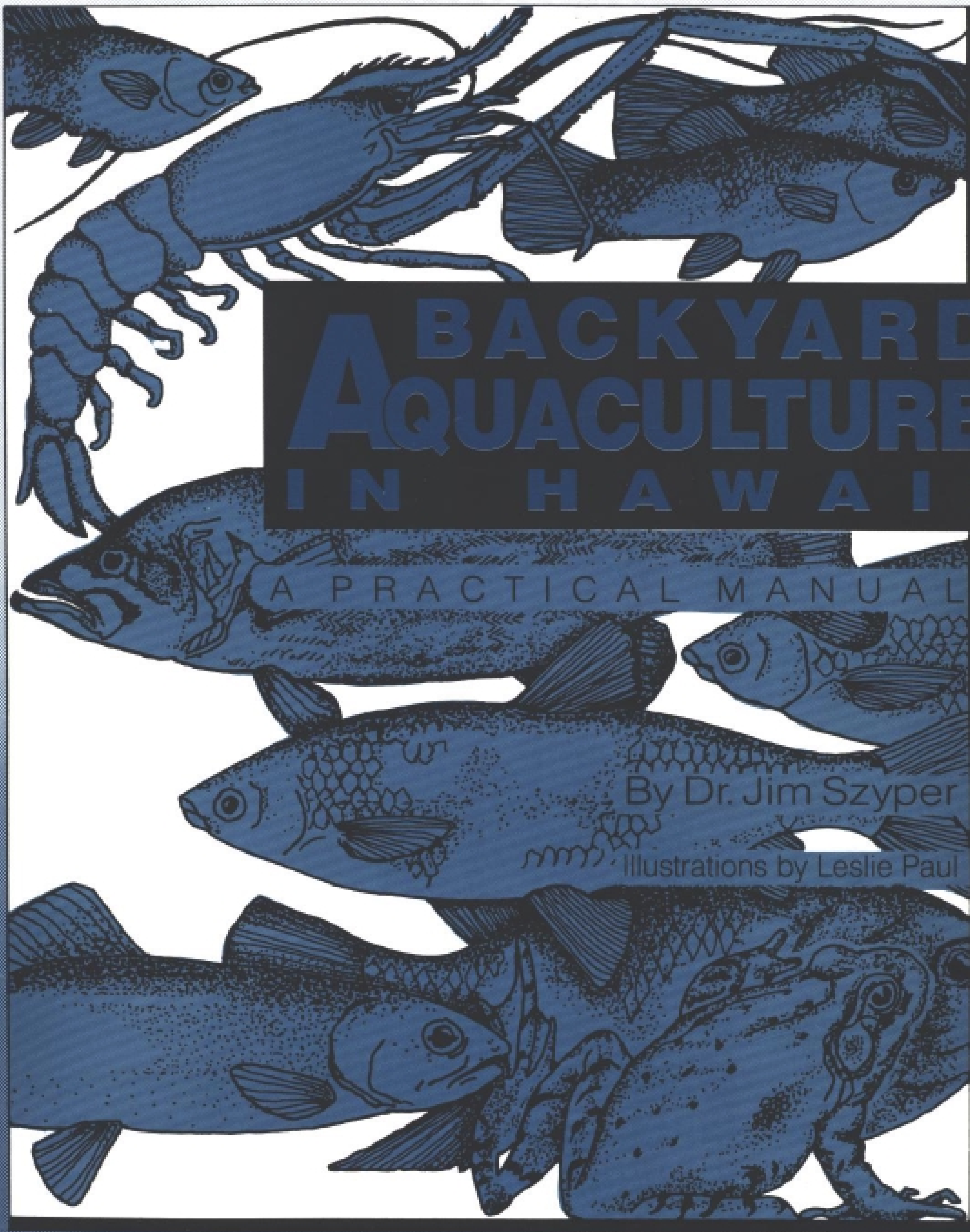


BACKYARD AQUACULTURE IN HAWAII

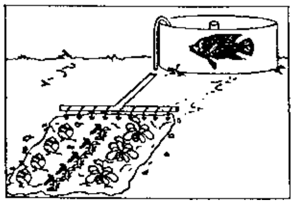
A PRACTICAL MANUAL

By Dr. Jim Szyper

Illustrations by Leslie Paul

Windward Community College, University Of Hawaii

Aquaculture Development Program,
Department of Land & Natural Resources, State of Hawaii



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and
Hawaii Institute of Marine Biology

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Appendix B, “Regulations, Permits, and Approvals Required
for Backyard Aquaculture Operations in Hawaii”
by Jeffery W. Hunt and Bernadette M. Pang,
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Preface

Aquaculture, the keeping or growing of aquatic (water-dwelling) plants and animals, is in its infancy compared with agriculture, but is progressing rapidly. Backyard aquaculture, similarly, is not nearly as well developed and described for the beginner as is home gardening. God written materials on backyard aquaculture do exist, and they are listed in Chapter 12 of this book, but most of them were produced in and for the continental United States. For this reason, they deal with the possibilities and limitations that exist in the northern temperate zone, which are rather different from the conditions in Hawaii. Basic principles of keeping plants and animals in artificial bodies of water, of course, apply everywhere, so these works contain much valuable information for a person interested in the subject.

