tanks. A producer seldom sets up less than 200 breeding tanks to obtain eggs to stock one pond. Many of the cichlids use flat substrates such as the aquarium walls or vertical glass plates placed there for their use. Species that eat their eggs must be separated from them almost immediately. For free-spawning fish, breeding traps or boxes with wire bottoms are commonly used to separate the eggs from the parents.

Feeding of hobby fish is a major consideration to the producer. It is sometimes necessary to offer brine shrimp nauplii to the fry of some species before they are stocked into ponds. Most of the varieties of fish must be fed in the ponds, and feeding is one of the major costs in production. Often different formulations and feeding techniques are required for the various varieties of hobby fish. Expensive carotenoids and other pigments are commonly included in the feed to promote bright coloration in the fish.

Ponds used for the breeding and culture of hobby fish must be managed carefully to

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ensure the growth of the particular type of plankton bloom required by each variety of fish. This bloom is maintained with organic and chemical fertilizers, and the undesirable plants are controlled by chemical algicides or herbicides. Because of the extreme clarity of the unfertilized waters used, the control of rooted aquatics is a particular problem in raising some species of hobby fish.

A major management problem in hobby fish farming is control of bird predation. Most hobby fish are small but colorful and prominent. As a result, it is easy for bird predators to see and capture the fish in unpatrolled, unprotected ponds. Growers must use a great deal of ingenuity and spend considerable sums to control herons, egrets, ibises, kingfishers, gulls, and other fish-eating birds. The problem of control is complicated by State and Federal laws that protect most birds. The use of frightening devices and pond covers to discourage the birds is well known. Producers have recently observed that the use of aerators or agitators eliminates much of the loss because the fish are attracted to the vicinity of the device, and the water turbulence tends to prevent birds from seeing the fish.

Marginal water temperatures are a major concern to producers of hobby fish in Florida. Most of the varieties produced are tropical or semitropical and thus are sensitive to water temperatures below 60°F. In winter, producers usually move the more sensitive and more valuable fish varieties to indoor facilities equipped with heated water and other environmental needs. The rest of the fish are left outdoors. Many farmers add groundwater (72°F) to buffer the effects of the cold air. Other producers cover their ponds with plastic covers similar to those on greenhouses (Fig. 9.8).

Harvesting is a major consideration because fish that die in retail stores, or soon after being purchased by the aquarium owner, ultimately must be replaced by the producer. Livebearers can be caught with traps and seines. Because trapped fish suffer little trauma, they can be shipped soon after capture; however, fish caught with seines must be held for several days before they can be shipped.



Fig. 9.8. Hobby fish held in plastic-covered ponds are partly protected from cold weather. Most of the varieties produced are tropical or subtropical and thus are sensitive to water temperatures below 60°F. *Photo by R. Socolof.*

Two basic types of traps are used. One, a plastic minnow trap, has a wide entrance funnel and a removable rear door, and is usually baited with dry dog food or cat food. This type of trap must be tended closely to prevent overcrowding. The other, a heart trap, consists of a wire basket with an indenture in the heart, which has an opening through which fish enter. Because this trap is open at the top and is much larger than a plastic minnow trap, it does not have to be tended as closely.

Although some egg layers can be caught with traps, most are captured with seines and therefore must be held several days before they are shipped.

Contamination of production ponds with undersized fish or aquatic animals is a real concern to the producer. Some of these animals burrow into the bottom when the pond is drained, and are unaffected by fish toxicants used in the pre-filling sterilization. Common examples are Oriental weatherfish, snails, and mosquitofish. When the pond is refilled and stocked with hobby fish, these predators leave the bottom muds and eat significant numbers of fish. Other aquatic animals migrate overland and contaminate production units.

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The introduction and establishment of exotic fish parasites and infectious diseases is a major concern to everyone connected with the hobby fish industry. As in the control of all infectious diseases, a program of inspection, treatment, and sterilization prevents most or all of the potential problems.

Hobby fish are normally shipped by air express. The fish are placed in plastic bags partly filled with water, and the rest of the volume of the bag is filled with pure oxygen. These bags are then placed in Styrofoam or cardboard shipping containers (see Chapter 13). Some 15,000 to 20,000 of these boxes are shipped each week from Florida wholesalers to retailers throughout the country.

A number of excellent texts and manuals are available to the aquarist on the feeding and care of hobby fish; several are listed in Chapter 21.

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10. POLYCULTURE

Harry K. Dupree and Jay V. Huner

Maximizing production is the goal of the aquaculturist. The production of a single size and species of an aquatic animal is limited by the ability of the system to produce the specific food organism required. Thus, the first limiting factor in the production of aquatic animals after the environmental needs are met is food. The producer can somewhat overcome this limitation by adding feeds from outside sources.

In monoculture, some natural foods are often underused. In polyculture all these natural foods are used in the aquatic production system.

Polyculture is often thought of as involving the production of fish and aquatic organisms with a short food chain. The combination stocking of herbivorous, omnivorous, planktivorous, and detritivorous species, as exemplified in Chinese aquaculture, is a well-publicized example. However, more polyculture is being practiced in the United States than might be readily apparent. The largemouth bass-bluegill stocking combination developed by the late Dr. H. S. Swingle of Auburn University in the 1930's is an example of the use of a large predator species to control the excess reproduction from a large forage species, and the forage species furnishing food for the predator species. When the two species are in proper balance, the result is sustained production of fish of usable size.

The rotation of rice and fish was investigated in Arkansas in the 1950's and is still practiced to a limited extent. The simultaneous production of rice and crayfish is the basis for the crayfish industry in Texas and Louisiana.

Multiple stocking and multiple harvesting of channel catfish is a recent innovation. Since different sizes of fish occupy different niches in the production pond, this technique can be considered to be polyculture in some respects. As fish of the larger sizes are harvested through periodic seining or trapping, equal numbers of small catfish are stocked. This technique provides continuous supplies of fish for harvest, and maximizes the total standing crop in the system.

Many types of polyculture applicable to aquaculture in the United States have been conceived but most require additional research and further development. Many other types of polyculture have not been tried. We outline here some potential developments that may interest enterprising aquaculturists.

Species Selection

Proper species selection can increase overall production and profit through polyculture. Fish and other aquatic animals with a short food chain, such as the herbivorous, omnivorous, planktivorous, and detritivorous feeders, produce more food than do the organisms with longer food chains. Aquatic animals that eat and perform well on waste products or other products unsuited for human nutrition should have preference in selection.

Rapidly growing organisms are advantageous in the production system. The more rapid the growth, the sooner the organisms can be harvested and sold and small organisms restocked for further production. Sturgeons may bring an extremely high price, but with the culture methods now being used, their growth is too slow to enable profitable production. A fast-growing tilapia, though worth much less per unit of weight, could result in

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high production and a substantial profit to the aquaculturist.

The culturist must select an organism or species combination that is suited to the region concerned. The major constraints are length of growing season and the temperature tolerance of the species. For example, the rainbow trout is a good production species in northern areas but not in warmwater areas. In turn, the Malaysian freshwater prawn is a good production animal in tropic areas with long growing seasons, but is of only limited value in the southeastern United States.

Ultimate use of the aquatic organism is important. When recreational fishing is the prime interest, a species such as the largemouth bass, striped bass, or walleye should be considered. However, when food production is the main goal, species such as the buffaloes or the common carp should be investigated. Species such as channel catfish or rainbow trout can serve both as sport and food fish.

Legal constraints must be evaluated when one selects aquacultural species for polyculture. Some non-native animals are known to be suitable for food, sport fishing, and fishery management. However, local or State laws may prevent their introduction or possession.

Economics must be considered. If the products in a polycultural program cannot be sold, they are not worth much to the producer. However, some otherwise nearly valueless species may enhance the production of another extremely profitable species. The producer must be aware of the cost of labor in a polyculture program. Labor costs are generally lowest in monoculture of a single size of fish and highest in polyculture of mixed sizes.

Mixing of Different Species and Ages

Classic polyculture involves the mixing of different species and sizes. This culture plan was probably first practiced in ancient China and has reached a high level of development there. The stocking plan is developed to mutually benefit each of the species that make up the population.

Stocking plans suitable for some regions may not be suitable for others. Research and field evaluations directed toward finding the most productive and profitable combinations are necessary in each region.

Mixing of Noncarnivorous Fishes

Food preferences for noncarnivorous aquatic animals often change with size and age. Small grass carp are omnivorous but larger ones are herbivorous. As previously mentioned, some producers are now stocking fingerling channel catfish with larger catfish. The small catfish eat zooplankton, small bottom organisms, and the otherwise wasted formulated feed fed to the large fish. The culture of the Malaysian prawn (Chapter 15) is based on the stocking of postlarvae with small adults, and then seining out the larger prawns before they become predatory.

The main caution in polyculture of noncarnivorous species is to keep out the unwanted carnivorous or competing species by filtration or by using a clean water supply. Overcrowding by these unwanted fish in these multi-year operating programs usually cannot be controlled because the stocking combination does not include a carnivorous fisn for this purpose.

Mixing noncarnivorous fishes of the same size but of different species is practiced in food-fish production to a limited extent. An example is the mixing of different species of buffaloes, common carp, and various hybrids, since their feeding habits differ and they occupy different niches in the system. The advantage of this type of combination is that overall production is increased and all fish reach harvestable size at about the same time, enabling the farmer to drain the pond and remove all the fish in a single operation.

A more common practice in the polyculture of food fish is that of mixing several sizes and species of noncarnivorous fish. The different sizes and species of fish have different food preferences and occupy different niches. The well-developed polyculture system with Chi-

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nese carps is an excellent example. A polyculture system including native buffaloes, channel catfish, and common carp could probably be developed in the United States. In this plan, the larger fish are periodically removed by seining, and the fish removed are replaced with fingerlings. Unless supplemental feeds are fed, however, the product tends to be made up of relatively small fish. The principal need in species selection is to choose aquatic animals with different feeding habits that live in different ecological niches. It is desirable also that growth rates be similar, so that the fish reach marketable size at about the same time.

Mixing of Carnivorous and Noncarnivorous Fishes

This technique essentially involves the stocking of small predator fish with larger omnivorous or herbivorous fish. An excellent example is the stocking of fingerling largemouth bass with large channel catfish, grass carp, and buffaloes. The bass eat forage fishes that contaminate the pond and that would otherwise compete with the production of the larger fishes. Largemouth bass or other small predator species can be used to control the reproduction of the principal cultivated species such as tilapias or brown bullheads, thus eliminating competition.

Although the largemouth bass has been used extensively as a predator in this type of polyculture, other fish such as striped bass or flathead catfish can be used. It is important to select a predator species that has sale or fishery management value after harvest.

An excellent example of mixing the larger forage fish with the larger predator species is the familiar largemouth bass–bluegill combination. Most management programs in reservoirs, lakes, and rivers are based on the theory that predator species control the excess forage, and the forage fish in turn support the predator fish. In commercial aquaculture, the use of a predator species allows for the production of the larger recreational or food fish, such as sunfishes or tilapias, where the control of reproduction is essential.

The fingerlings and yearlings of the high-value predator fish—striped bass, black bass, northern pike, and walleye—can be fed low-priced forage fish. These fish often do not feed well on prepared feeds. Generally 5 to 6 pounds of forage fish are required to produce 1 pound of predator fish.

In the United States the technique of feeding forage to maintain a brood stock of predator fish is discouraged by the unfavorable economics. It is often more economical for State and Federal fish hatchery personnel to capture brood fish for species such as striped bass, walleyes, and muskellunge from the wild and spawn them artificially than to maintain the brood fish year-round.

Culture of Nonreproducing Stocks

Monoculture and polyculture production systems can be enhanced by the use of sterile animals, monosex animals, and hybrids. Often the hybrids do not reproduce. This allows the aquaculturist to stock fish without considering the possibility of unwanted reproduction. Since these sterile hybrids do not direct energy into the development of sex products, their growth rate, feed conversion efficiency, and terminal size are often larger than those of reproducing animals.

Monosex populations have other advantages. Often growth rate is sex related. Female buffaloes grow faster and larger than males, and bring a better price on the market. On the other hand, the male tilapia is usually larger than the female. Techniques are available for producing single sexes of some species, and manual techniques can be used to separate the sexes of other species.

Polyculture as Controlled by Season

Multiple crops of aquatic animals can be produced in areas with long or continuous growing seasons. For example, in the tropics three or more crops of aquatic animals can often be produced in a single year. However, most areas in the United States are not suited

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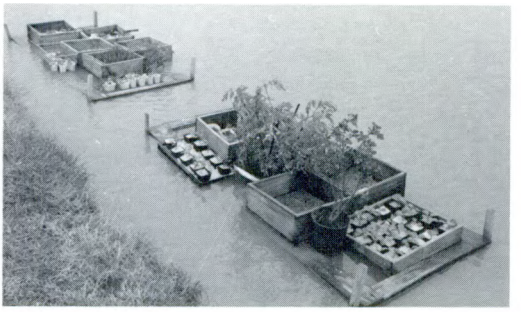


Fig. 10.1. Research on the growing of vegetable crops in ponds has not been successful. Pond waters generally do not contain enough nutrients to support the growth of vegetables.

for continuous production. Even in southern Florida, production is slowed during winter. In some winters, fish and plants may be damaged or killed by the cold.

Successive cropping in the same year can be practiced to a limited extent in the United States. Some fish culturists produce two crops of striped bass fingerlings and then a crop of channel catfish fingerlings. This procedure allows for the fuller use of ponds than that realized by the production of only a single crop.

The limitation in multiple cropping is that most fish spawn in spring, and thus must be stocked at about the same time. The spawning and growth rate of only a few species of cultural importance can be stimulated or retarded long enough to make multiple cropping feasible.

Some aquaculturists have produced trout and channel catfish in the same facility. Generally the catfish are produced in the open pond and trout in cages installed in winter. The uneaten feed from the trout culture provides supplemental winter feed for the catfish. Since the trout are confined to cages, they can be rapidly harvested when the water warms in spring.

Polyculture of Plants and Animals

Plants and animals can be produced together in the same year, or rotated from year to year. Polyculture in alternate seasons is

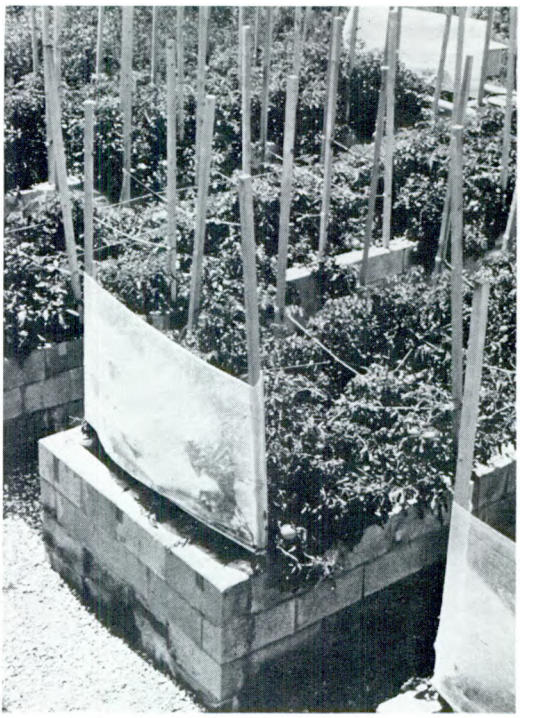


Fig. 10.2. Solids—uneaten feed and feces—obtained from raceway production of channel catfish and trout have produced good crops of tomatoes (shown here) and other vegetables. However, the usefulness of this production system is unproven. *Photo by W. Lewis.*

commonly referred to as fish-crop rotation. Generally, a crop that responds well to nitrogen and phosphorus is planted in the dry pond after several years of fish production. Rice, corn, sorghum, or millet are examples of crops that have been planted in dry fish production ponds. In turn, the terrestrial crop removes the excess nitrogen and phosphorus, and brings about through cultivation the oxidation of pond bottom detritus. Generally no herbicides need to be used because the pond bottom has been without terrestrial vegetation. Yields of rice, corn, sorghum, or millet approximate those of conventionally farmed lands.

Other studies involving the growing of plants in pond waters (hydroponics) have not been fruitful (Fig. 10.1). Generally the pond waters, even from intensive production systems, do not contain sufficient nutrients to meet the needs of the plants. In tests in which

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the solids from fish production—uneaten feed and feces—were used, good crops of some vegetables have been produced, but the economics are unproven (Fig. 10.2).

Crayfish and rice are produced simultaneously in the United States. A crop of rice can be produced during summer, while the crayfish are reproducing in their burrows. In fall the rice is cut and the fields are reflooded. The rice stubble provides food and protection for the emerged crayfish. Trapping and sale of the crayfish provides a significant supplemental income to some rice farmers. This technique is discussed further in Chapter 16.

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11. NUTRITION, FEEDS, AND FEEDING PRACTICES

Harry K. Dupree and Jay V. Huner

Successful fish farming demands that the aquaculturist have a knowledge and appreciation of nutrition, feeds, and feeding practices. Nutrition of warmwater fish is a relatively new field compared with the nutrition of poultry, swine, and trout. Nutritional studies with channel catfish began in the late 1950's. Nutritional and feeding studies with other warmwater fishes soon followed.

The numerous warmwater fish species collectively consume a wide variety of natural and manufactured foods. Carnivores eat only the flesh of other animals, herbivores eat only vegetative matter, and omnivores—which includes most of the fishes of interest to the fish farmer—eat a variety of both plant and animal foods.

The successful fish farmer recognizes the difference between natural foods and manufactured feeds, and the part that both can play in the economics of fish production. The successful fish producer also recognizes the importance of proper feeding practices, since uneaten feed, or feed that is eaten after it is water-leached, does not contribute fully to profitable production. The fish producer who understands the role of the various nutrients and the contribution of various dietary ingredients can use a variety of feeds in the profitable production of high quality fish—whether they consist of live food such as brine shrimp, fresh food such as organ meats or cut fish, single-ingredient products such as oilseed protein meal, or a manufactured multi-ingredient finished feed.

Nutritional Requirements

Fish require protein, lipids, energy, vitamins, and minerals in their diet to meet the physiological needs of growth and reproduction. The requirements vary from species to species, and with fish age, sex, reproductive state, and environment. Not all of the nutritional requirements for all the fishes of farming and recreational importance are known. There is considerable similarity in the dietary requirements of warmwater fishes, but there are also differences. The fish nutritionist realizes that research must be conducted on all species of aquacultural importance before the "best" formulation for each species can be made, but during the interim, the information known about some species can be used to formulate acceptable feeds for others. We offer here an overview of the nutritional requirements of warmwater fishes.

Protein and Amino Acids

Protein is essential in the diet of all fishes as a source of amino acids, which are the building blocks for flesh, enzymes, eggs, milt, antibodies, and some hormones. Protein can be used as a source of energy, but this is wasteful and should be avoided.

A liberal supply of protein of good quality must be available to fish throughout life. The quantity of protein required varies with fish species and age (Table 11.1), water temperature, and numerous other factors not clearly understood.

Weight gain of fish is essentially linear with protein content in the feed. When the effects of several protein levels (in practical rations) on growth were compared (Fig. 11.1), weight gain was essentially directly proportional to protein content of the diet at a range of 20 to 40%, but 50% protein did not improve growth. It is important not to feed more pro-

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Table 11.1. *Protein requirements (percent of total ration, by weight) for rapid growth in different kinds of fish.*[a]

Species	Fry to fingerlings	Fingerlings to subadults	Adults and brood fish
Eel	50-60	45-50	
Channel catfish	35-40	25-36	28-32
Largemouth bass	40	40	35
Striped bass	40	36	35
Common carp	43-47	37-42	28-32
Trout and salmon	50	35-40	30-32

[a]From H. K. Dupree. 1976. Studies on nutrition and feeds of warmwater fishes. Pages 65-84 *in* Proceedings of the First International Conference on Aquacultural Nutrition. University of Delaware, College of Marine Studies, Newark, New Jersey.

tein than can be used by the fish, because no benefit is realized in growth, the excess can be damaging to the fish, and the cost of the protein is high.

Water temperature appears to affect the use of the proteins in feed. Many plant and animal proteins are used almost equally well at summer water temperatures, but at lower temperatures plant proteins are used less efficiently than animal proteins.

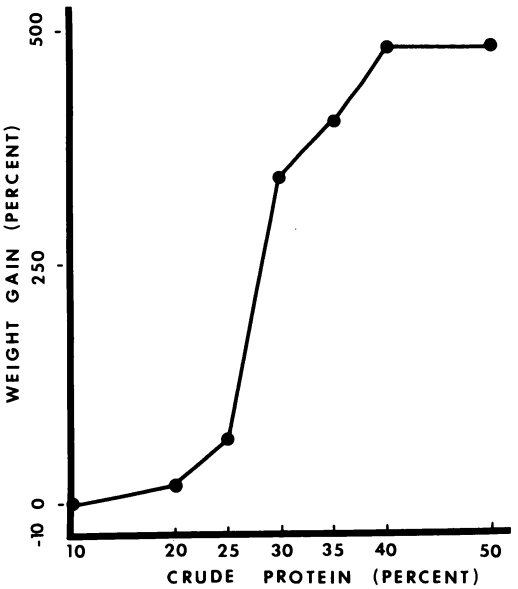


Fig. 11.1. Growth in aquaria of channel catfish fingerlings fed practical rations having different percentages of protein (water temperature 75 to 88°F). (From H. K. Dupree. 1976. Studies on nutrition and feeds of warmwater fishes. Pages 65-84 *in* Proceedings of the First International Conference on Aquacultural Nutrition. University of Delaware, College of Marine Studies, Newark.)

Quantitative requirements for the 10 amino acids essential in the diet of four species of fish and the chick are shown in Table 11.2. The protein component in the diet supplies these essential amino acids. The other amino acids, not essential in the diet, are tyrosine, cystine, glycine, alanine, aspartic acid, glutamic acid, and proline. However, the first two of these may have a sparing function—tyrosine can spare phenylalanine and cystine can spare methionine—thus reducing the quantity of phenylalanine and methionine required in the diet.

The addition of crystalline amino acids to meet the animals' requirements has been tested in warmwater aquaculture, but the results have been inconclusive. Common carp appear to use added amino acids poorly. In some studies the addition of lysine and methionine to catfish feeds has been successful, but in others no benefit could be measured. In studies with Atlantic salmon and rainbow trout, the addition of one or two of the most limiting amino acids was of little benefit, but the addition of a mixture of many amino acids resulted in gains approaching that of fish meal protein. Considerable research remains to be done to determine the benefit of adding individual amino acids.

Lipids

Lipids and fats are used by fish as a source of energy. Some lipid forms are essential in

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Table 11.2. *Amino acid requirements (as percent of protein in the diet) of several fishes and the chick.*[a]

Amino acid	Channel catfish	Common carp	Japanese eel	Chinook salmon	Chick
Arginine	4.3(1.03/24)	4.2(1.6/38.5)	4.5(1.7/37.7)	6.0(2.4/40)	5.6(1.00/18)
Histidine	1.5(0.37/24)	2.1(0.8/38.5)	2.0(0.8/37.7)	1.8(0.7/40)	1.4(0.26/18)
Isoleucine	2.6(0.62/24)	2.3(0.9/38.5)	4.0(1.5/37.7)	2.2(0.9/41)	3.3(0.60/18)
Leucine	3.5(0.84/24)	3.4(1.3/38.5)	5.3(2.0/37.7)	3.9(1.6/41)	5.6(1.00/18)
Lysine	5.0(1.50/30)	5.7(2.2/38.5)	5.3(2.0/37.7)	5.0(2.0/40)	4.7(0.85/18)
Methionine[b]	2.3(0.56/24)	3.1(1.2/38.5)	5.0(1.9/37.7)[c]	4.0(1.6/40)[c]	3.3(0.60/18)[c]
Phenylalanine[d]	5.0(1.20/24)	6.5(2.5/38.5)	5.8(2.2/37.7)	5.1(2.1/41)	5.6(1.00/18)
Threonine	2.0(0.53/24)	3.9(1.5/38.5)	4.0(1.5/37.7)	2.2(0.9/40)	3.1(0.56/18)
Tryptophan	0.5(0.12/24)	0.8(0.3/38.5)	1.1(0.4/37.7)	0.5(0.2/40)	0.9(0.17/18)
Valine	3.0(0.71/24)	3.6(1.4/38.5)	4.0(1.5/37.7)	3.2(1.3/40)	3.4(0.62/18)

[a]In parentheses, the numerators are requirements as percent of the total diet and the denominators are percent total protein in the diet. Adapted from National Research Council. 1983. Nutrient requirements of warmwater aquatic animals. National Academy of Sciences, Washington, D.C.
[b]In absence of cystine.
[c]Methionine plus cystine.
[d]In the absence of tyrosine.

certain metabolic processes and in certain cellular structures. Phospholipid is a major constituent in brain and nerve tissue.

Lipid requirements for energy have been studied in some warmwater fishes. Some levels have been suggested by these studies, but complete recommendations are not available. Some observations on the essentiality of certain unsaturated fatty acids such as ω3, ω6, and ω9 have been published.

The addition of increasing amounts of fat or oil in the diet of several warmwater fishes resulted in more gain and protein deposition up to a lipid level approaching 16%. Overall, the available data suggest that lipid percentages between 10 and 15 are most desirable.

Lipid quality must be considered in the manufacture of a fish feed. Corn oil and soybean oil have been observed to produce better-tasting channel catfish than some fish oils. In fact, any rancid odor or taste in the oil component of the feed is readily imparted to the fish flesh. This off-flavor can be in the added oil or fat, or in the lipid fraction of the feed ingredients. These off-flavor components are usually oxidative products and can include aldehydes, ketones, and peroxides of altered fats and fatty acids. These autoxidative compounds can also alter metabolism and nutritive values of the dietary components.

Long-term feeding studies with fats and oils containing different amounts of the unsaturated fatty acids of the ω3, ω6, and ω9 form suggest that most warmwater fishes require a mixture of ω3 and ω6. These fatty acids of the stearic family (18 carbons) are often written as follows: linolenic, 18:3ω3, and linoleic, 18:2ω6. The ω3 requirement for coho salmon has been reported to be between 1 and 2.5%; levels of ω6 above 1% depressed growth. Salmon nutritionists have reported the most desirable percentage of total polyunsaturated fatty acids (ω3 plus ω6) to be 2.5.

Coldwater fish nutritionists have also determined that the energy density of a fish feed can be increased by combining lard, tallow, or yellow grease (all of which are low in ω6 fatty acids) with fish oil (which is high in ω3 fatty acids). The requirement for ω3 fatty acids should then be met with only the minimum amounts of ω3 fatty acids in the diet, because little of the suppressive ω6 fatty acid is present. The feed formulator may also consider the ω3 fatty acid contributed by the oil residues in the feed ingredients.

Some fatty acid deficiency signs reported for trout include poor growth, elevated levels of ω9 in the tissues, necrosis of the caudal fin, pale and fatty livers, dermal depigmentation, increased muscle water content, mitochond-

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rial swelling, heart myopathy, and reduced hemoglobin.

Carbohydrate

Carbohydrate in the form of starch is included in fish feeds primarily for its binding characteristics. However, starch is the least expensive dietary energy source known. Fish can use carbohydrate, but no dietary requirement has been established. Carbohydrates also function as precursors for various metabolites such as nonessential amino acids and fatty acids.

Carbohydrate can be used best at a protein to energy ratio of 88 mg protein/kcal. Within the carbohydrate to lipid ratio of 0.45 to 4.5, and with a protein to energy ratio of 88 mg protein/kcal, energy substitutions can be made at the rate of 2.25:1 for carbohydrate to lipid. In a study with channel catfish, 0.23 g of carbohydrate per 100 g of feed was found to spare 0.05 g of protein.

Research has shown that channel catfish can use the more complex carbohydrates such as dextrin and cooked starch more efficiently than the simple sugars such as glucose and maltose. The reason is not understood, since the digestibility of glucose (88%) is considerably higher than that of dextrin (73%) in 30% carbohydrate diets.

Fiber has not been investigated fully in warmwater fish nutrition. Fiber in some feed additive forms improves the pelleting process and increases pellet stability, but large amounts may dilute the nutrients, impair digestibility, and decrease pellet quality. Fiber levels above 8% probably should be avoided in practical feeds.

Energy

Metabolic energy, which is essential in fish for growth and reproduction, comes from protein, fats, and carbohydrates through a process of oxidation or respiration. The amount of energy required by fish is affected by species, age, sex, water temperatures, activity, and water quality. Cold- and warmblooded animals use the energy sources differently. Fish preferentially use protein and fat for energy, and carbohydrate sparingly; however, carbohydrate is used more efficiently by warmwater than by coldwater fish. Warm-blooded animals use carbohydrate preferentially for energy. It is the role of the fish nutritionist to formulate feeds that increase the use of carbohydrate and fat for energy, and conserve the more expensive protein for growth.

The metabolic energy values (kcal/g) for the three warmwater fish diet components are as follows: protein, 3.5; fat, 8.1; and carbohydrate, 2.5. The available energy is calculated from the digestible energy values of the feedstuff, multiplied by the quantity of these nutrients present. Some digestibility values for common ingredients in feeds for warmwater fishes are listed later.

Warmwater fish nutritionists have demonstrated a relation between protein and energy levels of the diet. In studies with highly digestible ingredients, maximum growth of channel catfish was obtained with energy levels of 2,750 and 3,410 kcal/kg of feed, and with a protein to energy ratio of 88 mg protein/kcal. Feeds that contained 24% crude protein and 2,750 kcal/kg energy produced fish more efficiently in terms of protein deposition, but faster growth was obtained with feeds that contained more protein and more energy.

The feed formulator is cautioned that the reported protein to energy ratio of 88 mg protein/kcal may be inadequate when one is using practical feed ingredients. Tests have shown that values obtained in studies with practical ingredients ranged from 121 to 147 mg protein/kcal. The researchers speculated that if the higher protein requirements were recalculated on the basis of protein and energy digestion values, a requirement nearer the 88 mg protein/kcal energy would be obtained.

Digestibility

Feed ingredients must be digested and absorbed by fish before the nutrients can be used for growth, reproduction, and other

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aspects of metabolism. Digestibility differs among fish species under different environmental conditions. Digestibility of nutrients differs between fish and domestic animals such as poultry, swine, and cattle. Thus the extensive data available from poultry and other intensively farmed animals have only limited value in fish nutrition and the formulation of fish feeds. It is essential that research be conducted on the digestibility of fish feed ingredients so that nutritionally better but lower priced feeds can be formulated for the various warmwater fishes.

Digestibility values have been reported for protein, carbohydrates, and fats (Table 11.3).

Vitamins

Research on the vitamin requirements of channel catfish was begun in the late 1950's. These first studies identified the vitamins essential for channel catfish and described the deficiency signs (Table 11.4). Studies with other commercially important warmwater fishes soon followed. The increase in survival of warmwater fishes in intensive production systems correlated well with the addition of crystalline vitamins to practical feeds. Before 1970, only the "complete" feeds contained supplemental vitamins, but almost all feeds used today in intensive and extensive fish production contain a vitamin premix. This premix adds relatively little to the cost of the finished feed, and the potential benefit of these vitamins for disease resistance is well worth the expenditure to the fish farmer or owner of a fee-fishing or recreational pond. The benefit of more efficient fish production in earthen ponds usually cannot be demonstrated until the annual production of channel

Table 11.3. *Digestibility of proteins, carbohydrates, and fats in feedstuffs for channel catfish.*[a]

Feedstuff	Percent digestibility		
	Proteins	Carbohydrates	Fats
Animal products			
Fish meal (anchovy)	85–90		97
Fish meal (menhaden)	74–87		
Meat and bone meal	75		77
Feather meal	63–74		83
Fish oil			97
Oilseed meals			
Soybean meal (49% protein)	72–84		81
Soybean meal (44% protein)	77		
Cottonseed meal (41% protein)	76–81	17	81
Corn gluten meal (60% protein)	80		
Grains and grain by-products			
Ground corn, raw	60	59–66	76
Ground corn, extrusion cooked	66	62–78	96
Ground wheat	84	59	96
Wheat bran	82		
Wheat shorts	72		
Rice bran	71		
Distillers' dried solubles	67		
Fibrous components			
Alfalfa meal	12–13		

[a]From R. T. Lovell. 1977. Digestibility of nutrients in feedstuffs for catfish. Pages 33–37 *in* R. R. Stickney and R. T. Lovell, eds. Nutrition and feeding of channel catfish. Southern Cooperative Series Bulletin 218. Auburn Agricultural Experiment Station, Auburn University, Alabama.

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Table 11.4. *Vitamins required by channel catfish, deficiency signs, and vitamin sources.*[a,b]

WATER-SOLUBLE VITAMINS	
Thiamin	
Reduced weight gain, lethargy, and difficulty in maintaining equilibrium	Soybeans, cereal bran, dried yeast, fresh organ meats
Riboflavin	
Opaque lens of one or both eyes, weight loss	Fresh meats, cereal grains, and oilseed proteins
Pyridoxine	
Erratic swimming, tetany, gyrations, and muscular spasms when stressed, reduced weight gain	Cereal grains and by-products, yeast, and fresh organ meats
Pantothenic acid	
Flabby body tissues; mummy textured skin; excessive mucus on gill tissues, clubbed gill filaments; eroded gill membranes, lower jaw, fins, and barbels; lethargy, reduced weight gain	Cereal bran, yeast, organ tissues, fish flesh
Niacin	
Tetany induced by stress, lethargy, reduced coordination, and photophobia	Yeast, legumes, and organ meats
Folic acid	
Anorexia and lethargy	Yeast, fish tissues, and glandular tissues (e.g., beef liver and kidney)
Vitamin B-12	
Reduced weight gain	Meats and animal by-products, fish meals
Ascorbic acid	
Lordosis, scoliosis, dislocated vertebrae, hemorrhage, impaired collagen production, reduced growth	Beef liver and kidney, fresh fish tissue
Biotin	
Slight growth and appetite reductions, skin depigmentation	Fish meal, peanut meal, soybean meal, whey, yeast, distillers' by-products
Choline	
Hemorrhagic areas in the kidneys and enlarged livers; reduced weight gain	Wheat germ, soybean and other vegetable meals, heart, liver, and other organ meats
FAT-SOLUBLE VITAMINS	
Vitamin A	
Ascites, edema, exophthalmia, hemorrhagic kidneys	Fish oils, fish meals, and other fish products that contain fish oil residues
Vitamin E	
Exophthalmia, pericardial edema, reduced growth	Wheat germ, soybeans, and corn
Vitamin K	
Excessive hemorrhage resulting in death	Alfalfa leaves, soybeans, and animal livers

[a]Not listed are the water-soluble vitamins inositol and para-aminobenzoic acid, which are abundant in most fish feed ingredients, and the fat-soluble vitamin D, which occurs in fish oils. Deficiencies rarely if ever occur, and no specific deficiency signs are known from feeding practical diets.

[b]Adapted from H. K. Dupree. 1977. Vitamin requirements. Pages 26–29 *in* R. R. Stickney and R. T. Lovell, eds. Nutrition and feeding of channel catfish. Southern Cooperative Series Bulletin 218. Alabama Agricultural Experiment Station, Auburn University, Alabama.

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catfish exceeds 1,800 pounds per acre. Vitamin supplements are cost-effective in production systems that produce from 1,800 to 2,800 pounds per acre per year. Vitamin supplements are essential in feeds used in pond systems that produce more than 2,800 pounds per acre per year, and in all raceway and cage feeds.

Vitamins are available to fish from ingredients in the manufactured feed, and from natural organisms and products in the environment. The amounts of supplemental vitamins needed can be the difference between the requirement and the total dietary contribution. However, in practice the feed manufacturer considers these amounts only when formulating a "supplementation" feed. When the processor is formulating a "complete" feed, the contribution from the ingredients and natural foods is usually disregarded. The manufacturer places into the feed an amount of each vitamin required by the fish, as well as an additional amount to offset losses in processing and storage. The possibility of oversupplementation (and hypervitaminosis) is of little concern, because excess amounts of the water-soluble vitamins are rapidly excreted. Fat-soluble vitamins A, E, D, and K are retained in the body if fed in excess and may cause hypervitaminosis. Recommended amounts of vitamins in supplemental and complete rations for channel catfish are given in Table 11.5.

Vitamin losses in fish feeds are similar to those in other animal feeds. For example, thiamin is lost in the presence of sulfide or under alkaline conditions, riboflavin is destroyed by intense light, and pyridoxine must be protected from sunlight and air; pantothenic acid, folic acid, and vitamin B-12 must be kept cool and dry; vitamin K should be protected from sunlight; and vitamin E is sen-

Table 11.5. *Recommended amounts of vitamins in supplemental and complete rations for channel catfish.*[a]

Vitamin and unit	Amounts per kilogram of dry ration[b]	
	Supplemental	Complete
	International units	
Vitamin A activity	2,200	5,500
Vitamin D_3 activity	220	1,000
Vitamin E	11	50
	Milligrams	
Vitamin K	5	10
Choline	440	550
Niacin	17–28[c]	100
Riboflavin	2–7[c]	20
Pyridoxine	11	20
Thiamin	0	20
D-calcium pantothenate	7–11[c]	50
Biotin	0	0.1
Folacin	0	5
Vitamin B-12	2–10[c]	20
Ascorbic acid	0–100[c]	30–100[c]
Inositol	0	100

[a]From H. K. Dupree. 1977. Vitamin requirements. Pages 26–29 *in* R. R. Stickney and R. T. Lovell, eds. Nutrition and feeding of channel catfish. Southern Cooperative Series Bulletin 218. Alabama Agricultural Experiment Station, Auburn University, Alabama.

[b]The amounts shown do not allow for processing or storage losses. Other amounts may be more appropriate under various environmental conditions.

[c]Highest amounts probably appropriate when standing crop of fish exceeds 500 pounds/acre.

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sitive to oxidation. Supplemental antioxidants such as ethoxyquin, butylated hydroxyanisole, and butylated hydroxytoluene should be present at a level of 0.01 to 0.02% to prevent fat oxidation, and thus a loss of vitamin E.

Considerable interest has evolved in the role of vitamin C (ascorbic acid) in the diet of channel catfish. Signs of a vitamin C deficiency include, most noticeably, skeletal deformities such as scoliosis and lordosis; abnormal support cartilage of the eyes, gills and fins; and hemorrhaging. These abnormalities decrease the market value of the fish, and may increase susceptibility to disease. Vitamin C has been reported to detoxify toxaphene, a chlorinated hydrocarbon insecticide that has been used to control cotton insects. Thus, in many warmwater areas where crop production insecticides are used and are present in the feeds and soil, the vitamin C requirement is seemingly somewhat higher than the amount needed for normal physiological processes.

Minerals

Warmwater fish, like other fishes and domesticated animals, require minerals. However, the requirements for most minerals have not been determined.

Most studies of mineral requirements have involved calcium and phosphorus. Observations have shown that channel catfish and most other freshwater fishes can absorb sufficient calcium from the water unless the calcium content of the water is low. Waters that contained 5 ppm or more calcium carbonate apparently met the needs of the fish. However, the Japanese eel was found to require a dietary calcium source.

Studies have shown that fish require a dietary source of phosphate. Phosphate is almost unmeasurable in most pond waters because it is rapidly removed by plants. Some well waters and spring waters contain dissolved phosphate but the amounts are usually too small to meet the needs of fish. Dietary phosphate deficiencies have resulted in reduced growth and appetite, and deformed backs and heads have been reported in common carp.

The bound phosphorus from material such as phytate in grain is largely unavailable to fish. Also, phosphate in fish meal is only about 40 to 60% available. Nutritionists have reported the following availability values:[1]

Source	Available phosphorus (%)
Dicalcium phosphate	80
Fish meal	50
Meat and bone meal	50
Soybean meal	40
Grains	33

Minimum requirements for digestible or available phosphorus has been determined to be 0.4 to 0.5% in purified diets, and 0.8% in practical diets for channel catfish.

Inasmuch as the requirements for the other minerals have not been determined, we suggest that a trace mineral mixture suitable for poultry be included in feeds for warmwater fishes.

Formulation and Manufacture of Feeds

Feeds required in the production of warmwater fishes are of many types. The feeds that are oldest, but still in use, are organ meats and cut fish, bacteria, phytoplankton, zooplankton, insects, crustacea, fish eggs, and live fish. In recent years a number of artificial feeds have been developed, including three principal types of pellets—hard or sinking and extruded or floating (Fig. 11.2), and moist—and a number of small-particle pellets and meals. A feed ball bound with starch is a specific formulation for eels.

All of the types and formulations of feeds listed have their place in aquaculture. Fresh food and natural fish food organisms are frequently used to induce young fish to begin

[1]From R. T. Lovell. 1977. Mineral requirements. Pages 30-32 *in* R. R. Stickney and R. T. Lovell, eds. Nutrition and feeding of channel catfish. Southern Cooperative Series Bulletin 218. Alabama Agricultural Experiment Station, Auburn University.

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Fig. 11.2. These sinking pellets (left) and floating pellets (right) were manufactured for feeding to large fingerlings and food-sized channel catfish. The floating formulation is preferred by many catfish producers because growth and physical condition of the fish can be assessed while the fish are feeding.

feeding. Often these fish can later be trained to eat conventional manufactured feeds. Some fish eat only living organisms (including other fish) throughout life. The texture of a formulation may be a consideration: some fish eat moist pellets but reject the same formulation in dry pellets. Some fish eat only feeds on the water surface and cannot seem to locate feeds on the bottom. Feeding behavior and the characteristics of the holding facility can affect the type of feed that is accepted by the species being cultured. Thus good performance and good production depend on more than just a knowledge of nutrient needs and the manufacture of a feed that will meet these requirements.

Feed Formulation

The feed manufacturer and fish producer should consider a number of factors before deciding on the feed formulation. Nine particularly pertinent considerations are listed here.

1. The nutritional requirements of the species must be known. The nutritional requirements are the same, whether the fish are being produced in a raceway or cage, or intensively or extensively in ponds. The nutritional requirement values establish the needs of the species. When the nutritional requirements are unknown for a particular species, available data from closely related species must suffice.

2. The type of production system and the nutrient contributions from supplemental (natural) food sources should be known. Without this information, the feed manufacturer must provide all the nutrients in the recommended amounts. Since considerable natural food is available in some production systems, a supplemental type of feed (substantially less costly than a complete feed) can often be used without decreasing the performance of the fish.

3. The formulator must know the type of feed required to meet the behavioral needs of the fish being cultured. Some species require meals, and others require floating formula-

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tions, sinking formulations, or moist formulations. The content of these formulations may vary, depending on what is needed to impart the desired physical characteristics to the finished feed.

4. The feed formulator's recommendations should be based on desired production performance and acceptable fish quality. The effect of feed waste on water quality should also be considered. Lower priced plant protein feeds often contain considerable starch, which may decrease water quality. Also, the manufacturer should determine the type and quality of fish needed. Sport fish released into the wild, where physical stamina is essential for survival, may require a feed different from that required for fish produced for food, where only efficient weight gain is sought. Off-flavors resulting from feeding some fish oils may be no problem in fingerlings, but the condition is disastrous in food fish ready to be processed.