This book attempts to present possibilities and practical information that include the basic principles, with attention to the climate and other conditions particular to Hawaii and other warm-water situations. The table of contents is presented in an expanded outline form to permit the reader to select particular information right from the beginning, or for reference during a project. Appendix A, a glossary, gives definitions of terms that might be unfamiliar, and Appendix B contains details that may be valuable for some purposes.

With the breaking of relatively new ground about backyard aquaculture in Hawaii, at least minor problems in the text can be expected. As the author, I am solely responsible for errors and omissions in this book. Its existence, however, would not have been possible without the though, care, and work of many individuals.

Jeff Hunt was the founder of the Hawaiian Backyard Aquaculture Project (HBAP) at Windward Community College in 1981. He not only managed to build the pond facility entirely with student help, but he also arranged the funding and laid down the basic direction of the project that finally resulted in this book.

The project has long been supported by the State of Hawaii's Aquaculture Development Program (ADP, a part of the Department of Land and Natural Resources), under the direction of its manager, John Corbin. Both the financial support and the patient persistence of ADP have been essential to the completion of this book.

For many years, HBAP also was supported by the University of Hawaii Sea Grant College Program, under the direction of Dr. Jack Davidson, through the Marine Option Program (MOP). I owe many thanks for generous assistance an cooperation to both the MOP director, Dr. Sherwood Maynard, and to the Windward CC MOP coordinator, Dr. David Krupp.

The list of individuals who have helped in some way over the years is too large to present completely here. This acknowledgment must close with an expression of my appreciation to Dr. Barbara Polk, formerly of WC, Yara Lamdrid-Rose of ADP, and Hiroshi Kato and Roy Fujimoto of WCC, for management of the final production of the book; Louise Ondrik for the indispensable editing of the text and numerous valuable suggestions; Leslie Paul for the fine illustrations; and, in alphabetical order, Ed Bartholomew, Mark Brooks, Michael Fujimoto, Don Heacock, Tom Iwai, Sherwook Maynard, Barbara Polk, Dave Ringuette, Howard Takata, and Georgia Tien for careful and helpful reviews of draft materials.

Financial support of my work on the book was provided by ADP Contract 24956, 23122, 21121, and 18989, and by the U.H. Sea Grant College Program Project ET/E1A (1985-87).

Jim Szyper

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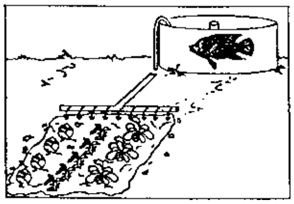


Chapter 1
Introduction

What is Backyard Aquaculture?

Previous writers about backyard and small-scale aquaculture have had different purposes, and have directed their information toward people in places other than Hawaii. In this book, "backyard aquaculture" refers to an activity that people can do and enjoy - on their own if they wish, or with the help of others - on plots of land as small as a private residential property or as large as an acre.

"Aquaculture" means the keeping or growing of aquatic plants and animals, just as "agriculture" denotes growing terrestrial (land-dwelling) organisms. Although private and commercial aquarium-keepers are not usually thought of as aquaculturists, they do seem to qualify under this definition, and their knowledge and techniques are useful.

In this book, the terms "backyard" and "small-scale" generally refer to systems larger than home aquariums, but no larger than ponds of about one acre, a size range that takes in many possibilities. Many excellent books on aquarium-keeping are available for people with that interest, and a great number of works have been written on large-scale commercial aquaculture.

Backyard aquaculture refers to systems and activities for personal or family use, without commercial or profit-making purposes. Of course, the many possible benefits include growing some of your own food and saving money. However, commercial activity is not permitted in many residential areas, and government regulations for businesses are very different from those that apply to backyard aquaculture (see Chapter 4).

The Purpose of This Book

This book will provide a starting point and information source for individuals interested in learning more about backyard aquaculture, or in starting up a small-scale culture system. It will present information to help you decide whether this kind of activity will be possible and enjoyable for you; suggest an orderly approach to maximize your chances for success; present some detail on how to accomplish necessary tasks and start up some specific culture systems; and serve as a source of reference materials for further or more detailed reading.

Specific suppliers for tools and materials, or plant and animal stock, will not be listed here. The "best" sources for such items change with time, and in many cases, the best will be a matter of your own opinion and convenience. Chapter 9 contains information on locating such sources.

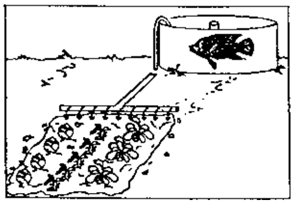
This book was produced with the hope that readers will obtain some or all of the many possible benefits from learning and practicing backyard aquaculture in Hawaii, such as the satisfaction of producing some of one's own food, learning about plants and animals, and taking pleasure in a valuable activity with family and friends.

A Basic Approach

Most of the readers of this book will probably not think of themselves as scientists, but many people do some things every day that scientists do: they observe the world around them, make measurements and write down the results, and learn from experience how to do things better. This approach to backyard aquaculture, using "scientific" personality traits such as curiosity and orderly behavior, will bring you the greatest chance of success for your efforts.

Some terms and phrases in this book may be new to you, but each will be explained, and a glossary in Appendix A will help you in remembering aquaculture terms. The reader's understanding of technical terms will make it possible to express ideas with far fewer words and less chance of confusion.

With this background, get ready for a journey along the steps to a successful and satisfying experience in backyard aquaculture!



Chapter 2

What Do You Want to Do?

(and Some Help With Deciding)

‘I’d Just Like to Start and See What Happens..’

To make a start in small-scale aquaculture, you, as a new aquaculturist, will need to invest some time, effort, and money before the cultured product will be ready for harvest. You will maximize your chances for a satisfying experience with small-scale aquaculture if you develop at least a tentative beginning answer to the questions “What do you want to do in small-scale aquaculture?” and “Why?” This chapter offers some hints on developing your goals.

Why a New Activity?

A good way to begin is to consider why you are reading this book and thinking about taking up a new activity like aquaculture. A common response is that people are curious about aquaculture, but there are a variety of other possible reasons.

• Sometimes a person needs to do something new. Daily life and making a living require a lot of effort, but do become routine, and a new activity that absorbs the attention, but one in which the individual controls the effort and the time devoted to it, can be refreshing.

• A person may want to expand, diversify, or take the next logical step from something he or she already knows how to do. For example, small-scale aquaculture follows naturally from home gardening, to the mutual enhancement of success at both.

• Sometimes an individual is inspired by new idea he or she has seen, heard, or read about. In the case of aquaculture, interest may focus on any aspect, from curiosity about a particular plant or animal, to a need or desire for potential benefits. Specific needs may include physical activity recommended by a doctor, a need to reduce food bills, or a desire for contact and cooperation with others, perhaps children, family, or neighbors.

How to Develop Your Goals

Goal setting is an important aspect of beginning a new venture. The process includes two major steps: the first is to write out your goals as clearly as possible, and the second, to review these goals from time to time, and make changes as needed. You may hesitate to state specific goals at the beginning, particularly when you don’t know much about how to achieve them. You may fear a let-down if your plans do not work out. For this reason, it is important to remember the second step: that goals can be reviewed and changed. A well chosen goal is one you can say you wish to achieve now. Reviewing and modifying a goal as you progress shows you are learning about what you are doing, and improving your chances of success all the time.

At first, even the clearest possible statement you can make about your goals may sound quite general, but such statements can help you eliminate possibilities that don't apply to what you want, which can be a big help. For example, a beginning small-scale aquaculturist should decide whether producing plants or animals with a certain degree of success is important. This choice separates goals like "supplementing the family diet" from "recreation" or "learning." A culturist with a goal of "increasing opportunities for family recreation" can obviously be a resounding success before the first fish is ever harvested and eaten! You may have more than one goal, but multiple goals should be listed in priority order.

As you learn more about what you can do, your goals will quite naturally become more specific. If you initially say that you want to produce supplemental food, you should be aiming to get to the point of saying, for example, "I want to produce the protein portion of one meal per week for my family of four." Always keep in mind that specific details of the goals should be subject to change, just as, particularly at first, your general goal statements are.

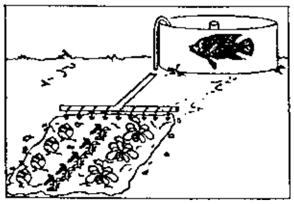
For example, perhaps cooler winter temperatures will cause your animals to grow too slowly to produce one meal per week during some months. This situation is the result of nature, not failure, and you will have learned something! If your general goal is recreation, this goal, too, should be made more specific, perhaps to read, "I wish to spend one-half hour a day outdoors, and enjoy watching the animals." It is likely that you will develop even more specific goals later, if you begin in this way and follow the steps outlined in this book.

'How Far Can I Go?'

Aquaculture projects, both backyard and commercial, nearly always begin on a note of great optimism. This feeling, one of the most exhilarating of human emotions, may best be preserved by recognizing some perfectly natural limitations to what can be done in small-scale aquaculture. It is even more exhilarating to later push back the limits you saw at first! 'Me beginning backyard aquaculturist probably has a limited amount of time, money, and space to give to the new activity. One of the major purposes in this book is to present realistic possibilities. It is much better for you to "start small," in terms of these resources, and to expand later if your desire and resources permit it.