5. The manufacturer must know the upper and lower levels of safety of the various feed ingredients. Certain ingredients may contain toxic natural substances such as gossypol, aflatoxin, or man-made pesticides. Other restrictions are based on pelleting considerations, nutrient content, and digestibility. For example, rice and wheat by-products or alfalfa meal are often included to improve pellet stability. Corn is used as a source of starch in the manufacture of floating feeds. Fish meal is an excellent source of supplemental amino acids to balance the plant proteins. Certain fish feed ingredient maximums and minimums have been published. Maximum percentages of seven ingredients are as follows:[2] cottonseed meal, 10; peanut meal, 25; sorghum, 30; dried whey, 5; distillers' dried solubles or dried fermentation solubles, 15; alfalfa meal, 5; and corn gluten meal, 12. Soybean meal (solvent extracted) should equal or exceed 10% of the total; and fish meal should compose at least 50% of the animal protein, which in turn should make up at least one-third of the total protein.

6. The feed formulator should know the feedstuffs market, and the ingredients locally available. Fish feed is usually a minor portion of the feed manufactured at a mill. Often a lower priced fish feed can be obtained if ingredients already on hand are used. The feed formulator should also specify the ingredients that will result in the best feed for the least cost.

7. The feed formulator must know the nutrient content and digestibility of the ingredients that he plans to use.

8. The feed formulator must be familiar with the industry's needs for specialty feeds and be willing to manufacture them or obtain them for resale. Several of these specialty feeds include 16% protein feeds that can be used for baitfish, low-protein feeds that can be used to maintain fish at a smaller size but in good health, and medicated feeds.

9. The feed formulator must select the kinds and amounts of the different ingredients that supply the dietary needs of the fish in a particular production system. A number of practical feed formulations being used for channel catfish (also useful for other warmwater fish) are given in Table 11.6.

Feed Manufacture

After a feed formulator has selected the kinds and amounts of feed ingredients, he can begin manufacturing the feed—and feed manufacture is fully as important as feed formulation. Quality control in the selection of ingredients is essential. The availability of amino acids from the same types of ingredients may vary due to processing variables. Fish meals and meat and bone meals may differ, depending on whether full-flesh animals or rendered parts were used. Some ingredients contain considerable indigestible material such as hair, collagen, and fiber. The ingredients should be free of pesticides and mold, and protected from on-site spoilage by animals.

Grinding to a small size probably does the most to improve water stability and pellet durability. Feed manufacturers should double

[2]From H. R. Robinette. 1977. Diet formulations. Pages 38-43 *in* R. R. Stickney and R. T. Lovell, eds. Southern Cooperative Series Bulletin 218. Alabama Agricultural Experiment Station, Auburn University.

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Table 11.6. *Feed ingredients and percent composition of some practical feed formulations for channel catfish.*[a]

Ingredient	Percent protein	Fish Farming Experimental Station[b]	Texas A&M University		Auburn University	
			1	2	Production (32% protein)	Fingerlings (36% protein)
Alfalfa meal	17.5	3.5				
Blood meal	75.3	5.0				
Bone meal	11.2					
Brewers' grain	25.0					
Corn, distillers' grains	27.1					
Corn, distillers' solubles	27.3	8.0				5.0
Corn grain, yellow	9.6		30.0	30.5	29.1	23.5
Corn grain, flint	9.9					
Cottonseed meal	40.8	10.0				
Cottonseed meal (without hulls)	50.0					
Dicalcium phosphate			0.25	1.5	1.0	1.5
Fats, animal				2.0	1.5	2.5
Fish meal, catfish	55.3					
Fish meal, menhaden	61.1	12.0		9.0	8.0	10.0
Fish meal, tuna	59.4					
Fish meal, white	61.9					
Grains, distillers'	27.4					
Liver meal, animal	66.5					
Meat meal, whole animal	54.3					
Meat meal (with bone)	50.5		15.0			
Oats, cereal by-product	14.6					
Peanut meal	44.0					18.0
Poultry by-product meal	57.8					
Poultry feathers, hydrolyzed	85.4	5.0				
Rice bran	12.7	25.0			10.0[c]	
Rice polishings (dust)	12.1	10.0				
Soybean meal	44.0		47.5			
Soybean meal (without hulls)	48.8	20.0		54.4	48.3	37.0
Wheat bran	15.1					
Wheat middlings	16.7		0.85			
Wheat grain	14.9					
Wheat shorts	16.4					
Whey (low lactose)	16.5		2.5			
Yeast (brewers)	45.1					
Vitamin premix		[d]	[d]	[d]	[e]	[e]
Mineral premix			0.50	0.50	[f]	[f]
Limestone			0.90			

[a]Adapted from National Research Council. 1977. Nutrient requirements of warmwater fishes. National Academy of Sciences, Washington, D.C.

[b]Herring fish meal (70% protein) may be substituted at 10% of the formulation. Wheat shorts, wheat middlings, or cereal grains may be substituted for the rice bran.

[c]Wheat shorts may be substituted for the rice bran.

[d]Vitamin premixes as published by the National Research Council (footnote a, above).

[e]Quantities of vitamins per ton (grams, unless otherwise indicated): vitamin A, 4 million IU; vitamin D_3, 2 million IU; vitamin B_{12}, 8 mg; vitamin E, 50; menadione, 10; choline chloride (70%), 500; niacin, 80; riboflavin, 12; pyridoxine, 10; thiamin, 10; pantothenic acid, 32; folic acid, 2; and ethoxyquin, 125. Ascorbic acid (335 g) is added to the feed during pelleting, or top-dressed on extruded feed.

[f]Quantities of minerals per ton (milligrams): manganese, 110; zinc, 105; iron, 36; copper, 4.5; iodide, 2.3; and cobalt, 0.5.

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grind through a U.S. 45-mesh (0.354 mm) screen before pelleting. Water stability is important because feeds that disintegrate quickly are not only lost to the fish but also reduce water quality.

Premixes of vitamins and minerals can be added during the grinding and mixing phase. Premixes should be diluted and blended to an amount equal to about 4% of the total mix before being incorporated into the feed.

Fats in the formulation reduce pellet compaction. Probably the total fat in the formulation should not exceed 6%. Additional fat should be applied on the surface if more dietary energy is desired. The presence of 4 to 5% fiber improves compressibility, and thus stability.

Starch in products such as corn, wheat, and sorghum is normally included as a pellet binder. The amount varies, depending on whether a hard sinking pellet or a floating pellet is desired. Other starch forms may be desired when flakes or moist feeds are being manufactured. Steam conditioning of the feed ingredients improves pellet stability. Temperatures for the dense sinking pellets should be 85 to 90°C to ensure the gelatinization of starch. Temperatures of 107 to 155°C and pressures of 5 to 7 kg/cm^2 are required in the manufacture of extruded floating pellets. Pellet binders, such as hemicellulose, lignin sulfonate, and bentonite can be used. However, the preferred binder is starch because it is cheaper than these artificial binders.

Pelleted feeds should be quickly dried to a moisture content of no more than 10%, and cooled to near room temperature. Additional oil and vitamin C may be applied to the finished feed at this time. The oil seals the feed, making it more water stable and also protecting the vitamin C from hydrolysis. The oil is also an inexpensive addition to the energy content of the feed. The feed can then be packaged in plastic-lined bags or shipped in bulk for storage on the farm (Fig. 11.3).

Feeds in storage should be protected from moisture and extreme heat. Heat and moisture accelerate the destruction of vitamins and oxidation of fats, and encourage growth of mold, which can produce toxic products. Propionic acid at the rate of 0.25% is helpful in retarding mold growth. Feeds should be used within 3 months after manufacture.



Fig. 11.3. Fish feeds bought in bulk are stored on the fish farm in raised bins to facilitate loading into mechanical feeders such as the one shown here. Feeds in storage must be kept dry, and because the temperature cannot be controlled, the storage time should be limited to 3 months or less. *Photo by J. Avault, Jr.*

The Fish Farming Experimental Station devised the following test to measure the water stability of pellets: Obtain the dry weight of a given quantity of pellets; place the pellets on a No. 10 Tyler mesh aluminum screen and immerse in water for 10 minutes; then remove, air dry to a constant weight, and reweigh the pellets. A good, stable pellet should not lose more than 10% of its original weight.

Minnow meals, fry starter meals, fry feeds, and fingerling feeds are generally made by crushing the pellets in a crumbler and then screening out the granules of the desired sizes. Sizes of pellets suitable for catfish and other warmwater fish are shown in Table 11.7.

Feeding Techniques

Good quality feeds and appropriate feeding techniques are essential in the intensive production of warmwater fishes. Feeds that are not eaten by the fish do not produce fish flesh, and often reduce production and fish quality by contributing to water quality deterioration. Consideration of the feeding preferences, behavioral characteristics, and physical limitations of each species and each size of fish is essential for the development of an effective feeding program.

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Table 11.7. *Optimum feed particle size, and screen number that separates that size, for channel catfish and other commonly produced warmwater fishes.*[a,b]

Length of fish (inches)	Designated particle size (No.)	U.S. screen No.	Range in diameter of particles (mm)
Fry (<0.5)	0	40	0.420–0.595
0.5–1.0	1	30	0.595–0.841
1.0–1.5	2	20	0.841–1.19
1.5–2.5	3	16	1.19 –1.68
2.5–4.0	4	12	1.68 –2.38
4.0–6.0	5	8	2.38 –3.36
>6.0	3/16-inch pellet		

[a]A system of screens is used to separate feed particles into designated particle sizes. For example, screen size 20 retains all particles larger than 0.841 mm and passes through all particles smaller than 0.841 mm onto screen size 30, and screen size 30 retains particles larger than 0.595 mm, and passes through particles smaller than 0.595 mm. Thus only particles of size No. 1 (0.595–0.841 mm in diameter) then remain on screen No. 30.
[b]Adapted from National Research Council. 1981. Nutrient requirements of coldwater fishes. No. 16 *in* Nutrient requirements of domestic animals. National Academy of Sciences, Washington, D.C.

The feed preferences for different species often change during the life span of fish, and are often influenced by the type of culture system being used and the level of production.

Natural Food and Feed

Natural foods for warmwater fishes include bacteria, phytoplankton, zooplankton, insects, crustacea, fish eggs, and other fish. The practical fish farmer usually produces these organisms by fertilizing earthen production ponds with chemical fertilizers, organic materials, and animal manures. At the present stage of aquacultural technology, a number of species must be started in this way: bait minnows, striped bass, black basses, sunfishes, goldfish, tropical food and aquarium fishes, common carp, Chinese carps, and buffaloes. Some larval fishes of high value, and some research fishes may be started on brine shrimp or on rotifers or other invertebrates cultured in the laboratory. These organisms are normally netted, concentrated, and then poured into the culture container. Newly hatched catfish fry can be started on artificial feeds, but their growth and survival are improved if they are fed small organisms and natural foods. Carp eggs are being used by culturists to feed small sport fishes. Most fish can be fed artificial feeds after they reach a length of about 1 inch.

Some fish of management and recreational importance do not readily accept artificial feeds. Several of importance are the flathead catfish, walleye, sauger, and northern pike. These fish must be fed living organisms or trained to feed on fresh organ meats and cut fish for the most part, although researchers have been partly successful in training them to eat moist pellets.

Most fish can be trained to feed on natural products such as fresh organ meats and fish by-products. For small fish, it is best to pulverize the flesh in a blender. Sufficient water should be added to the flesh to provide a mixture with the consistency of a milk shake. The stability of the material can be improved by adding about 1% carboxymethyl cellulose, and the nutrition can be supplemented by adding vitamins and fish oil.

Artificial Feeds

Artificial feeds for the commonly produced warmwater fishes include pellets of several types, crumbles, meals, and flakes.

Pellets

The common pellet types are floating or extruded, sinking or hard (Fig. 11.2), and moist.

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Most pelleted feed sold is of the floating (extruded) type. Its popularity in catfish farming is due to its usefulness in management. The producer can watch the fish feeding near the surface and evaluate them for health and size. Intensity of feeding activity is an indication of water quality and fish health. Also, floating feed is not lost in the bottom mud, and few "fines" are present and little water disintegration or leaching occurs, thus reducing feed loss and helping to maintain water quality. The major disadvantages of floating feed are its cost (8 to 15% higher than sinking feeds) and its bulk (which reduces total nutrient intake).

Floating pellets are manufactured as complete and supplemental formulations. The complete formulations are fully fortified with all the essential nutrients in the required amounts. The complete floating feed, sometimes referred to as "trout feed," is fed to fish in raceways, cages, net pens, and in intensive production ponds. The supplemental formulation is fed to fish in earthen ponds with standing crops of less than 2,000 pounds per acre.

Many fish species readily feed on floating feeds: catfishes, sunfishes, goldfish, large bait minnows, buffaloes, common carp, hybrid striped bass, and grass carp. Feeding rates are near 3% of the standing crop weight. Results are most satisfactory when the feed is applied along the entire perimeter of the pond. Feed allowances must be reduced during periods of hot weather, as well as in periods of cool or cold weather (when the water temperature is lower than 70°F).

Although sinking (hard) pellets are less expensive than floating pellets, management is more difficult because the amount of feed that is uneaten cannot be easily determined, the size of fish is difficult to observe, and durability in water is often less than that of floating feeds. However, an experienced fish producer can use sinking feed very effectively and maintain high production. One researcher observed that a mixture of 15% floating feed and 85% sinking feed provided the same management benefits as did the feeding of only floating feed. In this situation, the economics of feed purchasing thus favored the mixing of floating and sinking feeds.

Formulations are similar for sinking and floating feeds. However, most sinking feeds are of the supplemental type and are usually fed in ponds supporting an annual production of less than 2,000 pounds per acre. Species most often fed the hard sinking pellets are channel catfish, common carp, buffaloes, goldfish, and fathead minnows.

Both the extruded floating feed and the hard sinking feed can be fed in ponds with mechanical vehicular feeders (Fig. 11.4), or with stationary automatic self-feeders. The vehicular feeders are especially useful for feeding large amounts of feed to intensively produced fish. However, the stationary feeder is more efficient in extensive production systems where fish density is low.

Moist pellets are special feeds fed to fish that reject the dry formulations. These feeds for warmwater fish contain the same ingredients normally used in the manufacture of dry pellets. However, fresh fish or organ meats can be added to enhance its acceptance. In its manufacture, the dry ingredients are mixed with water, and carboxymethyl cellulose is mixed in as a binder at the rate of 3 to 5% of the weight of the dry feed. The resulting dough-like blend is extruded through a die. The pellets can be frozen until used.

When moist pellet feeds are offered to black basses and other fishes, it is usually fed until



Fig. 11.4. Motorized fish-feeding equipment provides the producer with a rapid and convenient way to offer large amounts of food to fish in large ponds. In this model, the feed is held in a bin atop the truck. The feed is funneled from the bin to a scale, and then to a blower. The blower throws the feed 20 to 40 feet from shore.

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the fish are satiated. The feed is offered slowly so that it will be eaten immediately. Uneaten feed quickly leaches and loses its palatability.

Crumbles

Crumbles are particle feeds fed to fish of different sizes, ranging from swim-up fry to advanced fingerlings. The size of crumble to be fed is governed by the size of particle that can be ingested by the fish. It is important that the particles not be so large that many or most of the smaller fish will be unable to eat them. However, the feeding of pellets that are too small results in waste and reduced water quality; thus the producer's judgment and experience play a major role in the choice. Feed crumbles can be either complete or supplemental.

Crumbles can be fed to a variety of warmwater fishes, including channel catfish, Chinese carps, goldfish, hobby (aquarium) fishes, buffaloes, and sunfishes. The recommended feeding rate (as percent of total fish weight) follows.

Fish length (inches)	Feeding rate (%)
0.5–1.5	6
1.5–2.5	5
2.5–6.0	3–4

The daily allowance is usually divided into three to eight feedings. However, the daily allowance should not exceed 30 to 50 pounds per acre unless water exchange, aeration, or other fully adequate water quality maintenance techniques are used.

Feed for fry and fingerlings should be distributed over a wide area to ensure that feed is available to all fish. The spreading of feed around the entire pond margin is recommended. If it is determined that the fish are not growing at an adequate rate, more feed should be offered, or some fish should be removed to provide more growing space.

Meal and Flakes

Meals, which are formulations similar to the starter feeds already described, are fed to bait minnows, goldfish, and the fry of striped bass, grass carp, and sunfish. The meals are often coated with vegetable oils or animal fats to improve flotation. They are usually scattered over the pond surface in a manner that permits the small fish to feed at the surface over the entire pond. Feed allowances are based on the rate of 2 to 3% of the standing crop weight, but the amount fed should not be large enough to result in water quality deterioration.

Flake feed is a special feed usually formulated for aquarium fishes. It is usually sprinkled on the water surface.

Feeding Limitations

Water temperature and water quality both affect the feeding rate of the fish and feed allowance in the production system. A typical feeding schedule for single-stocking, single-harvest, moderately intensive fish production is shown in Table 11.8.

In addition to the single-stocking, single-harvest production program, channel catfish are produced in multiple-stocking and multiple-harvest systems. Feed is offered in the maximum amounts that can be metabolized in the pond, rather than as a percent of the standing crop weight. This amount can exceed 100 pounds per acre per day, if water exchange and aeration are used to maintain suitable water quality. Feeding frequency is important in such a production system, and varies with water temperature (Table 11.9). Multiple daily feedings can increase growth rate. Days of no feeding must be avoided. For example, if a food conversion factor of 1.8 is assured, the failure to feed a daily allowance of 100 pounds per acre could result in a 28,000-pound 1-day loss of fish weight gain on a 500-acre farm ($100 \div 1.8 = 56$; $56 \times 500 = 28{,}000$).

Winter Feeding

Techniques of winter feeding are important to the successful fish farmer. Correct feeding in winter can result in heavier fish of higher quality in spring. Fish not fed in winter lose weight and are in poor condition in spring. Increased production and survival definitely

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Table 11.8. *Typical spring-summer-fall feeding schedule for channel catfish in ponds stocked at 2,000–3,000 fingerlings per acre as 5-inch fish and harvested as 1.1-pound food fish, in southeastern United States.*[a]

Date	Water temperature (°F)	Fish weight (pounds)	Feed allowance per day (% of fish weight)
Apr 15	68	0.04	2.0
Apr 30	72	0.06	2.5
May 15	78	0.11	2.8
May 30	80	0.16	3.0
Jun 15	83	0.21	3.0
Jun 30	84	0.28	3.0
Jul 15	85	0.35	2.8
Jul 30	85	0.42	2.5
Aug 15	86	0.60	2.2
Aug 30	86	0.75	1.8
Sep 15	83	0.89	1.6
Sep 30	79	1.01	1.4
Oct 15	73	1.10	1.1

[a]Feed allowances are based on data obtained with rations containing 36% protein and about 2.88 kcal of digestible energy per gram of protein. If feeds of lower protein and energy concentrations are used, daily allowances should be increased proportionally. Data adapted from R. T. Lovell. 1977. Feeding practices. Pages 50–55 *in* Nutrition and feeding of channel catfish. Southern Cooperative Series Bulletin 218. Alabama Agricultural Experiment Station, Auburn University, Alabama.

favor the feeding of fish in winter. However, improper feeding techniques can result in reduced water quality and encouragement of disease. A total loss of fish can result under ice cover when large amounts of uneaten and decaying feeds accumulate.

Feeds offered during winter may contain only 25% protein, but about 50% of this fraction should be animal protein, preferably fish meal. Energy levels should be higher in a winter feed, and this energy should be supplied by oils or fats with low melting temperatures.

Researchers in the mid-South have found that when the water temperature is 50–58°F the best feeding schedule consists of offerings of ¾ to 1% of estimated body weight in the early afternoon, on alternate days (Table 11.9).

Table 11.9. *Suggested maximum feeding rates and frequencies for channel catfish.*

Water temperature (°F)	Feeding frequency (times per day)	Feeding rates (% of total fish weight)
≥90	1	1
80–86	2	3
68–80	1	2½
58–68	1	1½
50–58	0.5[a]	¾–1
<50	0.3[b]	½–1

[a]Feed once on alternate days.
[b]Feed once every 3 to 4 days.

Feed should be supplied sparingly on warm, clear afternoons. Fish accustomed to floating feed eat it readily in winter; however, those accustomed to sinking feed usually cannot be trained to eat floating feed during winter.

Mechanical Feeders

Mechanical feeders include the demand type, which is activated by the fish, and the automatic type, which is activated by a time clock. The demand feeder has potential in extensive culture facilities such as irrigation reservoirs, mining pits, quarries, and some ponds. In this type of culture the fish density is usually too low to ensure that all the offered feed will be eaten, and thus waste can occur. The demand feeder allows the fish to graze over the total water area, and then return to the feeder for supplemental feed.

Some aquaculturists make good use of the demand feeder in raceways (Fig. 11.5). However, the culturist must ensure that sufficient units are in place so that a few of the more aggressive fish cannot dominate the feeding sites.

The automatic type of feeder (Fig. 11.6) is designed to offer a measured amount of feed at pre-determined times of the day. The use of this type of feeder should be approached with caution, because it may offer more feed than is eaten or less than is required. Also, the units tend to favor the more dominant individuals, and thus often lead to unequal growth of the fish. Since fish travel only short

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Fig. 11.5. Demand feeders, which are activated by tilapias, accelerate growth rate by making available a continuous food supply. Their use saves labor because the culturist needs only to fill the storage container once daily (or sometimes less often). Water quality deterioration, which can occur in ponds, usually does not occur in raceways because the waste products are flushed away.



Fig. 11.6. Automatic feeders are designed and programmed to offer measured amounts of feed at predetermined times of the day. The units shown here are being used to feed channel catfish.

distances, the number of units required in a pond can be large, thus increasing equipment costs.

Insect Traps

Insect traps are sometimes installed in ponds. A light attracts flying insects, which are stunned or killed and fall beneath the trap. Fish feed on the dead and dying insects on the surface of the water. The value of these additional insects in terms of improved fish performance has not been fully proved.

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12. HARVESTING, GRADING, AND HOLDING FISH

Jay V. Huner, Harry K. Dupree, and Donald C. Greenland

Harvesting and holding of market-size fish is a particularly important aspect of fish farming because the producer is dealing with his ultimate salable product. However, this phase of fish farming is frequently overlooked when a production facility is designed and constructed, and during the production of the crop. At best, harvesting is expensive and labor-intensive.

Damage to the fish during harvesting and holding can result in lowered sale value—or outright total loss if the fish die. Several harvesting plans and holding procedures are available to the fish producer.

Harvesting Techniques

Harvesting techniques are different for the various sizes and species of fish, and for the several culture systems. A number of techniques are discussed here.

Channel Catfish Fry and Fingerlings

Catfish fry can be stocked in large numbers and fish of the desired fingerling sizes harvested periodically (multiple harvesting), or smaller numbers can be stocked and all recovered in a "one-time" or single harvest.

The one-time harvest is somewhat of a misnomer. In practice the full or nearly full pond is seined to remove as many fish as possible—often more than 80% of the total crop. The pond is then drained and the rest of the fish are removed. Because drawdown is generally in fall when the water is cool, the fish are not overly stressed. This is the seine-and-drain method of one-time harvesting.

In multiple harvesting, fingerlings are normally baited into a corner with a feed that sinks to the bottom near shore. This baiting is done periodically during summer. Typically, a net 100 feet long or less that has been coated with tar, asphalt, or a similar commercial preparation is used. The seine is slowly pulled across the corner of the pond by using a cord of suitable length, or by wading quietly to avoid frightening the fish. After the seine is pulled close to shore and the fish are trapped in it, the gathered seine is moved quickly to deeper water, where water quality is better and the fish have more space. Small dip nets, also coated with tar, asphalt, or a similar commercial preparation, are used to transfer the fingerlings to buckets or tubs in which they are carried to the transport tank.

Special care must be taken during summer to reduce the stress from high water temperatures and low dissolved oxygen, especially when the surface water temperature is 80°F or higher. Seining should then be confined to early morning hours.

When the harvested fish are placed in units for transport to the holding shed, they may be put into water that is 10 to 15°F cooler and held for several hours with no damage. The lower temperature reduces self-induced injuries, and lowers stress and metabolism. The addition of 1% table salt, antibiotics or bacteriostats, and an anesthetizing agent to the transport water is often beneficial (see Chapter 13).

Food-size Channel Catfish

Food-size channel catfish are generally harvested by seining or trapping and pond drain-

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ing. There are many variations, ranging from one-time seining or trapping and annual draining to numerous seinings or trappings each year and complete draining each 6 to 8 years.

Seining

Multiple seinings of the full pond is the most commonly used harvest technique in dike-type ponds. Under no circumstance should fish be harvested without first checking a sample for off-flavor. Off-flavor fish will be rejected by processors and consumers.

Typical production ponds with depths averaging 3 to 4 feet can be readily seined with a net 8 feet deep and 200 to 1,600 feet long. These seines are treated (coated) with tar, asphalt, or a commercial product, and must have a mud line along the bottom edge in place of the usual lead line. The mud line is made of many strands of rope bound together. It is invaluable because it tends to stay above the mud, eliminating much of the bottom digging effect of lead-weighted lines.

Long seines are usually pulled by tractors or sometimes by mechanical seine haulers; short seines are often pulled by hand. Ropes attached to brails at each end or to toggles serve as haul lines to pull the seine. Essentially, the process is as follows: The net is payed out along the levee opposite the landing site, which is usually at the shallow end. Haul lines fastened to each end of the seine are led through snatch blocks (pulleys) installed along the lateral pond banks (to keep the ends of the net spread and close to the shoreline), and thence to a tractor equipped with a line hauler, or a powered line hauler (blocks are not used when tractors pull the net). As the net ends approach the snatch blocks, the haul lines are released from the blocks and taken along the bank to the next set of snatch blocks, or to the landing site. Since seines pick up mud even when they are equipped with a mud line, most harvesters use a small motor-driven boat with a tongue mounted on the bow. The seine is approached from the rear, the boat tongue is run through the net mesh near the top of the net, and the boat is then driven forward. The forward movement frees the bottom line of the seine from the bottom mud, and rolls the mud out of the bag of the seine without allowing many fish to escape.



Fig. 12.1. Seines up to 1,600 feet long and 8 feet deep are typically used to harvest food-size channel catfish in 20-acre and larger ponds. After the fish are crowded into a manageable area, a shorter seine is often used to further crowd a portion of the fish so that they can be scooped into the brailing bag, which is lifted to the hauling truck with a powered boom winch.

The seine is detached from the haul lines as the ends reach the landing area, and is stacked at the pond edge. Usually hauling is stopped while the bag of the seine is still well out in the pond to avoid premature overcrowding of the fish. When the catch is exceptionally large, and especially during hot weather, a small seine is used inside the large seine to concentrate manageable numbers of fish. The fish can be concentrated by rolling or folding the net just before the fish are scooped into a brailing bag. This bag is then lifted to the hauling truck with a powered boom winch (Fig. 12.1). The use of boom winches to lift fish from the seine to hauling trucks speeds transfer of the fish and reduces the amount of hand labor needed. Placement of an in-line scale on the winch cable permits weighing of the fish during the loading process and further reduces time and labor requirements.

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Although brailing bags are the method of choice for moving channel catfish to a transportation tank, considerable interest is being given to fish pumps. Early pump designs tended to function poorly and injure fish, but new designs have seemingly overcome these problems. However, it is difficult to meter fish into the intake at a steady rate without occasionally clogging the intake. Fish can be pumped to a sorting and grading bin above the hauling tank, where the harvestable fish are retained and the undersized fish are returned to the pond. The use of the grading bin has obvious labor-saving and fish-saving implications in polyculture, especially when species such as carp and buffaloes must be grown to sizes 3 to 4 times that of catfish before they are marketable.



Fig. 12.2. Boom-mounted brailers can be lowered into a live-car and filled by crowding the channel catfish into them, thus eliminating time-consuming dipnetting and hand-carrying up the levee to the transport truck. *Photo by J. Avault, Jr.*

Live-cars, or fish-holding bags, are widely used in the catfish industry. Typical live-cars are 20 to 40 feet long, 10 feet wide, and 4½ feet deep, and are constructed of a mesh size that retains harvestable fish and allows the escape of the smaller fish. The escape of market-sized fish is prevented by attaching a line of floats to the upper edge of the live-car, or sometimes by sewing an apron of netting, 1 to 2 feet wide, with supporting floats, inside the top of the live-car. Stakes should be used to anchor the unit.

Live-cars can be used advantageously by the catfish producer (Fig. 12.2). They can be coupled with a harvesting seine to serve as a temporary holding container and grader. Hauling trucks can then be scheduled accurately because the quantity of fish is known, and the truck can be loaded without delay. A filled live-car can be moved from the seine landing area to an area more accessible to the hauling truck. Hauling efficiency is also improved because the fish essentially empty their digestive tracts overnight, and can be precooled by positioning the live-car near the well outlet. Live-cars can be used to hold small quantities of fish for processing, or as repositories for selected fish during sorting. Loading is simplified because fish cannot escape by swimming under the seine; boom-mounted brailers can be lowered into the live-car and filled by crowding fish into them, thus eliminating time-consuming dipnetting. Workers can stand outside the live-car to load fish and are much less likely to be injured by spines of catfish fins. Many more uses are likely to be developed, as the live-car is an important working tool in fish farming.

The fish capacity of a live-car depends on unit size, pond depth and temperature, length of time fish are to be held, and whether a well discharge or a circulating pump is available. If the water is 60°F or lower, live-cars 10 feet wide, 4½ feet deep, and 10 feet long have a safe capacity of 5,000 pounds of fish. Each increase in length of 10 feet (other dimensions remaining the same) increases the capacity of the live-car by 5,000 pounds. (Thus a live-car 40 feet long has a capacity of 20,000 pounds.) At higher temperatures, and when extended holding time is anticipated, a lighter load is suggested.

In all holding situations, it is beneficial to move the fish to deeper water to give them more water room and to get them out of the muddy and roiled harvesting area. It is also a good practice to locate live-cars so that fresh water can be added or recirculating pumps or aerators used if the need arises.

Various mesh sizes are commercially available for nets used in grading catfish to the desired size for sale. Table 12.1 shows the approximate sizes of channel catfish retained by nets of different meshes.

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Table 12.1. *Approximate sizes of channel catfish retained by nets of different meshes.*

Mesh size (inches, bar measure)	Weight of smallest fish held (pounds)
1	½
1⅜	¾
1⅝	1
1¾	1½
2	2

Trapping

Ponds such as strip mines or gravel pits, irrigation reservoirs and some hill-type ponds with depths greater than 10 feet, ponds with very irregular bottoms, or ponds filled with trees and other debris cannot be efficiently seined by using the full-pond techniques just described. However, these waters can often be effectively trapped. Generally a seine 150 to 400 feet long and 6 to 8 feet deep is suitable. This seine differs from most haul seines in having components made of nylon and other decay-resistant materials and a bottom line of leaded rope. The seine is set in a location where there is good truck access. The pond bottom in the harvest area must be smooth and without roots, stumps, or rocks that interfere with seining. A water depth of 3 to 4 feet is ideal. It is often desirable to draw down the water sufficiently to construct such a site.

There are several ways to use a seine for trapping, but all depend on baiting the fish into the trap with feed. In one technique, the ends and middle portion of a "corral" seine are set 50 to 100 feet from shore and parallel to it. Alternatively, the seine can be set across the corner of a pond. Nylon ropes are attached to the ends of the seine and drawn to the shore where the seine is to be loaded. Feed is offered to the fish between the seine and the shore. The fish swim around the ends of the seine into the trapping area. Sometimes feed must be spread outside the catch area to lead fish into the trapping area. After several days, or when fish are well accustomed to feeding within the area, they are ready to trap. In the trapping event, feed is spread to attract the fish into the area between the seine and the shore, and the seine ends are then pulled to shore with the attached ropes, thus enclosing the fish. The seine ends are drawn together and the entire seine is pulled close to shore to collect the catch. The fish are merely dipped out and loaded.

The corral seine method of partial harvest usually cannot be used more often than once a week because fish become wary of the net. However, harvesting can be alternated among ponds and among different stations in large ponds.

A drop-seine technique developed at the Fish Farming Experimental Station is useful in weed-choked ponds, or ponds with small, cleared areas. In applying this technique, a seine similar to the corral seine is set in a semicircle around the feeding station and the ends of the seine are attached to the shore. Portions of the net are lifted off the pond bottom and hung on triggers, thus providing access ("doors") to the feeding site. When the triggers are pulled, the net falls to the bottom, encircling the fish that have come to feed. The trapped fish are then generally netted with a shorter encircling seine. Catfish do not usually feed in the trap for 1 to 2 weeks after the net has been positioned, and require 3 to 7 days to become re-acclimated after each drop.

A panel trap has shown encouraging results when used in conjunction with a demand feeder. It, too, could be used in ponds with seining obstacles. An experimental version of the trap was constructed of wooden frames 10 feet long by 5 feet high, covered with 1-inch-mesh wire poultry netting. (Heavier wire should be used for commercial trapping.) Panels were installed in a 45-foot-diameter semicircle around a demand feeder by adding one or two panels a day. A 10- by 4-foot gate hinged to the top of a supporting framework and propped open by a metal rod allowed fish access to the feeder. Weights on the gate's edge facilitated its rapid closing. Gradual construction of the panel trap did not interrupt fish feeding. Opened gates were placed along with the first three panels, and by the time the last panels were positioned, the fish were accustomed to using the gates. Normal feeding ac-

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tivity resumed 3 to 7 days after a trapping operation.

A lift net and submergible seine were developed for use in relatively small ponds, or in ponds with extremely muddy bottoms. A lift net is a square or rectangular net with risers attached to the corners. These risers are attached to a fulcrum, which provides the leverage to lift the net above the water. Fish are baited over the top of the net, which is raised periodically to trap them. Mesh size may be adjusted to make it self-grading.

The submergible seine has an inflatable tube in place of a permanent float line. It is set much as the drop seine is. Once the net is in place, the tube is deflated and the seine sinks to the bottom. Catfish are enticed by feed to swim over the top of the submerged net into the trapping area. When the fish have congregated there, the tube is reinflated to raise the net and thus encircle the fish. The fish are removed with a smaller seine or the submergible seine itself is drawn into the shore.

Slat traps, hoop nets, and electrical stunning or attracting devices that have been traditionally used to harvest wild catfish from rivers and large reservoirs perform poorly in catfish production ponds. Few catfish enter baited, conventional traps, perhaps because there are no currents in ponds as there are in rivers and large reservoirs; and studies at the Fish Farming Experimental Station have shown that the electrical shocker is not a good device for use with any type of active or passive fishing gear currently used for the live-harvesting of pond-cultured fish.

Depending on practical considerations, farmers may harvest fish from their ponds or arrange for someone else to do it. Most processing plants have custom harvesting crews that harvest and transport the fish for a fee. A small producer would do well to consider this alternative.

Scaled Species

Harvesting techniques for minnows, goldfish, aquarium fish, and most hatchery-cultured warmwater sport species are similar to those for catfish fingerlings. However, fish of these small, scaled species are more prone to injury, and thus must be handled more carefully.

Golden shiners are the most difficult species of baitfish to harvest, handle, and transport because they have large, easily shed scales. When several scales are lost, salability is drastically reduced because most of the injured fish die soon after transport. When confined, this fish is prone to jump from the container when disturbed or frightened. This behavior is especially troublesome at water temperatures above 60°F. Since golden shiners can tolerate a temperature drop of 15°F for short periods, the water can be cooled to slow the metabolic rate of the fish and make handling much easier for both the operator and the fish. However, fathead minnows and small bait-size goldfish cannot tolerate a sudden 15°F drop in water temperature. For these fish, the water temperature must be lowered slowly by adding cooler water to avoid temperature shock. Before fish are harvested, they can be confined to a small area where water temperature can be lowered overnight by adding well water or spring water. The fish producer is encouraged to add ½ to 1% table salt to the transport water, as well as antibiotics or bacteriostats and anesthetizing compounds.

Partial harvests of most scaled fishes are made by seining. The net should be made of untreated, woven nylon of suitable mesh size to retain the fish. Pond levels are usually not lowered for seining. Rather, the fish are baited into a corner of a pond with wet or pelleted feed. Some feed manufacturers produce a 16% protein feed for this purpose that is less expensive than production feeds and does not foul the water as much. After the fish gather in the area, the seine is pulled slowly and quietly across the corner with a length of rope. After being pulled in and gathered, the seine is quickly moved to deeper water so that fish can move away from the surface into deeper and cooler water. Trauma is reduced if the fish are gently dipped from the seine with small-mesh, untreated dip nets.

Summertime harvesting from ponds with surface temperatures of 75°F or higher re-

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quires great care and should be confined to early morning. Where baiting is not used for harvest, feed should be withheld at least 24 hours before harvest to reduce fouling of the transport water.

Lift nets are often used in harvesting golden shiners, goldfish, and fathead minnows. These nets are usually constructed of $^3/_{16}$-inch mesh on a steel frame 4 feet square or larger. The nets are usually suspended in a pond from a pipe resting on a fulcrum pole. Fish are baited into the trap while it is lying on the bottom of the pond; the net is then lifted to the surface.

In cold weather, cylinder traps with either one or two funnels are used to harvest fathead minnows. The traps are 1 foot in diameter and 2 feet long, and are baited with small bags of fish food.

Tanks for hauling fish from the harvest area to the holding facilities must be fitted with water-aerating devices suitable for the size and species of fish. Very small fish are sometimes injured by compressed air and agitators, but tolerate much better the small bubbles of (bottled) oxygen coming from carbide aerator stones. Other fish are little damaged by agitators, compressed air, or sprayed water. About 1 pound of fish per gallon of water can be moved in cold weather, but this amount should be reduced to about ⅔ pound in warm weather. The temperature of transport waters for golden shiners should be about 60°F. Since goldfish and fathead minnows cannot tolerate a rapid temperature change, they should be transported in water of the same temperature as that in the pond.

The culture of several species in the same pond often increases profits or benefits management in other ways, but it is not without disadvantages. Fish to be retained may have to be removed from the seine by hand. This procedure is often expensive and labor-intensive, and often the larger fish in the net splash about and injure or kill the smaller fish.

There are many ingenious techniques for separating fish. Some include the use of the appropriate seine mesh to retain or exclude fish. Other techniques are as simple as seining in only certain locations, or at only certain times of the day. In most instances, efficient methods of harvesting polycultured fish and separating them economically can be devised.

Grading and Holding Techniques

Some "on the farm" grading is done in the pond, especially in cool weather. Grading boxes, live-cars, and grading nets are often modified to float in the pond. Fish obtained by "cropping" are usually graded and only the larger fish retained (Fig. 12.3). The smaller fish escape to the pond. Shipping shed grading is usually done at the time of sale.

The grading of fingerling fish to a uniform size before stocking them improves accuracy in estimating numbers and reduces the number of fish that are too small to sell when the fish are harvested. Often the number of oversized fish is decreased, thus reducing their competition with the smaller fish. Overall feed conversion efficiency and survival are usually increased. Sorting tables, net graders, and grading boxes are used. The use of sorting tables also permits the culling of deformed fish.

Most producers use grading panels that are the same width as their holding tanks so they can grade the fingerlings without handling them with dip nets. Others use floating grading boxes with panels of metal bars on the sides or bottom. Spacing between the bars in



Fig. 12.3. Channel catfish of uniform size can be obtained by grading. These fish, weighing about a pound apiece, have excellent consumer acceptance. Smaller fish are returned to the pond for additional growth.

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bar graders determines the sizes of fish that are retained; fish small enough to pass between the bars escape. The graders are often color-coded for size. Some channel catfish producers prefer a mesh (net) grader. Sizes of catfish held by bar and net graders, and of minnows held by bar graders are shown in Table 12.2.

Some producers attach several hundred feet of grading net of the appropriate mesh to another seine to avoid having to maintain a large inventory of seines of different meshes. Grading should not be attempted until several hours after the fish have been removed from the pond. The quantity of fish in the grader at any one time should not exceed 5 pounds per cubic foot of grader capacity. Small fish can be driven from the grader by splashing the water within the grader. Small fish should be graded out of the population first, followed by successively larger ones. Catfish pass most readily through the bottom of a grader and minnows through the side.

Fish, especially channel catfish fingerlings and minnows and larger fish for sport fishing, are usually held in vats or tanks before they are shipped to buyers. This holding enables the producer to grade the fish to size, and to apply the appropriate parasite removal treatments. The fish are also acclimated to handling and transport. Food fish for processing are normally loaded directly into transport tanks. However, these fish generally purge their digestive tracts while being held in livecars. Large catfish are rarely held in vats during warm weather because they are very active and injure themselves readily.

Holding tanks are generally 4 feet wide, 10 to 40 feet long, and about 3 feet deep. A removable drain 4 inches in diameter or larger serves as a standpipe and maintains the water level. A holding tank 4 feet by 10 feet and 2 feet deep holds about 500 gallons of water and can carry 300 pounds of fish if sufficient water exchange and aeration are provided.

Holding tanks are usually located under cover. Open buildings with roofs to keep out the sun are adequate for the holding of baitfishes and fingerling catfish in the South; closed buildings are preferred in the central States. Inasmuch as the water for holding houses generally comes from wells or springs, its temperature may be as much as 20 to 30°F lower than that of pond waters in summer, and 30 to 40°F higher in winter. Since a temperature change of only 5 to 15°F shocks most fish, care must be taken to acclimate the fish by gradual tempering. Aeration can be supplied by compressed air, bottled oxygen, or agitation. Sufficient water exchange must be provided to maintain at least 5 ppm dissolved oxygen in the water, and to remove ammonia, carbon dioxide, and other toxic metabolic products.

Table 12.2. *Bar grader sizes for minnows and channel catfish, and mesh sizes for net grader for channel catfish.*

Fish, and spacing between grader bars, or mesh size of net (inches)	Length of fish held (inches)[a]
Minnows	
Bar grader	
11/64	1½
12/64	1¾
13/64	2
14/64	2¼
15/64	2½
16/64	2¾
Channel Catfish	
Bar grader	
27/64	3
32/64	4
40/64	5
48/64	6
56/64	7
64/64	8
96/64	11 (¾ lb)
Net grader	
¼	1-2
⅜	3-4
½	4-5
¾	7-8
1	8-10 (½ lb)
1⅜	¾ lb
1⅝	1½ lb
1¾	2 lb

[a]Weight where specified.

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13. TRANSPORTATION OF LIVE FISH

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Transporting live fish from the production facility to the purchaser or to the resource manager is an extremely important aspect of aquaculture. Purchasers include other commercial fish producers, fee-fishing operations, hobby fish retailers, baitfish retailers, private pond owners, and State and Federal agencies. Hatcheries transport fish to lakes, rivers, and streams for recreational and management purposes. The common goal of all these transporters is to provide at the destination only healthy fish that will live and satisfy the criteria of the purchaser or resource manager.

Fish are also transported live to the processing plants where they will be prepared for food. Although it is important that these fish be living at the destination, the stresses and other damages during transportation would often result in death of the fish if they were stocked. The techniques and procedures discussed here apply only in part to the transportation of fish to processing plants.

Transportation of live fish involves the moving of large numbers or weights of fish in a small space. The need is basically economic, since extra water is worthless at the end of the haul.

There are two basic transportation systems for live fish—the open system and the closed system. The open system consists of water-filled containers in which the survival needs are supplied continuously from outside sources. The simplest of these is a small minnow bucket with an aerator stone. The closed system is a sealed container in which all the survival needs are self-contained. The simplest of these is a sealed plastic bag partly filled with water and inflated with oxygen.