The following chapters describe the necessary steps in a journey toward planning and developing your small-scale aquaculture system. The next two chapters deal with evaluating a location, probably your residential property, for your project. A careful look at this information will ensure that you begin to develop your system with as few obstacles to completion as possible.

Finally, you need to remember that you had to learn to "walk before you could run." Small-scale aquaculture can be practiced and enjoyed by almost anyone. You certainly don't need to be a biologist or an engineer to achieve the goals discussed here. Your early goals, however, should be chosen with your present level of expertise in mind. You can look forward to learning a great deal from your first day onward!



Chapter 3

Where Will Your System Be?

A Backyard in Hawaii

Among the many advantages of living in Hawaii is the mild climate that permits year-round outdoor activity, including aquaculture. Hawaii, however, like other island locations, has particular features that make it necessary to select a site for aquaculture activity very carefully. The most important such feature is that islands the size of Hawaii's contain very different areas with respect to the land, water, and climate, with climates ranging from rain forest to desert, and physical landforms from sheer cliffs to flat plains. Although almost anyone who has access to sufficient space in Hawaii can operate some sort of aquaculture system, the characteristics of particular places will affect the possibility and chances of success for particular systems.

Another common feature of islands is that land and water may be in limited supply. Fortunately, as a backyard aquaculturist using your own land, you will not encounter the problems commercial farmers have in locating large areas on which to operate. However, even on your small-scale, you must consider the cost of using tapwater or arranging for another water source. On Oahu, the cost of residential water in early 1989 was $1.11 for 1,000 gallons. A backyard system may hold several thousand gallons, and some of the recommended management strategies involve exchanging the water once a week.

This chapter provides guidelines for collecting information about the site of your small-scale aquaculture system, assuming that most readers are thinking about their own property as a site, or one on which they live and exercise some control. However, you should gather a similar set of information if you wish to use a site under some other arrangement. You probably already know some of the information discussed in this chapter from your own experience with the site.

An excellent source of more information is the publication "Aquaculture Development for Hawaii," produced by the state Department of Planning and Economic Development, and available at Windward CC, at the offices of the state Aquaculture Development Program, and in public libraries. The maps included with that publication show, for each major island, the slope of the land, annual rainfall, and other' important information items.

Your Aquaculture Environment

Two obvious but important items to know about your site are the location and the owner. Your notes on site information should begin with, not only the street address, but also the code number called the "Tax Map Key," or TMK. This code number will be very helpful if you need to call any public agencies for information about your property, as discussed in the next chapter. The TMK can be found on a property tax statement or ownership documents, or may be looked up on real estate maps in a public library. If you are not the owner of the property, it would be valuable for the same reason to have the owner's name and address.

Knowing something about both the natural history and the previous human use of the land can be helpful, as well as interesting, in planning your culture system. If you can find out, before attempting to dig a pond for example, that your land consists of six inches of soil covering solid volcanic rock, you can make your choice of a system without having a disappointing start. You may already know (and would certainly want to know) whether or not your site is subject to flash floods or to tsunami inundation, which can be estimated from maps in the telephone book. More optimistically, you may find that your land has properties, such as good soil fertility resulting from old river deposits, that will give you more opportunities and ideas than you had originally.

The history of human use of the site can be helpful in the same way for avoiding problems or expanding possibilities. Former agricultural use may have improved the soil, or may have left persistent pesticide residues; former industrial uses, such as quarrying or landfill operations may be pertinent to your choice of a system. Some property owners enjoy knowing the ownership history of the land for reasons unrelated to aquaculture. A newly-arrived University of Hawaii professor once had ownership of his newly purchased property traced back to the Great Mahele, a major redistribution of land in Hawaii during the 1800's. Former ownership of land can be traced through the State Department of Land and Natural Resources.

Your aquaculture plans will be related very closely to the size and shape of the available land. At this point, you should make two sketches of your site in both side view and top view, like the examples shown in Figure 3.1. These sketches don't have to be of any particular artistic or architectural quality. The top view "map" should, however, be drawn "to scale," meaning that one inch on the drawing should always represent a definite real distance (say, four feet). If you scale the drawing carefully, you will be able to use it to estimate the area in square feet available for your culture system. You will use this information to follow directions in Chapter 6, when you begin to design the system. The top view drawing should show any buildings, streets, streams, large trees, and all other important features of the land. The side view, or "vertical section," should represent a vertical slice through the site along a line that you choose as being important to later design of the system.

For a residential property, a line from the street in front to the rear boundary may be suitable. However, if the greatest slope of the land runs from one side of the property to the other, a line running from side to side, which will show the slope, would be best. It may be advisable to make two such drawings, to show the slope in two perpendicular directions. You can easily measure the slope along the line. The slope is usually expressed as a "percent," which in this case means, "the height difference in feet for each 100 feet of horizontal distance." If, for example, the land drops off by 3 feet along a 100-foot long line, we say the slope is 3 percent.

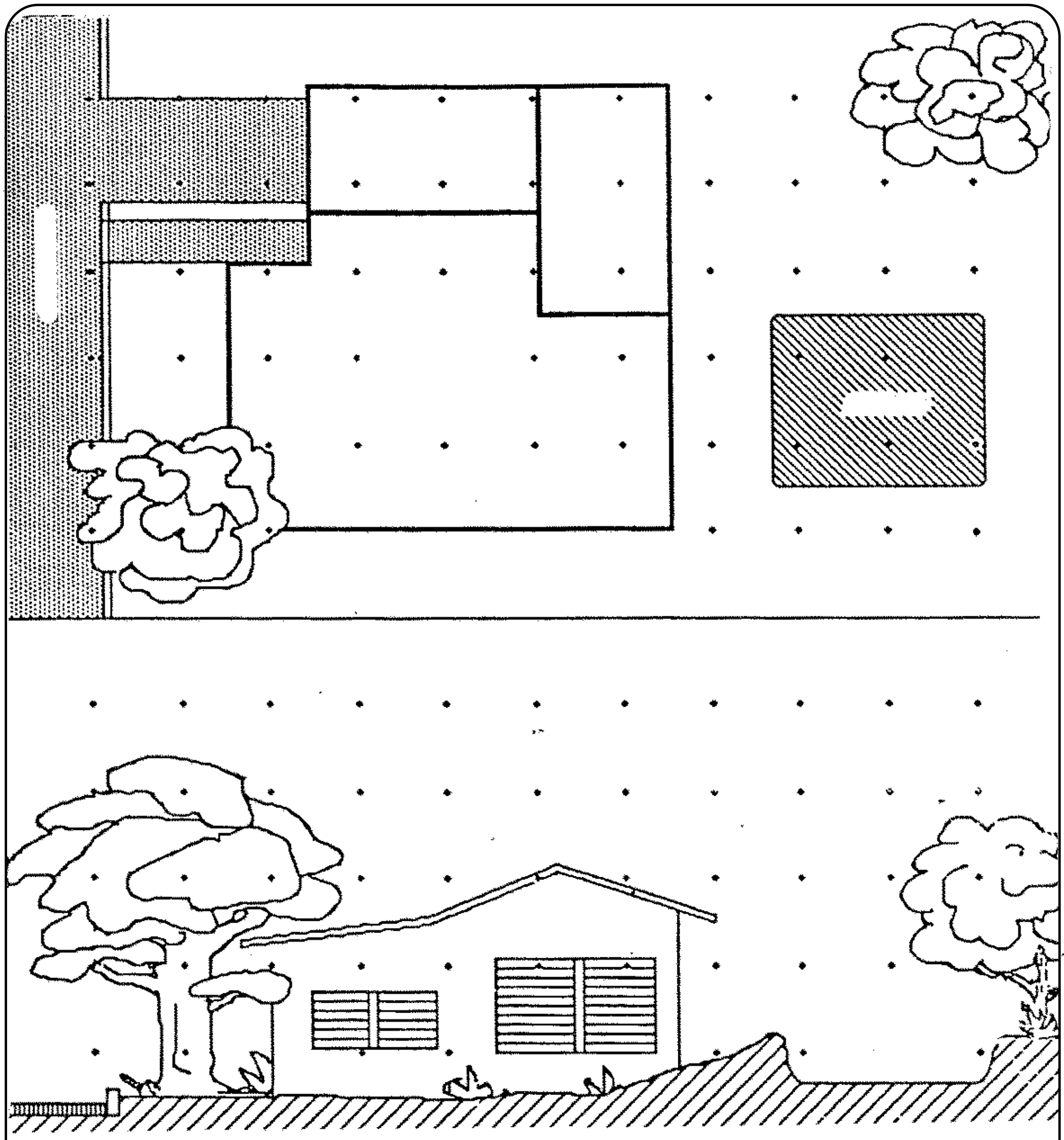


Figure 3.1 Examples of top and side view drawings for the evaluation of a site for small-scale aquaculture.

This idea also applies to distances shorter than 100 feet. A rise of 2 feet along a 25-foot line is equivalent to 8 feet in 100, or 8 percent. Figure 3.2 illustrates a simple way to measure the slope. Ideally, your. house foundation should be at a higher elevation than the water level of the pond. Also ponds should be a reasonable distance away from any structures, including a neighbor's house or a fence. When you have finished your sketches, it would be good idea to make several photocopies of them for later use.