Fish are transported by a number of conveyances. Although most live fish are moved by truck or airplane, needs still arise for transportation by bus, rail, packhorse, helicopter, or hand-carried buckets.

A number of factors are involved in the transportation of fish. The more pertinent of these are harvest and pre-shipment treatment, criteria for handling equipment, water quality requirements, and transport aids.

Harvesting and Pre-shipment Treatment

Harvesting

Harvesting techniques and procedures are extremely important to the successful shipping of live fish. Injured fish, regardless of the care taken during hauling, will not arrive in good condition, and most will probably die within 2 to 3 days after being received. Hauling is stressful at best and this stress, coupled with the stresses incurred during harvest and preparation for shipment, makes the fish extremely susceptible to invasion by infectious diseases and parasites. The hauler is often blamed for the fish dying, when in reality the loss was due to poor harvesting and pre-shipment treatment by the producer.

Harvesting is more difficult in summer than in winter. Often the surface water temperature in summer exceeds 100°F, which is damaging to the fish (especially small fish) being drawn up through it. Fish placed in tubs or buckets can experience a rapid rise in water temperature because they are being held in only small amounts of water. Oxygen deficiencies can occur rapidly, since the oxygen content of warm water is relatively low, and the high metabolic rate of small fish rapidly depletes the supply.

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In summer the successful fish producer traps fish if possible, because this technique is much less stressful and damaging than seining. If seining is required, it is done during the morning while the water is relatively cool; only in the deeper water (or at least the hot shallow areas are avoided); and, if possible, near an inlet pipe that is supplying cool fresh water. The summer harvester may prefer to use feed to concentrate the fish so that he can use small nets or seines to capture the required numbers of fish without disturbing a large area.

The fish producer should also be aware that cold shock can occur in fish harvested during winter. Fish (especially small ones) can be seriously damaged and stressed by removing them from the pond water and exposing them to the cold air, where the chilling effect is increased by wind. It is not unusual to remove fish from 50°F pond water while there is a wind chill factor of 10°F. This difference has the same effect as shocking the fish with a 40°F change in water temperature. The winter harvester of fish should immediately place the fish into tubs or other transport containers with as little exposure to the air as possible.

Transporting the fish from the production pond to the shipping shed is also an important part of the harvesting process. It is essential that the hauling unit be large enough to accommodate the fish without excessive crowding. The unit should be filled with clean, well-aerated water. For channel catfish and golden shiners, the water temperature in the hauling unit can be 15°F cooler than the pond water during summer. For most other species, and especially for the smaller fish, the temperature difference should not exceed 5°F. During winter the temperature of the water in the pond-to-shed transport unit can be the same as that of water in the pond.

The pond-to-shed transport unit must be equipped with suitable aeration devices to maintain adequate dissolved oxygen. Usually no cooling equipment is required. Most of the better transport units are equipped with a large-diameter quick-release gate and a large-diameter discharge pipe that enable a rapid transfer of the fish into the shipping shed vat. This release equipment reduces labor and saves an additional step in handling.

Treatment for control of infectious diseases and removal of parasites can be applied before the fish are shipped. Often the purchaser of the fish, or the State in which the fish are to be shipped, will require an inspection certificate. (Appropriate treatments are described in Chapter 14.) After applying the recommended treatment or treatments, the shipper should allow sufficient time for the fish to recover from the effects of the chemicals and drugs.

Usually the fish must be graded to size, and any foreign fish or undesired plants and animals removed. Tadpoles are commonly present in production ponds, and ponds in some areas may contain exotic or undesired fishes or plants that should not be transported to other sites. Many types of graders and sorting tables are available from commercial suppliers. The use of a grader recommended for the species and size of fish being handled is important. The use of inappropriate graders or grading techniques often results in scale loss and other damage that reduce the sale value of the fish, and sometimes cause mortality.

As in all aspects of aquaculture, water of good quality must be maintained in the shipping shed. Aeration equipment—including mechanical agitators, aerator stones, or water jets—or continuous water exchange can be used successfully.

Loading and Shipping

As much care should be given to loading the fish into the shipping unit as to the harvest and pre-shipment. The fish should be pretempered in the holding vats before being loaded into the shipping unit. Often this is not possible and the fish must be loaded and the temperature in the shipping unit then adjusted to the hauling temperature desired.

Tempering requires 20 minutes per 10°F decrease in water temperature. This cooling can be accomplished by mechanical refrigeration or with ice. One-half pound of ice reduces the temperature of 1 gallon of water by about 10°F.

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Table 13.1. *Estimated pounds of channel catfish that can be hauled per gallon of water per unit of transportation time at 65°F.*[a]

Weight of fish (number per pound)	Transit period (hours)		
	8	12	16
1	6.30	5.55	4.80
2	5.90	4.80	3.45
4	5.00	4.10	2.95
50	3.45	2.50	2.05
125	2.95	2.20	1.80
250	2.20	1.75	1.50
500	1.75	1.65	1.25
1,000	1.25	1.00	0.70
10,000	0.20	0.20	0.20

[a]From J. P. McCraren and J. L. Millard. 1978. III. Transportation of warmwater fishes. Pages 43-88 *in* Manual of fish culture. U.S. Fish and Wildlife Service, Washington, D.C.

The shipper should consider the water temperature at the destination when he is preparing the shipment. Although the fish can usually be transported more safely in cool water, the stocking of these fish into relatively warm water at the end of the transport period will require considerable tempering at the end of the trip. It is more difficult and more time-consuming to temper fish to higher temperatures than to lower ones. It may be more expedient to haul fewer fish at higher temperatures. Some producers and haulers do not reduce the water in the shipping units below 60°F during summer.

Loading rates differ with fish species, size, water temperature and quality, duration of transport, and type of shipping unit employed. Fish culturists and researchers have prepared general loading guides (Tables 13.1, 13.2, 13.3, and 13.4). The values shown may be revised upward or downward to meet the criteria of the shipper.

Other haulers may be interested in reviewing the recommendations of J. T. Davis, which are briefly summarized here.[1]

[1]From J. T. Davis. 1971. Handling and transporting eggs, fry, and fish. Pages 40-42 in Proceedings of the Conference on Production and Marketing of Catfish in the Tennessee Valley. Division of Agricultural Development, Tennessee Valley Authority, Muscle Shoals, Alabama.

Table 13.2. *Pounds of black bass or sunfishes that can be transported per gallon of water at temperatures of 65 to 85°F.*[a]

Weight of fish (number per pound)	Total length (inches)	Approx. number per gallon	Pounds per gallon
25	4	25	1.00
100	3	67	0.66
400	2	200	0.50
1,000	1	333	0.33

[a]From A. J. Wilson. 1950. Distribution units for warmwater fish. The Progressive Fish-Culturist 12(4):211-213.

- Four pounds of 1- to 2-pound channel catfish can be transported per gallon of water at 65°F.
- Change loading rates 25% for each 10°F change in water temperature.
- For a decrease in length of one-half, decrease loading rates by one-half (e.g., haul only 2 pounds of 8-inch fish or 1 pound of 4-inch fish per gallon of water).

Table 13.3. *Capacity (normal) load in pounds of fish per gallon of water for transportation by the tank method (with agitators or blower system) of fish in good condition in hard water at 65°F.*[a]

Type of fish and average length (inches)	Duration of transport (hours)			
	1	6	12	24
Fingerling food fish				
2	2	1½	1	1
8	3	3	2	1½
Adult food fish				
14	4	4	3	2
Baitfish				
2	2	1½	1	1
3	3	2	1	1

[a]The loading rate can be increased by 25% when pure oxygen is added. For each 10°F increase in water temperature, the loading should be decreased by 25%. Table adapted from S. K. Johnson. 1979. Transport of live fish. Pages 72-93 *in* Proceedings of the Fish Farming Conference and Annual Convention Catfish Farmers of Texas. Texas A&M University, College Station, 17-19 January.

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Table 13.4. *Weight (pounds) of 1,000 fish of different species, in relation to total length.*[a]

	Families and species[c]																		
TL[b]	Catfishes			Sunfishes						Suckers		Carps and minnows					Others		
(in.)	CC	BL	FC	LB	Bg	RS	GS	BC	WC	SB	BB	CC	Gf	GS	FM	RS	RT	TS	WB
2		2.8	3.3	3.5	5.0	5.4	5.2	3.7	3.5	4.1		7.6	5.4	3.9	3.3	2.5	3.2	3.0	
2½	4.6	5.4	6.3	7.0	9.8	10.1	10.1	7.2	7.0	8.1		13.7	9.0	5.4	7.6	4.6	5.1	5.8	7.8
3	7.7	9.0	10.7	12.3	17.2	17.6	17.4	12.2	11.8	14.0	16.2	22.2	17.0	8.6	11.0	8.8	8.8	9.6	13.3
3½	12.3	14.3	16.7	19.8	28.6	27.8	27.7	19.3	19.8	22.4	25.7	33.4	24.5	13.5	19.8		17.6	14.9	20.8
4	18.3	21.0	24.6	29.7	41.4	41.1	41.3	28.6	29.6	33.7	38.3	47.4	40.0	19.0	24.4		25.6	21.8	31.0
4½	26.0	29.9	34.6	42.9	59.5	58.2	59.9	40.6	42.4	48.2	54.2	64.6		31.5	28.3		35.0	29.9	44.3
5	35.2	40.7	46.9	59.0	82.4	79.5	81.9	55.7	58.4	66.3	74.2	85.0		44.0			63.9	40.3	60.6
5½	46.9	53.7	61.9	78.8	110	106	109	73.9	78.2	88.6	98.3	109		60.0				52.2	80.5
6	60.5	69.8	79.3	103	144	136	141	95.6	102	116	127	137					104		104
6½	76.4	88.1	100	132	185	173	179	121	130			167							132
7	95.2	110	139	165	234	215	223	151	163			206					174		165
7½	117	134	152	204	286	264	273	186	200			247							203
8	141	162	183	248	352	320	331	228	245			293					218		246
8½	168	194	218	299	416	383	396	269	295			344							294
9	199	229	257	354		453		321	351			399					328		349
9½	233	269	303	420		532		375	414			460							410
10	272	312	350	491		619		436	484			527					449		478
11	376	414	471	657				573	648			677					535		635
12	501	532	618	857					845			851					681		823
13	654	680	801	1,094					1,078			1,050					868		1,045
14	834	872	1,014	1,373					1,351			1,276					1,086		1,303
15	1,048	1,100	1,263	1,695					1,688			1,574					1,330		1,610
16	1,297	1,366	1,558	2,073					2,031			1,903					1,674		1,940
17	1,585	1,674	1,880	2,484								2,296					2,049		2,324
18	1,914	2,029	2,255	2,958								2,747					2,335		
19	2,288	2,433	2,678	3,490								3,233					2,910		
20	2,709	2,891	3,152	4,082								3,776					3,267		
22	3,183	3,414	3,717	4,738								4,401					3,634		

[a]Data from various sources, but primarily from W. Swingle and E. Shell. 1971. Tables for computing relative conditions of some common freshwater fishes. Alabama Agricultural Experimental Station Circular 183. Auburn, Alabama.

[b]Total length (inches).

[c]Abbreviations follow in the order shown, left to right (see Table 1.1 for scientific names). Catfishes: CC, channel catfish; BF, blue catfish; FC, flathead catfish. Sunfishes: LB, largemouth bass; Bg, bluegill; RS, redear sunfish; GS, green sunfish; BC, black crappie; WC, white crappie. Suckers: SB, smallmouth buffalo; BB, bigmough buffalo. Carps and minnows: CC, common carp; Gf, goldfish; GS, golden shiner; FM, fathead minnow; RS, red shiner. Others: RT, rainbow trout; TS, threadfin shad; WB, white bass.

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- When transportation time exceeds 12 hours, decrease loading rates by 25%.
- When transportation time exceeds 24 hours, decrease loading rates by 50%, or arrange for a complete water change en route.
- Hauling temperatures of 45 to 50°F are preferred during winter, and 60 to 70°F during summer.

Unloading

Transportation of live fish is not successful until the fish arrive at the stocking or receiving site, and are placed into the receiving waters in a healthy condition. The fish must be slowly tempered to the temperature of the receiving water. The temperature difference of the shipping-unit water and the receiving water should not exceed 5°F. About 20 minutes of tempering are required for each 10°F adjustment in water temperature. For some species, and in some receiving waters, ion shock can also occur. Even though no adjustment in water temperature may be required, some time may be required to adjust the fish physiologically to a different ion concentration. This ion shock can be particularly damaging when fish are cultured in hard water and stocked into extremely soft water. Slowly exchanging the hard water for soft water reduces the stress. There is usually no problem when fish from soft culture water are stocked into hard receiving water.

If the receiving waters are distant from the unloading point, and the fish must be transported by hand, it is important not to incur an oxygen deficiency in the carrying container. It is far better to move a few fish at a time and have them live than to move a large number and risk having high mortality later.

Transportation Equipment

Types

Fish are generally transported by truck or airplane. In a few instances an airplane has been modified and equipped to transport the fish holding unit, and occasionally to transport an entire truck equipped with a fish hauling unit. However, the airplane is usually used to transport sealed or closed packages (discussed later).

Truck units are of many sizes and of several types. Single-axle units of ½, ¾, 1, and 1½ tons are commonly used. Some haulers use tandem (double-axle) units and trailer units. Some producers have begun using gooseneck trailers attached to a pickup truck. This innovation frees the truck for other uses. Some truck units have one driver for the shorter hauls but have two drivers and a sleeper attachment for longer hauls.

Transporting Containers

Containers for the transporting of live fish are generally constructed of aluminum, fiber glass, or plywood. In some, two or more construction materials are combined. Tanks for trucks are usually constructed of aluminum 3/16-inch thick, and are rectangular or elliptical. Some are insulated with polyurethane but others are uninsulated. The aluminum units are usually on the larger trucks and the fiber glass and marine plywood units on the smaller trucks. The fiber glass-only units are usually made of material ¼-inch thick, which enables one person to easily load or unload the unit. Some units are insulated with polyurethane and can be used for short and medium-length hauls. The marine plywood units can be covered with fiber glass and insulated. Some of the lower-cost units are only painted. Both the uninsulated fiber glass and marine plywood units are used for short hauls.

Tanks can be rectangular or partly rounded. Governmental agencies often use V-shaped or elliptical tanks, believing that water is more readily mixed and more rapid removal of the fish ensured. The commercial industry—especially warmwater fish producers—prefer rectangular tanks. The unitized or compartmented tank has the advantage that several sizes or species of fish can be transported with the same vehicle at the same time, and that several partial unloadings can be made (Fig. 13.1). The warping of the bed of long trucks can break the welds in single-unit com-

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Fig. 13.1. Trailer unit used for long-distance hauling of channel catfish and baitfishes. The unit is composed of 18 compartments, each having an air supply and other life-support equipment. Separate compartments are useful for hauling several species or sizes of fish. Each compartment is equipped with a quick-opening gate for rapid release of the fish.

partmented tanks, but not in the unitized tanks. The hauler can purchase the number of standard unitized tanks needed to equal the weight capacity of the vehicle. Both the compartmented and unitized hauling tanks are usually equipped with quick-opening gates for the rapid dumping of the fish, and holders for chutes to carry the fish from the tank to the vat or receiving water. Many of the units used by commercial fish farmers have extra-large top doors to facilitate loading with boom devices.

Support Equipment

The life support or survival equipment for the open units consists of spraying devices, baffles, screens, venturi units, compressed and liquid oxygen, and agitation (Fig. 13.2). From



Fig. 13.2. The basic equipment needed by all fish haulers is a tank, truck, and an aeration device. This is a well-equipped system on a ¾-ton heavy duty truck. The tank is constructed of stainless steel and is divided into two compartments. Quick-release gates and removal chutes permit rapid unloading of the fish. Agitators provide aeration, but compressed oxygen is available for emergencies. Nets, tubs, and a scale are standard for all transport units. *Photo courtesy of Alabama Cooperative Extension Service.*

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the standpoint of ease of installation and light weight, plastic pipe is usually preferred for the plumbing. However, many haulers prefer metal pipe because of its greater durability.

Gasoline-powered water pumps can be used to recirculate and aerate the water. The water is usually removed from the bottom of the tank through a screened inlet, and is exhausted as an overhead spray through a perforated pipe above the waterline. Oxygen can be added to the suction line at the point just before the water enters the circulation pump. The system is usually equipped with an oxygen flowmeter located in the truck cab. The major disadvantages of water pumping is that it heats the water and mixes the water among compartments. One research report stated that a 3-inch gasoline-powered pump increased the water temperature in a 1,250-gallon tank by 2.5°F per hour. Mechanical cooling or ice is required to maintain the desired water temperature in the transportation unit.

Electrical agitators can also be used to oxygenate the water and to "beat out" metabolic ammonia and carbon dioxide. These agitators can be 12-volt units powered by the truck engine alternator or 120-volt units powered by a gasoline or gas generator. Some haulers add supplemental oxygen through airstones or other aerator materials. Agitators eliminate the large space and weight requirement for pumps, chillers, and plumbing. Any weight or space that is saved can be used to carry fish.

Aerators can also be used to supply air or gaseous oxygen to a transport system. The aerators are constructed of carbon rods 2 inches in diameter, carborundum rods 1 inch in diameter, micropore tubing, or perforated tubing. Aeration efficiency differs with the size of the air or gaseous bubbles released, the smallest bubbles being the most efficient. Carbon and carborundum rods are used to dispense the more expensive gaseous oxygen, and compressed air is usually dispensed through micropore or perforated tubing.

Oxygen is available in a compressed (bottled) or liquid form. Bottled oxygen is expensive and the amount that can be carried on the truck is limited. Liquid oxygen is less expensive per unit volume but the storage tanks are expensive. If liquid oxygen is released into the water as a liquid instead of a gas, it may "burn" and injure the gills and eyes of fish. Both bottled and liquid oxygen allow carbon dioxide and ammonia to build up in the water, since neither form is added in sufficient volumes to drive off significant amounts of other gases.

Atmospheric oxygen is added with a blower or compressor. These devices can "roll" the fish and result in scale loss and fin damage, especially in small fishes such as minnows and fingerling basses, sunfishes, and carps. For other fish, even though there is no scale loss, the continuous rolling of the water can result in exertion and fatigue, and cause a buildup of lactic acid in fish tissues. Delayed mortality can result. However, for large fishes and especially the catfishes, blowers or compressors provide an economical method for adding oxygen to the water and driving off ammonia and carbon dioxide. Air pumps also heat the water, and this heat addition must be compensated for by the addition of ice or the use of refrigeration equipment.

Filtering equipment has been used in some hauling units to remove bacteria, slime, mucus, scales, and feces—all of which contribute to the biological oxygen demand—from the hauling water. Most of the filter units are rather primitive and consist of cheesecloth or metal strainers. Most commercial and governmental units are not equipped with filter units. Most haulers now change water one or more times if the trip is long, or if heavy loads are being transported.

A number of judgments must be exercised by a fish hauler in determining the type of equipment that is to be used in a particular situation.

Emergency Equipment

Transportation units—particularly those powered by electrical equipment driven by the truck engine—should be equipped with standby emergency equipment. A standby generator is a good investment, since it will power

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the equipment until the truck can be repaired or the fish transferred to another truck.

For units equipped with centrifugal pumps, blowers, or compressors, a standby unit that has already been installed into the system will furnish almost immediate conversion. The hauler must inspect and maintain the equipment to ensure that it will start immediately and operate dependably.

For short-term emergencies of 1 or 2 hours, compressed oxygen bottles can be used. Maintenance of this equipment is relatively inexpensive, and generally no expenses are incurred until the compressed oxygen is used.

Water Quality Considerations

Oxygen

Oxygen is the first limiting factor in the successful transport of fish. Oxygen must be present in adequate amounts throughout the total transport period. Oxygen requirements are affected by water temperature, pH, ammonia, carbon dioxide, size of fish, species of fish, length of transit, and level of activity.

Lowering the water temperature is the quickest way to reduce oxygen consumption; it reduces metabolic rate of the fish, decreases fish activity, and slows the growth rate of organisms that compete for the oxygen. Water temperature can be reduced by adding ice or by using mechanical water coolers.

Fish with an empty stomach and intestine consume less oxygen than do fish that are digesting food. Also, the biological oxygen demand that results from the decay of the feces is increased in fish that were fed just before shipping.

When all other factors are the same, small fish consume more oxygen than larger ones because the metabolic rate of the smaller fish is the higher. The only practical solution is to decrease the concentration of small fish in the transport unit.

Any excitement or activity markedly increases the oxygen consumption of fish. More oxygen is consumed within the first 15 minutes in the hauling unit than during any subsequent 15-minute period. It is crucial to add more oxygen at this time to prevent the development of an oxygen deficiency.

Ammonia

Ammonia (NH_3) builds up in transport water due to protein metabolism of the fish and bacterial action on the waste. Decreasing metabolic rate of the fish by lowering the water temperature, and thus lessening fish activity, reduces the production of NH_3. The production of NH_3 by bacterial action can be decreased by shipping fish only after food has been withheld long enough to void the stomach and intestine.

Ammonia toxicity is due to the un-ionized NH_3 molecule rather than the ionized NH_4^+ ion. The amount of un-ionized ammonia increases as water temperatures and pH increase (Table 13.5). For example, only 0.02% of the total ammonia present is in the toxic or un-ionized form at pH 6 and water temperature of 50°F, but 89% is in the toxic form at pH 10 and water temperature of 86°F.

It is not uncommon for the total ammonia concentration to reach 10 ppm in fish-hauling units. No maximum permissible values can be given because the toxicity of ammonia is so greatly affected by water temperature and pH. However, the hauler should exercise caution when the total ammonia exceeds 5 ppm.

The best way to reduce the ammonia levels is to ship only fish that have no food in their digestive tract, and to ship them in cool water. A common practice among fish haulers is to withhold feed from fish for 48 to 72 hours before they are to be transported.

Carbon Dioxide and Other Compounds

The toxicity of CO_2 in hauling units is usually associated with the reduced ability of hemoglobin to transport oxygen to the fish tissues. Fish in transport units are exposed to increasing concentrations of CO_2 as a result of respiration, as demonstrated by the following equation.

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Table 13.5. *Percent un-ionized ammonia in water at 32 to 86°F and pH 6 to 10.*[a]

Temperature		pH				
°C	°F	6.0	7.0	8.0	9.0	10.0
0	32.0	0.008	0.08	0.82	7.64	45.3
2	35.6	0.01	0.10	0.97	8.90	49.4
4	39.2	0.01	0.12	1.14	10.3	53.5
6	42.8	0.01	0.14	1.34	11.9	57.6
8	46.4	0.02	0.16	1.57	13.7	61.4
10	50.0	0.02	0.19	1.83	15.7	65.1
12	53.6	0.02	0.22	2.13	17.9	68.5
14	57.2	0.03	0.25	2.48	20.2	71.7
16	60.8	0.03	0.29	2.87	22.8	74.7
18	64.4	0.03	0.34	3.31	25.5	77.4
20	68.0	0.04	0.40	3.82	28.4	79.9
22	71.6	0.05	0.46	4.39	31.5	82.1
24	75.2	0.05	0.53	5.03	34.6	84.1
26	78.8	0.06	0.61	5.75	37.9	85.9
28	82.4	0.07	0.70	6.56	41.2	87.5
30	86.0	0.08	0.80	7.46	44.6	89.0

[a]From K. Emerson, R. C. Russo, R. E. Lund, and R. V. Thurston. 1975. Aqueous ammonia equilibrium calculations: effect of pH and temperature. Journal of the Fisheries Research Board of Canada 32(12):2379-2383.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Simple sugar — From respiration — Expelled from the gills

Fish produce 0.9 mL of CO_2 for each 1.0 mL of oxygen consumed. It is common to measure 20 to 30 ppm of CO_2 in fish transport waters, and fish can tolerate these rather high levels of CO_2 if the buildup is slow. However, if the buildup is rapid, as the result of a heavy fish load, high metabolic rate, extensive bacterial activity, or stress, the fish soon become severely distressed.

Carbon dioxide can be removed from the transport water by aeration or agitation. Bicarbonate ions buffer the water from the effects of carbonic acid, the product of carbon dioxide in water. Alkalinity can be increased by 100 ppm by adding 2 ounces of sodium bicarbonate (baking soda) to each 100 gallons of transport water.

No materials that are toxic or that remove oxygen should be in the hauling unit. Hydrogen sulfide (H_2S) is toxic, and ferrous iron can coat the gills of fish. Clean water should also be used because any organic matter present adds to the biological oxygen demand.

Hauling Aids

Water-hardening Chemicals

Handling stress and delayed mortality can be decreased by the addition of 0.1 to 0.3% table salt and 50 ppm calcium chloride ($CaCl_2$) to the hauling water. Some of the fishes that tolerate wide ranges of salt in the water, such as striped bass, tilapias, and threadfin shad can benefit from as much as 0.5% salt. The sodium ion tends to "harden" the fish and reduce slime formation, and the calcium ion suppresses osmoregulatory and metabolic dysfunction. Calcium chloride may not be needed in hard waters already containing high concentrations of calcium.

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Anesthetic Chemicals

Hyperactivity of fish increases oxygen consumption and CO_2 and NH_3 production. Fish may also damage themselves by bumping into the sides of the unit. Sedation is desirable, since oxygen consumption and CO_2 and NH_3 production are all decreased. However, deep sedation is undesirable because the fish may fall to the bottom, pile up, and smother. If pumps are used, the fish may be pulled into the screen, and air may move the deeply sedated fish about and cause a loss of scales.

Some species may be more sensitive than others to the anesthetizing chemicals. Trials are suggested to determine the proper concentration of a chemical on each producer's farm, and when it should be used in each operator's equipment.

Several chemicals have been tested: quinaldine[x] at 15 to 30 ppm; MS-222 (tricaine methanesulfonate) at 0.1 to 1.0 g/gallon; tertiary amyl alcohol[x] at 5.5 to 48 mL/gallon; methyl pentynol[x] at 2 to 12 mL/gallon; carbonic acid at 0.5 to 2 mL/gallon; and sodium bicarbonate at 2.4 g/gallon.

Of these chemicals, quinaldine[x] appears to be the most practical for warmwater fishes, although it may be damaging to trout and some other species. MS-222 must be buffered between pH 7 and 8, and is expensive to use, but may be the chemical of choice for trout.

Bacteriostatic, Buffering, and Antifoam Chemicals

Four of the more common chemicals and drugs used to reduce bacterial respiration, and to lessen mortality due to infectious diseases are nitrofurazone[x] (Furacin) at 10 ppm, acriflavin[x] at 1 to 2 ppm, Combiotic[x] at 15 ppm, and oxytetracycline (Terramycin) at 20 ppm.

Two of the more common chemicals sometimes added to buffer the water and prevent extreme pH changes in the transport unit are "tris" buffer[x] (tris-hydroxymethyl-aminomethane) at 5 to 10 g/gallon, and sodium bicarbonate at 1 ppt.

Foam interferes with gas exchange and observation of the fish. Some haulers use a 10% solution of Dow Corning AF (antifoam) at the rate of 1 ounce (25 mL) per 100 gallons of water.

Disinfection of Fish Transport Tanks and Equipment

Diseases, especially viral diseases such as channel catfish virus disease, could be spread from place to place if transport tanks and equipment were not disinfected after each use. The California Department of Fish and Game uses a regular management protocol to reduce the risk of disease or transmission of parasites. The procedure is summarized here (excerpted from an article in *California Aquaculture* [Cooperative Extension Service, University of California, Davis, May 1982, CA-82.3]).

All planting tanks and equipment used off the hatchery grounds (except as qualified below) are disinfected as soon after each use as possible, and before reuse. Equipment such as boots and nets, used in any off-hatchery ground activity, is also sanitized before reuse. If there is no contact between the planting tank and planted water, the tank is disinfected at the discretion of the hatchery manager. Nets, buckets, and items such as rubber boots should never be overlooked as a source of contamination. Any equipment, including transfer pipes that make contact with the planted water, should not be allowed to contaminate the planting tank and should be disinfected before reuse.

Fish transport tanks can be disinfected by using ½ ounce (dry weight) of HTH (calcium hypochlorite base, 65% available chlorine) per 25 gallons of water for 30 minutes. In waters that have a pH above 6, it is necessary to add 1 fluid ounce of glacial acetic acid per 100 gallons of water.

To disinfect tanks and other implements with HTH, the proper procedure is as follows:

1. Fill the tank or other container with the desired amount of water.

2. Add the proper amount of glacial acetic acid to the water.

3. After the water and acetic acid are mixed, add the required amount of HTH to the acidi-

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fied water. *Do not add the acid to the dry HTH.* Adding the acid to the dry powder may cause an explosion.

4. Flush the tanks and pumps thoroughly before reuse.

Reaching the required concentration for tanks of different capacities requires use of the amounts of HTH and glacial acetic acid shown here:

Tank capacity (gallons)	HTH (oz)	Glacial acetic acid (oz)
150	3	1.5
600	12	6.0
1,200	24	12.0
2,500	50	25.0

Closed System of Fish Transport

Transportation of live fish in sealed containers apparently began in the United States after World War II (Fig. 13.3). Various groups, including commercial baitfish producers, fish and game departments in several States, and the hobby (tropical) fish industry, all appeared to develop the technique along parallel lines. Airlines and busses are the principal conveyances used, although automobiles and small airplanes are used for special functions and activities.

The equipment in its simplest form consists of 3-mil polyethylene bags, 18 by 32 inches. For channel catfish and other fish with spines the 6-mil bag is often used. Some workers use a bag 18 by 32 inches made of 4-mil plastic for large fish. The bags are usually doubled so that they remain airtight if one develops a leak.

The bags are placed in uninsulated cardboard boxes measuring 12 by 12 by 24 inches (2 cubic feet). Some shippers put the bags in Styrofoam boxes, 24 by 24 by 12 inches. These insulated boxes are then put into cardboard shipping boxes.

The standard 18- by 32-inch plastic bag is generally filled with 14 to 16 pounds (about 2 gallons) of water. As little as 10 to 12 pounds of water can be used on air flights if weight is a limitation. Water is generally



Fig. 13.3. Fry of channel catfish (shown here) and of many other species can be shipped conveniently and for long distances in plastic bags filled with water and oxygen. *Photo by J. Avault, Jr.*

suitable if it is free of carbon dioxide, hydrogen sulfide, and dissolved iron, and has a total alkalinity of 90 ppm or above (as $CaCO_3$) and a pH near 7.5. Some culturists add dibasic sodium phosphate, tris buffer, or sodium bicarbonate (1½ tablespoons per 14 to 16 gallons of water). However, this is probably not needed if the water is naturally well buffered.

The carrying capacity of the shipping bag depends on species and size of the fish, water temperature, and the duration of the trip (Table 13.6). It is desirable to test the stocking rate and packaging before the fish are placed in transit.

The bags containing water and fish are normally deflated by manually pressing out the atmospheric air and then reinflated with compressed oxygen. For short trips with low concentrations of fish, compressed air may be satisfactory.

To effect a seal, most aquaculturists twist the end of the plastic bag and then tie the gathered bag with rubber bands so that the oxygen cannot escape. As an alternative to rubber bands, rubber elastrators (used to castrate bulls) have proved to be efficient and labor saving. Heavy plastic tape can be used but it is more difficult to manage than rubber bands or elastrators.

Research has shown that acriflavin[x] at 1 to 2 ppm, nitrofurazone[x] (Furacin) at 5 to 10 ppm, or oxytetracycline at 20 ppm reduces bacterial growth and thus the amount of CO_2 and NH_3 produced in transit. It has also been

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Table 13.6. *Carrying capacity (in pounds) of fish in 18- × 32-inch plastic bags containing 2 gallons (about 15 lb) of water at 65°F.*[a]

Stage or (for fingerlings) total length in inches	Duration of transport (hours)			
	1	12	24	48
Eggs	1.0- 3.0	1.0-2.5	1.0-2.0	0.5-1.0
Fry				
Yolk-sac	2.0- 6.0	1.4-5.0	0.8-4.0	0.2-2.0
Swim-up	1.0- 4.0	0.9-3.2	0.8-2.5	0.4-1.3
Fingerlings				
½	1.8- 6.0	1.5-5.0	1.2-4.0	0.6-2.0
1	2.0- 7.0	1.7-6.0	1.3-5.0	0.7-2.5
2	2.0- 8.0	1.8-7.0	1.5-6.0	0.7-3.0
3	2.0- 8.0	1.8-7.0	1.5-6.0	0.7-3.0
Large fish	4.0-10.0	3.0-7.5	2.0-5.0	1.0-2.5

[a]Before transporting fish, it is imperative that the shipper package trial boxes of fish and subject them to the extremes of temperature and anticipated time en route to the destination. An experienced shipper provides a sizable safety factor in loading weight to allow for delays en route and exposure to heat.

shown that 0.5% common salt alone, or combined with MS-222 at 0.1 to 1 g/gal or quinaldine[x] at 15 to 30 ppm, often aids in the transit of fish.

Heat and time are the major adversaries in the transport of fish in plastic bag containers. Fish that are left in direct sun during summer—a common occurrence when transfers are made at airports—may be killed. If possible, the schedule should be limited to as few transfers as possible, and these transfers should be made at night. A margin of safety should be built into the shipment time. Delays and misroutings occur, and it is not uncommon for a shipment to be delayed 24 to 36 hours.

Some temperature control can be provided by using ice. It can sometimes be placed directly in the shipping bag. However, for some fish such as fathead minnows, and fry of all species, the direct application of ice may cool the water too rapidly and harm the fish. One can keep such fish cool by putting the ice in a small plastic bag or putting commercial "blue ice" inside the insulated box. Tropical fish and tilapias probably should not be cooled.

When the fish arrive at the destination, the temperature of the water in the shipping bag and in the receiving water should be equalized. This can be accomplished by floating the bag in the receiving tank, aquarium, or pond until the temperatures are equal. In tanks and aquaria where the water temperature can be adjusted, the receiving water temperature can be made equal to the water temperature in the bag, and the fish immediately released. With either procedure it is important not to open the plastic bags until the fish are ready to be stocked.

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14. PARASITES AND DISEASES OF POND FISHES

Brenda Rodgers Moore, Andrew J. Mitchell, Billy R. Griffin, and Glenn L. Hoffman

Intensive production of fish increases the likelihood and severity of parasite and disease outbreaks. Many fish farmers have learned that some parasites and diseases can kill an entire fish population in a short time. Diseases cause economic losses not only from mortality, but also from treatment expense, growth reduction during and after an outbreak, and postponement or loss of the opportunity to ship or sell the fish.

The parasites described here include protozoans, trematodes (flukes), cestodes (tapeworms), nematodes (roundworms), leeches, and crustaceans (fish lice and anchor parasites). Serious infectious diseases are also caused by bacteria, fungi, and viruses. Erratic behavior and syndromes characteristic of infectious diseases may be produced by environmental stressors (low oxygen, supersaturation of dissolved gases such as nitrogen or oxygen), toxins (hydrogen sulfide, ammonia, nitrite, many pesticides, and even therapeutic agents used to treat infectious diseases), and nutritional deficiencies.

It is essential that a fish farmer observe the fish daily and be able to recognize the signs of fish diseases, and to notice problems when they first appear. Good management is the key to successful production of healthy fish.

Fish Disease Signs

Diseased fish usually exhibit either physical or behavioral signs, or both. These signs can be helpful, but also misleading; in almost all instances an accurate evaluation can be made only at a diagnostic laboratory.

The following behavioral signs indicate that certain diseases may be present:

- Failure to feed—many diseases
- Swimming weakly, lazily, erratically, or in spirals—many diseases
- Scratching, flashing, or rubbing against objects in the pond—external parasites
- Twitching, darting, convulsions—toxins; nutritional disease; external parasites
- Failure to flee when exposed to fright stimuli—low oxygen; metabolic factors; many diseases
- Crowding or gathering in vegetation, shallow water, or at water inflow, hiding under objects to avoid light—many diseases; low oxygen; toxins
- "Topping" or "piping" at water surface, floating head-up, moribund (dying)—low oxygen; toxins; external parasites; bacteria

Some physical signs suggest disease. The following associations are often made:

- Dead or dying fish—many diseases
- Open lesions or sores, bloody or reddened areas—bacteria; bacteria secondary to parasite infections; external parasites; toxins
- Gaping mouths—low oxygen; diseased gills
- Scale loss—*Myxobolus notemigoni* (milk scale disease); external parasites; fighting; predation; rough handling
- Gills pale, eroded, puffy, bloody, or brown, or gill covers flared—anemia; vitamin deficiency; gill disease; environmental stress; toxins; external parasites; *Branchiomyces* (fungus); *Flexibacter columnaris* (bacterium)
- Bleached skin color—vitamin E deficiency; low oxygen

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- Exophthalmia (popeye), stargazing—bacterial dropsy; brain flukes; gas bubble disease; malnutrition; environmental contaminants
- Bloated belly (dropsy)—bacteremia; white grubs (flukes); *Ligula* (tapeworm); catfish virus (affects fingerlings)
- Excess mucus (light gray film), sloughing of skin, scratches on body—external parasites; fungus; fighting; predation
- Spinal curvature—vitamin C deficiency; pesticides; genetic deformities
- Folded fins or tail, pectoral fins pointed forward—toxins; many diseases
- Nodules, pustules, white spots—myxosporidian cysts (protozoans); larval trematodes (flukes); *Ichthyophthirius* or "Ich" (protozoan); yellow grub (fluke); larval nematodes
- Fluid in body cavity (cloudy, bloody, or clear)—bacterial dropsy; channel catfish virus; malnutrition
- Bloody internal organs—bacteria; virus; vitamin A or B deficiency
- White "fungus" patches—external fungus; *Epistylis* (protozoan)
- Frayed fins or tail, eroded tail—external parasites; *Flexibacter columnaris* or other bacteria; chemical contaminants
- Emaciation (thin fish, pinheads), reduced growth—any disease that causes fish to reduce feed intake or cease feeding; underfeeding; malnutrition; intestinal worms (helminths); vitamin deficiency
- Air bubbles under skin—gas bubble disease (excessive nitrogen or oxygen in the water)
- Cloudy eyes—eye flukes; nutritional deficiencies
- Red spots near bases of fins—larval *Lernaea* (copepod); external parasites; bacteria
- Gray, chalky white, or dull opaque yellowish ovaries or eggs in golden shiners—*Pleistophora ovariae* (protozoan)
- Ruptured abdomen—toxic algae (in fry); *Ligula* (cestode); white grub (trematode)
- Dirty gray or yellow lesions—bacteria; external parasites; external fungi
- Foul-smelling lesions—*Edwardsiella tarda* (bacterium)
- Hole-in-the-head—*Edwardsiella ictaluri* (bacterium)
- Brown blood—nitrite toxicity

Farmers with major investments in fish culture should seriously consider arranging for training in parasite identification and disease diagnosis for themselves and key personnel, and setting up basic facilities for examining fish and monitoring water quality. This training may provide diagnosticians with vital information that could save time in verifying or selecting the proper treatment.

Submitting Fish and Samples for Diagnosis

After observing fish with disease signs, the farmer must provide the diagnostician with specimens and information to ensure an accurate evaluation of the problem.

Preferably, about 10 sick or dying fish exhibiting one or more disease signs should be brought to the diagnostician. Dead fish samples are of little value in diagnostics. The fish should not be medicated before they are collected because treatment may reduce or eliminate the disease-causing organism and confuse the diagnostic results. The diagnostician needs to know several facts about the pond and history of the fish: (1) water information (source, temperature, pH, alkalinity, nitrite and ammonia content, dissolved oxygen concentration, condition of plankton bloom); (2) area and depth of the pond, and recent management history; (3) fish age, original source; (4) estimated organic content of pond (concentration of plankton [Secchi disk reading], and depth of detritus on the bottom); (5) previous diseases and treatments; (6) information about possible pesticides and herbicides used in the area; (7) disease signs observed in sick or dying fish; and (8) number of fish involved, and rate and duration of die-off.

Fish are submitted for diagnosis live, iced, frozen, or preserved. Live fish are preferred by most diagnosticians. Live fish should be transported in containers of sufficient size to maintain good water quality, and supplied with oxygen by aeration or with agitators. If

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the fish are shipped in plastic bags, the amount of water and oxygen must be adequate to support the fish during the transit period. Because sick fish frequently die in transit, their density must be reduced to offset the oxygen loss and water quality deterioration resulting from their decay. We recommend that 5 to 10 of the smallest, least seriously affected fish be placed in a tropical fish box that contains a plastic bag with about 1 gallon of water. The remaining volume in the bag is filled with pure oxygen and the bag is made airtight by securing the top with rubber bands. The bag is packed in a sturdy box with a Styrofoam liner (these lined boxes are sometimes available from pet shops and aquarium supply stores that receive shipments of tropical fish). During hot weather, a watertight bag of crushed ice or "artificial" ice should be placed beside the bagged fish (unless the fish are tropical varieties that cannot tolerate low temperatures). The box should be labeled "Biological Specimens—Perishable" and shipped by the fastest service available (often this is express delivery by a commercial bus line). The receiving laboratory should be notified when the shipment is scheduled to arrive.

Iced fish are sometimes satisfactory for diagnosis. Sick fish that may not survive the transfer to the laboratory can be shipped in crushed ice and ice-cold water if they will be en route for only a few hours.

To prepare frozen specimens, place the fish in a small quantity of water in a watertight plastic bag before putting them into a freezer. After they are thoroughly frozen, place the bag in a well-insulated, leak-proof Styrofoam container, with dry ice (which should keep fish frozen for 72 hours) or artificial ice (which should keep fish frozen at least 48 hours), or regular ice (if the shipment takes less than 24 hours). Never pack dry ice in an airtight container. The fish must not come into contact with dry ice or its fumes, because some viruses are inactivated by carbon dioxide.

Preserved fish may be suitable for a diagnosis of outbreaks of certain parasites, such as Ich, anchor parasites, or leeches; however, a complete routine fish disease diagnosis cannot be done on fish preserved in formalin or alcohol. If a check with the laboratory indicates that preserved fish may be suitable, they are prepared as follows: Slit the body cavity of freshly killed, small, sick fish, or remove the affected areas from larger fish, and place them in a jar of 10% formalin (1 part commercial formaldehyde solution to 9 parts water). Use about five times as much formalin solution as the volume of the sample preserved. Leave the sample in the solution for 1 day or more; then remove the fish, wrap them in newspaper or (even better) absorbent paper toweling soaked with formalin, and seal them in a plastic bag. Cushion them well with packing material and use a sturdy shipping box. Postal authorities usually do not forward containers that have leaked formalin.

If, after consulting a diagnostic laboratory, you suspect insecticide toxicity, wrap the fish in aluminum foil (not in plastic) and freeze them immediately for delivery to the laboratory. It is also important to immediately refrigerate about 2 gallons of pond water in clean glass containers (use aluminum foil to line the lids) for analysis.

Always contact the laboratory by phone before bringing or shipping fish for diagnostic services, to ensure that someone will be available when the specimens arrive.

Diagnostic services may be obtained from persons or agencies listed in Chapter 20. Some facilities provide free diagnostic assistance; others charge for their services.

Environment and Disease

Because fish are totally dependent on water, it is essential for the farm manager to know as much as possible about this complex environment—not only the water source and volume for each pond, but also such characteristics as dissolved oxygen concentration, total hardness, pH, alkalinity, nitrite and ammonia content, and temperature. Variations of any of these factors could affect the health of fish.

Stress caused by extremes in environmental conditions plays an important role in fish diseases. Low-oxygen stress is considered to be a major cause in outbreaks of *Aeromonas* (a

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bacterial pathogen), and channel catfish virus (CCV) disease during summer. *Flexibacter columnaris* (a bacterial pathogen) is associated with stress due to high water temperature and organically rich water.

Various management practices such as handling, hauling, excessive chemical treatments, overcrowding, and the feeding of nutritionally inadequate feeds may also impair fish health. Overcrowding of fish is common and is associated with many bacterial and protozoan diseases. Disease organisms are nearly always present in the water—ready to become problem-causing pathogens when fish are weakened by stress. Holding stress within the tolerance limits of the particular fish species being raised is a role of good management. The profit motive often overrules good management techniques, however; consequently, coping with a host of problems caused by poor water conditions is often considered a necessary headache.

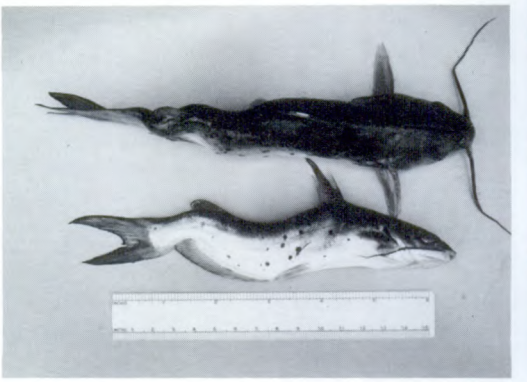


Fig. 14.1. Spinal curvature—lordosis and scoliosis—and dislocated vertebrae may be caused by a dietary deficiency of vitamin C. The presence of toxaphene, a chlorinated hydrocarbon insecticide used to control cotton insects, accelerates the onset of these signs. *Photo by Andrew J. Mitchell.*

Nutrition and Disease

The absence or a deficiency of essential food ingredients can cause nutritional diseases. Vitamin deficiency signs may be similar to many of the infectious disease signs. A reduced rate of weight gain and low food consumption are signs common to both infectious disease and poor nutrition. Signs of pantothenic acid deficiency include clubbed gill filaments and excessive mucus on the gills; choline deficiency can cause hemorrhagic areas in the kidneys and enlarged livers; and vitamin E deficiency can result in bulging eyes (exophthalmos or popeye).

Deficiencies of vitamin C are probably best known because some of the disease signs are obvious—e.g., reduced growth; crooked back or spinal curvature (Fig. 14.1); popeye; bloated belly; excess accumulation of fluid in the body tissues that causes swelling; bloody kidneys; discoloration or bleached color; and death.

Some of the most apparent vitamin deficiency signs are shown in Table 14.1. In addition to causing direct growth and development problems, vitamin deficiencies often increase the susceptibility of fish to infections (notably by *Aeromonas hydrophila,* and probably external parasites).

Disease Prevention

Only a few federally registered therapeutics are available for treatment of fish diseases, and it is generally recognized that disease prevention is more economical than treating sick fish with costly drugs and chemicals. Experience has shown that the following three management practices often prevent disease outbreaks.

1. *Suitable pond management.*—Where infectious disease organisms are known to occur, most can be eliminated from the pond after the fish have been harvested. If possible, the pond should be drained and allowed to dry. If it cannot be completely dried, all remaining fish can be killed by applying just enough fresh calcium hydroxide (hydrated lime) to cover the entire pond area (about 2 tons per acre), and additional liberal amounts to the puddles and wet spots. This chemical leaves no final toxic residue. The application of calcium hypochlorite (HTH) to water at the rate of 40 pounds per acre-foot (10 ppm available chlorine) has been used for killing fish, and also kills many types of disease organisms. The chemical should remain

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in the pond 2 or more days before the pond is drained or flushed. The HTH must be used with caution, because the chemical is corrosive and very irritating to the skin, eyes, and nose.

If all fish are kept out of the pond for several weeks, many fish pathogens (but not their spores) will die. Treatment of brood stock or fingerlings to remove the external parasites is a simple pecautionary measure. Also, the exclusion of wild fish that enter fish ponds may help avoid disease outbreaks.

2. *Maintenance of a disease-free water supply.*—Ordinarily, no pathogens are introduced with well water. Water from springs, however, may contain wild fish that pass infectious organisms along to the cultured fish. If water from streams or reservoirs containing fish is used, one can expect pathogens to be introduced into the culture ponds. At some trout hatcheries and warmwater fish farms, the contaminated incoming water is passed through sand and gravel filters to remove certain protozoans and larger parasites. Reservoir water can be treated with rotenone[x] to remove unwanted fish, or with HTH to remove predators and parasites. The chemicals must be dissipated or neutralized before fish are stocked into the pond. There is no practical way to remove bacteria and viruses from large, flowing supplies of surface water.

3. *Constant surveillance.*—Where there is danger of transmitting infectious diseases through fish transfer, the fish should first be inspected by a diagnostician. The practice of disinfecting nets, seines, tubs, and other

Table 14.1. *Vitamin deficiency signs in channel catfish.*[a,b]

WATER-SOLUBLE VITAMINS	
Thiamin	Reduced weight gain, lethargy, difficulty in maintaining equilibrium
Riboflavin	Opaque lens of one or both eyes, weight loss
Pyridoxine	Erratic swimming, tetany, gyrations, and muscular spasms when stressed, reduced weight gain
Pantothenic acid	Flabby body tissues; mummy-textured skin; excessive mucus on gill tissues, clubbed gill filaments; eroded gill membranes, lower jaw, fins, and barbels; lethargy; reduced weight gain
Niacin	Tetany induced by stress, lethargy, reduced coordination, photophobia
Folic acid	Anorexia and lethargy
Vitamin B-12	Reduced weight gain
Ascorbic acid	Lordosis, scoliosis, dislocated vertebrae, hemorrhage, impaired collagen production, reduced growth
Biotin	Slight growth and appetite reductions, skin depigmentation (caused by prolonged feeding period or addition of biotin antagonist)
Choline	Hemorrhagic areas in the kidneys and enlarged livers; reduced weight gain
FAT-SOLUBLE VITAMINS	
Vitamin A	Ascites, edema, exophthalmia, hemorrhagic kidneys
Vitamin E	Exophthalmia, pericardial edema, reduced growth
Vitamin K	Excessive hemorrhage resulting in death

[a]Not listed are the water-soluble vitamins inositol and para-aminobenzoic acid, which are abundant in most fish feed ingredients, and the fat-soluble vitamin D, which occurs in fish oils. Deficiencies rarely, if ever, occur and no specific deficiency signs are known from feeding practical diets.

[b]Adapted from H. K. Dupree. 1977. Vitamin requirements. Pages 26–29 *in* R. R. Stickney and R. T. Lovell, eds. Nutrition and feeding of channel catfish. Southern Cooperative Series Bulletin 218, Alabama Agricultural Experiment Station, Auburn University, Alabama.

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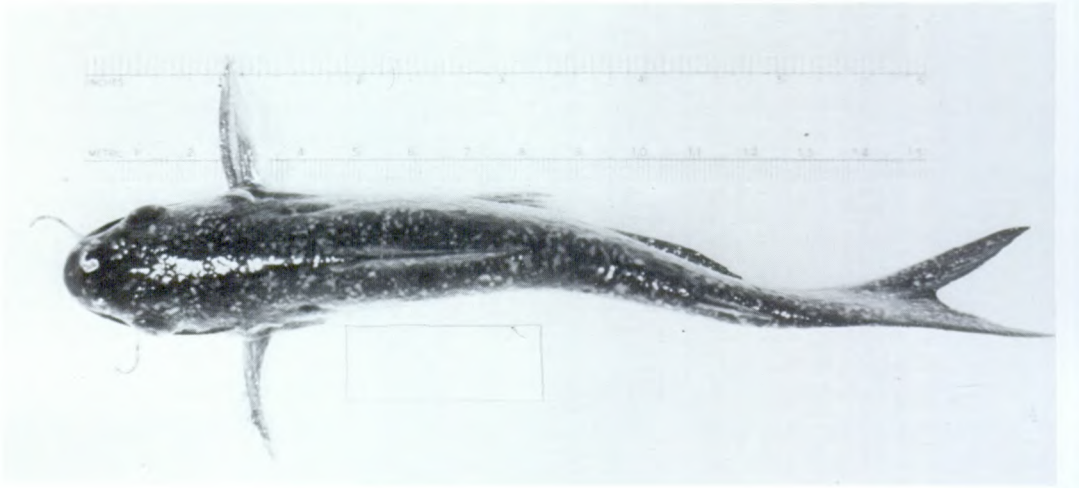
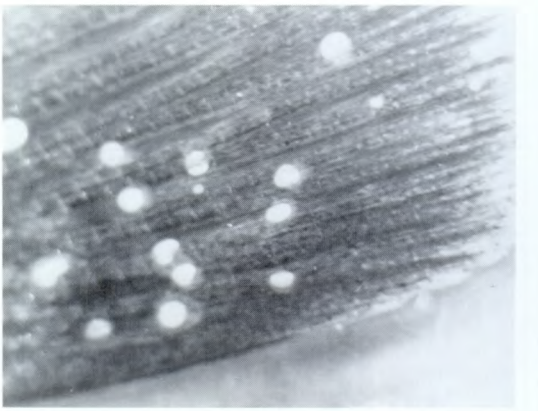




Fig. 14.2. *Ichthyophthirius* on a channel catfish. Ich infects almost all species of freshwater fish and is one of the most devastating pathogens. Cyst-like stages known as trophonts can often be seen (top photo) covering the entire surface of the fish. *Photo by Glenn L. Hoffman.*

Fig. 14.3. *Ichthyophthirius* on a scaled fish (grass carp; center photo). The spots on the fins and skin are most noticeable after Ich has reached the mature stage. Such heavy infestations are most often seen in the spring when water temperatures are rising. *Photo by Brenda Rodgers Moore.*

Fig. 14.4. Microscopic view of *Ichthyophthirius multifilis* on a fin of a fish (photo at right). From these trophonts embedded in the tissue, the infective free-living theronts are produced. *Photo by Glenn L. Hoffman.*



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equipment before and after harvesting and transporting fish, even though no disease problems are observed, reduces the possibility of introducing or spreading infectious diseases.

Infectious Parasites and Diseases

Externally Visible Signs and Parasites

Often the fish producer sees the results of an infection rather than the organism that causes it. These visible characteristics or signs aid in the identification of the infective pathogen, although they are not positive proof that a certain pathogen is present. Listed here are some diseases that result in signs visible to the unaided eye.

Protozoans

Ichthyophthirius (Ich; Figs. 14.2, 14.3, 14.4) has one major visible sign: tiny white spots on the fins and skin are noticeable after Ich has reached the mature stage. When very numerous, the spots are so close together that they form whitish patches on the fish. Ich is not visible in the infective (theront) stage, although infected fish can sometimes be seen flashing, twitching, or rubbing against something in the pond or vat. Ich is very difficult to treat because the organism burrows into the surface tissue of the host fish; however, the theronts can be killed because they are free in the water before they infect the host. Ich infects almost all species of freshwater fish at water temperatures from 32 to 80°F and is rarely seen as a light infection, except in cyprinids. It sometimes extensively covers the body and fins, often damages the gills, and can cause 100% mortality of an infected group of fish.

Any population of fish in which the parasite has previously been found must be considered as a potential reservoir for Ich. If it occurs in a pond or raceway, boots, seines, buckets, and other equipment that have been in contact with the water must be disinfected. The practice of disinfection is one of the best ways to prevent the spread of any disease organism. Roccal,® or a similar compound, is satisfactory for this purpose when used as recommended on the label.

Epistylis (Figs. 14.5, 14.6) has the following visible signs: thick white or dirty yellow patches or streaks on scales, fins, and sometimes the body. It is difficult to control, and tends to flourish in water with a high organic content. It is reported to infect many species, but most often sunfishes, catfish raised in raceways, catfish egg masses, and striped bass. *Epistylis* is not a true parasite. It attaches itself to the fish and feeds on small organisms in the water. There is much irritation at the

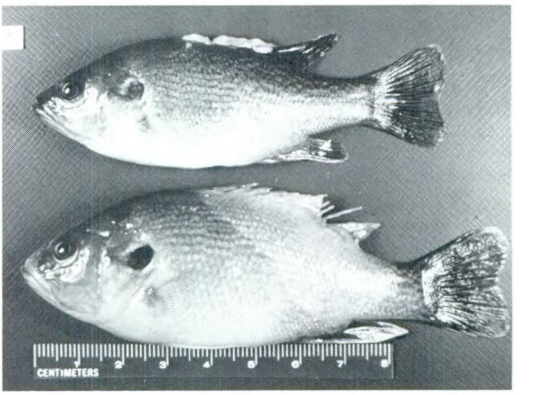


Fig. 14.5. *Epistylis* on green sunfish. The fin and scale damage is the result of fungal and bacterial invasion of the irritated surfaces. If transferred to clean water, the fish may recover with no lasting damage. *Photo by Glenn L. Hoffman.*



Fig. 14.6. This microscopic view of an *Epistylis* infection on channel catfish illustrates how dense these commensal organisms (here roughly triangular or inverted bell-shaped) can become when water quality is allowed to deteriorate. *Photo by Glenn L. Hoffman.*

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attachment site, however, which often leads to secondary bacterial involvement. To help prevent an outbreak of this parasite, the farmer should avoid excessive crowding and high organic levels in the ponds or raceways. Although *Epistylis* is mainly a coolwater (spring and fall) problem, it sometimes occurs in summer.

Myxobolus notemigoni (Fig. 14.7) causes milk-scale disease. Visible signs are raised scales and white cysts that sometimes cause a milky appearance when they are ruptured. This disease forms cysts beneath the scales of golden shiners, causing them to raise or loosen, giving the fish a milky, swollen appearance. When a large number of cysts rupture (releasing the spores) the scales are sloughed off, making the fish highly susceptible to secondary diseases. There is no available treatment for this sporozoan, but prophylactic treatments can be given to prevent the onset of secondary invaders. After about 1 month, the scales usually regenerate sufficiently to prevent secondary infection.

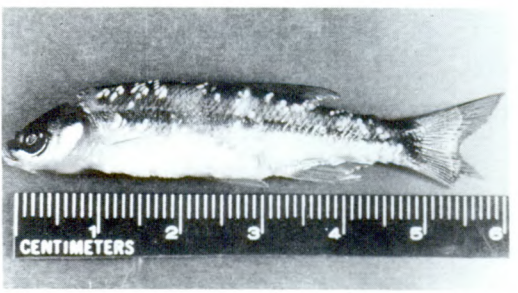


Fig. 14.7. *Myxobolus notemigoni* infection of a golden shiner. In addition to weakening fish, this protozoan reduces their marketability. *Photo by Glenn L. Hoffman.*

Myxobolus argenteus (Fig. 14.8) is a sporozoan disease characterized by large white cysts on the body. The cysts rarely kill the host fish, but may adversely affect its salability or increase its visibility to predators.

Trematode

Diplostomulum spathaceum (Fig. 14.9), the eye fluke, is a larval digenetic trematode that develops in the lens of the eye of channel catfish and other warmwater fishes. The visible sign is an opaque, white lens. Although heavy infections may cause blindness, this parasite causes little economic loss.



Fig. 14.8. *Myxobolus argenteus* infection of a mature golden shiner. When these cysts rupture, the fish may recover without any visible signs. *Photo by Glenn L. Hoffman.*

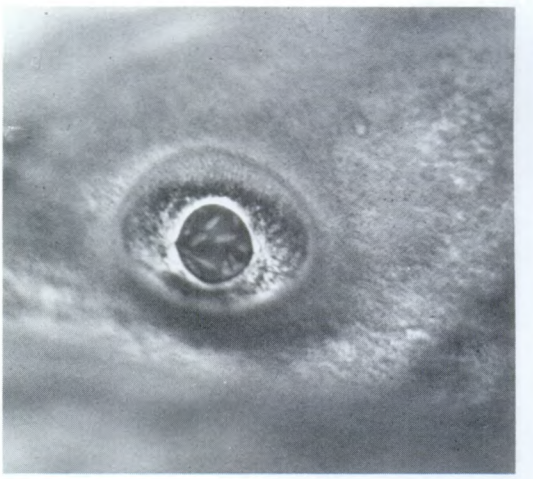


Fig. 14.9. The fluke *Diplostomulum spathaceum* develops in the lens of the channel catfish and other warmwater fishes. Individual flukes are visible in the eye of this channel catfish. Heavy infections cause blindness. *Photo by S. K. Johnson.*

Cestode

Ligula intestinalis (Fig. 14.10) is a large visceral tapeworm found in pond-cultured and some wild populations of many fishes, including the fathead minnow. The visible sign is a greatly swollen belly. The tapeworm larva burrows through the stomach wall into the body cavity and grows, eventually causing the

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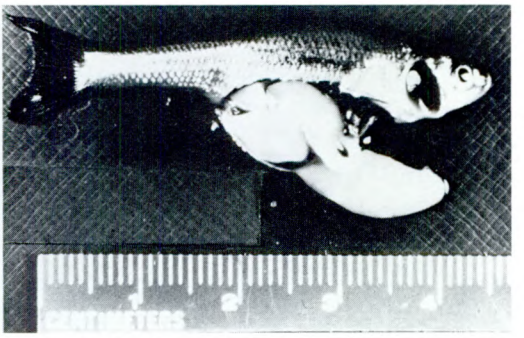


Fig. 14.10. *Ligula intestinalis* in the body cavity of a fathead minnow. The tapeworm—shown here as a white mass—sometimes becomes larger than the fish it infects.

belly to rupture and the fish to die. Infected fish—usually less than 3% of the total population—are not marketable.

Crustaceans

Lernaea, a copepod known as the anchor parasite (Fig. 14.11), is visible to the unaided eye as an adult. The larvae may be suspected when red spots are seen near the bases of fins and the fish are sometimes seen twitching or flashing. The anchor parasite affects a large number of warmwater fish, particularly golden shiners, goldfish, fathead minnows, buffaloes, and grass carp. The female larva burrows into the fish and grows out as a short splinter-like extension. A large fish can support a large number of these parasites, but a small fish can be killed by even one of them. The parasite seems to have an affinity for the heart region of small fish and often kills by piercing the heart or other vital organs. In larger fish the mortality is much lower and death occurs slowly, sometimes due to electrolyte (salt) loss through the wounds made by the parasites, or from a secondary fungal or bacterial infection of the wound. *Lernaea* is extremely difficult to control because only the free-living larvae are susceptible to treatment. The adult female produces three sets of eggs, after which she dies; these eggs produce larvae over about a 4-week period. Since the larvae remain free-living for about 1 week, it is necessary to treat once a week for 4 weeks to eliminate this parasite.

Argulus, Ergasilus, and ***Achtheres*** are three other crustaceans that appear on warmwater fish; usually the adults, but not the immature forms, are visible to the unaided eye.



Fig. 14.11. Female anchor parasites (*Lernaea cyprinacea*) protruding from beneath the throat of a golden shiner (the male is a non-infective microscopic organism). The attached form will eventually die—but usually not until after it has released more infectious forms, unless a corrective treatment is administered. *Photo by Glenn L. Hoffman.*



Fig. 14.12. Fish louse (*Argulus flavescens*) from a channel catfish. It resembles the lice that infect humans and other terrestrial mammals. Individuals ¼ inch in diameter are not unusual. *Photo by Glenn L. Hoffman.*

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Fig. 14.13. A leech attached to the operculum of a rainbow smelt. Leeches are also found on the fins and ventral surfaces of fish, but seldom cause death. *Photo by N. Ehlinger.*

Argulus (Fig. 14.12), the fish louse, occasionally causes problems with channel catfish, but is more often found on goldfish, on which it forms a flat disc up to ¼ inch in diameter. The sting of one fish louse can kill a small fish. Many lice sometimes collect on large fish and cause extreme irritation over the body surface. Research shows that they can usually be controlled effectively with one or two treatments of Masoten[x].

Ergasilus and *Achtheres* are found on the gills and in the mouth of channel catfish and several species of sunfish. *Ergasilus* rarely kills fish, and *Achtheres* has not been reported to cause significant problems.

Leeches

Leeches (Fig. 14.13) are often seen on wild fish, and occasionally on cultured fish. The visible signs are undulating worms attached to the body, fins, gills, and mouth; in catfish they usually congregate beneath the chin. If the leeches leave or are removed, the attachment site is open for secondary fungal and bacterial infections.

Fungi

In fishes, external fungus (usually *Saprolegnia*) appears in the form of fuzzy gray-white or dirty brown patches on the body (Fig. 14.14). Fungal infections cause significant losses in most fish production facilities. Many fungal problems follow a primary bacterial or parasitic infection, or a mechanical injury or other trauma; thus they are usually secondary invaders, although some species are pathogenic enough to initiate infections. Such infections are usually preceded by the presence of a strong environmental stressor such as low oxygen or a contaminant in the water. Fungus

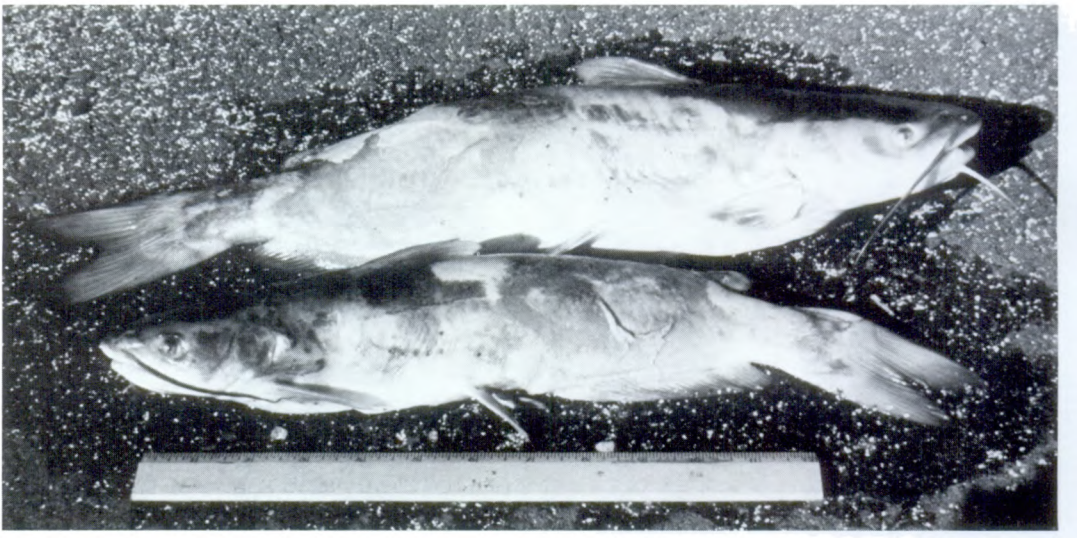


Fig. 14.14. External fungus on channel catfish can cause extensive damage, as shown here. Not only are affected fish weakened and likely to die, but they are also unmarketable because of their appearance. *Photo by Andrew J. Mitchell.*

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Fig. 14.15. Gill rot caused by *Branchiomyces,* an internal fungal infection. Portions of the gill of this common carp have died and the decayed tissue has fallen away, severely reducing the fish's ability to respire. *Photo by N. Fijan.*

infections usually occur in late winter or early spring but sometimes follow bacterial infections during the warmer periods of the year.

Fungal lesions occur almost anywhere on the body of fish, often appearing "dirty" because they collect debris from the pond. In ponds with dense populations of channel catfish, the gills often become infected and large losses of fish can occur. This is a difficult disease to treat because the mycelium (mature parts of the fungus) cannot be killed or removed; therefore the zoospores (free-living units) must be killed.

Branchiomyces (Fig. 14.15) is an internal fungus that occasionally occurs in freshwater fish and is responsible for one type of gill rot. Portions of the gill appear brown and decayed. *Branchiomyces* has been found in most species of pond fish and can kill up to 30% of the fish. It has a rapid onset, lasts 5 to 7 days, and then disappears equally fast. Occasionally it has already run its course by the time it can be diagnosed. It lives in the gill lamellae and filaments, cutting off the circulation to some areas of the gill. The affected areas die and decay—hence "gill rot." In recovered and healed fish, large sections of the gill may be missing. This disease is most commonly seen in rich organic ponds; no known effective drug exists, but the disease can be somewhat controlled by reducing the organic load (adding more water), liming frequently, and drying out the pond after harvest. This fungus is distributed worldwide, and could probably infect all species of freshwater fish.

Bacteria

Flexibacter columnaris (Figs. 14.16, 14.17) is probably the most significant stress-related warmwater fish pathogen, and the cause of the well-known columnaris disease. It shows up on scaled fish as dull patches on the sides with some scale loss, and often the fins—particularly the caudal fin—are badly frayed. In advanced cases, the tail fin is lost and the musculature is eroded to the bone. In sunfishes, a lesion often appears just behind the pectoral fin and frayed fins are common. On scaleless fish, such as catfishes, the lesions appear as dull patches (caused by lack of mucus) which often pass under the belly or over the back, giving a saddle-back appearance. In channel catfish the fin and barbels become badly eroded, and sometimes a yellowish hue is seen on the mouth. In spite of all these signs, the presence of the bacterium should be verified microscopically and in culture. The organism causes disease problems throughout most of the year, but is at its worst in summer. Golden shiners are so highly susceptible that the fish must be prophylactically treated after handling. This disease can kill 100% of the fish in a short period (2 or 3 days) or kill a few fish each day for several weeks. It often is systemic, requiring a medicated feed for full control. Sensitivity tests to determine antibiotic resistance should be performed before medicated feed is given.

Edwardsiella tarda causes one of the most repulsive bacterial diseases of harvestable-size channel catfish. Its visible signs are large deep lesions on the sides of fish, usually behind the pectoral fin, which when cut open emit a highly objectionable odor. The fish must be inspected for this disease before being removed from the production pond for processing. A large scar can usually be seen on fish that have recovered from this infection.

Edwardsiella ictaluri (Fig. 14.18) is a newly recognized pathogen that attacks channel catfish in ponds and raceways. The infection occurs at water temperatures of 77 to 86°F, and has caused mortalities exceeding 50%.

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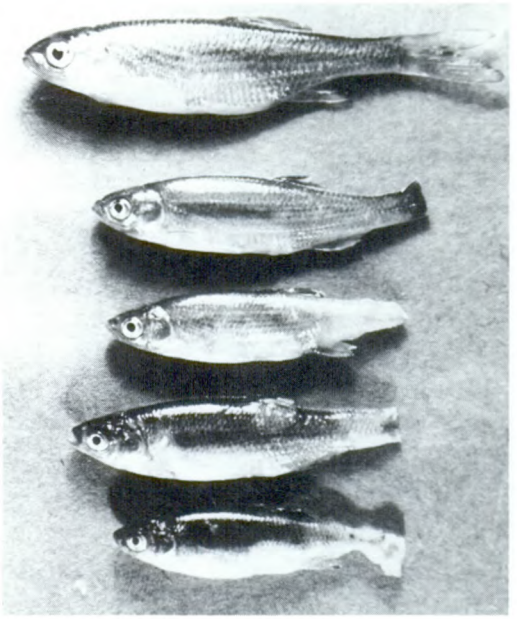


Fig. 14.16. *Flexibacter columnaris,* with a secondary fungal infection, on golden shiners. These disease signs are the result of a chronic infection that slowly destroys the flesh and bony structures. Acute infection can kill fish within 2 days, before these signs develop. *Photo by Andrew J. Mitchell.*



Fig. 14.17. Gross signs of *Flexibacter columnaris* are very distinctive to the unaided eye. However, the presence of the bacterium should be verified microscopically. The bacteria form "haystacks" or columns as shown here—hence the name "columnaris." *Photo by Andrew J. Mitchell.*



Fig. 14.18. *Edwardsiella ictaluri* may cause quick and violent death in channel catfish. The disease is an infection of the covering of the brain and spinal cord—similar to human meningitis—and may rupture the surface, thus causing the "hole in the head." *Photo by Glenn L. Hoffman.*

Visible signs include small lesions on the sides of fish and redness at the bases of the fins and on the belly, but one of the most obvious signs is a raised white or reddish lesion progressing into a slit between the eyes, exposing the brain (hence "hole-in-the-head" disease); however, this condition is not always present. Behaviorally, the fish hang listlessly at the surface and, just before death, spin rapidly in circles.

Aeromonas hydrophila causes large economic losses in channel catfish and bait-minnow culture during summer. Often the first visible signs are a cessation of feeding; the fish then develop redness at the bases of the fins, merging into the body; the abdomen may be bloated; the eyes may bulge (popeye); a cloudy fluid may be present in the body cavity; and gas pockets may be visible in the gut. The internal organs may appear pale or whitish. Lesions with irregular edges on the body surface are apparent on catfish, but may be masked on scaled fish—although the scales may be raised. Fish appear listless, congregating along the edge of the pond or tank. The occurrence of this disease usually is associated with environmental stress. Because the course of an *Aeromonas* infection is usually rapid—less than a week—it is important to diagnose it as soon as possible. One of the first signs of this disease is a reduction in feed consumption, and because the treatment involves feeding medicated feed, fish that do not eat will receive no medication. Treatment should be started as soon as possible to provide medication for the fish still feeding. Sensitivity of

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Fig. 14.19. *Aeromonas salmonicida* (goldfish strain) is now considered the most serious pathogen of goldfish. Problems with this disease can usually be avoided if feeds and water quality management are good, and the brood stock is pathogen-free. *Photo by Glenn L. Hoffman.*

the bacterial organisms to antibiotics should be determined.

Aeromonas salmonicida (goldfish strain; Fig. 14.19) is now considered the most damaging pathogen of goldfish, sometimes killing over 50% of a farmer's brood stock. The disease is especially damaging to ornamental goldfish. The visible signs include ulcers that develop on the sides of the fish. They can be sharply defined, or appear as a large, bloody lesion (often associated with some scale loss). Ulcers may also be present on the gill cover and mouth. The organism seems to favor spawning fish, and especially fish that are handled just before spawning. The disease begins to cause problems when water temperature reaches 55°F, but seems to subside when water temperatures exceed 75°F, although some infected fish may be seen year-round. No treatments, with the exception of chloramphenicol[x] injections, are effective. Nitrofuran[x] medications in the water help, but do not eliminate the problem. The key for prevention seems to lie in avoiding the handling of fish during or just before the spawning period, and offering the fish the most nutritious feed available.

Viruses

Golden shiner virus disease causes low-grade chronic mortalities in ponds and has been reported to cause high mortality in golden shiners held in tanks. Visible signs of the disease include a red-back or red-head condition caused by expanded blood vessels beneath the surface of the skin (hyperemia), and intestinal hemorrhage and hyperemia on the ventral surface of the fish. Often the larger fish in a pond are most severely affected; just before dying, they become listless and swim in a slow spiral. The economic impact of the disease is not yet known. There is no cure and the only recommendations are avoidance, disinfection (drying, disking, and liming pond bottoms), and the use of uninfected fish stocks.

Lymphocystis disease affects certain freshwater and saltwater fishes worldwide. Visible signs are whitish rounded lumps on the fins or skin (sometimes exceeding ¼ inch in diameter) caused by the enlargement of single skin cells that results from the action of the virus in the cells. Sometimes nearly the entire body surface is affected. The fish are presumably more vulnerable to prey because of their increased visibility, but the virus itself is rarely, if ever, lethal. The condition may continue for several weeks, but the enlarged cells then often slough off, leaving no trace or scar. Positive identification can be made in tissue culture; however, the gross and microscopic appearance of the disease is fairly reliable for diagnosis.

Channel catfish virus disease (Fig. 14.20) affects only fingerling channel catfish and blue catfish. Visible signs include popeye, bloated abdomen, and a redness on the ventral surface (belly) and at the bases of the fins. Sometimes these signs are not evident, but rapid and high mortality occurs. The gills are pale, and a yellowish fluid is usually present in the body cavity, along with a very dark spleen. The virus can kill all of the infected population within 2 to 3 days, or the losses can continue for as long as 2 weeks; mortalities range from 10 to 100%. Usually young fish—less than 5 inches long or 4 months old—are the most susceptible. Fish about 7 inches long or longer rarely contract the disease. The infection is believed to be transmitted from carrier brood fish (fish that were previously infected but survived), but this form of transmission has not been conclu-

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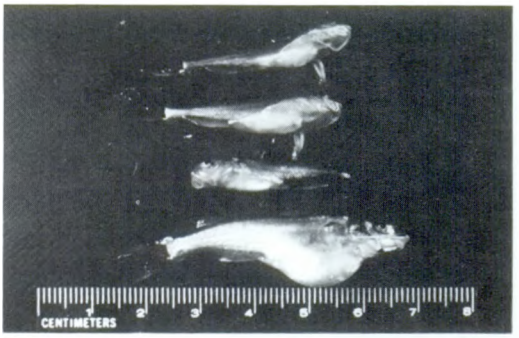


Fig. 14.20. Channel catfish virus disease affects only fingerlings. The bloated abdomen shown here, a characteristic sign of the disease, is caused by the accumulation of fluid in the abdominal cavity. *Photo by Andrew J. Mitchell.*

sively proven. The disease is known to occur during summer, from June to September. The occurrence of the disease is related to handling of the fish or low oxygen, with an accompanying water temperature above 73°F. Limited control can be effected by holding fingerlings in water below 73°F.

No treatment exists for channel catfish viral disease or any other viral fish disease. Management practices involve disinfection and the use of carrier-free brood stock, obtained from virus-free stocks. However, few virus-free populations are known. Ponds from which diseased fish are removed should be drained, dried, disked, and either limed or disinfected with HTH. Survivors of epizootics should not be stocked in uncontaminated waters, nor should they be used as brood stock.

Microscopic Parasites

Protozoans

Trichodina (Fig. 14.21) is probably the most common of all parasites affecting warmwater fishes, causing serious problems during spring and fall in the Southeast. It is found on the fins, body, and gills of catfish and goldfish, golden shiners, and other cyprinids, and appears to "graze" on the mucus of the fish, sometimes causing extensive gill damage. It usually occurs in ponds that have a high organic load and are somewhat crowded with fish, but can occur in almost any water.

Ambiphrya (Fig. 14.22) is a troublesome single-celled animal that attaches to gills or fins of a fish and feeds on organisms in the water. It often becomes a problem when large populations build up on the gills and block respiration. It sometimes causes moderate losses in farm ponds and is often associated with other parasites such as *Trichodina*. It becomes abundant during spring and fall in highly organic waters on catfish farms in the Southeast.

Chilodonella (Fig. 14.23) causes major problems with channel catfish and other species from fall to spring. Two species, *C. cyprini* and *C. hexasticha,* tolerate a wide temperature range (41 to 71°F) and cause massive clubbing of the lamellae and fusion of the gill filaments. *Chilodonella* may also amass in great numbers on the body and fins and, like Ich, is then usually devastating. Its incidence is related to highly organic waters, low to moderate temperatures, and crowded conditions.

Ichtyobodo (previously known as *Costia;* Fig. 14.24) can cause serious problems for all freshwater fish in spring and summer in the Southeast. It damages gills, reducing the respiratory surface below the critical level for life, and also sometimes covers the fins and amasses on the skin. Although treatments are effective in tanks, the parasite is usually not completely eliminated and its population quickly rebuilds and presents a continual treatment challenge. In ponds, it is difficult to cure in one treatment because the attached stage lies below the mucus of the gills, fins, and skin.

Trichophrya (Fig. 14.25) is reported to be a major problem during spring by channel catfish producers in the delta region of Mississippi. It occurs mainly on gills and causes irritation, destroying the effective respiratory surface.

Henneguya (Figs. 14.26 and 14.27) is a sporozoan parasite commonly found in almost all populations of channel catfish. Most species of the genus are of little consequence; however, *H. postexilis* (an interlamellar form) sometimes kills large numbers of channel catfish. The growing cysts block off areas of the gills, preventing adequate respira-

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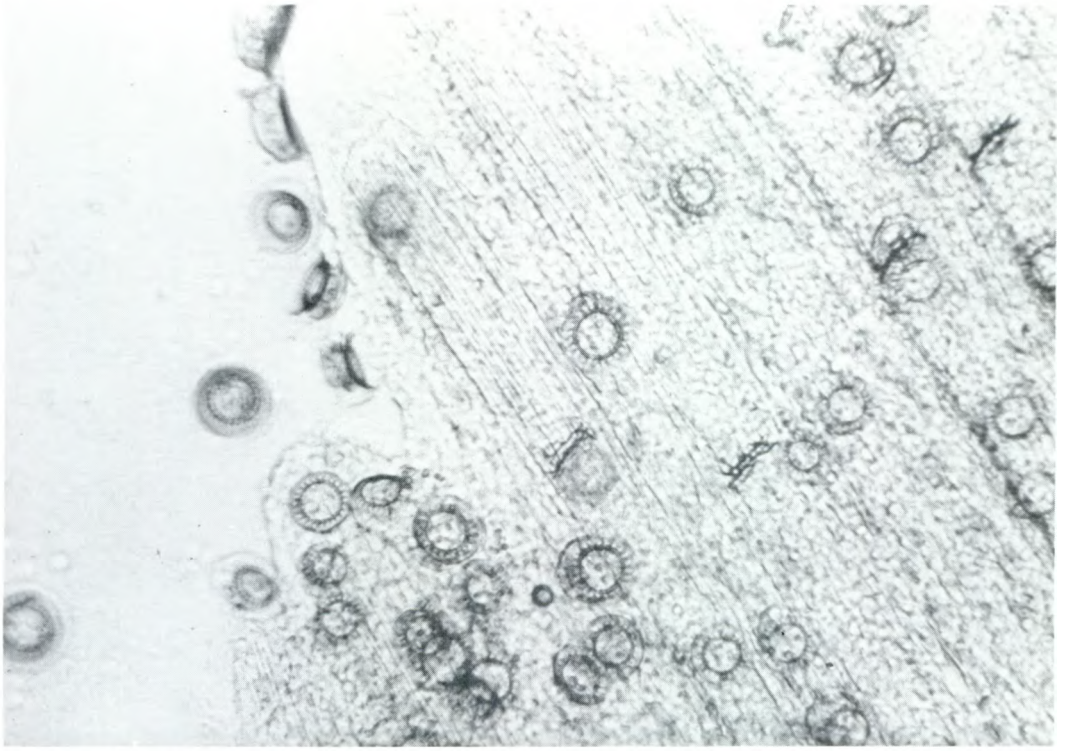


Fig. 14.21. *Trichodina* as seen microscopically on a fin of goldfish. This parasite can cause extensive damage as it moves over the gill surface. *Photo by Andrew J. Mitchell.*

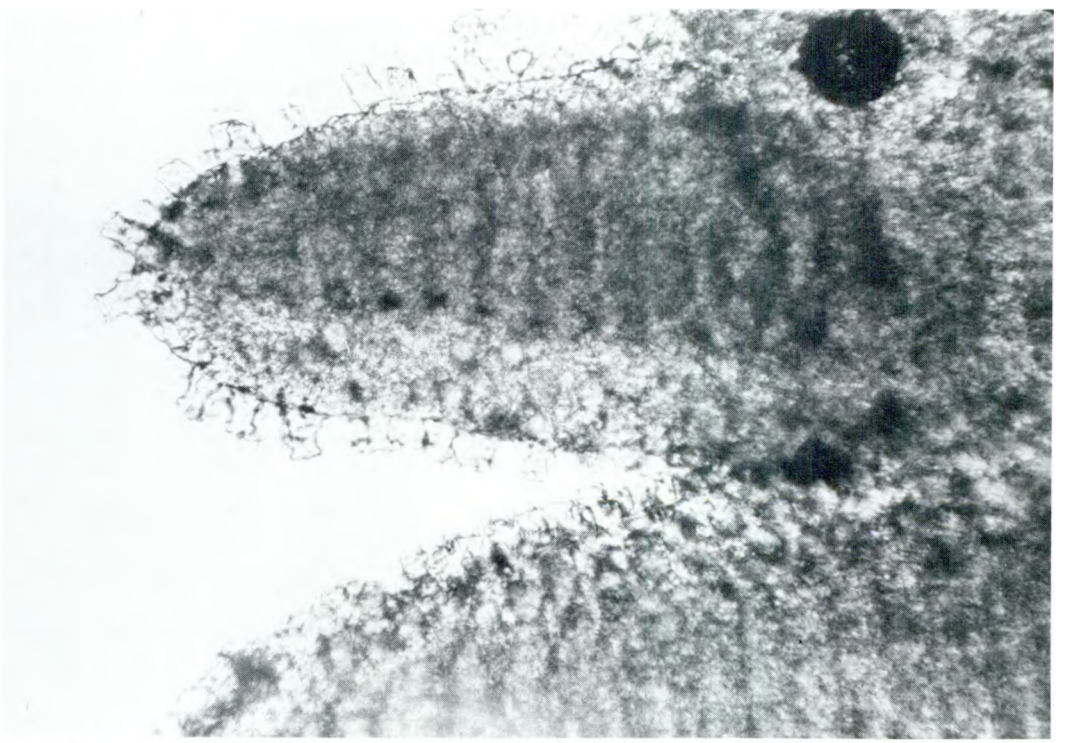


Fig. 14.22. *Ambiphrya* on channel catfish gill, seen microscopically. Shown here is a gill lamella with the urn-shaped parasite attached. When present in large numbers, the parasite blocks respiration. *Photo by Glenn L. Hoffman.*

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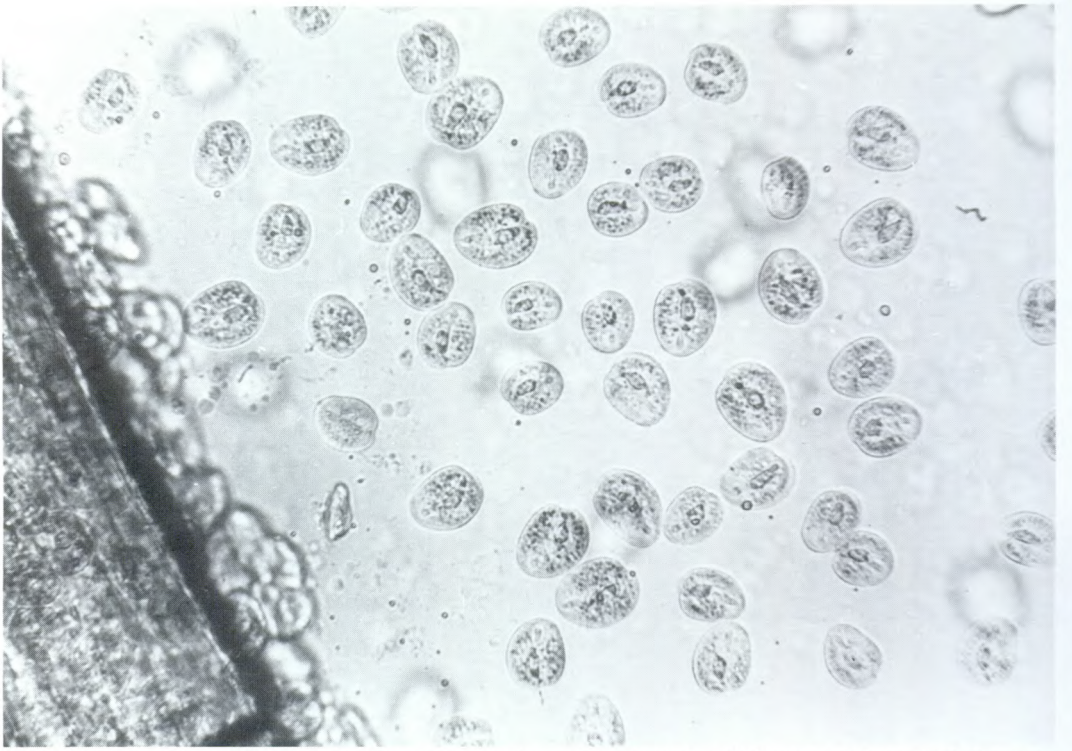


Fig. 14.23. *Chilodonella* may cause clubbing of the lamellae and fusion of the gill filaments. It is particularly prevalent in highly organic culture systems at temperatures of 40 to 70°F. *Photo by Glenn L. Hoffman.*

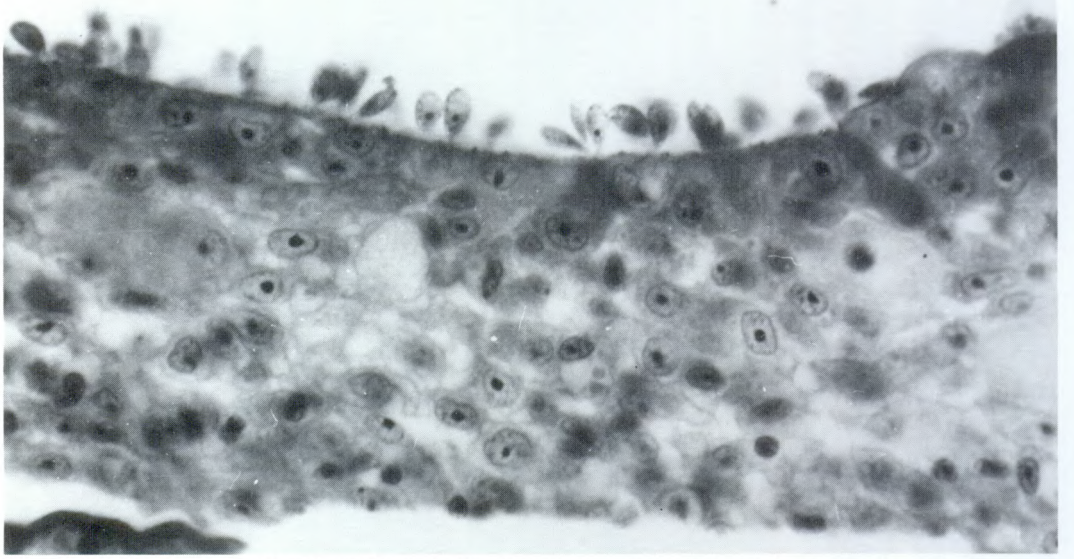


Fig. 14.24. *Ichtyobodo* (= *Costia*), as shown in this cross section of channel catfish, attaches beneath the mucus of gills, fins, and skin. The pear-shaped structures projecting above the skin surface are individual parasites. *Photo by H. S. Davis.*

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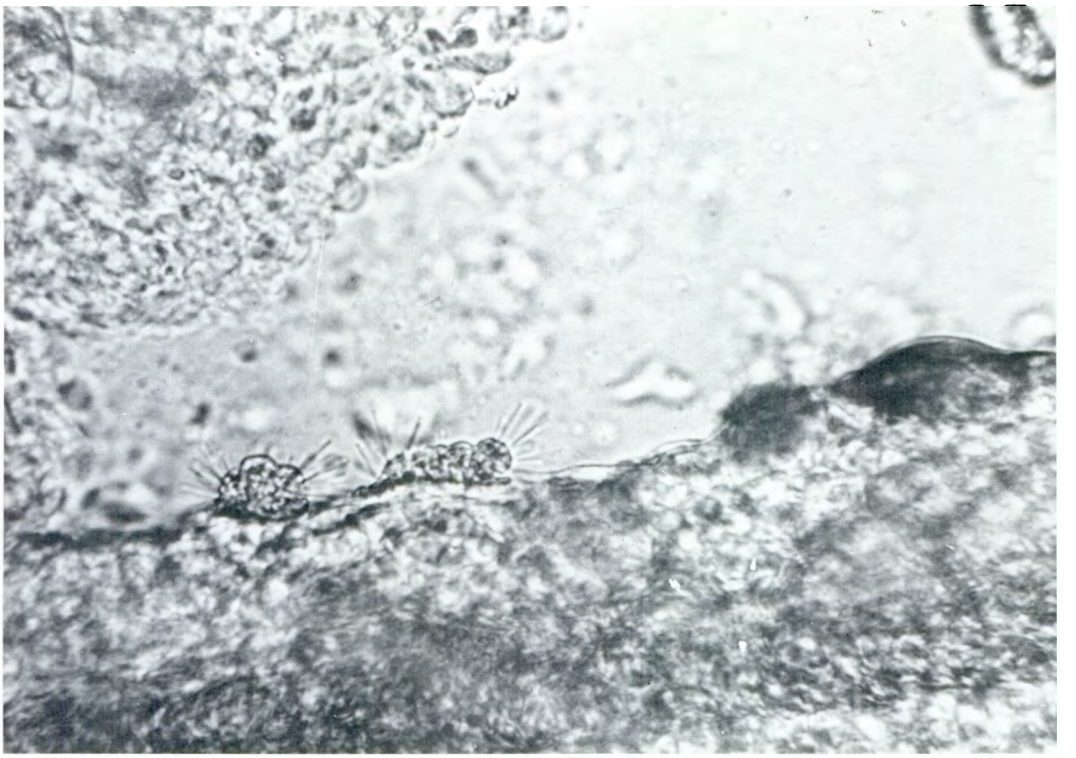


Fig. 14.25. *Trichophyra* on channel catfish, as seen through a microscope. The parasite damages the gill surface, increasing the sensitivity of fish to low dissolved oxygen. *Photo by Andrew J. Mitchell.*

tion. The gills appear whitish, and in unusually severe cases support hundreds of microscopic cysts that cause death of the host. The time of cyst development is uncertain, although cysts have been seen principally in early spring. There is no treatment for this parasite, but drying, disking, and liming of the pond bottom might prove beneficial in reducing the number of infective spores.