The next step in evaluating your site is to consider your source (or sources, if you have a

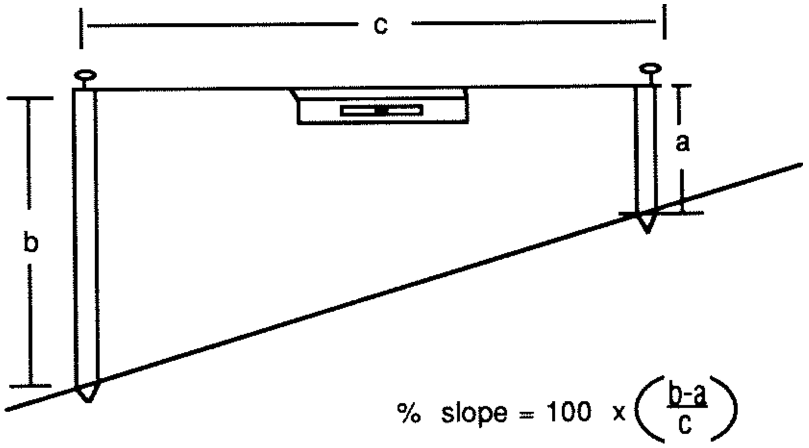


Figure 3.2 A method for measuring the slope of the land

choice of more than one) of water. This book is oriented toward fresh-water aquaculture, but much of the information also applies if you are able to consider a saltwater system. For many culturists, the only possible freshwater source will be tap water. In that case, you should find a water bill or call the Board of Water Supply to find out the cost per gallon at the present time. This information will help you later to evaluate, later, the possible value of developing an alternative water source (for example, catching rainwater), or of setting up a system to re-use the tapwater that goes into your system.

Most of the water sources in Hawaii provide water of excellent quality for small-scale aquaculture, including tapwater, rainwater, surface stream water, or well water. The Board of Water Supply may be contacted for information about the quality of water from most possible sources on Oahu. Chapter 7 describes important water properties and how to assess them during operation of your culture system. After reading that chapter, you may want to measure some of these properties for the water source you will use.

Finally, you will need information on the weather and climate at your site. Now would be a perfect time to get an outdoor thermometer, if you don't already have one, and begin to gain experience with measuring and recording the temperature changes that will affect your culture system. You will want to know the usual and the largest temperature differences between day and night, for different seasons, and under different weather conditions. You can use a sheet like that shown in Figure 3.3 to keep temperature records. If you can find a thermometer that reads both Fahrenheit (F) and Celsius (C) degrees, that would be an advantage when you are choosing the plants and animals to be pat of your system, because biological information sources usually discuss temperatures in degrees C. If not, you can easily convert from one system to another as shown in Figure 3.4.

In addition to temperature, you should consider some other important factors about your site. The total yearly rainfall, the seasonal pattern of rainfall, and the usual amount or percentage of time the sun shines, will affect your choices of water sources, plants, and animals. The typical and most extreme wind speeds and directions, and the general degree of wind exposure at your site, can be important to the way your culture system will work and the best means for caring for it. You can obtain some of this information simply by recording the conditions, on a sheet like that shown in Figure 3.3, when you record the temperature. If you are consistent about estimating the conditions, you will after a time have a good knowledge of the site without needing weather instruments. More specific information on these factors can be obtained from the maps mentioned above, from the National Weather Service offices, and from library resources.

Other Resources

A piece of land and its properties are, of course, your greatest resources. The "art" of aquaculture (and agriculture) consists partly of seeing and using an environment as a resource to achieve your goals. The properties of your soil, the slope of the land, the sun, rain, wind, and flowing water if any, are not "Problems to overcome," but your "materials to work with" in this endeavor.

Figure 3.3 A sample air temperature for evaluation of a site for small-scale aquaculture

Year _______

Month	Day	Time	Temperature	Weather Conditions	Notes

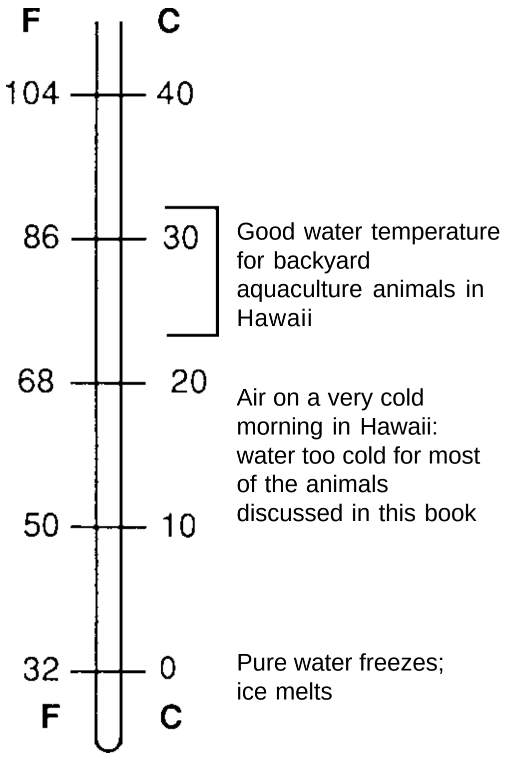


Figure 3.4 A comparison of Fahrenheit and Celsius temperature scales

Particularly if you live on the site, you probably have many additional resources available to help you. Now is a good time to take stock of such items and features of your situation, using a sheet like the one shown in Figure 3.5. You may already have a variety of home, garden, and automotive tools; a workshop, shed, or garage space for storage; a garden, compost pile, or watering system; and one or more motor vehicles.