Pleistophora ovariae (Fig. 14.28), another sporozoan, can cause partial to complete destruction of the ovaries of golden shiners, thus causing problems by reducing egg production of brood fish. Infected ovaries often have discolored areas or appear to have an uneven texture. The problem is sometimes serious enough to necessitate obtaining new brood stock every year. No practical effective cure is available, but replacing brood stock annually has proved to be an effective management tool on some farms.

Flukes

External flukes are found on most species of warmwater fish. The body fluke ***Gyrodactylus*** (Fig. 14.29) usually attacks baitminnows or goldfish, but can kill almost any freshwater fish. "Gyros" of pond fishes are found primarily on the body, but sometimes spread to the gills. On the body they occasionally amass at extremely dense levels, causing irritation and hemorrhage at the bases of fins and on the body and resulting in the death of many fish. The flukes occur throughout the year but do not usually cause problems during summer in the Southeast. There are reports that *Gyrodactylus* may be developing a resistance to both formalin and Masoten® (the preferred chemicals), even when used at twice the usual dosage.

The gill fluke ***Dactylogyrus*** (Fig. 14.30) affects many fish species and has been reported to cause mortality in goldfish (particularly fry). Larger fish, such as salable golden shiners, can be killed by the gill damage resulting from the presence of large numbers of these parasites. *Dactylogyrus* is difficult to treat, and two or more applications of chemi-

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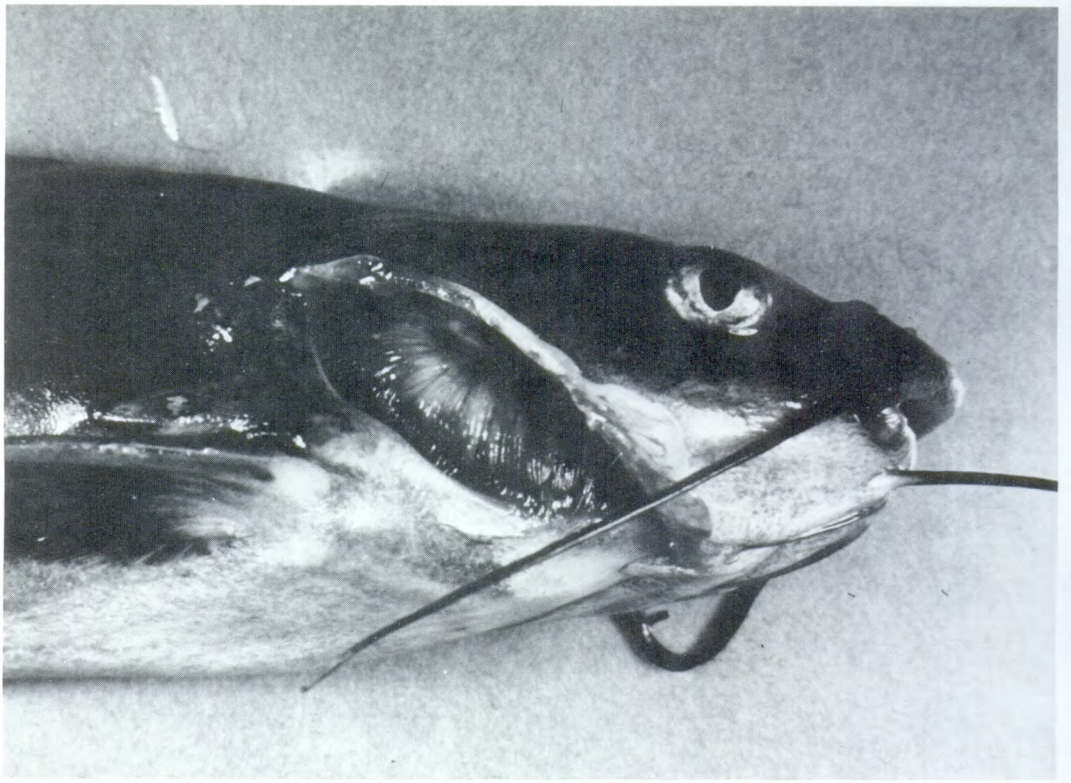


Fig. 14.26. Interlamellar *Henneguya* in gills of channel catfish. The cysts block the blood supply to the gills, causing death and decay of the tissues. *Photo by Andrew J. Mitchell.*

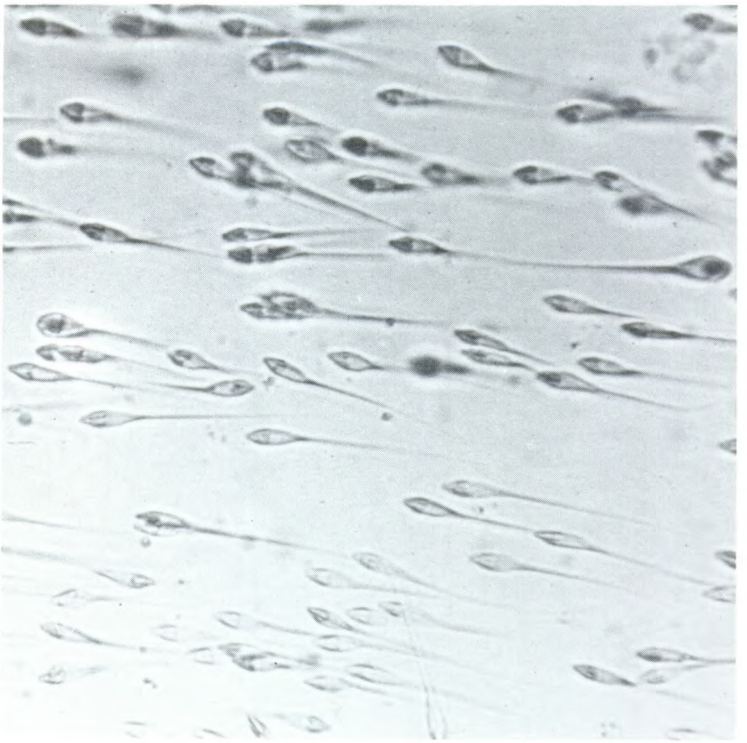


Fig. 14.27. Spores of interlamellar *Henneguya* from a cyst on the gills of channel catfish. This form is infective for other fish. *Photo by Andrew J. Mitchell.*

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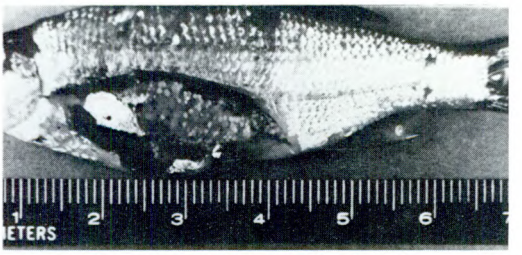


Fig. 14.28. *Pleistophora ovariae* in the ovary of mature golden shiners. The white areas in the ovary are eggs killed by the parasites. This reduction in egg production can be prevented by using parasite-free brood stock. *Photo by Glenn L. Hoffman.*

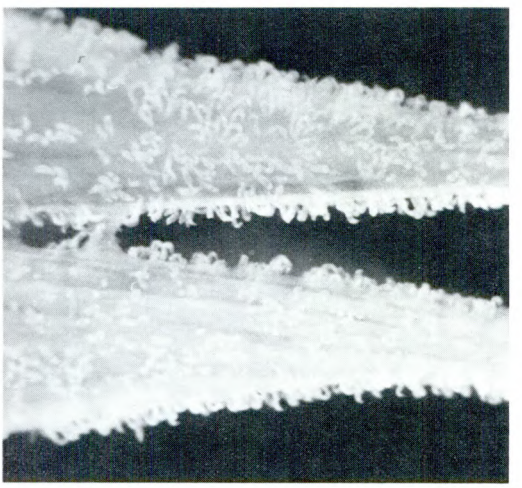


Fig. 14.29. *Gyrodactylus* on the tail of a goldfish. These parasites are held to the skin by anchors (not visible), which cause irritation and hemorrhaging, and an entrance site for bacteria. *Photo by Glenn L. Hoffman.*

cals may be required. Other gill flukes, such as *Cleidodiscus,* occur on channel catfish but seldom cause problems.

Internal Macroscopic Parasites

Trematodes

Clinostomum complanatum (previously known as *C. marginatum;* Fig. 14.31), the yellow grub, embeds itself in the flesh, visceral cavity, and sometimes the gills of fish, forming large, cream-colored cysts. These larval flukes become adults in the intestine of birds that eat infected fish. They seldom cause problems, except when they amass in the musculature of young fish. No practical treatment is available; however, some control can perhaps be achieved by reducing the numbers of snails, an intermediate host of the parasite.



Fig. 14.30. The gill fluke *Dactylogyrus* can cause death of goldfish, golden shiners, and many other species by its destruction of gill tissue. *Photo by W. Rogers.*

Posthodiplostomum minimum, the white grub, seen as a small white spot, seldom harms fish, but may become so numerous in the muscles of striped bass and body cavity of fathead minnows that the fish are killed by trauma to the vital organs and rupture of the body wall. No treatment is available but these trematodes can sometimes be controlled by reducing the numbers of snails that carry the parasite. The use of chemicals that kill snails and the stocking of snail-eating fish such as redear sunfish have reportedly been helpful.

Cestodes

***Bothriocephalus opsarichthydis* (*B. acheilognathi, B. gowkongensis*),** the Asian tapeworm, sometimes causes complete intestinal blockage in golden shiners (Fig. 14.32). A slow, extended mortality of the infected fish occurs as they starve to death. This problem has been reduced by appropriate management and the use of medicated feed, but the tapeworm still presents a potential threat.

Proteocephalus ambloplitis (Fig. 14.33) is commonly found in sunfishes and black bass. A buildup of these worms in the ovaries of

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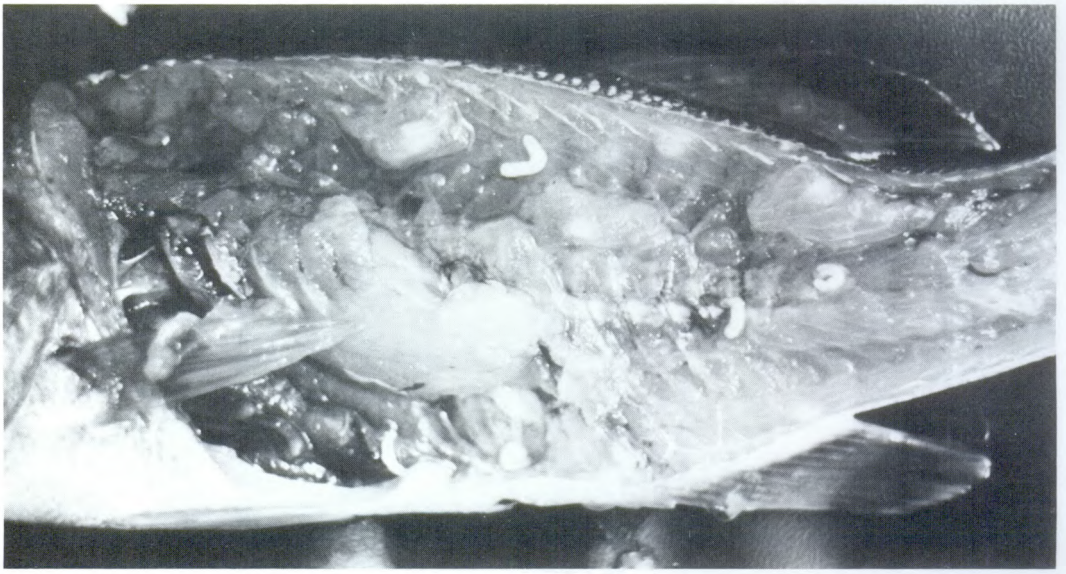


Fig. 14.31. The yellow grub *Clinostomum complanatum* embedded in the flesh of largemouth bass. Individual grubs can be seen in the flesh, and cysts containing larvae can be seen in the abdominal cavity, as well as in the flesh along the spine. *Photo by S. K. Johnson.*

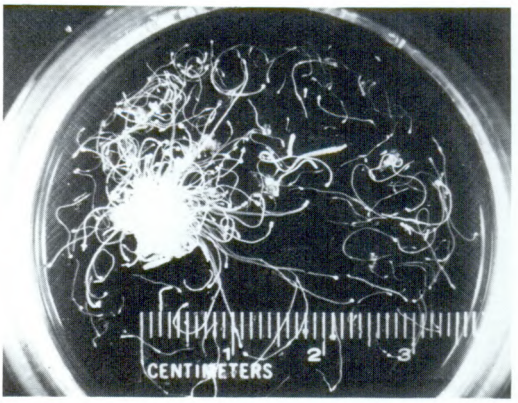


Fig. 14.32. *Bothriocephalus opsarichthydis,* the Asian tapeworm, from the intestinal tract of a single golden shiner. Each filament-like structure is an adult tapeworm composed of hundreds of infective units. The presence of the tapeworm can be confirmed only by examination of the intestine. *Photo by Glenn L. Hoffman.*

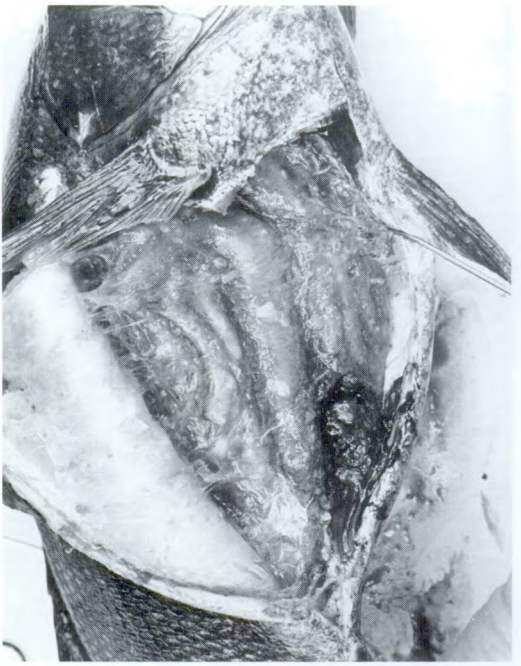


Fig. 14.33. These fibrous adhesions in the internal tissues of smallmouth bass were caused by larvae of *Proteocephalus ambloplitis,* the bass tapeworm. The larvae sometimes accumulate in the ovaries, and greatly reduce egg production. *Photo courtesy of Maine Department of Inland Fisheries and Wildlife.*

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bass greatly reduces egg production. No practical treatment is known.

Corallobothrium fimbriatum and related forms are found in the intestines of channel catfish, but rarely, if ever, are implicated as problem parasites. The adult tapeworms can be seen with the naked eye when the intestinal tract is opened.

Ligula intestinalis was described and illustrated earlier (Fig. 14.10).

Environmental Diseases

Gas bubble disease occurs when water is supersaturated with dissolved gases, particularly nitrogen and sometimes oxygen. Well water is often supersaturated with nitrogen. Oxygen supersaturation rarely occurs, and then usually in the afternoon, when heavy blooms of blue-green algae are present. The most obvious sign of gas bubble disease is the appearance of tiny bubbles under the skin of the body or fins. In severe cases, the eyes protrude.

Brown blood disease is a response to elevated levels of nitrite in the water. Other chemicals (e.g., hydrogen sulfide) can also cause the condition. The most obvious sign is brown gills and chocolate-colored blood. The addition of table salt to the pond often alleviates this condition.

Pesticide problems may be suspected if fish act especially nervous and exhibit convulsive behavior when no obvious water quality problems or pathogens can be identified. Any possibility of a potential poisoning incident (e.g., agricultural or industrial) should be considered. Fish, and sometimes water, can be tested if a particular toxicant is suspected. Broken-back or spinal curvature often associated with a vitamin C deficiency can also be caused indirectly by toxic substances (notably toxaphene) in the water. The available vitamin C in the fish serves to detoxify absorbed pesticides rather than to maintain bone structure integrity. This shunt in vitamin C use can result in broken and bent backbones, even in fish fed diets with high vitamin C content.

Algal toxicity sometimes occurs during blooms of certain blue-green algae.

Further details about adverse water quality conditions that cause environmental diseases—e.g., low oxygen, high pH, hydrogen sulfide, ammonia, and nitrite—are given in Chapter 3.

Diseases of Channel Catfish Eggs

Diseases of eggs are caused by fungi and bacteria, and occasionally by the protozoan parasite *Epistylis*. The visible signs of a fungal infestation appear first as a small white area covering only a few eggs, but the affected area sometimes spreads rapidly and covers the entire egg mass within 2 days. The smothering effect of the fungus kills more eggs, and thus provides a nutrient base for the growth of more fungus. As the infection progresses, the fungus appears as a cottony mass, sometimes discolored by particulate matter from the water. The mass of eggs and fungus usually holds together for several days (in contrast, bacterial infections of eggs cause the mass to fall apart), even though the eggs may be dead. It is best to treat before the infestation starts because it is difficult to kill actively growing fungus. If fungus is a continuing problem in a hatchery, prophylactic treatment should be given to prevent initial growth of the fungus. Overstocking of egg masses, insufficient water exchange, and inadequate agitation of the eggs and water may encourage the growth of fungus.

Bacterial infections of egg masses can be as serious as fungal infestations, and entire spawns can be lost. Visible signs of bacterial infections include slimy, discolored egg masses having a rotten smell. Often the water in the hatching trough is covered with foam, and may appear cloudy. The masses may seem to disintegrate, and some eggs may hatch prematurely. Several treatments are available, but prevention through a program of water exchange and daily cleaning of the hatching trough is preferred. Some water supplies are better than others for egg hatching. For example, the presence of insoluble iron has been associated with bacterial infections and poor hatching of eggs.

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General Treatment of Fish Diseases

After obtaining an accurate diagnosis and selecting the proper chemical, the fish culturist should consider several points before treating the fish:

- Is the treatment warranted?
- Is the treatment economically feasible?
- Are the fish strong enough to withstand treatment stress?
- What application alternatives are available (injections, dipping, flushing)?
- Are there complicating factors (algal bloom, high or low temperatures, low oxygen, cloud cover)?
- Is this disease contagious to fish in other ponds?
- What are the chances of the treatment being successful?

After consideration of these questions and having decided to treat, the fish culturist should be aware of several factors that could cause variations in the effectiveness of the treatment. One fish farmer's favorite treatment may not work for another, and what was effective last year may be a waste of time and money this year. There are at least five major reasons for such differences, and a working understanding of them can help eliminate much of the variation.

1. *Environmental factors.*—Temperature, pH, turbidity, total alkalinity, and rain can greatly influence the effectiveness of some treatments. Two important fishery chemicals, potassium permanganate ($KMnO_4$) and copper sulfate ($CuSO_4$), are excellent examples, since both can be inactivated by natural substances in the water.

The effectiveness of potassium permanganate varies greatly, depending on the organic content of the pond. Eight pounds per acre-foot of water can kill channel catfish in relatively clear water, whereas 30 pounds may not even begin to treat, let alone kill, catfish in highly organic ponds. An effective treatment requires that just enough chemical be applied to maintain a faint pinkish color in the water for about 12 hours. If the color rapidly fades or turns brown soon after the first application, a second application of 5 pounds per acre-foot can be made and repeated if necessary. However, if the color fades slowly after about 1 hour or more, only about 2 pounds per acre-foot should be added. The use of this method may require a major effort on the farmer's part, but it does ensure a safe and usually effective treatment. This treatment is expensive and may even be cost-prohibitive on some farms, depending on the species and number of fish raised. A potentially time-saving method of determining the $KMnO_4$ demand is given in Chapter 3.

Copper sulfate, a much less costly chemical, is most affected by the total alkalinity or the buffering capacity of the water. To avoid shortcomings and dangers in its use, it is important to determine the total alkalinity value of the pond water. Farmers can purchase inexpensive, easily operated water analysis kits for this purpose. At an alkalinity of 200 to 300 ppm, up to 5.4 pounds of $CuSO_4$ per acre-foot can often be applied safely; at alkalinities below 40 ppm, $CuSO_4$ should not be used. As a general rule of thumb, for every 100 ppm alkalinity, 0.75 to 1.0 ppm $CuSO_4$ can be used. It does not pay to undertreat; a stronger, safe, single treatment could eliminate the cost and effort of re-treating. Inasmuch as heavy rains may lower the total alkalinity of pond water and make previously safe treatments lethal, total alkalinity should be determined before each treatment. Insofar as we know, almost all chemicals used for fish disease control are affected by the amount and kind of material, living or dead, in the water.

2. *Chemical factors.*—Another cause of variation in treatment effectiveness is the chemical itself. Correct chemical storage and use are important. For example, formalin loses its potency when stored for several years, particularly if temperatures are sometimes near freezing. Other chemicals in powder or crystal form may lose their effectiveness if they become wet. All chemicals should be dated at the time of purchase, and the expiration date noted, if given. Differences in the formulations, diluents, or carriers used by various manufacturers also cause chemical effectiveness to vary. The size of crystals may

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also affect the efficacy of treatment. For example, powdered copper sulfate goes into solution well, whereas larger crystals commonly sink into soft bottom muds before being completely dissolved, thereby making a treatment inadequate.

The viscosity and dispersion characteristics of liquid chemicals are important. Formalin used at suggested levels sometimes either kills fish or provides an inadequate treatment because it disperses slowly in water. In a large pond, incomplete dispersal can result in localized areas of high concentration and other areas where the chemical never attains an effective treatment level. The use of a boat, outboard motor, and siphon system helps to ensure a well-mixed and evenly distributed solution in the pond. Boat bailers—devices that attach behind the propeller and draw water out of the boat bottom or container in the boat—are probably even more efficient than siphon-flow systems. Some fish farmers use airplanes to distribute chemicals over large ponds or groups of ponds.

3. *Disease factors.*—An accurate diagnosis of the problem-causing organism is important. Chemicals are generally effective only against certain groups of pathogens. The use of the wrong chemical is not only a waste of money, but also a waste of time (during which large numbers of fish may die) when the correct chemical could be counteracting the problem.

Resistance is also a key cause of inconsistent treatment results. Resistance may build up within a population of disease organisms after repeated exposure to almost any drug or chemical. If a disease problem arises, the strongest treatment concentration recommended should be used for the full time suggested. This dose may kill all the disease organisms and eliminate the need for a second treatment. The less often disease organisms are challenged in the environment, the less likely they are to develop resistance. It is best to avoid using most prophylactic or preventive treatments, or treating because one believes that a problem is developing. Treatment should be begun only when a disease organism presents a problem and, for some systemic bacteria, only when it is known that the organism is sensitive to one of the antibiotics that can be used. Prophylactic treatments are necessary, however, in ponds where disease agents such as Ich or external fungus appear in the same ponds at about the same time each year.

Occasionally the life cycle of a parasite requires that the treatment be applied at daily or weekly intervals to prevent reinfestation, whereas for some parasites only one treatment is required. Differences in species and strains of bacteria and parasites also account for variations in treatment effectiveness. Different species are recognized among *Trichodina,* fungi, *Gyrodactylus, Chilodonella,* and others, as well as different strains among certain bacteria and the parasite Ich. Consequently, when a "standard" treatment is ineffective for a particular pathogen, the fish farmer may be dealing for the first time with a new species or with a new strain of the now resistant organism. He should then seek assistance from fishery specialists who can help in determining the most effective way of attacking the new problem.

The presence of a continuing source of infection can affect treatment results. A chemical normally effective against a particular pathogen may be useless if the source of the pathogen is not removed. Even though the chemical may be 100% effective, the pathogen can again become numerous and cause disease as soon as treatment ceases, leaving the manager with the same problem—and with a poor opinion of the chemical. The source of the disease pathogen should always be considered before a treatment is made. Filters and disinfection systems can be set up for decontaminating limited amounts of incoming water, and disinfectants are available for fishery equipment. Various management procedures can be worked out to control other sources of contamination.

4. *Fish species and age.*—It is important to be aware of the limitations of the fish species to be treated. Certain species are much more sensitive than others to a particular chemical. Young fish are usually more vulnerable than older ones—although adult golden shiners are

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more susceptible than channel catfish fingerlings to copper sulfate toxicity.

5. *Human factor.*—Devastating treatment results can be caused by such errors as treating the wrong pond, using inaccurate scales, using the wrong chemical, misdiagnosis, or not knowing the exact area and depth of the pond to be treated. If a chemical is being used for the first time, it is prudent to test it on a small number of fish in a vat, tank, or tub before treating an entire pond. The potentially serious effects of the human factor can be greatly reduced by applying good management practices. It is essential to make on-site records of the kind and amount of chemical used, and all other pertinent information.

Reported Treatments for Controlling Parasites and Diseases in Cultured Fishes

Parasites or diseases are listed here in the same order as reviewed earlier in this chapter. The most effective treatments reported in the literature are listed in alphabetical order.

Aeromonas hydrophila and other internal bacteria—chloramphenicol,[x] Combiotic,[x] Erythromycin,[x] Furacin,[x] Furanace,[x] Furazolidone,[x] Kanamycin,[x] oxytetracycline, streptomycin,[x] sulfamerazine

Aeromonas salmonicida of goldfish—Betadine,[x] injection of chloramphenicol,[x] Furacin,[x] Furanace,[x] Furazolidone[x]

Argulus—Baytex,[x] malathion,[x] Masoten[x]

Bothriocephalus and ***Corallobothrium fimbriatum***—Di-n-butyl tin oxide,[x] Tinostat,[x] Yomesan[x]

Clinostomum complanatum, Diplostomulum spathaceum, and ***Posthodiplostomum minimum***—control snails (see Chapter 3)

Edwardsiella spp.—oxytetracycline

Egg disinfection—Betadine,[x] formalin, Furacin,[x] methylene blue[x]

Epistylis—table salt

Flexibacter columnaris and other external bacteria—acriflavine,[x] copper sulfate,[x] Diquat,[x] Furacin,[x] Furanace,[x] Hyamine 3500,[x] potassium permanganate, oxytetracycline, Roccal[x]

Fungus—copper sulfate,[x] potassium permanganate

Gyrodactylus and ***Dactylogyrus***—formalin, Masoten,[x] methylene blue,[x] potassium permanganate

Holding and **hauling prophylaxis**—acriflavine,[x] Furacin,[x] methylene blue,[x] oxytetracycline, potassium permanganate, table salt

Ichthyophthirius (Ich)—copper sulfate,[x] formalin, Furanace,[x] methylene blue,[x] potassium permanganate, table salt (Tanks: clean and flush daily, raise water temperature to 90°F. Ponds: summer, see instructions for specific chemical; winter, treat once a month.)

Ichtyobodo (= *Costia*)—acetic acid, copper sulfate,[x] formalin, methylene blue,[x] potassium permanganate

Leeches—Baytex,[x] Masoten,[x] table salt in tanks

Lernaea (anchor parasite)—malathion,[x] Masoten,[x] methyl parathion,[x] potassium permanganate, table salt

Pond, tank, and equipment disinfection—burnt lime, HTH, household bleach, hydrated lime

Trichodina, Ambiphrya, Chilodonella—copper sulfate,[x] formalin, methylene blue,[x] Metronidazole,[x] potassium bichromate,[x] potassium permanganate, table salt

Trichophrya—copper sulfate[x]

Fishery chemicals, the diseases or conditions treated, and treatment rates are summarized in Table 14.2.

Registration of Chemicals

One of the most persistent problems of the fish farming industry is that the U.S. Food and Drug Administration has approved relatively few drugs or chemicals for fishery purposes. The use of a drug, especially on food fish, is allowed only after extensive testing has proved that such use presents no hazard to human or animal health. Securing the data for registration of a chemical is costly, and unless the market for the drug is substantial, a chemical manufacturer will not bear the ex-

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pense of the necessary research. Researchers must demonstrate its effectiveness for the target disease and show that no harmful residue remains; the time required for the chemical to enter and leave the tissues of the fish must also be shown. When a fish producer needs information on the status of registration and use of specific chemicals and drugs, he should contact a knowledgeable fishery specialist (see Chapter 20).

Table 14.2. *Fishery chemicals, disease organisms and functions, and treatment schedules.*[a]

Acetic acid, glacial
Ichtyobodo
Dip: 1:500 (2.6 fl oz/10 gal) for 30 seconds.

Acriflavine[x] or trypaflavine[x]
External bacteria and hauling prophylaxis
Tank treatment and hauling: 3 ppm (11.4 mg/gal, 0.4 oz/1,000 gal or 3 oz/1,000 ft^3).

Baytex[x]
Argulus and leeches
Use 0.25 ppm active ingredient (0.26 oz [93% concentrate]/1,000 ft^3, 11.7 oz/acre-foot): apply two treatments, 1 week apart for *Argulus*. In warm weather use 0.17 ppm active ingredient when treating sunfish (higher rates may be lethal). Use half as much chemical when water temperature is lower than 60°F.

Betadine[x] (iodophore containing 1% iodine)
Egg disinfectant
Dip: 1:100 (1 pint/12.4 gal) for 10 minutes (not recommended for cyprinid eggs).
Aeromonas salmonicida (goldfish)
Tank treatment: 1:20,000 (6.4 fl oz/1,000 gal, 3 pints/1,000 ft^3) for up to 30 minutes. Use immediately after fish are handled and remove fish immediately after treatment ends to avoid loss due to toxicity. The chemical should be used in water with pH between 6 and 8 and with a low organic content. Betadine is toxic at pH 6 and declines in effectiveness above pH 8.

Burnt lime (calcium oxide, quicklime)
Pond disinfectant
See uses and rates for calcium hydroxide. Calcium oxide becomes calcium hydroxide when added to water. Use with extreme caution and wear protective clothing.

Calcium hydroxide (slaked lime, hydrated lime)
Pond disinfectant
Drained pond treatment: sprinkle fresh chemical on drained wet pond bottom and sides at the rate of 2 tons/acre. This chemical is not effective in water. Corrosive; use with caution.

Calcium hypochlorite (HTH—70% chlorine)
Pond or tank disinfectant
Filled pond treatment: apply 10 ppm available chlorine (1.9 oz HTH/1,000 gal, 14 oz/1,000 ft^3, 38.8 lb/acre-foot). Kills all fish and some parasites. Mix with water and distribute over the pond surface.

Drained pond treatment: sprinkle or spray onto wet bottom and into water-filled depressions at a rate of 10 ppm available chlorine. Allow the chlorine to dissipate (several days) or neutralize with sodium thiosulfate or sodium sulfite. Use with extreme caution.

Calcium oxide (quicklime, burnt lime)
See calcium hydroxide.

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Chloramphenicol[x] (Chloromycetin)

Internal bacteria

Oral administration: feed medicated food at the rate of 3% of body weight per day for 5 to 10 days. Add to feed at the rate of 1 g/lb feed, 3.5 oz/100 lb feed.

Injection: 20 mg/lb body weight.

Water treatment: 10 to 50 ppm (1.3 to 6.7 oz/1,000 gal).

Combiotic[x] (penicillin plus streptomycin)

Internal bacteria

Injection: 20 mg/lb body weight. This treatment is usually used for only limited numbers of fish (e.g., valuable brood stock).

Copper sulfate[x] ($CuSO_4$)

External parasites and external bacteria

General pond treatment: The effectiveness of copper sulfate is related to the total alkalinity of the water in which it is used. The amount of $CuSO_4$ applied should be at the rate of 0.75 ppm for every 100 ppm total alkalinity and should be used only when total alkalinity exceeds 40 ppm. Its effectiveness may be limited in water in which total alkalinity exceeds 250 ppm. For certain parasites and bacteria, repeated treatments may be necessary. Reports indicate that the effectiveness is reduced at temperatures below 40°F and that treatment with $CuSO_4$ can result in oxygen depletion. The chemical should not be used with fry because of its high toxicity to young fish.

Ichthyophthirius

Treat ponds with the amounts shown above, applied a total of three times on alternate days. If total alkalinity is below 100 ppm, the time between treatments should be extended or the level of the second and third treatments reduced. One treatment per week for a few weeks during early spring can serve as a preventive in areas where the disease is recurrent.

Winter fungus

Make three applications (as described above) at 3-day intervals.

Dimetridazole[x]

External parasites

Water treatment in tanks or aquaria: apply 4 ppm (15 mg/gal, 4 oz/1,000 ft^3) for 3 to 4 days.

Di-n-butyl tin oxide[x]

Tapeworms

Feed application: mix in feed at the rate of 4.8 oz/100 lb or 6 lb/ton and feed for 3 to 5 days at 3% of body weight. Effective treatment requires that the fish be feeding well.

Diquat[x] (25% active)

Flexibacter columnaris and other external bacteria

Water treatment in tanks: apply 2 to 4 ppm (8 to 16 oz/1,000 ft^3).

Dylox[x]

Lernaea

Water treatment: apply 0.25 ppm active ingredient (1.2 g/1,000 gal, 0.31 oz/1,000 ft^3, 0.85 lb/acre-foot) each week for 4 weeks. Dylox kills the larvae but not the adults. Use 0.5 ppm when water temperature is 80 to 85°F. Dylox is ineffective above 85°F.

Dactylogyrus, Gyrodactylus

Apply 0.5 ppm active ingredient as needed at 2- to 3-day intervals. Higher treatment levels may be necessary because some strains have become resistant.

Capillaria

An application of 0.5 ppm active ingredient may be partly effective.

Argulus and leeches

An application of 0.5 ppm active ingredient is usually effective against the larvae and adults.

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Erythromycin[x]

Internal bacteria

Feed application: mix antibiotic with feed at the rate of 5.3 oz/100 lb and offer at the rate of 3% of body weight per day for 14 days.

Formalin (37% formaldehyde)

External parasites

General pond application: 25 ppm (1.5 pints/1,000 ft^3, 8.1 gal/acre-foot) mixed into the pond water. In ponds with light algal blooms, use 15 ppm. The use of formalin in hot weather may result in oxygen depletion.

Tank treatment: 166 ppm (1.4 pints/1,000 gal, 10 pints/1,000 ft^3) for up to 1 hour. Most fish in good condition can tolerate as much as 250 ppm (2 pints/1,000 gal, 15 pints/1,000 ft^3) if they are not crowded. Feed should be withheld for 24 hours before treatment. Good aeration and constant surveillance are essential. If stress is excessive, immediately drain and flush the tank with fresh water.

Ichthyophthirius

Pond treatment: apply two or three treatments as described above at 2- to 4-day intervals, depending on the temperature.

Gyrodactylus (specific for use with goldfish)

Pond treatment: apply up to 35 ppm (2.1 pint/1,000 ft^3, 11.3 gal/acre-foot).

Egg disinfectant

Dip: 2,000 ppm (2.6 fl oz/10 gal, 2 gal/1,000 gal) for 15 minutes.

Furacin[x] (NFZ, Nitrofurazone)

Internal and external bacteria

Feed application: add 5.4 lb of 4.59% Furacin formulation/100 lb feed and offer the feed mix at the rate of 3% of body weight per day for 14 days. Apply one-half the concentration if the 9.2% Furacin formulation is used.

Water treatment: apply 5 to 20 ppm active ingredient (0.9 to 3.6 lb/1,000 gal or 6.8 to 27.1 lb/1,000 ft^3 of the 4.59% formulation) for at least 1 hour for larger fish and 5 ppm for fry, fingerlings, and tropical fish unless the toxicity of the Furacin has been found to be low.

Aeromonas salmonicida (goldfish)

Water treatment: apply 20 ppm active ingredient in the water (3.6 lb/1,000 gal or 27.1 lb/1,000 ft^3 of the 4.59% formulation) for 4 hours; repeat in 2 days.

Bacteria on eggs

Dip: 200 ppm active ingredient (3.6 lb/100 gal or 2.7 lb/10 ft^3 of the 4.59% formulation) for 15 minutes. Flush with fresh water at the normal flow rate.

Hauling prophylaxis

Water treatment: apply 5 to 10 ppm active ingredient (0.9 to 1.8 lb/1,000 gal of the 4.59% formulation) for the duration of the haul.

Furanace[x] (P-7138, Nifurpirinol)

Flexibacter and other bacteria

Water treatment: 1 ppm (0.13 oz or 3.8 g/1,000 gal, 1 oz/1,000 ft^3) in tank for 1 hour for 1 to 3 consecutive days.

Aeromonas spp.

Apply 1 to 2 ppm active ingredient (0.13 to 0.27 oz/1,000 gal, 3.8 to 7.6 g/1,000 gal, 2 oz/1,000 ft^3) for 2 to 8 hours.

Ichthyophthirius

Apply 0.2 ppm (0.76 g/1,000 gal, 0.2 oz/1,000 ft^3) and repeat three times on alternate days.

Furazolidone[x] (NF-180, Furoxone)

Internal bacteria

In feed application, offer feed that contains 3.9 oz Furazolidone/100 lb at the rate of 3% of body weight per day for 10 to 14 days.

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Household bleach (sodium hypochlorite—5.25% available chlorine)
Equipment and tank disinfectant
Water treatment: use 10 ppm available chlorine (1.6 pints/1,000 gal, 1.5 gal/1,000 ft^3).

HTH
See rates and uses for calcium hypochlorite.

Hyamine 3500[x]
Flexibacter columnaris and gill bacteria
Water treatment: apply 2 ppm (2 oz active ingredient/1,000 ft^3) if total alkalinity is less than 100 ppm, 3 ppm if total alkalinity is 100 to 200 ppm, or 4 ppm if total alkalinity is over 200 ppm.

Hydrated lime
See calcium hydroxide.

Kanamycin[x] (Cantrex, Kamycin, Resistomycin)
Internal bacteria
In feed application, offer feed that contains 1.67 g/kg (1.7 lb/1,000 lb) Kanamycin at the rate of 3% of body weight per day for 1 week.

Injection: 20 to 25 mg/kg (9 to 11 mg/lb) of live weight of fish.

Malathion[x] (50% active)
Lernaea and *Argulus*
Water application: 0.25 ppm active ingredient (1.3 pints/acre-foot) once a week for 4 weeks. Ineffective if water temperature exceeds 85°F.

Masoten[x]
See uses and rates for Dylox[x].

Methyl parathion[x]
Lernaea larvae
For water treatment: apply 0.25 to 0.50 ppm active ingredient (0.68 to 1.36 lb/acre-foot). In water between 80 and 85°F, apply 0.5 to 1 ppm. Repeat weekly for 4 weeks.

Methylene blue[x]
External parasites and hauling prophylaxis
Water treatment in tanks or aquaria: apply 2 to 3 ppm (0.27 to 0.4 oz/1,000 gal, 2 to 3 oz/1,000 ft^3). For control of Ich, use three times on alternate days. Methylene blue is toxic to aquarium plants.

Metronidazole[x] (dimetridazole, 1-beta hydroxyethyl, 2-methyl 5-nitroimidazole)
See uses and rates for Dimetridazole.[x]

Oxytetracycline (Terramycin)
Internal and external bacteria
Water treatment: apply 20 ppm (for TM_{50} [11% active ingredient] use 24.3 oz/1,000 gal) for both tank treatments and hauling prophylaxis.

Oral administration: add 3.5 to 7.4 oz active ingredient/100 lb feed or 2 to 2.7 lb TM_{50} [11% active ingredient]/100 lb feed and offer at the rate of 3% of body weight for 10 to 14 days. Increased concentrations of the drug have been used when fish are feeding poorly.

Injection treatment: 20 mg/lb of body weight.

Potassium bichromate[x] (potassium dichromate)
External protozoans
Water treatment in tanks and aquaria: apply 5 ppm (0.67 oz/1,000 gal, 5 oz/1,000 ft^3) on alternate days as needed.

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Potassium permanganate ($KMnO_4$)

External bacteria and parasites, and winter fungi

Water treatment is obtained when a faint pinkish color persists for about 12 hours after the chemical is applied. Apply 2 ppm (0.26 oz/1,000 gal, 2 oz/1,000 ft^3, 5.4 lb/acre-foot) in successive treatments until the faint color remains.

External parasites

Dip fish in a 1:1,000 concentration (1.3 oz/10 gal) for 10 to 40 seconds or place channel catfish and goldfish in bath containing 5 ppm (0.67 oz/1,000 gal) for 30 minutes to 1 hour. The fish must be observed for stress.

Hauling prophylaxis (parasites, organic matter, and bacteria)

Water in hauling tanks: 2 to 3 ppm (0.26 to 0.38 oz/1,000 gal). Maximum rate for channel catfish is 2 ppm.

Roccal[x] (10 to 50% solution of benzalkonium chloride)

Gill bacteria

Water treatment: add 1 to 4 ppm active ingredient for 1 hour for channel catfish. Toxicity is increased in soft water.

Streptomycin[x]

Internal bacteria

Inject at the rate of 70 mg/lb of body weight.

Table salt (rock salt, sodium chloride)

External parasites and *Epistylis*

Dip: 1 to 3% (83 to 250 lb/1,000 gal) for 30 minutes to 2 hours; for *Epistylis,* 1.5% for 3 hours has been used on green sunfish. A prolonged bath of 0.5% salt (41.7 lb/1,000 gal) for 3 days eliminates adult *Lernaea.* A continuous bath of 0.2% (16.7 lb/1,000 gal) prevents the development of Ich and other external parasites. This rate is effective as a hauling prophylaxis. Leeches are controlled with 0.1% (8.3 lb/1,000 gal) salt in long-term exposure.

Hauling prophylaxis

Water treatment: 1 to 2 lb in 100 gallons of water.

Terramycin

See oxytetracycline.

Tinostat[x] (dibutyl tin dilaurate)

Intestinal worms

See uses and rates for di-n-butyl tin oxide.

[a]In the United States, fish that are intended for human or animal food can be treated with drugs and chemicals only in accordance with current regulations of the U.S. Food and Drug Administration, U.S. Environmental Protection Agency, U.S. Department of Agriculture, and State and local agencies. Furthermore, the status of drugs and chemicals is always subject to change due to research findings or regulatory agency rulings. Therefore the user should always read and carefully follow the instructions on the label. References to drugs and chemicals whose usefulness has been demonstrated by fish culturists appear throughout this report. Compounds that have not been approved for use with food fish, or whose use for the purpose being discussed is restricted, are marked by the superscript symbol x (e.g., Furacin[x] is an excellent bacteriostat); compounds that have been approved for the indicated use bear no superscript. The use of trade names does not imply U.S. Government endorsement of commercial products.

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15. PROPAGATION OF AQUATIC ANIMALS OTHER THAN FISH: CRAYFISH, PRAWNS, BULLFROGS, AND ALLIGATORS

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Propagation of crayfish, prawns, bullfrogs, or alligators is practiced by some farmers to maximize the productivity of their land and labor, and to use fish farm wastes. The best example of this is the propagation of crayfish in Louisiana and Texas. Crayfish are farmed on rice lands as a secondary crop, and their harvest occupies the farm labor not normally used during winter. Another example is the use of injured and dead chickens from a poultry broiler operation for alligator feed.

In most instances, the propagation of these aquatic animals is successful only as a secondary crop or sideline. The markets for the products may be limited and thus production expansion, which ordinarily increases profit, may actually reduce profit. Labor and facilities should be supported largely by the primary agricultural program. Research and development, except for crayfish, have not reached the state where profit from commercial production can be assured.

We offer here a summary of the techniques used by researchers and farmers to produce crayfish, prawns, bullfrogs, and alligators.

Crayfish

Production and harvest of crayfish as a gourmet food is a major aquacultural industry in southern Louisiana and eastern Texas. About 50 million pounds of "crawfish" (the name preferred over "crayfish" by some farmers) are harvested from 116,000 acres in those two States. Annual harvests range from about 500 pounds per acre on extensively managed units to 1,000 to 2,000 pounds per acre on intensively managed farms. Considerable interest in the production of crayfish for food has been shown by farmers in Mississippi, South Carolina, and Arkansas. Since the demand for crayfish is high, production is increasing as a supplemental income to rice farmers, and as a primary income to crayfish producers.

Outside Louisiana, Texas, Mississippi, and South Carolina, crayfish are "cultured" incidentally with fish. That is, they spontaneously appear in ponds from time to time and are harvested during routine fish harvests. Most such crayfish are sold for fish bait.

The species that contributes the most pounds to the wild harvest and managed production in Louisiana and Texas is the red swamp crayfish, *Procambarus clarkii* (Fig. 15.1). It also occurs in the other States of the deep South and in southern Missouri, Illinois, Ohio, and California, and has been successfully introduced on the East Coast. This crayfish is one of the larger species in the United States and its bright red color makes it popular with consumers.

Other cultured species are the white crayfish (*P. acutus acutus*), located in the Midwest and equivalent latitudes on the East Coast; and the paper shell crayfish (*Orconectes immunis*), which occurs in the Midwest and Northeast. Since there are over 300 species of crayfish in the United States, there are doubtless others that are suitable for culture.

General Life History Under Culture

Crayfish are cultured by establishing sustaining populations in an earthen pond. Cray-

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Fig. 15.1. The red swamp crayfish is harvested from the wild in the southern States, and is the principal cultured species of crayfish farmers in Louisiana, Texas, and Mississippi. The bright red color and large size of the adults make it popular with consumers. *Photo courtesy of Louisiana Cooperative Extension Service.*

fish normally undergo a seasonal resting or quiescent period during which reproduction takes place in burrows. This period is usually controlled by temperature. In the deep South, water temperatures of 85 to 90°F force most crayfish into burrows. In northern States, water temperatures of 45 to 50°F or lower have the same effect.

Crayfish are usually encased in a hard shell. To grow, they must shed the shells. The new shell is initially soft, and animals in this stage—"soft-shell" crayfish—are delicious when fried and make excellent bait. To obtain soft-shell crayfish, one needs to collect and hold crayfish that are about to shed their shells. After they shed the shell, the live crayfish are refrigerated for up to 5 days or frozen. Alternatively, they can be held (unfed) in distilled water (e.g., pure rainwater). Use of this very soft water eliminates much of the calcium required to harden the shell. One must be careful to separate crayfish that will shed in several days from those that will shed almost immediately, to prevent cannibalism. Most young pond-run crayfish shed about 10 days after capture, but mature crayfish shed only one to three times a year.

In the South, adult crayfish are usually stocked in spring for the harvest that begins the following fall. Stocking rates are 25 to 100 pounds per acre, depending on the availability of food, cover, and the size of the carry-over crayfish population. The water is slowly drained in late spring, forcing the adults to burrow into the levees and pond bottoms. These adult crayfish lay eggs and hatch out large numbers of young during summer and early fall. These young provide the harvest in late fall and spring.

During summer, a cover crop of wild grasses is allowed to invade the pond, or rye grass, rice, or millet is planted. The exact time of planting depends on latitude, but is generally in late spring or early summer.

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The young crayfish leave the female when the pond is flooded in fall. They grow rapidly, depending on water temperatures and food availability. The size of the individuals and the total production per unit of area are usually greater in the South than in the North, partly because the potential size of the red swamp crayfish (Fig. 15.1) and white river crayfish is greater than that of the northern paper shell crayfish, and partly because the growing season is longer in the South.

After the harvest in fall, winter, and spring, the ponds are slowly drained. Unharvested crayfish seek out the old burrows or build new ones. Restocking for the next production season is usually not necessary.

Crayfish can be produced by intensive culture in indoor tanks. However, economics do not favor such culture when compared with the extensive or semi-intensive culture being practiced in Louisiana and Texas. Production of young crayfish for pond stocking may prove feasible in areas where crayfish prices are high and stable for most of the year.

As one proceeds north from Louisiana–Texas, winters become so severe that crayfish do not grow well. In the Midwest and Northeast, growth does not begin until late spring and the crayfish are harvested only in summer. Some water is required during winter to prevent freezing of unprotected burrows.

Pond Construction

Techniques and cautions for the construction of channel catfish production ponds are appropriate for crayfish ponds. The cost of constructing crayfish production ponds is generally less than that of constructing catfish ponds because water depth need not exceed 2 feet and may be considerably less. Fallow rice fields are ideal for crayfish ponds because they are usually constructed on heavy clays that retain water and are drainable. Potential pond sites with shallow clay pans overlying sand and gravel are to be avoided because burrowing crayfish are likely to penetrate the pan and cause leaks.

Water Quality

Water of the quality suitable for the production of channel catfish, baitfish, and other pond fishes is generally suitable for crayfish. Most specialists recommend that total hardness exceed 50 ppm (as $CaCO_3$). If total hardness is lower, treatment of the ponds with agricultural limestone can be expected to improve crayfish production.

Water quality management is difficult when the pond is flooded, the vegetation starts to decay, and dissolved oxygen is consumed by microbes (i.e., the biological oxygen demand is high). The oxygen content of the water should be kept above 3 ppm. Chemical or electrode analyses of the water are preferred, but if the crayfish are seen clinging to vegetation near the surface, it is reasonably safe to assume that dissolved oxygen is low.

Water quality is managed basically by limiting the amount of vegetative matter present when the pond is flooded. However, farmers should have the capability of adding fresh, well-oxygenated water to the pond, or of circulating and aerating the water if dissolved oxygen becomes low. The general recommendation is that one should be able to exchange the water volume every 3½ days to ensure maximum production.

Static ponds produce crayfish crops as large as 1,000 pounds per acre, but the average is usually 500 pounds per acre. Ponds in which water is constantly recirculated when temperatures exceed 65 to 70°F can produce up to 2,000 pounds per acre. Experimental ponds with constant circulation during warm weather have produced 3,000 to 4,000 pounds per acre, but pumping costs and water charges make this technique only marginally profitable in many areas.

Feeds

Feeds for crayfish include natural food and agricultural by-products. The feeding of a specific formulation manufactured for crayfish is neither necessary nor economically sound.

If a good cover of pasture grasses, rye grass, rice, or millet is present, supplemental feeding is usually not required. A good cover crop provides 6,000 to 8,000 pounds of dry plant matter per acre. Crayfish feed on the decomposing vegetation, which is essentially microbe-enriched detritus. Also available to the crayfish are the worms, insect larvae,

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snails, and zooplankton associated with the detritus. Living animal protein is important in the diet of young crayfish, and green vegetation is necessary to ensure normal pigmentation.

Agricultural by-products such as spoiled hay, cottonseed cake, and rice bran may be added to the crayfish production pond if the quantity of green plant materials is limited. The farmer should add no more than 1,000 pounds of hay per acre at one time, or 10 to 15 pounds of rice bran or cottonseed meal per acre per day.

The crayfish producer must inspect the ponds daily when supplemental feed is being supplied. If the added feed does not quickly disappear from the feeding site, overfeeding is indicated and the allowance should be decreased. No supplemental feed should be added when the water temperature is lower than 55°F. Best results are obtained by feeding along the edges of the entire pond.



Fig. 15.2. A typical chicken-wire crayfish trap generally used by Louisiana and Texas producers. The bottom is enclosed and funnels are constructed into the sides near the bottom. The cylinder is placed upright on the pond bottom with the open end extending above the water. *Photo by J. Avault, Jr.*

Species Selection

For the beginning farmer, the species selected should have proved itself suitable for intensive or extensive management. It should be adapted to living in a shallow aquatic system with periodic dewaterings. Examples are crayfish that live in roadside ditches, sloughs, swamps, and marshes. Burrowing crayfish, which may dig burrows as deep as 20 to 30 feet, readily withstand dewatering; however, they are seldom found at the surface and do not perform well in ponds. Crayfish that live in permanent lakes, ponds, streams, and rivers usually require stable environmental conditions, and thus are poorly suited for managed culture.

Three species of crayfish that have been investigated and found to perform well in management are the red swamp crayfish (Fig. 15.1), white crayfish, and the paper shell crayfish, which were mentioned earlier. Certainly, a species already thriving at a nearby fish farm should do well.

As a note of caution, the red swamp crayfish can be cultured just about anywhere south of the Canadian border. It is very aggressive and sometimes displaces or destroys native plants and animals. One should never introduce this species or any other species to an area where it is not native without consulting local conservation authorities.

Harvesting

Crayfish can be harvested with a variety of traps, by seining, or by the complete draining of ponds. Most food-sized crayfish are trapped. Bait-sized crayfish are trapped or seined. Seines are more effective if weighted with a chain; they are especially suitable for collecting soft-shell crayfish and those about to shed their shells and become soft-shelled. In this form the animals are easily injured, however, and must be handled carefully.

Traps used in Louisiana are basically cylinders of chicken wire fencing (Fig. 15.2). The bottom is enclosed and funnels are constructed into the sides near the bottom. The cylinder is placed upright on the pond bottom and propped so that the open end extends above water. Although most crayfish will not crawl out of an open-ended trap, an inner collar of aluminum or plastic, 3 to 4 inches wide, is advisable.

Many variations are possible. If the open end of the cylinder trap is closed, it can be

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submerged and fished in deep water. Some popular traps are shaped like rocket nose cones and others look like minnow traps. Bait in any trap set is usually fresh or frozen fish—e.g., common carp, gizzard shad, or suckers.

When the water temperature exceeds 70°F, canned dog food and cottonseed cake and artificial baits can be used effectively. Artificial baits have become popular with crayfish harvesters. One type of crayfish bait has a formula similar to that of mash fed to laying hens; others are similar in content to channel catfish feeds. Most of these crayfish baits are formed into pellets specially manufactured to remain intact in water for long periods.

The trap mesh selected depends on the size of the crayfish desired. Meshes of the following sizes hold crayfish of the lengths indicated: ¾-inch mesh, 3 inches and longer; ⅝-inch mesh, 2½ inches and longer; and ½-inch mesh, 1¾ inches and longer.

Handling and Shipping

Hard-shell crayfish can be held for several months with little feed, in shallow troughs, at densities of 70 per square foot (if 2 to 3 inches long) or 45 per square foot (if 3 to 4 inches long). Water should not be allowed to rise above their legs and should be changed at least once each day. If the crayfish are completely covered with water, the water should be well aerated.

Crayfish 3 inches long or longer are usually shipped in porous bags. The bags are kept cool (40°F) and damp. The gill chambers of crayfish are located on both sides of the head. As long as these chambers are damp, the crayfish can breathe and survive.

Soft-shell crayfish remain in the soft paper-shell stage as long as 3 weeks if they are held in distilled water (rainwater) and are separated from each other. Very soft crayfish can be obtained by removing them from the water within 3 to 4 hours after they shed. Soft-shell crayfish may be kept alive for 3 to 5 days if they are packed in loose, damp moss or coarse sawdust and refrigerated (45 to 50°F).

Smaller bait-sized crayfish are usually shipped in damp moss or coarse sawdust. This material must be packed loosely in order to prevent the crayfish from being crushed, and to permit air circulation. Temperatures should range between 40 and 75°F.

Crayfish that have soft shells or are ready to molt must be immediately separated from the hard-shell crayfish. As many as 50 to 60% of the crayfish caught in seines, but less than 1% of those caught in traps, may have soft shells. Crayfish about to molt cease feeding and thus are not attracted to the bait in traps.

Monoculture Techniques

The intensity of effort varies greatly among crayfish culturists. The simplest type of culture involves the trapping of crayfish from marginal wetlands, usually adjacent to crop or timber lands. Little is done to enhance production except water management. The production system becomes more complex if the raising of crayfish supplements the growing of rice or other farm crops. The highest level of intensity is the construction and management of ponds specifically for crayfish. Many factors, including economics and expertise, affect the choice of production systems.

Crayfish in all types of production systems—unmanaged to intensively managed—are fairly resistant to diseases and parasites. Parasites common to their environment for the most part cause no lasting damage or harm. Eggs of the water boatman, an aquatic insect, sometimes nearly cover the shell of an adult crayfish (Fig. 15.3), but seemingly cause no injury.

Polyculture Techniques

Crayfish can be produced in conjunction with other aquacultural crops. The major constraint is the choice of species and sizes of fish that will not eat the crayfish, and sizes of crayfish that will not eat the fish. Small fish of several species—channel catfish, largemouth bass, tilapia, and sunfish—generally eat few crayfish, and thus have little effect on the crayfish yield; other species such as the Chinese and other carps, buffaloes, and minnows generally eat no crayfish.

Alternatively, the fish and crayfish can be

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Fig. 15.3. The water boatman, an aquatic insect, commonly deposits its eggs on crayfish. The eggs can be unsightly, but rarely harm the temporary host and do not reduce its palatability.

physically separated. The most common technique is the combining of the fish in cages or pens, and the culturing of crayfish in the open pond. Some farmers culture crayfish in the outside sump area, outside burrow ditch, and in the water control ponds above, between, or below the fish production ponds.

Food of crayfish is primarily detritus, a by-product from the feeding of the fish in the cages and in the ponds. Overflow water from the ponds carries the detritus into the outside sump areas.

If there are fairly extensive areas of shallows in a pond and it can be flooded at the appropriate time by water level manipulation, fair crayfish populations can develop. It is necessary, however, to have good cover crops of grasses and emergent vegetation in such areas to provide food and cover for the growing crayfish. This combination of factors is often seen in fry-rearing ponds where such fish as minnows, buffaloes, or largemouth bass have been stocked into ponds after being spawned elsewhere. The grass, which is intended to serve as green manure for zooplankton production, provides protection and food for crayfish. Many catfish fingerling producers once intentionally poisoned ponds to eliminate crayfish, but are now finding that crayfish are a valuable second product.

The rotation of field crops, specifically rice and soybeans, with crayfish is discussed in Chapter 16.

Prawns

Prawns, shrimps, lobsters, and certain other crustaceans are in tremendously heavy demand in the United States and throughout much of the world. Some of these crustaceans are now being cultured in the United States to help meet this demand. The National Marine Fisheries Service reported a farmed

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production of 350,000 pounds of freshwater prawns worth $1.4 million in 1982. Because of the heavy demand and the potentially huge monetary returns, some aquaculturists have investigated the commercial production of these animals.

Because prawns of the genus *Macrobrachium* grow readily in fresh water and are large, tasty animals, some aquaculturists have become interested in the production of prawns of this group because they are more manageable than the marine forms. Coastline land is expensive and limited, and there are usually many legal constraints on the use of this land. Additionally, construction costs are much higher in salt water, and concerns about storms are continuous. The economics and legal constraints in freshwater prawn culture are similar to those for established culture industries, such as those for channel catfish, baitfish, and crayfish, and thus are basically nonrestrictive.

There are, however, several major hindrances to the production of freshwater prawns in the United States. Because larvae must spend some time in brackish water, seed stocks must be specially handled before being made available to the freshwater culturist. The requirement of water temperatures of 75 to 95°F for prawn culture greatly limits the length of the growing season in the United States. Whether research can overcome the effect of these limitations remains to be determined.

Freshwater prawns belong to the family Palaemonidae and include the small grass shrimps (*Palaemonetes*) common throughout the United States, and the larger river shrimps (*Macrobrachium*). Several species of *Macrobrachium* reach weights of 0.8 to 1.3 ounces in a 5- to 6-month growing season; however, the only species common in the United States, *Macrobrachium ohione,* rarely reaches sizes larger than 100 per pound (less than 0.2 ounce). Aquaculturists have devoted most of their attention to the culture of *Macrobrachium rosenbergii,* a native of the tropical Indo-Pacific region, commonly referred to as the giant Malaysian prawn (Fig. 15.4).

This prawn is cultured throughout the tropics. A prawn culture industry has developed in Hawaii, and studies in southeastern and southwestern United States have been promising. However, areas in the continental United States are limited to a 5- to 7-month growing season because this species cannot survive water temperatures below 60°F.



Fig. 15.4. A pair of giant Malaysian (freshwater) prawns, *Macrobrachium rosenbergii.* Notice the long claw of the male (top). This species can reach weights of 0.8 to 1.3 ounces in a 5- to 6-month growing season. *Photo by J. Avault, Jr.*

Prawn farmers in the United States usually purchase their seed stocks from growers in tropical areas. The larvae are unique in that they must live through several instars or moltings in brackish water with a salinity of 12 to 15 ppt before they can be stocked, as postlarvae, into fresh water for culture.

A farmer can produce his own postlarvae if he has a source of brackish water at a temperature of 80 to 85°F. The prawns breed and spawn in fresh water. Breeding occurs when the female sheds or molts her shell. Breeding males have large claws roughly twice the length of their bodies. They use these to protect the female until her shell hardens. The female attaches the eggs to small legs (called swimmerets) beneath her tail and incubates them there. Over a 2- to 3-week period the color of the eggs changes from orange to gray-

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green. Eggs hatch into free-swimming larvae soon after this change in color. The newly hatched larvae are then placed in brackish water.

Prawn larvae are difficult and expensive to feed in their early life stages. One of the better feeds consists of live brine shrimp nauplii; however, brine shrimp are expensive. During the 25- to 45-day larval development period, finely ground fish and fish eggs are gradually introduced. At the end of this period the metamorphosed prawns are ½ inch long, and are called postlarvae. Production of 30 to 40 postlarvae per quart of water is considered good.

Prawn postlarvae may be stocked directly into fresh water as soon as they metamorphose. This is usually done because holding them requires additional expenditures of time, space, and capital. Unfortunately, recently metamorphosed postlarvae are still expensive by any standard, and survival in freshwater ponds is sometimes poor because latent mortality from shipping stress can be great. Indeed, losses can be unacceptably high for commercial operations.

Ponds that are only fertilized should be stocked with 5,000 or fewer recently metamorphosed postlarvae per acre; those that are fertilized and in which the prawns are also fed can be stocked with 15,000 to 20,000 postlarvae per acre. After a 140- to 150-day growing season, the average weight of the prawns should be 0.6 to 1.1 ounces (Fig. 15.5); if survival exceeds 75%, production ranges from 400 to 1,200 pounds per acre. Ponds should be filled just before they are stocked, and treated to kill predaceous air-breathing insects, as described previously for culturing catfish fry (Chapter 4). The same pre-stocking fertilization recommendations should be followed. Feeding need not begin until the small prawns reach a length of 1 to 1½ inches—usually 30 to 40 days. Special shrimp rations or the cheaper sinking catfish feeds, offered at about 3% of body weight of the prawns, are suitable.

In sampling prawns for growth rate and survival, the culturist must be aware that they are very agile and easily avoid small seines. Cast nets or large seines should be used to sample them. It is difficult to catch them in traps. Water quality requirements for prawns are comparable to those required for channel catfish. However, prawns are less susceptible to catastrophic dissolved oxygen deficiencies than are catfish because they can lie in shallow water with their carapaces above the surface, to obtain atmospheric oxygen. However, a good culturist never allows conditions to get that bad, because stressed prawns grow no better than do stressed catfish.

Prawns of 0.6 to 1.1 ounces can be harvested in about 150 days, and are then ready for sale or the table. Anyone contemplating prawn culture must approach the endeavor with a great deal of caution. There is no doubt that small-scale hobby culture of prawns can be rewarding in ponds of less than 1 acre. However, we know of only one bonafide commercial prawn-growing operation (a Texas firm) in the continental United States, although there are several small pilot operations along the East Coast. In addition to the problems already discussed, a prospective prawn culturist should know that about half of the prawn's weight is made up of the head, thorax, and claws. The processing loss is even greater for the large-clawed males. If the prawns are beheaded and sold in the form of tails, the reduction in the quantity of marketable product is substantial. There are, however, specialty markets along all coasts of the United States where whole crustaceans, including prawns and shrimps, are actively sought. The size of this market should be investigated before one begins production.

A major culture limitation confronts the prawn farmer. Male Malaysian prawns grow at different rates, and this is a detriment to aquaculturists because prawns are both aggressive and cannibalistic. When large numbers of prawns (30,000 or more per acre) are stocked in ponds, the growth of males is inhibited, and only 30 to 35% can be expected to weigh as much as 0.6 to 1.1 ounces within 5 to 7 months after being stocked. In tropical climates, this differential size does not present a problem because the larger male prawns are selectively harvested year-round, and smaller males quickly grow to take their places. Thus,

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Fig. 15.5. Freshwater prawns grown in southern Arkansas reached weights of about 0.6 to 1.1 ounces in a 140-day growing season. The short growing season limits the production of these crustaceans in the United States. *Photo by J. Mayo Martin.*

ponds can be harvested and stocked continuously once harvesting begins. Temperature restrictions in the continental United States necessitate batch harvesting and reduction in stocking rates, the only known way to overcome growth inhibition in the larger male prawns.

Some research and development findings have improved the economics of production. Prawn culturists have found that recently metamorphosed postlarvae can be grown at high densities for 2 to 3 months with little mortality. These juveniles reach lengths of 1½ to 2 inches and are much hardier than recently metamorphosed postlarvae. Rearing juveniles in heated nurseries lengthens growing seasons substantially. Although growth slows toward the end of the nursery rearing period, it resumes at a rapid pace when the juveniles are stocked into open ponds.

Growth inhibition is not as great at high densities when juveniles, rather than recently

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Fig. 15.6. This bullfrog is identifiable as a male because the ear covering is much larger than the eye. In the female the ear covering and eye are nearly the same size. *Photo by K. Lyle.*

metamorphosed postlarvae, are stocked. Grading juveniles into distinct size classes further reduces growth inhibition. Researchers in South Carolina have found that maximum production can be obtained by stocking postlarvae and juveniles together at rates as high as 26,000 per acre. Distinctly different size classes are present at harvest, but most of the prawns reach salable size.

Prawns may be cultured with fish. Recent studies have shown that polyculture of prawns with blue tilapias or with channel catfish fry or fingerlings can be successful in experimental ponds. Catfish swim-up fry should be stocked about a month after the postlarval prawns are released. In a normal growing season, the channel catfish fingerlings do not become large enough to interfere with prawn growth. Catfish fry have been stocked at 10,000 to 20,000 per acre with 10,000 postlarvae, or 50,000 to 100,000 per acre with 1,000 juvenile prawns. Results suggest that further research is warranted. The major problem with polyculture of prawns and fish is that prawns must be harvested by early fall and hand-sorted.

Bullfrogs

Frog legs are gourmet items on the menus of many fine restaurants. Most come from the wild. However, the demand is greater than the supply, and availability is seasonal. Managed culture or production of bullfrogs (*Rana catesbeiana;* Fig. 15.6) could make the supply of frog legs more predictable and possibly lower the cost to the consumer. Then, too, there is a substantial market for live frogs for use in biological research.

Because of the high sale prices for frog legs and live frogs, unscrupulous persons have tried to convince prospective producers that bullfrog culture is a lucrative business. Generally, it has not been possible to culture bullfrogs commercially because they have a complicated life cycle that includes completely aquatic, gill-bearing tadpoles and semi-aquatic, lung-breathing juveniles and adults. Although bullfrogs breed readily in shallow, vegetation-choked ponds, controlled laboratory breeding and rearing have been achieved only within the past few years. Bullfrog culture is now technically feasible, but profit-

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ability is questionable—we know of only one commercial operation in the United States.

The Japanese and Taiwanese practice open-pond culture of bullfrogs from eggs to adults, but their techniques have never been applied successfully in the United States. Most specialists believe that the culture of bullfrogs here requires several major facilities: brood ponds and rearing ponds for the production of suitable fish to feed juvenile and adult frogs, culture tanks for hatching bullfrog eggs and raising the larvae (tadpoles), and a building or roofed area to house the growing frogs. Breeding ponds for bullfrogs are also needed as an adjunct to the hormonal stimulation of breeding. In addition, space is needed for office work and for such activities as processing larval feed, stimulating females for reproduction, storing equipment and supplies, and processing and packaging.

Frog culture is thus not a simple operation. Considerable investment in time, training, and capital is required.

A brief outline of the operations involved in frog culture follows. Egg masses can be obtained from brood ponds where frogs are allowed to breed spontaneously, or (preferably) by hormonal injections. The eggs are hatched in specially constructed troughs. The fish-like tadpoles are reared in troughs until metamorphosis, when the legs and lungs develop and the tail and gills are lost. Water quality and nutritional requirements are precise. The newly metamorphosed frogs are cultured in pens or troughs with little standing water. They are fed living foods; small, hardy, minnow-like fishes are preferred to other "traditonal" frog foods such as crickets, worms, and flies. As the frogs grow, food size must be increased. Producing adequate quantities of fish of suitable size for the frogs is very demanding. Sanitation is absolutely essential if diseases—particularly bacterial diseases—are to be avoided or controlled. Temperatures must range from 68 to 80°F year-round. One cycle, egg to salable frog, requires 6 to 12 months.

Two markets are available for domestically produced frogs. Small, ¼-pound frogs, about 4 to 5 months post-metamorphosis, command favorable prices in the research market (e.g., biological supply houses). Larger, ½-pound frogs, 6 to 10 months post-metamorphosis, might be sold for food, but prices are not now high enough to make this market as attractive as the market for live frogs.

Alligators

The alligator (*Alligator mississippiensis*) is a large, aquatic reptile highly valued for its hide and meat. It was once abundant in the lower South, before overhunting and habitat destruction reduced its numbers throughout the region. However, extensive conservation efforts have restored alligators to pre-exploitation levels wherever suitable habitats remain, principally in southern Louisiana and south-central Florida.

One result of the conservation effort led to the development of alligator culture techniques. Several commercial alligator farms are now being operated in Louisiana and Florida. They have become successful because restrictions against the sales of alligator products, incuding hides and meat, have been revised. The demand for alligator products is so great, in fact, that prices are high and alligator farming can be lucrative.

A prospective alligator farmer can raise alligators extensively in fenced outdoor earthen ponds or in indoor sophisticated incubation and rearing containers. An alligator grows to a harvestable length of 5 to 6 feet in a period of 26 months during which temperatures range between 80 and 90°F. Inasmuch as growth stops when temperatures fall below 60°F, the effective growing season is 5 to 6 months per year in most of the South unless supplemental heating is provided. In unheated farms, 48 to 52 calendar months are required to raise alligators of marketable size.

Brood Stock

Domesticated alligators should be used for brood stock. Wild alligators, even when available, are very aggressive, and no more than one adult male and three adult females can be stocked in a 4-acre brood enclosure. In con-

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trast, as many as 75 domesticated female alligators 6 to 7 feet long, and 25 males 8 to 9 feet long, can be stocked in such an enclosure. Obtaining brood stock could be a problem because producers may be reluctant to sell domesticated stock to a prospective competitor. Alternatively, wild alligators can be purchased during legal trapping seasons. The Louisiana Department of Wildlife and Fisheries and the Florida Game and Freshwater Fisheries Commission have provided legitimate farmers with newly hatched alligators or wild adults. In return, the farmer agrees to return a pre-arranged number of yearling or older alligators for stocking suitable natural habitat.

Brood enclosures can be about 4 acres in area and must be built of sturdy materials to prevent escape. The most practical and economical materials are welded wire and treated posts; the fences should be 6 feet high, and the mesh size either 2 × 4 inches or 1 × 2 inches. To prevent escape beneath the fence, 1- by 6-inch treated boards should be installed underground along the base of the entire fence line. A poultry wire retainer must be installed at the top of the fence and angled inward to prevent escape of wild alligators, which are agile climbers. The retainer may not be necessary for domesticated stock. Fencing should be placed no closer than 30 feet from the nearest water inside the enclosure. The farmer must make frequent inspections for evidence of tunneling activity near the fences. A 4-acre enclosure should contain a 1½-acre pond 4 to 6 feet deep.

The alligator feeding program developed by the Louisiana Department of Wildlife and Fisheries involves three phases: phase I applies to alligators from day 1 to year 3 in intensive culture under controlled conditions; phase II to alligators from year 3 to year 6 in the pen; and phase III to alligators older than 6 years in the pen breeding program.

Alligators are fed ground fish when they are newly hatched, chopped fish as they grow larger, and finally whole fish. The most cost-effective food has proved to be fresh or frozen marine trawl fish ("croaker mix"). Dead chickens and chicken offal have been used by some farmers. Carcasses of nutrias and muskrats collected and frozen during the winter trapping season are excellent feeds, but costs of storage and handling may be prohibitive. Feeding stations should be established on sloping banks in various areas of the pen. The feed should not be thrown into the water. At summer temperatures, feeding rates for phase II and III alligators should be 7 to 8% of body weight per week, divided between two feedings per week. Feeding rates should be adjusted as temperatures change. There is no need to feed alligators when water temperatures fall below 60°F.

A special vitamin premix (Table 15.1) is added to the diets at a minimum rate of 0.5% by weight of food for domestic alligators of all ages. The concentration of vitamins A and D are often doubled during the last 2 years of feeding in an attempt to increase reproduction and productivity.

Table 15.1. *Composition of vitamin premix for alligators. Premix is added at the rate of 0.5% to the feed.*[a]

Vitamin and unit	Quantity per pound of premix
Vitamin A (IU)	1,800,000
Vitamin D (IU)	200,000
Vitamin E (IU)	5,000
Vitamin B-12 (mg)	1.35
Folic acid (mg)	90
Biotin (mg)	20
Riboflavin (g)	1
d-Pantothenic acid (g)	2.76
Niacin (g)	4.5
Choline chloride (g)	86.3
Pyridoxine hydrochloride (g)	1
Menadione sodium bisulfite (g)	4.28
Thiamin (g)	1
Inositol (g)	5
Para-amino benzoic acid (g)	5
Ascorbic acid (g)	45
Ethoxyquin (g)	5
Whey or other premix diluent to equal 1 pound (g)	284

[a]From L. McNease and T. Joanen. 1981. Nutrition of alligators. Alligator Production Conference, Gainesville, Florida; Louisiana Department of Wildlife and Fisheries, Grand Chenier, Louisiana. 21 pp. (mimeographed)

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Although alligators fed fish have been shown to grow well, there is evidence that reproductive success is reduced unless the diet is changed to include meat products from warm-blooded mammals. The Louisiana Department of Wildlife and Fisheries has found that growth of phase 11 alligators (years 3 to 6), and egg production of breeding alligators, increase markedly when the animals are fed nutria carcasses. The feed also affects behavior: Alligators fed fish are shy, but those fed nutrias are aggressive at feeding stations and are generally much more active.

Nesting and Incubation

Breeding activity begins when air temperatures approach 70°F in spring. Bellowing and courtship displays are conspicuous activities. The females build nests from sedges, rushes, grasses, and mud, although some use only mud. Vegetation must be provided for nest-building if little is present in the breeding pen. Usually a 10- to 11-year-old domesticated alligator 7½ to 8½ feet long lays 38 to 40 eggs in a single laying.

It is advisable to remove alligator eggs from nests soon after all are laid, and to incubate them artificially. Most females do not actively guard the nests, and predators such as raccoons have been observed ransacking nests, in plain view of the females. Females that do defend nests can be driven off with a stout pole while the eggs are being removed for incubation. *It is essential to mark the top of each egg before removing it from the nest and to keep it in the same upright position during incubation.*

Incubation temperature is critical in determining sex. Temperatures lower than 86°F produce all-female broods, and temperatures higher than 93°F produce all males. An incubation temperature of 88°F is recommended to obtain mixed sexes. Humidity should be near 100%. The eggs are put into grass hay in wire-mesh trays, in the same upright position in which they were taken from the nest, and must be kept in this position throughout the incubation period of about 65 days. Recently hatched alligators should not be removed from the trays for about 24 hours, to allow them to cleanly break the umbilical cord. Hatching success for fertilized eggs averages 60% for eggs from domesticated alligators; however, up to one-third of the eggs may be infertile. Virtually all fertile eggs from wild alligators hatch.

In nature, bacteria on the surface of the eggshells gradually degrade the shell so that it becomes weak enough for the hatching alligators to break. Thus it is absolutely essential that eggs be incubated in grass hay at about 100% humidity to ensure that this microbial growth proceeds.

Post-hatching Culture

Newly hatched alligators do not feed immediately, but subsist on stored yolk material in their stomachs. The yolk sometimes compacts and may kill hatchlings if it is not removed with a syringe. Controlled temperatures of 90 to 92°F accelerate metabolism and result in young hatchlings feeding by the 9th or 10th day after hatching.

Stocking density must not exceed 12 hatchlings per square yard, since there is danger of overcrowding and suffocation.

The farmer must keep the tanks stringently clean, provide a proper diet, maintain sufficient fresh water, and make constant inspections for potential problems. The best temperature at this stage is 84 to 86°F. The stocking rate should be reduced to about nine animals per square yard on about day 40, and to three per square yard after 1 year.

Juvenile alligators grow continuously when cultured at temperatures near 85°F. The most efficient method of culturing them to 3 years of age is in heated environmental chambers. Chambers developed by the Louisiana Department of Wildlife and Fisheries measure about 10 × 16 feet and are about 3 feet deep. Their construction permits free movement from water areas to dry concrete resting and feeding areas (Fig. 15.7).

Small alligators are fed finely ground marine fish to which multi-purpose vitamins are added (phase I feeding program). This feed is placed near the water's edge. It must

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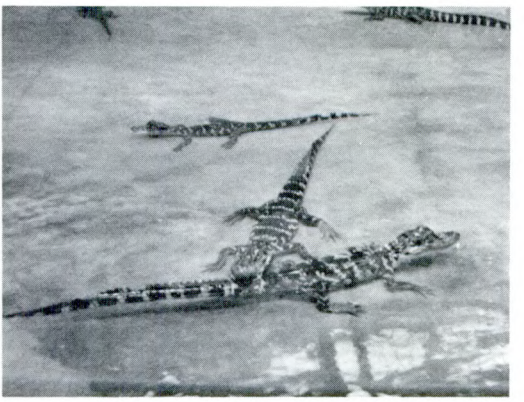


Fig. 15.7. Environmental chambers 10 × 16 feet and 3 feet deep, maintained at a constant 86°F, ensure rapid and continuous growth of young alligators. These 15-inch-long yearlings are fed a diet of chopped and whole fish for about 3 years in the chambers. *Photo by J. Witzig.*

remain frozen until just before it is offered, to prevent spoilage and possible sickness of the alligators. Uneaten feed must be removed within 3 to 4 hours and the feeding area thoroughly cleaned. Overfeeding is to be avoided because it causes gout. Once gout signs appear (the affected animal moves around stiffly, slides on its belly, and does not use its legs), simple fasting quickly eliminates the problem. As the alligators grow, first chopped and then whole fish are fed, as soon as the alligators are large enough to eat such food.

For the first year, actively growing alligators should be fed 5 days per week at the rate of 5% of their body weight at each feeding. Thereafter, they are fed 3 times per week at the rate of 6% of their body weight at each feeding.

Alligators grown in temperature-controlled environmental chambers average 3½ feet in length and weigh about 9 pounds in month 12, and are 5¼ feet long and weigh about 43 pounds in month 36.

Juvenile alligators can be cultured in unheated outdoor pens, but growth is restricted or stops during cool or cold weather.

Economics

Prospective alligator farmers must be aware that stringent regulations govern intrastate and interstate commerce in alligators and alligator products. These regulations affect the cost of doing business. The regulations are intended to ensure that wild alligators are not harvested and sold illegally. Severe criminal penalties apply to persons convicted of illegal commerce in alligators or alligator products.

Most prospective alligator farmers think of alligators in terms of hides; however, the demand for alligator meat is great, and it can be as valuable as the hides. Body parts such as teeth and skull can also be sold as curios.

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16. MULTIPLE USE OF LAND AND WATER

Jay V. Huner and Harry K. Dupree

Multiple use of land and water is far from a recent innovation. The Chinese long have used organic detritus swept from the bottom of fish culture ponds to fertilize mulberry trees, gardens, and other crops. A major reason for establishing the Fish Farming Experimental Station was to facilitate research on the rotation of fish and field crops. Researchers and fish producers have come to realize the benefits of multiple use of land and water from the standpoint of economics and enhanced production of both fish and field crops.

Several species of fish—including the golden shiner, fathead minnow, and channel catfish (and more recently the crayfish in Louisiana, Texas, and Mississippi)—have been rotated with rice, soybeans, milo, wheat, and corn. The multiple stocking and multiple harvest fish production programs now becoming popular are particularly suited to the rotation of fish and field crops. Because channel catfish ponds in intensive production are seldom drained before 4 years of continuous fish production, organic detritus builds up on the pond bottom. It also builds up in baitfish ponds and other ponds that are drained annually, if these ponds are refilled before sufficient rain has fallen to erode away the sediment. Detritus on the pond bottom can reduce water quality, increase the incidence of diseases, cause off-flavor in fish flesh, and reduce pond water volume. This organic detritus, which is composed of dead phytoplankton, uneaten feed, feces, and soil particles, can reach a depth of several feet, and in extreme situations may leave relatively little space for fish.