You should also consider how accessible and secure the site may be, answering such questions as: "Can vehicles reach the site to carry materials to and away from it?," "Will a fence or shrubbery need to be removed, and will this removal encourage unwanted traffic through the property?," and "Will this site be a safe place for people who participate in this activity?" It is highly recommended (and required in some cases see Chapter 4) to fence in backyard ponds, particularly in urban areas, to minimize accidents with small children. It would be wise to check to see if homeowners' insurance would cover any possible mishaps on the site.

People, and their help and good will, can be a resource at least as valuable as the, other items discussed here. You may have friends or acquaintances who will wish to help, or who may lend their tools or equipment. At the very least, you will want to be sure that your activities and your system create no disturbances to your neighbors. Use common sense, and whenever possible, let them know what you are doing, and assure them that you want your aquaculture project to be an asset to the neighborhood.

Does Any of This Change Your Goals?

It is quite natural, when you are thinking about goals as you did in Chapter 2, to let your imagination jump ahead to later stages, such as building the system or eating homegrown fish dinners. This reaction is not only natural, but fun, and probably part of the way great achievements begin.

The main reason for the methodical approach of this book is to help you maintain the greatest chance of seeing "the final product." This chapter has recommended careful evaluation of the site for your aquaculture system because aquaculture must work with nature. Following chapters will refer to your information about the "nature" of your site time and time again.

Figure 3.5 A Sample Inventory of tools, other materials, and support facilities available for an aquaculture project

INVENTORY

I. Tools

II. Storage Spaces

III. Garden Areas (plot, compost pile, etc)

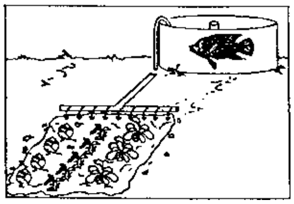
IV. Water Sources and Systems (sprinklers, taps, etc)

V. Vehicles

VI. Site Access and Security

VII. Site Safety

VIII. Neighbors



Chapter 4

You, Your Government, and Backyard Aquaculture

First, the Good News

You are probably aware that the government has quite a few regulations related to running a business for profit. Such regulations help the government to keep track of and assist the business activity in its area, and to protect the consumer, the environment, and even the business people themselves from possible abuses or other ill effects of the activity. Complying with all the regulations and obtaining the required permits, however, do take up time and resources from the people who start and run businesses.

Fortunately, backyard aquaculture has fewer regulations and permits to deal with because the aquaculturist does not expect to sell any of the cultured product. This chapter briefly reviews the aspects of backyard aquaculture that may be regulated by the government, or should be looked into for other legal reasons, before a culture system is started.

More detailed information on each of the items in this brief review will be found in a publication of the University of Hawaii Sea Grant College Program entitled, “Regulations, Permits, and Approvals Required for Backyard Aquaculture Operations in Hawaii” (See Appendix B). This publication was writ-ten at Windward Community College by Jeff Hunt, the founder of the program, and Bernadette Pang, a former student.

You will probably find that some of the items discussed here apply to your situation, and that the persons and agencies you will need to contact will be helpful, even if they sometimes have to refer you to another agency or telephone number. As is true in most situations, patience and politeness will go a long way toward helping to get your business done. The final result will be that you, your neighbors, and the government will all be on the same side, namely, in favor of your backyard aquaculture project.

Who Owns the Land?

In Hawaii, homeowners live on land that they hold either in “fee simple” (the usual method of residential landholding in the United States) or by lease. For fee simple land, in most cases, the owner can decide how the land may be used. Sometimes, however, land is sold with attached agreements about its future use; such agreements are called “covenants.”

Owners of fee simple land should check their documents, or have an attorney do so, to see if any covenants apply. If the land is being leased, the lease contract should be read for regulations and restrictions pertaining to the use of the land. It is possible that the lessor’s permission would be required for backyard aquaculture activity. Even if it is not legally required, some lessors request that they be consulted regarding proposed backyard aquaculture systems so that they may review the plans. Lessors may be individuals, large landholding estates, or other organizations. In general, they will allow backyard aquaculture ponds and support facilities to be built, as long as the activities do not disturb others and do not disfigure or damage the land.