Rotating the fish pond into crop production often provides an economical alternative to the declining fish production that results from detritus buildup. Profit from the production of a suitable terrestrial crop often exceeds that typically expected, since the farmer can omit most or all of the fertilizers and herbicides that normally must be used. Profit from producing terrestrial crops may equal the profit from fish production, thus enabling a fish farmer to "rest" his ponds for 1 or 2 years. Alternatives that are not usually feasible include the pumping of the detritus to other sites, leaving the drained pond exposed to rains for extended periods, or allowing the pond bottom to become grass-covered for cattle grazing.

Farming of fish can improve land for terrestrial crop production. Badly eroded land, or land from which the topsoil has been removed or where the topsoil is covered, can be rather quickly reclaimed by the farming of fish. Detritus from fish production adds organic material to the soil, as well as nitrogen, phosphate, and other essential plant growth elements. Several studies have shown that 2 or 3 years of fish production can improve the land as much as 10 years of row crop production, and the cost is significantly less. The digging activity of some fish species, and the waves caused by winds often tend to level land and increase its suitability for crop farming.

Croplands that have been ruined by salting can be reclaimed through fish farming. The activity of the fish and the solubility of many salts in large volumes of water can help to dilute or flush away these minerals. Often the salts improve fish production.

Production of fish can also benefit the farmer whose primary interest is terrestrial crops. The cost of an irrigation reservoir could be shared by both crops. In a properly con-

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structed reservoir, extra water could be released by gravity flow to the surrounding fields. Marginal lowland normally unsuited to terrestrial crop production can often be leveed to keep out flood waters. The higher income from fish production enables the farmer to pay for the earthwork and pumps, and later return the field to terrestrial crop production. Water from deep wells, used for the irrigation of terrestrial crops, can usually be improved by running it through fish ponds because the temperature is raised and nutrients are added. It is obvious to the innovative farmer that the use of water from a deep well to produce both fish and terrestrial crops decreases his production costs.

A developing form of supplementary income for farms is the leasing of land during winter for wildlife hunting. Croplands that have been leveed for crop production and fish farming can be easily flooded during winter. Ducks and other waterfowl are attracted to these sites. This technique has an added advantage: seeds and other reproductive parts of many noxious plants are eaten by the foraging birds.

There are, however, a number of disadvantages to the rotation of fish and field crops, and to the multiple use of water and land. The levees and ditches occupy much land, and few alternate uses of these structures exist. A 40-acre plot of land usually makes only a 28- to 31-acre pond (or field). The other 9 to 12 acres of land are usually lost from production. Ponds and field sizes also must be compromised, since desirable pond sizes are usually less than 50 acres, and desirable field sizes larger than 50 acres. When ponds are used for both fish production and irrigation, they must be large enough to allow time for the incoming well water to warm and to develop a bloom to shade out unwanted rooted vegetation. Smaller ponds with rapid water exchange are often nearly transparent and develop severe weed problems. Planting and harvesting schedules must be adjusted to both fish and field crops. Consequently, one crop may be reduced if it cannot be sown (or stocked) or harvested during the optimum period.

The practice of fish and crop rotation limits the use of certain plants. Terrestrial crops that require the use of residual pesticides are unsuitable, because the chemicals may later kill the stocked fish. The use of certain herbicides in fish production is limited because some herbicides may kill the terrestrial crop planted later, or pond water that is also used for irrigation may kill the terrestrial crop. The high nutrient content of the bottom detritus of ponds can cause some crops to over-grow, and the seed heads to lodge (fall or lie down). Excessive amounts of plant nutrients—primarily nitrogen—may kill young plants. Flooding does not kill some weed seeds such as those of barnyard grass, and thus an herbicide may have to be used. The terrestrial crop must then be compatible with the herbicide applied.

Rotation of Fish and Rice

The rotation of fish and rice in fish ponds has created the most interest among farmers. The income from rice is generally higher than that from most other crops, and since the farmers can often eliminate the application of fertilizers and herbicides, the profit from rice might be expected to equal that from fish. The use of waste water from adjacent fish ponds to irrigate the rice further reduces production costs.

Rice responds well to nitrogen. Bottom detritus of fish ponds may contain over 200 pounds of nitrogen (as nitrate) per acre after 2 to 4 years of intensive fish production. Yields have exceeded 110 bushels of dry rice per acre in Arkansas, which is comparable to the yields on land where conventional rice farming practices are used.

Rice is farmed by minimum tillage and by intensive tillage. Minimum tillage is commonly used the first year after fish have been raised. The seed is sown by air on the pond bottom, which is covered with water to a depth of only a few inches. Machines usually enter the field only at harvest. Variations in minimum tillage are practiced by some farmers. Ponds can be seeded by air or by boat while all the fish are still in the pond. The pond is then drained and the fish are removed.

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Some growers put up a few low rice levees after they drain the pond.

Several conditions must be met before minimum tillage can be practiced on a farm. Seed used to plant the fields must be free of chemicals such as fungicides or insecticides normally used to protect rice seedlings or ensure their establishment. Harvesting of the fish must be delayed until the crop-planting season if the "drain and seine" method of harvesting is practiced. Drawdown of the pond must be sufficiently rapid to avoid excessive water depths, which adversely affect the germination of the seed, and to prevent uprooting of plants by wave action.

In intensive tillage of rice, all fish and water are removed, the pond is allowed to dry, and a conventional seed bed is prepared (Fig. 16.1). Levees are constructed and the water is managed as in intensive rice farming.

A major problem in rice farming following fish production is that of the lodging of the grain. Rice overresponds to high nitrogen and produces seed heads so heavy that the plant stem breaks and the seed heads fall to the ground. In conventional rice production the weight of the seed head is controlled by the amount of fertilizer applied. In growing rice after fish, the nitrogen often is present in excess amounts and thus results in excessive grain production and wasteful lodging.

A number of techniques are available to reduce lodging. Probably the best technique, since it conserves fertilizers, is the planting of a variety of rice with a short, thick stem that can hold up the heavy seed head. A Belmont variety of rice developed at the Texas Agricultural Experiment Station, Beaumont, Texas, appears suitable for this type of farming. Rice stems can be further shortened by mowing the rice when it is about 6 inches high. This often increases total yield due to tillering (an increase in the number of sprouts).

The farmer may wish to consider two other methods of reducing lodging in rice planted in a highly fertile pond. In one method the farmer may drain the pond in the fall or early spring and allow it to dry until the latest possible planting date. Sufficient nitrogen may be removed through leaching and denitrification



Fig. 16.1. A 100-acre catfish production pond is rotated to rice after 4 years of fish production. After the fish and water are removed, the pond is dried, a conventional seed bed is prepared, and the water is managed as in conventional rice farming.

to eliminate rice lodging. Disking and plowing the soil accelerates the oxidation of the organic material and the removal of the nitrogen. Another alternative is to plant a crop such as soybeans, which does not respond well to nitrogen, and follow it the next year with rice.

Rotation of Fish and Corn, Milo, Wheat, or Soybeans

Economics tend to favor the production of rice the first year after the removal of the fish. However, the selection of the crop for the second season, or possibly the third season, depends on many factors, some of which have not been fully investigated and evaluated. In some soils the organic matter and fertilizers remaining from fish production may last into the second or third summers, thus making the replanting of rice a distinct possibility. In other soils, the planting of corn, milo, wheat, or soybeans is indicated, since the organic matter declines rapidly. In some soils it may be more desirable to return the pond to fish production after one year's crop of rice has been harvested.

Rotation of Crayfish and Terrestrial Crops

Rice and soybeans or rice and cattle are frequently rotated with crayfish in Louisiana and

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Texas. Crayfish are stocked in flooded rice fields at 25 to 50 pounds per acre in early spring. Before rice is planted in March to May, the water is drained. The crayfish burrow into levees about the fields. Presprouted rice is sowed aerially on the wet field bottom, and the field is reflooded. Most brood crayfish remain in the burrows during summer. The fields are drained before the rice is harvested in late summer, and then reflooded. Crayfish emerge from their burrows with their young. These crayfish grow to maturity during fall and are then harvested during winter and spring. After this harvesting period, soybeans are planted, usually in June, either by aerial seeding with the water still in the pond, followed by immediate draining, or by aerial seeding of the dry pond bottom, followed by cover disking. Traditional cultivation is also still practiced.

Alternatively, the pond may be allowed to grow up in volunteer vegetation to serve as cattle pasture until the next fall, when the pond is reflooded. Crayfish ordinarily do not need to be restocked and crayfish production is usually good. However, the second season of crayfish production can interfere with rice planting the following spring. The relative values of rice and crayfish crops generally determine management strategies.

Some farmers continually double-crop crayfish and rice in the same year. Rice must be planted in March or April to ensure maximum rice yields, but crayfish must be harvested as late as May to ensure maximum crayfish yields. Again the relative value of the crops determines the management strategy.

In rice and crayfish culture, it is advisable to avoid the use of insecticides when ponds are flooded. Fields in which insects such as the rice water weevil are known to pose a problem should not be used because insecticides must be applied to control them.

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17. FISH FARMING CHECKLIST[1]

Jay V. Huner and Harry K. Dupree

Commercial fish farming can be profitable, but it can also be expensive. Commercial fish farming is generally more complicated than the potential producer first believes. The producer must be a combination business and sales person, as well as a biologist, lawyer, manager, and (possibly most of all) a hard worker.

It is important for the potential fish producer to determine first what aspect of fish farming is of interest and how much it will cost to enter business. The aquaculturist should calculate the operating cost and then the potential profit. The checklist that follows is in the form of a long series of questions that should be fully answered. Time and work spent on planning is profitable, and the greatest profit or reward may be the decision not to go into fish farming: it definitely is not for everyone.

Sources of Information

1. Have you made the following personal contacts?
   a. Federal and State agencies
   b. Universities and colleges
   c. Fish farming associations (State and national)
   d. Professional consultants, fish farmers, feed distributors, merchandisers
2. Have you obtained publications and printed materials from the following sources?
   a. Federal, State, university, and United Nations Food and Agriculture Organization (FAO)
   b. Industry journals and magazines
   c. Popular and professional books and pamphlets on pertinent subject matter

Economics, Management, and Marketing

1. Do your State laws and regulations on aquaculture production and merchandising permit introduction, commercial rearing, and sale of the species of fish you are interested in?
2. What permits or licenses are required?
3. Are there other Federal and State regulations that will affect operations, such as those on interstate shipment, predator control, water rights, processing, and retailing?

Capitalization and Operating Costs

1. Have you developed a business prospectus detailing land or space costs; capital expenditure for fish to stock; equipment, buildings, and water impoundment construction; operating capital needed; labor requirements; costs of financing, production, harvesting and marketing; depreciation schedules, and a profit and loss estimate? Such a prospectus is often necessary to obtain financing but, more important, it forces a prospective investor to take a hard look at the economic factors involved.
2. Do you have, or can you obtain, adequate financing for capital outlays and operating expenses for the period preceding the marketing of the first harvest—perhaps a year or more?

[1]This chapter is based largely on a 1970 article by W. Jones, entitled "How to get started" *in* The American Fish Farmer 1(2):5–8. (This magazine was later consolidated with Aquaculture Magazine, 23 Sunset Terrace, Asheville, North Carolina 28801.)

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3. Are you psychologically and financially prepared to only break even, or perhaps take a loss, for the first several years of operation?
4. Can your fish in the water or warehouse be used as collateral for financing future operation or expansion?
5. Are you aware of all your production and processing costs, so that you can accurately evaluate your ability to meet competition and make a profit? Some of these costs follow.
   a. Overhead and operating costs
   b. Percent of shrinkage or processing losses to expect from live harvest weight to processing plant or consumer product weight
   c. Fringe benefit costs in labor expenses

Management

Personnel

1. Do you or your production manager have the technical training or experience to manage your operation at optimum efficiency? If not, have you arranged for management counseling and periodic checks on your operation by expert consultants?
2. Are you, or do you have available, a fishery biologist competent to make immediate diagnosis and proceed with proper chemical treatment of diseases and parasites for fish stocks and to deal with other biological problems of hatching and rearing?
3. Do you have adequate skilled help to efficiently carry out all phases of your operation, to maintain schedules, and to meet emergencies?

Production Plant Facilities and Layout

1. Are your ponds, tanks, hatcheries, and processing and shipping areas laid out for optimum efficiency in use of labor and time?
2. Are your facilities accessible during prolonged adverse weather?
3. Do you have, or can you arrange for (on short notice), holding facilities for quarantining incoming or diseased fish stock, for accumulating payload shipments, or for merchandise display?
4. Have you accounted for expansion in your production plant layout?
5. Are adequate utilities such as three-phase electrical power, potable water, and sewage disposal available?
6. What alternate production facilities should be considered—static ponds, earthen or concrete raceways, pen confinement, aquariums?

Equipment

1. What apparatus and laboratory equipment will you need to test dissolved oxygen concentration, detect presence of disease, and make other diagnostic evaluations of your operation?
2. What emergency power unit is available in the event of an electric power failure?
3. Do you have adequate power equipment, such as tractors, lifts, conveyors, and winches, to ensure efficient operations?

Biological and Chemical Controls

1. What is a safe margin of dissolved oxygen that must be maintained? Do you have provisions for emergency oxygenation of water?
2. What other chemical and physical water quality characteristics must be monitored? What equipment is needed to monitor them? What are the safe and unsafe levels of each, and how can unsafe levels be controlled?
3. What chemicals or other methods are required, and in what amounts for (1) aquatic plant control, including microscopic phytoplankton and macroscopic plants, and (2) control of undesirable fish and other aquatic organisms?
4. Can you obtain, or have you obtained, special permits and the cooperation of State and Federal wildlife agencies for control of fish competitors and predators?

Marketing

1. Have you studied your market outlets?
   a. Do you have reasonably firm market

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commitments as to quantity, price, and form of product?
   b. Do you have alternate market outlets?
   c. Can you adjust your harvest time to take advantage of high points in seasonal demand and price fluctuations, if they exist?
   d. Can you provide maximum quality, type, form, and weight of products and other services that your market outlet requires?
   e. Do you have, or can you arrange for, adequate distribution facilities and dependable supply sources to meet the time, quality, and quantity demands of your markets?
   f. Are you aware of trends in product forms, packaging, convenience, and prices of your and competing products in the market?
   g. Do you have a market outlet for your processing scrap?
2. Have you planned for market promotion and education activities?
   a. Have you scheduled an advertising budget to stimulate sales?
   b. Have you participated in and contributed to industry association programs to create an appealing image for fish farming, and products for consumers and merchandisers?
   c. Have you cooperated with news media staffs to develop reports and programs to increase public awareness of the industry?

Physical Features of Production Complex

Site Location

1. Does your site have natural elevations that, with proper engineering, will allow each pond to be drained independently and completely?
2. Is it necessary to obtain a permit from the U.S. Army Corps of Engineers to build a pond on the selected site (some sites are considered wetlands and you may not be permitted to construct a pond regardless of ownership)?
3. Is an Environmental Impact Statement required by State or Federal agencies before an aquaculture site may be developed?
4. Does the land elevation permit biological supervision and general physical maintenance without excessive travel?
5. Has analysis of the soils been made to determine physical qualities for water retainment and fish culture?
6. Have core drillings been made to determine impervious qualities of subterranean soils?
7. Are adjacent lands subject to aerial crop spraying for insects and weeds?
   a. Are your production facilities protected by State law from aerial crop spraying on adjacent lands?
   b. Have you tested your land for toxic chemical residues from previous years of crop spraying for insect or weed control?
8. Is the site free of all possible overflow by flooding?
9. Is drainage available to natural waterways without crossing other private lands?
10. Will your Federal, State, and local water management agencies permit drainage into existing streams?
11. Does the topographic elevation of your site make it possible to use the prevailing summer winds without creating excessive water erosion problems on levees?
12. Can you economically secure your production facilities from poaching and prevent escape of stock?
13. Can you receive or deliver fish regardless of weather conditions?

Water Supply

1. What is the source of your water supply—reservoir, well water, groundwater, or running stream? Is it adequate for present and future needs? Is there an alternate source available in emergencies?
2. Is it possible to secure water permits for the volume of water needed to meet your present and future needs?
3. What are the temperature variations of your water supply?

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4. Has the water been tested for chemical adaptability to fish production? Have provisions been made for aerating well water? Are surface waters free of harmful chemicals?
5. Do the volume, depth, and location of your well make it economically feasible to use?
6. Is your water supply adequate to replace evaporation and seepage?
7. If surface water is used, can you control predators and unwanted fish species?

Source of Fingerling Stock

Spawning and Raising Your Own Fingerlings

1. Procurement of brood stock
   a. What age of brood stock should be purchased?
   b. Where will brood stock be obtained?
   c. At what age will a female reproduce?
   d. At what size and age is the female most profitable?
   e. How many brood pairs should be stocked per surface acre of water volume in spawning areas?
2. Care of brood stock before spawning
   a. How long must the brood stock be placed in spawning surroundings before spawning?
   b. How closely must the male and female brood fish be paired in size?
   c. What special feeds must be fed and for what length of time before spawning?
   d. What hormone injections or other treatments can be administered to hasten or retard spawning?
   e. What prespawning chemical treatment should the pond receive?
   f. Do noise or physical activities have any effect on spawning? If so, what consideration should be given to location of spawning areas?
3. Spawning
   a. What water temperature must be maintained, and for how long, to induce spawning?
   b. What physical apparatus must be made available in the spawning areas?
   c. In what location and at what water depth should such apparatus be placed?
   d. Is available spawning apparatus compatible with the size of the brood fish?
   e. How are eggs to be protected from predators before hatching—by parents, by chemical treatment, or by physical manipulation of the environment?
4. Artificial Incubation
   a. What types of equipment are required, such as troughs, hatching containers, incubation jars, and aeration or agitation devices?
   b. What are the particular water requirements for the species being cultured, such as temperature, water chemistry, and flow rate?
   c. What provisions are required to ensure continuous operation in the event of power failure?
   d. Will fry be reared in troughs, tanks, or ponds? If they are to be reared in troughs or tanks, what are the specific requirements (e.g., water, feed, lighting)?
   e. How will you prevent or control cannibalism?
5. Procedure to be followed with fry upon hatching
   a. What diseases can be encountered in fry? What are the chemical treatments for such diseases? Are the chemicals readily available, and are they registered for use by the United States Food and Drug Administration?
   b. What measures should be taken to prevent cannibalism of the brood stock on their own young?
   c. What food (amount and form) should be fed to the fry? Where can it be obtained?
   d. How important are natural foods to the young and how can growth of natural foods be stimulated?
   e. How are the fry to be protected from predators and competitors?

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Purchasing Fingerlings from Other Producers

1. What price can you economically pay for fingerlings?
2. What size are the smallest fingerlings—usually the cheapest—that can be grown to marketable size most economically in your production program?
3. What is the fingerling producer's reputation for producing disease-free fingerlings of good quality? Have you visited prospective fingerling producers to investigate their operations? Will you inspect fingerlings before purchasing them?
4. Do you have an alternate source or sources of fingerlings if your primary supplier cannot meet your needs?
5. What chemical treatment for disease control should the fingerlings be given before they are planted into rearing waters? Who will treat the fingerlings—you or your supplier?
6. What water preparation is necessary before the fingerlings are planted?
7. How will your fingerlings be graded before they are planted to produce maximum uniformity at harvest?
8. How many fingerlings or other young fish should be stocked per surface acre or volume of water?
9. How many fry per unit of water can be feasibly carried through the growing season to produce fish for stocking in the following year?
10. What maximum temperature change will the fingerlings withstand in transporting, treating, or planting without experiencing thermal shock?
    a. Is permanent damage caused by thermal shock, and what treatment is effective if such shock occurs?
    b. What equipment is needed to handle fingerlings to overcome thermal shock?
11. How far in advance must you order fingerlings to be relatively confident that you will have the fish that you require?
12. Are you prepared to inspect the fingerlings upon delivery and, if unsatisfactory, reject them?

Feeding

Feed Source

1. Is feed readily and constantly available in the quantities needed?
2. Have your feed rations been proved through experimentation to provide optimum growth or maintenance for the stock you are feeding?
3. Are the ingredients of your feed dependable and relatively constant from batch to batch?
4. Do you have laboratory facilities available for periodic feed analysis?
5. What kinds and amounts of fertilizers are needed to induce plant and plankton growth for natural food organisms?

Feeding Procedure

1. What special equipment will be needed for an efficient feeding system?
2. How will you determine daily feeding rates? What factors will determine the allowance of feed to maintain desired consumption and growth?
3. At what water temperatures do you plan to begin, reduce, or cease feeding?
    a. If you continued feeding during cold weather, how much feed would you provide?
    b. What system will you use for control of ice cover in winter? Will cloudy ice cover create problems?
4. What physical apparatus or observation procedure will you use to check food consumption?
5. What adjustments will you make in your feeding program to compensate for cloudy, humid, hot days?
6. What feeding schedule will you follow?
    a. How often will you feed?
    b. What is the best time of day?
    c. What is the best water depth?
7. How many areas in a given pond and over how large an area must you feed for best results?
8. Have you considered the problems associated with the uses of pelleted feed?
    a. What percentage of fines in your pel-

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leted feed is permissible without creating water contamination?
   b. What sizes of feed pellets are best suited for fry, fingerlings, and larger juvenile fish?
   c. Does your pelleted feed have adequate binder to prevent disintegration in water before it is eaten?
   d. Should you use a floating or sinking feed?
9. What effects do various feeding rates have on water quality and when are those effects most serious?
10. What is the shelf life of your feed and what precautions must be taken to prevent heat and moisture deterioration, rodent damage, and chemical and toxin contamination?
11. Are adequate storage facilities available for the type and amount of feeds required in your program?

Harvesting, Transporting, and Processing

Harvesting

1. What is the most economical type of harvesting method for your present and future facilities?
2. How will you construct your ponds or other production facilities to provide the most efficient harvesting techniques?
3. What special equipment will be needed for expeditiously handling fish from harvest facilities to transportation vehicles?
4. Will you need special holding tanks or ponds to keep quantities of fish ready for immediate delivery?
5. If you are producing food fish, how will you test them for off-flavor? If off-flavor is detected, how will you correct it? Are you prepared to hold harvestable fish 2 to 8 weeks (or longer) if they cannot be harvested because of an off-flavor problem?

Transporting

1. What facilities do you have available for transferring harvested fish to market or to a processing plant?
2. What will you use for water cooling in transporting live fish (e.g., ice-refrigerated vans, mechanically refrigerated water tanks)?
3. What amount of chlorine in the water will the fish tolerate?
4. How will a suitable water exchange for long-distance shipments be made available in transit? What aeration equipment is needed?

Processing

1. If you plan to dress or package fish for retail, will your facilities conform with State food processing and sanitation codes? Do you need processing and retail sales licenses?
2. Are your production facilities reasonably convenient to a processing plant?
3. Is it to your advantage to contract with a processor for your annual production?
4. Good service and good quality are major keys to sales expansion. Are you equipped to give both?

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18. WARMWATER FISHERY RESEARCH NEEDS

Harry K. Dupree, J. Mayo Martin, Donald C. Greenland, Glenn L. Hoffman, John J. Giudice, Andrew J. Mitchell, Dewey L. Tackett, Ray R. Carter, and Jay V. Huner

Various fish farming industry groups and individual users, and some State and Federal agencies, have periodically identified to us their research needs. Included, among others, are the Catfish Farmers of America, American Fish Farming Federation, Florida Tropical Fish Farms Association, numerous State fish farming associations, State and Federal fish hatcheries, and several Federal agencies such as the Department of Agriculture, Department of Commerce, Food and Drug Administration, Environmental Protection Agency, Small Business Association, and U.S. Army Corps of Engineers. In preparing the list of suggested topics of research and development that follows, we emphasized warmwater fish farming research, but some items also apply to sport fishes, crustaceans, and other aquatic animals.

Life History and Biology

- Summarize the scientific literature and other information on life history and biology of commercial, sport, and aquarium (hobby) fishes.

Genetics and Reproduction

- Identify and test the various strains of the principal aquacultural animal species for specific culture, production, and management needs.
- Selectively breed the principal commercial food fishes to improve growth rate, feed conversion efficiency, survival, and uniformity.
- Hybridize, and test for commercial production values and specific management needs, the principal aquacultural species such as catfishes, trouts, basses, sunfishes, polyculture species (carps, buffaloes, and tilapias), and crayfish.
- Develop and evaluate techniques for production of monosex and sterile fishes for specific management and production needs.
- Conduct research on techniques for the breeding and reproduction of identified and potentially useful non-native aquacultural animal species.

Nutrition and Diet

- Identify and evaluate substitute proteins for fish meals in feeds for finfishes.
- Formulate and test feeds for fish larvae and fry. Develop low-cost feeds for intensively produced fishes, including channel catfish, carps, tilapias, minnows, and striped bass.
- Continue research on the basic nutritional requirements of the aquacultural finfishes, including channel catfish, bait minnows, carps, tilapias, and striped bass.
- Develop feed formulations and feeding techniques for various sizes and ages of commercial food fishes, bait minnows, aquarium fishes, and sport fishes.
- Formulate methods for the addition of drugs, chemicals, and other additives to fish feeds.
- Identify man-made and natural toxins, growth inhibitors, and contaminants in fish feed ingredients and develop techniques for their removal or detoxification.

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Environmental Requirements

- Evaluate in terms of the well-being of fish in fish production systems the interrelationship between metabolites such as carbon dioxide and ammonia, and water temperature, pH, alkalinity, and hardness.
- Develop methods for predicting and correcting water quality deterioration in intensive fish production systems.
- Develop simple and low-cost analytical equipment and methods to identify and quantify the chemical factors that limit fish production.
- Perfect biological, mechanical, and chemical methods to remove natural and manmade contaminants that limit fish production.
- Develop methods and techniques (management, mechanical, and chemical) for controlling the production of undesirable aquatic plants and animals.
- Determine the soil factors that enhance production of natural fish food organisms, and develop the management practices needed to apply this knowledge.
- Develop techniques for detecting, monitoring, and removing environmental contaminants affecting fish health.
- Design equipment and evaluate techniques such as aeration, filtration, recirculation, water exchange, and chemicals to improve water quality in intensive production systems.
- Develop methods and techniques to maximize the production of desirable fish food organisms, and to make available suitable spawning substrates and cover that meet specific management requirements.

Effluent Control and Water Availability

- Continue research and development on methods for removing waste materials and organisms from the effluents of intensive culture facilities.

Control of Diseases and Parasites

- Continue studies on identification, description, and life cycles of parasites and diseases of finfishes of commercial, aquarium, management, and recreational importance.
- Develop better chemical, biological, and management methods for the prevention or control of organisms detrimental to aquacultural species.
- Continue research on immunology and development of vaccines for controlling diseases of important commercial, aquarium, and sport fishes.
- Continue research on the development of techniques for clinical diagnosis of fish diseases.
- Continue to develop better methods for histopathological diagnosis of infectious and nutritional diseases, and those resulting from chemical contamination or that are environmentally related.
- Conduct research on surveillance and control measures that will prevent importation or transfer of detrimental diseases and parasites of aquacultural species.

Predation and Competition

- Identify and evaluate the predators and competitors, and their impact on various life stages of important commercial, aquarium, and recreational fishes.
- Develop chemical, biological, and management techniques to control or eliminate insects, fish, reptiles, birds, and mammals that prey on important cultured species of finfish in culture facilities or management areas.

Harvesting, Processing, and Distribution

- Continue to devise and evaluate methods for selective harvesting of fishes from ponds, raceways, and cages.
- Develop and evaluate practical methods and equipment for selectively capturing fish from strip-mine pits, large reservoirs, lakes, and rivers.
- Continue research on loading methods and equipment for transferring fish from capture devices to transportation units.
- Conduct research on capture devices and techniques for removing exotic or unwanted

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fishes from intensive culture facilities. Continue development of grading and sorting devices and techniques for finfishes of various life stages and species.

Transportation

- Continue research to improve transportation efficiency by decreasing the ratio of water to fish.
- Identify the water quality and physiological factors that reduce fish carrying capacity in transportation equipment.
- Develop practical methods of using chemicals, aeration, and anesthetics to neutralize or eliminate the factors that limit hauling capacity.
- Continue refining the design of hauling units to simplify loading and unloading, and to increase load capacity without damage to the different life stages of the fishes transported.

Introduction of Non-native Species

- Develop criteria for selecting aquatic organisms as potential candidates for culture as food, sport, management, or hobby (aquarium) species.
- Develop a protocol for the limited importation of candidate species for research and evaluation.
- Conduct research on the development of techniques for the production of identified and potentially useful non-native species of fish and other aquacultural animals.

Drug and Chemical Registration

- Establish protocol for identifying priority chemicals that includes species and needs of culturists of commercial, aquarium, and sport fishes.
- Identify, and screen for efficacy, candidate chemicals and drugs for specific aquacultural uses such as disease control, vegetation control, and fish and predator control.
- Conduct the appropriate tests and studies required to meet requirements of the U.S. Food and Drug Administration for the registration of high-priority drugs and chemicals for the production of commercial, sport, and aquarium fishes.

Production of Rare (Commercially Unavailable) Seed Stocks

- Identify (with the help of producers of commercial, aquarium, and sport fishes) commercially unavailable species that have aquaculture potential.
- Acquire and maintain groups of brood stocks of candidate species, and develop methods and equipment for reproducing and rearing these species until brood stock becomes readily available.

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19. CONVERSION FACTORS AND CALCULATION OF TREATMENTS

Jay V. Huner and Harry K. Dupree

Chemicals and drugs are applied to fish in ponds, vats, raceways, cages, and hauling units to control diseases, alleviate water quality deterioration, eliminate undesirable plants, and do many other things. Although chemicals and drugs can be highly beneficial to the fish producer when properly used, improper use can be costly from the standpoint of wasted compounds and possibly death of the fish. Knowledge of treatment units and their conversion values is essential for prudent use of chemicals and drugs in aquaculture. Knowing the recommended treatments, methods of application, and cautions is a hallmark of a competent fish producer.

We offer temperature conversion factors (Table 19.1); weight and volume conversion factors most commonly used by fish farmers (Table 19.2); and a series of formulas or other aids for calculating treatments, determining areas and volumes, and measuring certain water quality characteristics.

Table 19.1. *Temperature conversion factors, Celsius (Centigrade) to Fahrenheit (°C × 9/5 + 32; e.g., 100°C × 9/5 = 180 + 32 = 212°) and Fahrenheit to Celsius (°F - 32 × 5/9; e.g., 212°F - 32 = 180 × 5/9 = 100°C).*

°C	°F	°C	°F
0	32.0	20	68.0
2	35.6	22	71.6
4	39.2	24	75.2
6	42.8	26	78.8
8	46.4	28	82.5
10	50.0	30	86.0
12	53.6	32	89.6
14	57.2	34	93.2
16	60.8	36	96.8
18	64.4	38	100.4

Determining Amounts of Chemicals Needed for Treatments in Tanks and in Feeds

Chemical treatments for disease control are of four general types: dip, standing water, continuous flow, and dietary (chemicals included in the feed). The treatment of choice depends on the fish species and size, culture system, and the cost of the chemical.

Dip Treatments

The dip treatment is generally used for small numbers of fish when the application time is less than 1 minute. The quantity of the chemical to be measured can be calculated by the following formula:

$$\text{No. mL, cc, or g of chemical} = \frac{\text{gallons of water treated} \times \text{mL per gallon}}{\text{concentration (ratio) of chemical desired}}$$

Sample problem: Your golden shiners are infected with a stalked ciliate. You plan to use acetic acid for a dip treatment in a wooden barrel that holds 50 gallons of water. How much acetic acid will you need to add to the 50 gallons of water to obtain a final concentration of 1:500 (2,000 ppm)?

$$\text{No. mL or cc of acetic acid needed} = \frac{50 \text{ gallons} \times 3{,}785 \text{ mL/gallon}}{500}$$

$$= 378.5 \text{ mL of acetic acid}$$

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Table 19.2. *Common weight and volume conversion factors useful in fish farming.*[a]

Unit and equivalents	Unit and equivalents
Acre	2.20 lb of water
43,560 ft^2	⅓ tbsp
4,840 yd^2	Ounce (weight)
4,046.8 m^2	28.35 g
Acre-foot (A-ft)	0.063 lb
43,560 ft^3	0.96 fl oz of water
325,851 gal	Ounce (fluid)
2,718,144 lb of water	29.57 g of water
1 surface acre covered with 1 foot of water	29.57 mL or cc
1,233,489 L	1.043 oz of water
Cubic foot (ft^3)	⅛ cup
28.32 L	6 tsp
28,317 mL or cc	2 tbsp
7.48 gal	Part per million (ppm)
1,728 $in.^3$	1 mg/L of water
0.037 yd^3	3.78 mg/gal
62.43 lb of water	3.78 g/1,000 gal of water
957.5 fl oz	0.13 oz/1,000 gal of water
Cup	1 oz/1,000 ft^3
8 fl oz	28.35 g/100 ft^3
½ pt	2.72 lb/A-ft of water
Gallon (gal)	Pint (pt)
3.75 L	473.17 mL or cc
3,785.4 mL or cc	½ qt
128 fl oz	16 fl oz
8 pt	16.69 oz of water
4 qt	⅛ gal
0.13 ft^3	1.04 lb of water
133.52 oz of water	Quart (qt)
8.35 lb of water	946.34 mL or cc
Gram (g)	32 fl oz
0.035 oz	4 cups
1 mL or cc of water	2 pt
1,000 mg	¼ gal
Kilogram (kg)	2.09 lb
2.20 lb	Tablespoon (tbsp)
35.27 oz	14.79 mL or cc
1.0 L of water	3 tsp
Liter (L)	½ fl oz
33.82 fl oz	Teaspoon (tsp)
1.057 qt	4.93 mL or cc
0.26 gal	⅓ tbsp
1 kg of water	⅙ fl oz

Abbreviations not given in table:

Cubic centimeter = cc	Meter = m	Pound = lb
Cubic inch = $in.^3$	Milligram = mg	Square foot = ft^2
Cubic yard = yd^3	Milliliter = mL	Square meter = m^2
Fluid ounce = fl oz	Ounce = oz	Square yard = yd^2

[a]Conversions provided by Brenda Rodgers Moore and Andrew J. Mitchell, Fish Farming Experimental Station. (unpublished)

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Standing Water Treatment

The standing water treatment is generally used when the application time is longer than 1 minute. Supplemental aeration should be provided unless the fish load is light. The quantity of the chemical to be measured can be calculated by the following formula (dimensions of tank in feet):

$$\text{No. mL, cc, or g of chemical needed} = \frac{\text{total mL of water to be treated (length} \times \text{width} \times \text{average depth} \times \text{mL/ft}^3)}{\text{concentration (ratio) of chemical desired}}$$

Sample problem: Your hatchery tank measures 25 ft by 3 ft (inside dimensions) and is 1½ ft deep at midpoint (average depth). Your channel catfish are infected with *Ichtyoboda*. You wish to treat them with formalin at a concentration of 1:6,000 (167 ppm). How much formalin do you need to add to the tank?

$$\text{No. mL or cc of formalin needed} = \frac{3{,}185{,}438 \text{ mL of water } (25 \times 3 \times 1.5 \times 28{,}315 \text{ mL/ft}^3)}{6{,}000}$$

$$= 530 \text{ mL of formalin}$$

Continuous Flow Treatment

The continuous flow treatment is generally used when the application time is longer than 1 minute and the water flow cannot be interrupted. The quantity of chemical to be added during the treatment period can be calculated by the following formula:

$$\text{No. mL, cc, or g of chemical} = \frac{\text{gallons of water} \times \text{minutes of treatment} \times \text{mL per gallon flow per minute}}{\text{concentration (ratio) of chemical desired}}$$

Sample problem: You notice that the fingerlings in a trough are beginning to show signs of disease so you decide to treat them with formalin at 1:6,000 (167 ppm) for 1 hour. The water flow through the trough is 6 gallons per minute. How much formalin do you need?

$$\text{No. of mL or cc of formalin} = 6 \times 60 \times 3{,}785$$

$$= 227 \text{ mL of formalin}$$

Gallons of water flow per minute when flows are small can be conveniently determined by simply timing the flow of water in a 1-, 2-, or 5-gallon pail. Larger flows that cannot be conveniently collected in a container of known volume can be determined by timing a 4- or 6-inch rise in a hatchery tank, multiplying length × width × 4 or 6 inches (whichever is chosen), and converting to gallons.

Ratios (1:4,000) are converted to parts per million (ppm) by dividing the ratio (4,000) into 1,000,000, which in this example is equal to 250 ppm, and vice versa (ppm divided into 1,000,000 equals the ratio).

$$\text{Ratio} = \frac{1{,}000{,}000}{250} = 4{,}000 \text{ or } 1{:}4{,}000$$

Dietary Treatment

The feed treatment is generally used when an oral administration of the drug is required, or if it is more economical to administer the drug orally than by water treatment. The following examples are provided (adapted from J. Camper and R. Ivarie [Norfolk (Arkansas) National Fish Hatchery; unpublished]).

Amount of medication to use:

$$\text{Amount of drug needed} = \text{weight of fish} \times \text{dosage rate} \times \text{days of treatment}$$

Example: How much oxytetracycline will you need to treat 2,500 kg of fish with 2.5 g oxytetracycline per 50 kg of fish for 10 days?

$$\text{Grams of oxytetracycline} = 2{,}500 \text{ kg} \times \frac{2.5 \text{ g}}{50 \text{ kg}} \times 10 \text{ days}$$

$$= 1{,}250 \text{ (active ingredient)}$$

Amount of feed needed for treatment period:

$$\text{Amount of medicated feed needed} = \text{weight of fish} \times \text{feeding rate (\%)} \times \text{days to be fed}$$

Example: How much feed would be needed if 2,500 kg of fish are to be fed at a rate of 3% of body weight for 10 days?

$$\text{Amount of medicated feed needed} = 2{,}500 \text{ kg} \times \frac{3}{100} \times 10 \text{ days}$$

$$= 750 \text{ kg}$$

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Mixing medication with the feed:

1. Determine how much medication is to be mixed with a specified amount of feed. For example: 1,250 g (active ingredient) medication required for 750 kg of feed. Select a volume that can be easily handled.
2. Weigh out the amount of medication required and weigh out the required amount of feed.
3. Coat the feed surface with the medication by mixing and stirring the two components. Add sufficient vegetable oil or animal fat to cover the medication and feed. Mix well but do not powder the feed pellets.

Determining Area and Volume of Ponds

Chemicals and drugs are generally applied on the basis of area, volume, or weight of the water to which they are to be applied.

Area

Herbicides, fertilizers, liming materials, and some insecticides are generally applied on the basis of amount per unit area (usually a square foot or acre). For example, agricultural lime is applied on the basis of tons or pounds per acre.

To determine the surface area of a rectangular dike pond, raceway, or vat that is 300 feet long and 100 feet wide, merely multiply the length by width ($300 \times 100 = 30{,}000$ ft^2).

Determination of surface area of a hill pond or an irregular-shaped pond or raceway is somewhat more complicated. Often such ponds must be surveyed, the outline plotted to scale on paper, and the area determined with a planimeter. Alternatively, the pond owner may mark off the map of the pond into squares of known size. The squares that fall within the pond can be totaled. The incomplete squares—those that fall only in part within the pond—can be added as estimates of the number of complete squares that they compose. The total squares of known area provide a close estimate of the pond size.

Ponds of several acres in area that appear on aerial photographs can be measured with a planimeter. Maps covering most farming areas are available at local offices of the Soil Conservation Service, U.S. Department of Agriculture.

Volume

The quantity of chemicals and other compounds used in ponds, raceways, and vats is usually based on water volume. To determine the volume of a circular pond, raceway, or vat that is 10 feet in diameter and 4 feet deep, proceed as follows:

Area = Pi R^2 where Pi is a constant with a value of 3.14 and R^2 is the radius squared
= $3.14 \times (5)^2 = 3.14 \times 25 = 78.5$ square feet (ft^2)
Volume = area × depth
= $78.5 \times 4 = 310$ cubic feet (ft^3)

To determine the approximate volume of a hill pond or an irregular-shaped pond or raceway, merely multiply the area by average depth. The area must be calculated as previously described for irregular-shaped ponds. Since an irregular-shaped pond often also has an uneven bottom, an average depth is obtained by dividing the pond or raceway surface into equal squares, and then measuring the depth in each square. The average depth is obtained by averaging these depth measurements.

When an exact value is not needed, a simple but useful rule-of-thumb formula can be used to estimate the volume of a pond constructed by damming a valley or hollow:

Volume (ft^3) = 0.4 × maximum depth (ft) × surface area (ft^2).

Other Factors to Consider

Treatment or Application Concentration

Careful attention to the details of the treatment procedure and to the manufacturer's recommendations for the product is nearly always essential to the attainment of satisfac-

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tory results. A number of factors for consideration are offered here.

The manufacturer or technical advisor usually supplies information on treatment levels. These values are usually expressed in parts per million, or 1 unit per 999,999 units of water.

Chemical Activity

Some chemicals are applied on an "as is" basis, which assumes that they consist of 100% active ingredient. Other chemicals are applied on the basis of percent active ingredient and the aquaculturist must adjust the application rate accordingly. An incorrect dosage can be ineffective, kill the fish, or increase application costs. If the concentration is less than 100% active ingredient, divide the desired amount by the percent active ingredient. For example, if you need 10 g of oxytetracycline and your chemical is 50% active ingredient, divide 10 g by 0.50 (50%) to get 20.

Changing Volume

The fish producer must remember that pond volume is affected more by water depth than by any other single factor. A 6-inch decrease in water depth reduces the water volume of most ponds by at least 10%. Thus, pond volumes must be available at the water depths normally present in spring and summer. Also, the fish producer must be aware that water volume decreases as bottom sediments increase. It is not uncommon for ponds to accumulate bottom sediments 1 foot thick, which may decrease the water volume by 25%. Failure to check sediment depth can lead to fatal overtreatments. Many farmers find that a permanent gauge graduated in feet and inches provides a quick reference to pond depth. Other producers prepare charts for their ponds showing the pond volume at each depth.

Treating Containers with Small Amounts of Chemical

The weighing of small amounts of chemicals (less than 1 ounce) or measuring small volumes is usually impractical when one is treating vats, tanks, and aquaria. For best results, 10 times the amount needed should be measured out. A balance used by sportsmen for reloading ammunition is an inexpensive but accurate instrument for weighing small amounts of chemicals, and suitable volumetric measuring cylinders graduated in fluid ounces can be obtained at most photographic supply stores. The weighed or measured chemical is then placed in a volumetric cylinder and sufficient water is added to make 10 fluid ounces of solution. Measuring out 1 fluid ounce of this solution and adding it to the container provides the desired amount of the chemical.

Example when liquid chemicals are used: The calculated treatment of a chemical for an entire minnow vat is 0.11 fluid ounce of a liquid chemical. Use a measuring pitcher to measure 1.1 ounces of the chemical and then fill the pitcher to the 10-ounce mark. Mix thoroughly and add 1 ounce of the solution to the minnow vat. The 1 fluid ounce of the mixture will contain 0.11 fluid ounce of the chemical.

Example when dry chemicals are used: The calculated treatment for a catfish vat is 0.25 ounce of a dry chemical. Use the weighing device to weigh out 2.5 ounces of the chemical, place it in a liquid measuring cylinder, and fill the pitcher to the 10-ounce mark. Mix thoroughly and then add 1 ounce of the solution to the vat. The 1 fluid ounce of the mixture will contain 0.25 ounce of the dry chemical.

The purpose of this procedure is to ensure accurate initial weighing of the chemical because balances commonly available are not scaled to weigh small amounts accurately.

Measuring Water Quality Characteristics

Dissolved oxygen (DO) is the single most important water quality variable to be monitored in fish culture ponds. Consequently, serious culturists should purchase a sturdy, portable DO meter. The meters are priced according to their quality. Inexpensive devices

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designed for use by sport fishermen are to be avoided. Some meters that measure DO simultaneously measure water temperature—another highly significant variable in aquaculture.

Being mechanical devices, DO meters can malfunction no matter how much they cost. Farmers are strongly urged to become familiar with their meters and DO variations in their ponds. This familiarity will help them identify erroneous readings so that the meter can be checked. An inexpensive chemical test kit can be used to check a DO meter and also to determine DO, if the meter unexpectedly fails.

Other water quality characteristics such as total hardness, alkalinity, pH, and ammonia, can be measured by using relatively inexpensive test kits. These kits include all reagents (chemicals) needed to conduct water analyses on the pond bank. They are sometimes not accurate enough for research but provide an acceptable basis for pond management decisions. It is always important to read instructions carefully before using a water analysis kit. Test kit reagents deteriorate with time and should be replaced every 6 to 12 months, or more often if recommended by the manufacturer. The reagents should be protected from heat, light, and moisture to the extent possible. It is a poor practice to store the kit in a pickup truck.

Transparency of water is measured with a Secchi disk. This reading is directly proportional to phytoplankton concentrations and to chemical oxygen demand (COD) in ponds with low silt-clay turbidity. The readings provide valuable management information when related to DO levels, temperature, and other water quality characteristics. The Secchi disk is 8 inches in diameter, and has alternate black and white quadrants on the upper surface (Fig. 2.5). An eyebolt fixed at the center of the upper surface provides attachment for a graduated rope (sometimes a yardstick is used) and the bottom is weighted to facilitate sinking. A Secchi disk can be purchased, or can be easily constructed from almost any readily available metal or plastic material.

Most fish producers measure the Secchi disk reading at the water depth where the disk disappears from view. A more exact Secchi disk reading is made by averaging two depths—the one at which it disappears when lowered and the one at which it reappears when raised. (The values should be nearly identical.)

When one is selecting water analysis equipment, it is important to obtain equipment that can be repaired quickly and inexpensively. Equipment that requires few or no repairs and is easily maintained and calibrated is highly desirable. The producer might profitably discuss the needs with technical assistance personnel and other producers before selecting equipment.

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20. PEOPLE TO CONTACT: SOURCES OF INFORMATION ON AQUACULTURAL NEEDS

Harry K. Dupree, J. Mayo Martin, Jay V. Huner, and John J. Giudice

Information is needed at different points in the development of a productive and profitable aquacultural program. The successful planner considers many aspects, including market potential, economics, site selection, labor, sources of credit, extension and diagnostic assistance, and legal and environmental constraints. Various persons and organizations can provide assistance. Time and money spent in planning will return many dollars in the future operation of an aquacultural program, and timely and appropriate assistance in extension services and diagnostics is valuable beyond measure to the practicing fish farmer. Listed here are a number of the many persons and governmental, university, and private organizations that can provide a helping hand.

U.S. Department of Interior

Fish and Wildlife Service

Research Centers and Laboratories

Alabama
Southeastern Fish Cultural Laboratory
Route 3, Box 86
Marion 36756
Phone: (205) 683-6175

Arkansas
Fish Farming Experimental Station
P. O. Box 860
Stuttgart 72160
Phone: (501) 673-8761

Florida
National Fishery Research Laboratory-Gainesville
7920 N.W. 71st Street
Gainesville 32606
Phone: (904) 378-8181

Idaho
Tunison Laboratory of Fish Nutrition
Hagerman Field Station
Route 1, Box 256
Hagerman 83332
Phone: (208) 837-4457

Michigan
Great Lakes Fishery Laboratory
1451 Green Road
Ann Arbor 48105
Phone: (313) 994-3331

Missouri
Columbia National Fisheries Research Laboratory
Route 1
Columbia 65201
Phone: (314) 442-2271

New York
Tunison Laboratory of Fish Nutrition
28 Gracie Road
Cortland 13045
Phone: (607) 753-9391

Pennsylvania
National Fishery Research and Development Laboratory
Rural Delivery No. 4, Box 47
Wellsboro 16901
Phone: (717) 724-3322

Washington
Seattle National Fishery Research Center
Building 204, Naval Support Activity
Seattle 98115
Phone: (206) 527-6282

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West Virginia
National Fish Health Research Laboratory
Box 700
Kearneysville 25430
Phone: (304) 725-8461

Fish Genetics Station
Box 700
Kearneysville 25430
Phone: (304) 725-8461

Wisconsin
National Fishery Research Laboratory-LaCrosse
P. O. Box 818
LaCrosse 54601
Phone: (608) 783-6451

Demonstration and Development Centers

Montana
Fish Cultural Development Center
4050 Bridger Canyon Road
Bozeman 59715
Phone: (406) 587-9256

Pennsylvania
National Fish Hatchery and Development Center
P. O. Box 75
Lamar 16848
Phone: (717) 726-4247

South Dakota
Spearfish Fisheries Center
P. O. Box 158
Spearfish 57783
Phone: (605) 642-3616

Texas
National Fish Hatchery and Development Center
Route 1, Box 159D
San Marcos 78666
Phone: (512) 392-1214

Washington
Abernathy Salmon Cultural Development Center
1440 Abernathy Road
Longview 98632
Phone: (206) 425-6072

West Virginia
Aquaculture Production/Demonstration Station
Box 700
Kearneysville 25430
Phone: (304) 725-8461

National Fish Hatcheries (Warmwater Species)

Alabama
National Fish Hatchery
Carbon Hill 35549
Phone: (205) 924-4321

Arkansas
National Fish Hatchery
P. O. Box 160
Mammoth Springs 72554
Phone: (501) 625-3912

Florida
National Fish Hatchery
Welaka 32093
Phone: (904) 467-2374

Georgia
National Fish Hatchery
Cohutta 30710
Phone: (404) 694-3451

National Fish Hatchery
Route 5, Box 272-1
Millen 30442
Phone: (912) 982-1700

National Fish Hatchery
Route 1, Box 105
Warm Springs 31830
Phone: (404) 655-3620

Kansas
National Fish Hatchery
Route 2
Ellis 67637
Phone: (913) 726-4883

Kentucky
National Fish Hatchery
Route 1, Box 1
Frankfort 40601
Phone: (502) 227-9818

Louisiana
National Fish Hatchery
615 Highway 1, South
Natchitoches 71457
Phone: (318) 352-5324

Minnesota
National Fish Hatchery
P. O. Box 304
New London 56273
Phone: (612) 354-2310

Mississippi
National Fish Hatchery
Route 5, Box 450

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Meridian 39301
Phone: (601) 483-1362

National Fish Hatchery
111 Elizabeth Street
Tupelo 38801
Phone: (601) 842-1341

Missouri

National Fish Hatchery
Neosho 64850
Phone: (417) 451-0554

Montana

National Fish Hatchery
P. O. Box 756
Miles City 59301
Phone: (406) 232-4753

New Mexico

National Fish Hatchery
P. O. Box 217
Dexter 88230
Phone: (505) 734-5910

North Carolina

National Fish Hatchery
P. O. Box 329
Edenton 27932
Phone: (919) 482-4118

National Fish Hatchery
Hoffman 28347
Phone: (919) 895-5330

Ohio

National Fish Hatchery
Rural Route 1
57199 Seneca Dam Road
Senecaville 43780
Phone: (614) 685-5541

Oklahoma

National Fish Hatchery
Route 1
Tishomingo 73460
Phone: (405) 384-5463

South Carolina

National Fish Hatchery
Route 2, Box 620
Cheraw 29520
Phone: (803) 537-7628

National Fish Hatchery
P. O. Box 410
Orangeburg 29115
Phone: (803) 534-4828

South Dakota

National Fish Hatchery
Rural Route 1, Box 293
Yankton 57078
Phone: (605) 665-3352

Texas

National Fish Hatchery
Route 2
Burnet 78611
Phone: (512) 793-2474

National Fish Hatchery
P. O. Box 708
Uvalde 78801
Phone: (512) 278-2914

Virginia

National Fish Hatchery
Route 2, Box 93
Charles City 23030
Phone: (804) 829-2421

Wisconsin

National Fish Hatchery
Route 1
Genoa 54632
Phone: (608) 689-2605

National Fish Hatchery
Lake Mills 53551
Phone: (414) 648-8012

Cooperative Fishery Research Units

Alabama

Alabama Cooperative Fishery Research Unit
Fisheries Building
Auburn University
Auburn 36830
Phone: (205) 826-4786

Alaska

Alaska Cooperative Fishery Research Unit
138 Arctic Health Research Building
901 Koyukuk Avenue South
Fairbanks 99701
Phone: (907) 474-7661

Arizona

Arizona Cooperative Fishery Research Unit
210 Biological Sciences East
University of Arizona
Tucson 85721
Phone: (602) 621-1959

California

California Cooperative Fishery Research Unit
Department of Fisheries
Humboldt State University
Arcata 95521
Phone: (707) 826-3268

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Colorado
Colorado Cooperative Fishery Research Unit
Room 201, J.V.K. Wagar Building
Colorado State University
Fort Collins 80523
Phone: (303) 491-6942

Florida
Florida Cooperative Fishery and Wildlife Research Unit
117 Newins-Ziegler Hall
University of Florida
Gainesville 32611
Phone: (904) 392-1861

Georgia
Georgia Cooperative Fishery Research Unit
School of Forest Resources
University of Georgia
Athens 30602
Phone: (404) 546-2234

Hawaii
Hawaii Cooperative Fishery Research Unit
2538 The Mall
University of Hawaii
Honolulu 96822
Phone: (808) 948-8350

Idaho
Idaho Cooperative Fishery Research Unit
College of Forestry, Wildlife, and Range Sciences
University of Idaho
Moscow 83843
Phone: (208) 885-6336

Iowa
Iowa Cooperative Fishery Research Unit
Science Hall II
Iowa State University
Ames 50011
Phone: (515) 294-3057

Louisiana
Louisiana Cooperative Fishery Research Unit
Room 245, Agricultural Center
Louisiana State University
Baton Rouge 70803
Phone: (504) 388-6051

Maine
Maine Cooperative Fishery Research Unit
313 Murray Hall
University of Maine
Orono 04469
Phone: (207) 581-2580

Massachusetts
Massachusetts Cooperative Fishery Research Unit
204 Holdsworth Hall
University of Massachusetts
Amherst 01003
Phone: (413) 545-2757

Mississippi
Mississippi Cooperative Fishery and Wildlife Research Unit
Dorman Hall
Box BX
Mississippi State University
Starkville 39762
Phone: (601) 325-2643

Missouri
Missouri Cooperative Fishery Research Unit
Stephens Hall
University of Missouri
Columbia 65201
Phone: (314) 882-3234

Montana
Montana Cooperative Fishery Research Unit
Biology Department
Montana State University
Bozeman 59717
Phone: (406) 994-2450

New York
New York Cooperative Fishery Research Unit
Fernow Hall
Cornell University
Ithaca 14853
Phone: (607) 256-2151

North Carolina
North Carolina Cooperative Fishery Research Unit
Department of Zoology
Box 5577 State College Station
North Carolina State University
Raleigh 27607
Phone: (919) 737-2631

Ohio
Ohio Cooperative Fishery Research Unit
Department of Zoology
Ohio State University
1735 Neil Avenue
Columbus 43210
Phone: (614) 422-8961

Oklahoma
Oklahoma Cooperative Fishery Research Unit
Room 433 Life Sciences West Building

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Oklahoma State University
Stillwater 74074
Phone: (405) 624-6342

Oregon
Oregon Cooperative Fishery Research Unit
Department of Fisheries and Wildlife
Oregon State University
Corvallis 97331
Phone: (503) 754-4531

Pennsylvania
Pennsylvania Cooperative Fish and Wildlife Research Unit
113 Ferguson Building
Pennsylvania State University
University Park 16802
Phone: (814) 865-4511

South Dakota
South Dakota Cooperative Fishery Research Unit
Department of Wildlife and Fishery Sciences
South Dakota State University
Brookings 57006
Phone: (605) 688-6121

Tennessee
Tennessee Cooperative Fishery Research Unit
Biology Department, Box 5063
Tennessee Technological University
Cookeville 38501
Phone: (615) 528-4194

Utah
Utah Cooperative Fishery Research Unit
Department of Wildlife Science, UMC 52
Utah State University
Logan 84322
Phone: (801) 750-2509

Virginia
Virginia Cooperative Fishery Research Unit
Virginia Polytechnic Institute and State University
106 Cheatham Hall
Blacksburg 24061
Phone: (703) 961-7294

Washington
Washington Cooperative Fishery Research Unit
College of Fisheries WH-10
University of Washington
Seattle 98195
Phone: (206) 543-6475

Wisconsin
Wisconsin Cooperative Fishery Research Unit
College of Natural Resources
University of Wisconsin
Stevens Point 54481
Phone: (715) 346-2178

Wyoming
Wyoming Cooperative Fishery and Wildlife Research Unit
Box 3166 University Station
University of Wyoming
Laramie 82071
Phone: (307) 766-5415

U.S. Department of Agriculture

Cooperative State Research Service

Agricultural Experiment Stations

A partial listing of Agricultural Experiment Stations, and some branch stations, is given here. The Stations and several of their branches in the southern United States, California, Hawaii, Puerto Rico, and the U.S. Virgin Islands conduct research on warmwater fish and aquatic animals. Some Agricultural Experiment Stations in other States work with coldwater and marine fishes. The address of the Agricultural Experiment Station in your State, if not listed, may be obtained from the Cooperative Extension Service specialist in your county.

Alabama
Agricultural Experiment Station
Auburn University
Auburn 36849
Phone: (205) 826-4840

Arkansas
Agricultural Experiment Station
University of Arkansas
Fayetteville 72701
Phone: (501) 575-4446

Agricultural Experiment Station
University of Arkansas at Pine Bluff
Pine Bluff 71601
Phone: (501) 541-6868

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California
Agricultural Experiment Station
University of California
317 University Hall
Berkeley 94720
Phone: (415) 642-9300

Agricultural Field Station
University of California
Davis 95616
Phone: (916) 752-0126

Georgia
Agricultural Experiment Station
University of Georgia
Athens 30602
Phone: (404) 542-2121

Coastal Plain Experiment Station
University of Georgia
Tifton 31794
Phone: (912) 386-3338

Hawaii
Agricultural Experiment Station
University of Hawaii
Honolulu 96822
Phone: (808) 948-8234

Kentucky
Agricultural Experiment Station
University of Kentucky
Lexington 40506
Phone: (606) 257-4772

Agricultural Experiment Station
Kentucky State University
Frankfort 40601
Phone: (502) 564-5734

Louisiana
Agricultural Experiment Station
Louisiana State University
Baton Rouge 70803
Phone: (504) 388-4181

Agricultural Experiment Station
Southern University
Baton Rouge 70813
Phone: (504) 771-3660

Mississippi
Agricultural Experiment Station
Mississippi State University
Starkville 39762
Phone: (601) 325-3005

Delta Branch Experiment Station
Mississippi State University
Stoneville 38776
Phone: (601) 686-9311

North Carolina
Agricultural Experiment Station
Agricultural Research Center
North Carolina State University
Raleigh 27650
Phone: (919) 737-2718

Puerto Rico
Agricultural Experiment Station
College of Agricultural Sciences
University of Puerto Rico
Mayaguez 00708
Phone: (809) 833-2665

South Carolina
Agricultural Experiment Station
104 Barre Hall
Clemson University
Clemson 29631
Phone: (803) 656-3140

Tennessee
Agricultural Experiment Station
P. O. Box 1071
University of Tennessee
Knoxville 37901
Phone: (615) 974-7121

Texas
Agricultural Experiment Station
Texas A&M University
College Station 77843
Phone: (409) 845-8484

Virgin Islands
Agricultural Experiment Station
College of Virgin Islands
St. Croix 00850
Phone: (809) 778-0246

Soil Conservation Service

The U.S. Soil Conservation Service provides biologists who are able to assist in matters relating to aquaculture in each State. These biologists may be contacted through the Soil Conservation Service personnel or the State Cooperative Extension Service personnel located in the courthouse of most counties, or at the Federal Building in the capitol city of your State.

Agricultural Research Service

Louisiana
Southern Regional Research Center

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U.S. Department of Agriculture
1100 Robert E. Lee Blvd.
P. O. Box 19687
New Orleans 70179
Phone: (504) 589-7544

U.S. Department of Commerce

National Marine Fisheries Service

Research Laboratories (Warmwater)

South Carolina
Southeast Fisheries Center
Charleston Laboratory
P. O. Box 12607
Charleston 29412
Phone: (803) 762-1200

Texas
Gulf Coast Fisheries Center
Galveston Laboratory
4700 Avenue U
Galveston 77550
Phone: (409) 766-3500

Tennessee Valley Authority

Alabama
Agricultural Resource Development Branch
F-4 National Fertilizer Development Center
Tennessee Valley Authority
Muscle Shoals 35660
Phone: (205) 386-2865

Tennessee
Waste Heat Aquaculture
Gallatin Steam Plant
Gallatin 37066
Phone: (615) 452-9556

Local Universities

Universities and colleges may be an excellent source of assistance in your area. The type of assistance varies—some can diagnose diseases, others provide general biological or chemical analyses, and some offer a full range of services. Often the faculty at nearby facilities can provide the assistance that may save the beginning fish farmer the time and cost of traveling to the better-known institutions. The prospective or beginning fish farmer may consult with County Cooperative Extension Service personnel for information on the nearest institution providing the service needed.

Financing and Credit Sources

U.S. Government

Farmers Home Administration
U.S. Department of Agriculture
Washington, D.C. 20250
Phone: (202) 447-4572
(State offices of the Federal Home Administration are usually in the Federal Building in the capitol city of each State.)

Small Business Administration
Washington, D.C. 20250
Phone: (202) 653-6416
(District offices, one or more in each State, should be contacted first.)

Private Companies

Federal Land Bank
(Refer to local telephone directory or consult the State and national fish farmers associations for a list of offices in your area.)

Production Credit Association
(Refer to local telephone directory or consult the State and national fish farmers associations for a list of offices in your area.)

Commercial banks, Savings and Loan companies, and Insurance companies.
(Consult the State and national fish farmers associations for a list of participating institutions in your area.)

Insurance

U.S. Government

Federal Crop Insurance Corporation
U.S. Department of Agriculture

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Washington, D.C. 20250
Phone: (202) 477-6795

Private Companies

(Consult the State and national fish farmers associations for the list of companies in your area.)

Licenses and Permits

Some States and some Federal agencies have restrictions on aquacultural construction sites, water use, species to be cultured, and other aspects of fish farming. It would be prudent to consult with fish farmers associations, other producers, State fish and game departments, State natural resources departments, State and Federal environmental protection agencies, State health boards, and the nearest district office of the U.S. Army Corps of Engineers. Although this list is not complete, it will give the planning aquaculturist a start.

Site Selection and Development

Soil Conservation Service
U.S. Department of Agriculture
(An office is usually in each county seat, and in the Federal Building in the capitol city.)

Geological Survey
U.S. Department of the Interior
(An office is usually in the Federal Building in the capitol city.)

State Geological Survey
(An office is usually at the State Capitol.)

State Cooperative Extension Service
County Agricultural Cooperative Extension Agent
Private engineers and consultants
Other fish producers

Marketing and Marketing Statistics

Arkansas

National Marine Fisheries Service
U.S. Department of Commerce
Park West Bldg., Suite 200
11215 Hermitage Road
Little Rock 72211
Phone: (501) 378-5888

District of Columbia

Economic Research Service
U.S. Department of Agriculture
Washington 20250
Phone: (202) 447-8636

Statistical Reporting Service
U.S. Department of Agriculture
Washington 20250
Phone: (202) 447-6351

Agricultural Marketing Service
U.S. Department of Agriculture
Washington 20250
Phone: (202) 447-2650
(Information on government purchase program when in effect.)

Mississippi

American Catfish Marketing Association
1602 Walter Sellers Bldg.
P. O. Box 34
Jackson 39205
Phone: (601) 948-5938

Mississippi Catfish Farmers Marketing Association
P. O. Box 230
Indianola 38751
Phone: (601) 887-5758

State and Extension Specialists in Fisheries and Wildlife

The following list of fishery and aquaculture specialists was modified from J. E. Miller. 1982. State cooperative extension service fisheries and aquaculture specialists, and extension service, USDA, contact persons for fisheries/aquaculture. Pages 47-53 *in* Directory of Aquaculture Information Resources, National Agricultural Library, Bibliographies and Literature of Agriculture No. 25, U.S. Department of Agriculture.

Alabama

Alabama Cooperative Extension Service
Fisheries Specialist
Swingle Hall
Auburn University

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Auburn 36849
Phone: (205) 826-4786

Alabama Fish Farming Center
Highway 69, North
Greensboro 36744
Phone: (205) 624-3651

Alaska

Marine Advisory Program
2651 Providence Avenue
Anchorage 99504
Phone: (907) 263-1890

Arizona

Arizona Cooperative Extension Service
Extension Specialist, Wildlife and Range
4341 East Broadway
Phoenix 85040
Phone: (602) 255-4033

Arkansas

Arkansas Cooperative Extension Service
Extension Fish and Wildlife Biologist
P. O. Box 391
Little Rock 72203
Phone: (501) 376-6301

Arkansas Cooperative Extension Service
Extension Fishery Biologist
Agricultural Experiment Station
University of Arkansas—Pine Bluff
Pine Bluff 71601
Phone: (501) 541-6868

Fish Farming Experimental Station
U.S. Fish and Wildlife Service
Extension Biologist
P. O. Box 860
Stuttgart 72160
Phone: (501) 673-8761

California

California Sea Grant Extension
Aquaculturist
Cooperative Extension
554 Hutchison Hall
University of California
Davis 95616
Phone: (916) 752-7490

Sea Grant Marine Advisory Program
Seafood Technology Specialist
101 A Cruess Hall, FS&T
University of California
Davis 95616
Phone: (916) 752-2193

Colorado

Colorado Extension Wildlife Specialist
Department of Fishery and Wildlife Biology
109 Wagar Building
Colorado State University
Fort Collins 80523
Phone: (303) 491-6411

Connecticut

Connecticut Cooperative Extension Service
Extension Forester/Environmentalist
Box U-87
University of Connecticut
Storrs 06268
Phone: (203) 486-2839

Delaware

Delaware Cooperative Extension Service
University of Delaware
Newark 19711
Phone: (302) 738-2504

District of Columbia

District of Columbia Cooperative Extension Service
Agriculture and Natural Resources
929 E Street NW
Washington 20004
Phone: (202) 727-2002

U.S. Department of Agriculture Extension Services
Fish and Wildlife
Room 5925, South Agriculture Building
Washington 20250
Phone: (202) 447-5468

Florida

Florida Wildlife Ecology and Extension Wildlife Specialist
118 Newins-Ziegler Hall
University of Florida
Gainesville 32611
Phone: (904) 392-5420

Georgia

Georgia Cooperative Extension Service
Extension Fisheries Specialist
Room 209, Barrow Hall
University of Georgia
Athens 30601
Phone: (404) 542-3447

Guam

Guam Extension Agent
College of Agriculture and Life Sciences
University of Guam Station
Mangilao 96913
Phone: (617) 734-2421

Hawaii

College of Tropical Agriculture and Human Resources

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University of Hawaii
3050 Maile Way, Gilmore 202
Honolulu 96822
Phone: (808) 948-8234

Idaho
Idaho Cooperative Extension Service
Fish and Wildlife Resources Building
University of Idaho
Moscow 83843
Phone: (208) 885-6336

Illinois
Illinois Extension Forester
219 Mumford Hall
1301 W Gregory Drive
University of Illinois
Urbana 61801
Phone: (217) 333-2777

Indiana
Indiana Extension Wildlife Specialist
Department of Forestry and Natural Resources
Forestry Building, Purdue University
W. Lafayette 47907
Phone: (317) 494-3586

Iowa
Iowa Extension Wildlife Conservationist
Department of Animal Ecology
Iowa State University
Ames 50011
Phone: (515) 294-7429

Kansas
Wildlife Damage Control
Umberger Hall
Kansas State University
Manhattan 66506
Phone: (913) 532-5785

Kentucky
Aquacultural Research Program
Kentucky State University
Frankfort 40601
Phone: (502) 564-5734

Louisiana
Louisiana Extension Assistant, Aquaculture
202-A Knapp Hall
Louisiana State University
Baton Rouge 70803
Phone: (504) 388-4569

Maine
Maine Cooperative Extension Service
100 Winslow Hall
University of Maine
Orono 04469
Phone: (207) 581-2211

Maryland
Maryland Cooperative Extension Service
Marine Advisory Programs
Symons Hall
University of Maryland
College Park 20742
Phone: (301) 454-4190

Massachusetts
Wildlife Biology
324 Holdsworth Hall
University of Massachusetts
Amherst 01003
Phone: (413) 545-2757

Michigan
Aquaculturists and Fisheries Specialists
Fisheries and Wildlife Department
Natural Resources Building
Michigan State University
East Lansing 48824
Phone: (517) 355-7493

Minnesota
Extension Aquaculture Specialist
Department of Entomology, Fisheries and Wildlife
University of Minnesota
St. Paul 55108
Phone: (612) 373-1016

Mississippi
Leader, Extension Wildlife and Fisheries
P. O. Box 5405
Starkville 39762
Phone: (601) 325-3174

Fish Farming Field Station
U.S. Fish and Wildlife Service
Diagnostic Laboratory
P. O. Box 4389
2531 N West Street
Jackson 39616
Phone: (601) 354-6089

Cooperative Extension Program
Alcorn State University
P. O. Box 479
Lorman 39096
Phone: (601) 877-2916

Mississippi Wildlife and Fisheries Specialist
Delta Branch Experiment Station
Stoneville 38776
Phone: (601) 686-9311

Missouri
Missouri Fisheries Extension Biologist
P. O. Box 180
Jefferson City 65102
Phone: (314) 751-4115

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Missouri School of Forestry, Fisheries
and Wildlife
Room 1-34
Agriculture Building
University of Missouri—Columbia
Columbia 65211
Phone: (314) 882-4444

Montana
Montana Extension Entomologist
Lewis Hall
Montana State University
Bozeman 59717
Phone: (406) 994-2440

Nebraska
Department of Forestry, Fisheries and Wildlife
202 Natural Resources Hall
University of Nebraska
Lincoln 68583
Phone: (402) 472-6823

Nevada
Nevada Renewable Natural Resources
University of Nevada
Reno 89557
Phone: (702) 784-4616

New Hampshire
New Hampshire Aquaculture Program
Room 110-C, Pettee Hall
University of New Hampshire
Durham 03824
Phone: (603) 862-1029

New Jersey
Fisheries Management Specialist
Department of Horticulture and Forestry
Cook College—Rutgers University
New Brunswick 08903
Phone: (201) 932-9333

New Mexico
New Mexico Cooperative Extension Service
Extension Wildlife Specialist
Box 4901
New Mexico State University
Las Cruces 88001
Phone: (505) 646-1164

New York
New York Cooperative Extension Service
Department of Natural Resources
Fernow Hall
Cornell University
Ithaca 14853
Phone: (607) 256-2114

North Carolina
North Carolina Extension Fisheries Specialist
North Carolina State University
P. O. Box 5577
Raleigh 27650
Phone: (919) 737-2741

North Dakota
North Dakota Cooperative Extension Service
North Dakota State University
Fargo 58102
Phone: (701) 237-8944

Ohio
Ohio Extension Wildlife Specialist
375-C ANRPP Building
2021 Coffey Road
The Ohio State University
Columbus 43210
Phone: (614) 422-1981

Oklahoma
Oklahoma Wildlife Specialist, CES
017 Agricultural Hall
Oklahoma State University
Stillwater 74704
Phone: (405) 624-5515

Oregon
Oregon Sea Grant College Program
320 Administrative Services Building
Oregon State University
Corvallis 97331
Phone: (503) 754-2714

Oregon Department of Fisheries and Wildlife
104C Nash Hall
Oregon State University
Corvallis 97331
Phone: (503) 754-4531

Pennsylvania
Forest Resources
109 Ferguson Building
Pennsylvania State University
University Park 16802
Phone: (814) 863-0401

Puerto Rico
Puerto Rico Extension Service
College Station
University of Puerto Rico
Mayaguez 00708
Phone: (809) 833-7637

Rhode Island
Rhode Island Cooperative Extension Service
Department of Forest and Wildlife Management
University of Rhode Island
Kingston 02881
Phone: (401) 792-2370

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South Carolina
South Carolina Extension Wildlife Specialist
Room 102, Long Hall
Clemson University
Clemson 29631
Phone: (803) 656-3113

South Dakota
South Dakota Agriculture and Natural Resources/Rural Development
Box 2207, Ag-H
South Dakota State University
Brookings 57007
Phone: (605) 688-4147

Tennessee
Tennessee Extension Fisheries Specialist
Cooperative Extension Service
University of Tennessee
Box 1071
Knoxville 37901
Phone: (615) 974-7164

Texas
Texas Fisheries Specialist
Cooperative Extension Service
Nagle Hall, Room 202
Texas A&M University
College Station 77843
Phone: (713) 845-7471

Fisheries Specialist
Cooperative Extension Services
P. O. Box 38
Overton 75684
Phone: (214) 834-6191

Utah
Fish and Wildlife Extension Specialist
Department of Wildlife Science
Utah State University, UMC 52
Logan 84322
Phone: (801) 750-2461

Vermont
Extension Water Resources Specialist
School of Natural Resources
University of Vermont
601 Main Street
Burlington 05405
Phone: (802) 656-3258

Virginia
Virginia Cooperative Extension Service
Fisheries Extension Service
152 Cheatham Hall
Virginia Polytechnic Institute and State University
Blacksburg 24061
Phone: (703) 961-5059

Virgin Islands
Virgin Islands Extension Service
College of the Virgin Islands
P. O. Box L, Kingshill
St. Croix 00850
Phone: (809) 778-0246

Washington
Washington Marine Extension Agent
Courthouse, Box 552
Montesano 98563
Phone: (206) 249-4332

West Virginia
Extension Specialist, Forestry
329 Percival Hall
West Virginia University
Morgantown 26506
Phone: (304) 293-3721

Technical Information Services
U.S. Fish and Wildlife Service
Box 700
Kearneysville 25430
Phone: (304) 725-8461

Wisconsin
Extension Wildlife Specialist
Department of Wildlife Ecology
226 Russell Labs
University of Wisconsin
Madison 53706
Phone: (608) 263-2071 or 262-2671

Wyoming
Wyoming Extension Range Management Specialist
P. O. Box 3354
University Station
Laramie 82071
Phone: (307) 766-5258

Diagnostic Services Available

The list that follows was originally prepared and published by Glenn L. Hoffman and Andrew J. Mitchell, U.S. Fish and Wildlife Service, Fish Farming Experimental Station.[1] These authors first contacted (in 1980) everyone they believed might be interested in providing limited or general assistance in fish dis-

[1]G. L. Hoffman and A. J. Mitchell. 1983. Diagnostic services available. Pages 26-31 *in* Buyers guide. Aquaculture Magazine, 23 Sunset Terrace, Asheville, North Carolina.

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ease diagnosis. The present list was revised by Hoffman and Mitchell in 1983. Any unintentional omissions are regretted. We cannot attest to the competency or qualifications of each of the persons or facilities listed here. It is always advisable to contact the diagnostician before submitting fish for diagnosis.

Alabama

Alabama Fish Farming Center
Highway 69 North
Greensboro 36744
Phone: (205) 624-3651

O. L. Green
Farm Fresh Catfish Co.
P. O. Box 188
Greensboro 36744
Phone: (205) 624-3064

Southeastern Cooperative Fish Disease Laboratory
Department of Fisheries and Allied Aquaculture
Auburn University
Auburn 36849
Phone: (205) 826-4786

Alaska

Roger S. Grischkowsky, Ph.D.
Fish Pathologist
333 Raspberry Road
Anchorage 99502
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21. PUBLICATIONS TO READ: SUGGESTED REFERENCES FOR WARMWATER AQUACULTURE

Jay V. Huner and Harry K. Dupree

Various publications on technical aspects of fish farming, on local or regional solutions to problems, and on the future of the industry should help the fish farmer get the most from his effort and investment. Most of the references listed here are arranged under subjects corresponding to some of the chapters or parts of chapters in this report. The heading of each list is followed (in parentheses) by the number of the chapter to which the list principally applies. Note that the publications listed under "General Aquaculture" include information that overlaps that in many of the more specific lists. The novice is advised to review such general publications before reading more specific ones.

General Aquaculture

Books and Other Works

ALLEN, L. J., AND E. C. KINNEY, editors. 1981. Proceedings of the bio-engineering symposium for fish culture. FCS Publication no. 1. Fish Culture Section of the American Fisheries Society, Bethesda, Maryland, and Northeast Society of Conservation Engineers. 307 pp.

AYERS, J. W. 1976. Directory of aquaculture in the Southeast. U.S. National Marine Fisheries Service, Washington, D.C. 29 pp.

BARDACH, J. E., J. H. RHYTHER, AND W. O. MCLARNEY. 1972. Aquaculture: The farming and husbandry of freshwater and marine organisms. John Wiley & Sons, Inc., New York. 868 pp.

BORTZ, B., J. RUTTLE, AND M. PODEMS. 1977. Raising fresh fish in your home waters. Rodale Resources, Inc., Emmaus, Pennsylvania. 34 pp.

BOYD, C. E. 1982. Water quality management for pond fish culture. Developments in Aquaculture and Fisheries Science 9. Elsevier Scientific Publishing Co., New York. 318 pp.

BROWN, E. E., AND J. B. GRATZEK. 1983. Fish farming handbook: food, bait, tropicals and goldfish. AVI Publishing Company, Inc., Westport, Connecticut. 391 pp.

BUSH, J. C., E. D. NORWOOD, JR., E. E. PRATHER, AND S. F. BAIMA. 1981. Catfish farming. Rev. ed. U.S. Department of Agriculture, Farmers' Bulletin 2260. 29 pp.

CHAKROFF, M., 1976. Freshwater fish pond culture and management. VITA [Volunteers in Technical Assistance] Publications Manual 36E. Peace Corps Program and Training Journal Manual 1B. U.S. Government Printing Office, Washington, D.C. 191 pp.

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GRAY, D. L. 1978. The biology of channel catfish production. Arkansas Cooperative Extension Service, Circular 535. 14 pp.

HICKLING, C. F. 1971. Fish culture. Faber and Faber, 3 Queen Square, London. 317 pp.

HUET, M. 1972. Textbook of fish culture. Fishing News (Books) Ltd., 23 Rosemont Avenue, West Byfleet, Surrey, England. 436 pp. (Translated by Henry Kahn from the Fourth French Edition of Traité de Pisciculture, published by Editions Ch. De Wyngaert, Brussels, 1970).

JENSEN, J. 1981. Channel catfish production in ponds. Alabama Cooperative Extension Service (Auburn University) Circular ANR-195. 15 pp.

KLONTZ, G. W., I. R. BROCK, AND J. A. MCNAIR. 1978. Aquaculture techniques: water use and discharge quality. Idaho Water Resources Research Institute, University of Idaho, Moscow. 114 pp.

LEE, J. S. 1981. Commercial catfish farming. 2nd ed. The Interstate Printers and Publishers, Inc., Danville, Illinois. 310 pp.

LIMBURG, P. R. 1980. Farming and waters. Beaufort Books, New York. 223 pp.

NATIONAL AQUACULTURE DEVELOPMENT PLAN. 1983. Joint Subcommittee on Aquaculture (Departments of the Interior, Agriculture, and Commerce), Washington, D.C. 257 pp. (mimeograph). Available in limited quantity from Technical Information Services, U.S. Fish and Wildlife Service, National Fisheries Center, P. O. Box 700, Kearneysville, West Virginia 25430.

NATIONAL RESEARCH COUNCIL, COMMITTEE ON AQUACULTURE. 1978. Aquaculture in the United States: constraints and opportunities. Report of the Committee on Aquaculture, Board on Agriculture and Renewable Resources, Commission on Natural Resources, National Research Council. National Academy of Sciences, Washington, D.C. 123 pp.

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PILLAY, T. V. R., AND W. A. DILL, editors. 1979. Advances in aquaculture. Papers presented at FAO Technical Conference on Aquaculture, Kyoto, Japan, 26 May–2 June 1976. Fishing News Books, Ltd., Surrey, England. 653 pp.

PIPER, R. G., I. W. MCELWAIN, L. E. ORME, J. P. MCCRAREN, L. G. FOWLER, AND J. R. LEONARD. 1982. Fish hatchery management. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 517 pp.[1]

STEINBACH, D., AND W. KLUSSMANN. 1971. Channel catfish farming. Texas Agricultural Extension Service, Publication B-1024. 16 pp.

STICKNEY, R. R. 1979. Principles of warmwater aquaculture. John Wiley & Sons, Inc., New York. 375 pp.

TIEMEIER, O. W., AND C. W. DEYOE. 1980. Channel catfish produced in Kansas ponds for profit and pleasure. Kansas Agricultural Experiment Station, Bulletin 635. 36 pp.

U.S. FISH AND WILDLIFE SERVICE. 1982. Directory of selected U.S. Fish and Wildlife aquacultural facilities and services. U.S. Department of the Interior, Washington, D.C. 21 pp.

U.S. SOIL CONSERVATION SERVICE. 1982. Ponds—planning, design and construction. U.S. Department of Agriculture, Agriculture Handbook No. 150. 51 pp.

WHEATON, F. W. 1977. Aquacultural engineering. John Wiley & Sons, Inc., New York. 708 pp.

Trade Magazines and Other Periodicals

AMERICAN FISHERIES SOCIETY FISH CULTURE SECTION NEWSLETTER (irregular). Verl Stevens, Editor, RR 2, Box 54A, Pratt, Kansas 67124.

AMERICAN FISHERIES SOCIETY FISH HEALTH SECTION NEWSLETTER (quarterly). Peter G. Walker, Editor, Maine Department of Inland Fish and Wildlife, Hatchery Laboratory, 8 Federal Street, Augusta, Maine 04330.

AMERICAN FISHERIES SOCIETY WATER QUALITY SECTION NEWSLETTER (irregular). Paul M. Mehrle, Editor, Columbia National Fisheries Research Laboratory, U.S. Fish and Wildlife Service, Route 1, Columbia, Missouri 65201.

AQUACULTURE (quarterly). Elsevier Scientific Publishing Co., Amsterdam, The Netherlands.

AQUACULTURE DIGEST (monthly). Subscription address: 9434 Kearny Mesa Road, San Diego, California 92126.

AQUACULTURE MAGAZINE (bimonthly). Subscription address: P. O. Box 2329, Asheville, North Carolina 28802.

CRAWFISH TALES (quarterly). Louisiana Crawfish Farmers' Association, P. O. Box 91544, Lafayette, Louisiana 70509.

FAO FISHERIES TECHNICAL PAPER (irregular). Publications Division, Food and Agriculture Organization of the United Nations, via delle Terme di Caracalla, 00100 Rome, Italy.

FARM POND HARVEST (quarterly). Professional Sportsman's Publishing Company, RR 2, Momence, Illinois 60954.

FISH FARMER (seven issues per year). U.S. Sales Office: IPC Business Press Ltd., 205 East 42nd Street, New York 10017.

FISH FARMING INTERNATIONAL (monthly). Subscription address: Arthur J. Heighway Publications Ltd., 4 Kildare Close, Eastcote, Ruislip, Middlesex HA4 9XB, England.

FISHERIES (bimonthly). American Fisheries Society, 5410 Grosvenor Lane, Bethesda, Maryland 20814.

FISHERIES AND WILDLIFE RESEARCH: ACTIVITIES IN THE DIVISIONS OF RESEARCH FOR THE FISCAL YEAR (annual). U.S. Fish and Wildlife Service. U.S. Government Printing Office, Denver, Colorado 80225.

FISHERY BULLETIN (quarterly). Scientific Publications Office, National Marine Fisheries Service, NOAA, 7600 Sand Point Way, NE, Bin C15700, Seattle, Washington 98115. (Also available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.)

JOURNAL OF FISH BIOLOGY (monthly). Academic Press, Inc., P. O. Box 805, Cooper Station, New York 10003.

NORTH AMERICAN JOURNAL OF FISHERIES MANAGEMENT (quarterly). American Fisheries Society, 5410 Grosvenor Lane, Bethesda, Maryland 20814.

PROGRESSIVE FISH-CULTURIST (quarterly). American Fisheries Society, 5410 Grosvenor Lane, Bethesda, Maryland 20814.

SALMONID (bimonthly). United States Trout Farmers Association, P. O. Box 171, Lake Ozark, Missouri 65049.

SPORT FISHERY ABSTRACTS (quarterly). U.S. Department of the Interior, Fish and Wildlife Service, Editorial Office, Aylesworth Hall, Colorado State University, Fort Collins, Colorado 80523. (Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.)

TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY (bimonthly). American Fisheries Society, 5410 Grosvenor Lane, Bethesda, Maryland 20814.

TROPICAL FISH HOBBYIST (monthly). T.F.H. Publications, Inc., 211 W. Sylvania Ave., Neptune City, New Jersey 07753.

[1]This book is especially recommended to fish farmers and other aquaculturists. It comprises six chapters (Hatchery Requirements; Hatchery Operations; Broodstock, Spawning, and Egg Handling; Nutrition and Feeding; Fish Health Management; and Transportation of Live Fishes), nine appendices, and an extensive glossary. It complements, supplements, and to some extent overlaps this *Third Report to the Fish Farmers.* Inasmuch as an advanced draft of the present work had been completed before *Fish Hatchery Management* was published, detailed cross-referencing was not undertaken.

Pond Culture Systems (2)

ARCE, R. G., AND C. E. BOYD. 1980. Water chemistry of Alabama ponds. Alabama Agricultural Experiment Station, Bulletin 522. 35 pp.

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AVAULT, J. W., JR., W. G. PERRY, JR., AND K. O. ALLEN. 1969. Growing catfish in brackish-water ponds. Louisiana Agriculture 13(1):3,16.

BOYD, C. E. 1979. Water quality in warmwater fish ponds. Agricultural Experiment Station, Auburn University, Auburn, Alabama. 359 pp.

BOYD, C. E., R. P. ROMAIRE, AND E. JOHNSTON. 1979. Water quality in channel catfish production ponds. Journal of Environmental Quality 8(3):423-429.

BOYD, C. E., J. A. STEEBY, AND E. W. MCCOY. 1979. Frequency of low dissolved oxygen concentrations in ponds for commercial culture of channel catfish. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 33:591-599.

BUSCH, C. D. 1980. Water circulation for pond aeration and energy conservation. Proceedings of the World Mariculture Society 11:93-101.

BUSCH, C. D., AND C. A. FLOOD, JR. 1980. Water movement for water quality in catfish production. Transactions of the American Society of Agricultural Engineers 23:1040-1042.

COLT, J., R. LUDWIG, G. TCHOBANOGLOUS, AND J. J. CECH, JR. 1981. The effects of nitrite on the short-term growth and survival of channel catfish, *Ictalurus punctatus*. Aquaculture 24(12):111-122.

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