Zoning and Specially Regulated Areas

Each county in Hawaii has different land use requirements and zoning ordinances, so you should contact the appropriate agency for information. On Oahu, it is the Department of Land Utilization; for the counties of Hawaii, Maui, and Kauai, it is the respective planning department. Appendix B contains phone numbers of the major agencies that may need to be contacted. Also, an updated aquaculture resource manual is under development by the U.H. Sea Grant College Program. It will list government agencies and sources for supplies, equipment, and animal stock.

The primary effect of zoning on backyard aquaculture on residential land is to impose “setback” requirements, which may limit the location of the culture system on the land. For example, certain types of ponds and structures must be set certain distances back from the borders of the property. Backyard culturists who live near the shoreline, on agricultural land, or in flood- or tsunami-designated areas should check Appendix B carefully, and contact the appropriate agencies for more information.

Pond Construction

Depending on the size and design of your culture system, you may need to obtain a grading (earth-moving) or building permit by contacting the appropriate county building department. Also, a pond deeper than 46 centimeters (1.5 feet) on Oahu will be interpreted as being similar in nature to a “swimming pool.” If so, the area around the pond must have a barrier at least 1.4 meters (4.5 feet) high. The barrier may be either a four-sided fence or one side of a building and a three-sided fence; and gate latches must be self-latching and self-closing, and located at 1.2 meters (4 feet) in height.

Water Sources and Water Discharge

Either tapwater or rainwater may be used in backyard aquaculture ponds. Tapwater may be added directly to the pond through water hoses or a permanent pipe system. In some cases, the plumbing code should be examined (with help, if necessary) for the possible requirement for a back-flow prevention device.

Rainwater may be collected in holding tanks approved by the appropriate county building department. On Oahu, well water outside of groundwater control areas may be used if a permit is obtained from the Board of Water Supply, City and County of Honolulu; the other counties do not have a well permit requirement.

The Board of Water Supply encourages the recycling of pond water for watering lawns or gardens and the recirculation of pond water whenever possible. On Oahu, the discharge of pond water into storm drains requires Department of Public Works clearance; discharge of water into the sewer system requires permits also.

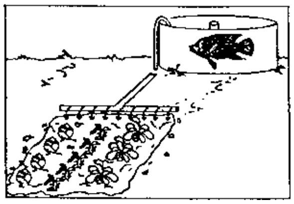
Energy Sources

Potential sources of energy to operate backyard aquaculture systems include electrical, solar, and wind power. An electrical connection to the backyard aquaculture system must satisfy all applicable electrical codes, and a building permit is needed for electrical work. The use of appropriate “alternate” energy sources (other than public utility electric power) can significantly decrease the cost of raising the aquaculture crop. These sources are discussed in a later chapter.

Public Health Considerations

No health permits are required to operate a backyard aquaculture system, for a properly managed system will create no detrimental public health problems. Mismanaged or neglected systems, however, may produce noxious odors, result in mosquito breeding, and cause other problems. The backyard aquaculturist must operate responsibly and with concern for family and neighbors.

Finally, no one should ever consume freshwater organisms raw, because they may contain parasitic worms or harbor other diseases.



Chapter 5

What Will You Grow?

Deal in the Possible

By this time, you are probably eager to begin thinking about the "living things" that will go into your system. Now that you know something about your goals, your site, and other important details, you are ready to learn how to evaluate and select the plants and animals you will grow. You may find, as others have, that this step is the most fascinating part of developing an aquaculture system. It also is likely to be the part that new culturists feel least confident about, especially if they have had little or no Previous experience with aquarium-keeping, gardening, or biology courses. This feeling, while perfectly natural, will pass once you have some real living things to deal with. Many aquatic plants and animals can easily be grown by people who are willing to try, as is proved by the more than 2500-year history of aquaculture.

This chapter continues with the step-by-step approach to developing a system that will help you achieve your goals. The approach is still a basic one. Although the worldwide list of cultured "organisms" (the technical term that covers both plants and animals) is fairly long, the list presented here is much shorter, and contains the best beginning choices for small-scale culture in Hawaii. Information used to select- them is included so that you can make your own informed choices.

Your goals, your site, and the resources you have to work with are the first and most important factors to consider in the selection process. If, for example, your goal is to produce regular supplemental food for a family, you will want to grow very well-understood, relatively fast-growing, good-tasting animals that do not require excessively large amounts of space or water to thrive. Their appearance, or other characteristics that make them "interesting," will be secondary, though of course you may come to see them as beautiful and interesting - most aquaculturists do! On the other hand, if your primary goal is recreation or education, you may wish to select organisms that might not be suitable for reliable production, but provide the opportunity to manage your system more simply, or that may offer a different challenge from that of regular production.

Culturists with recreational or educational goals may wish to keep plants or animals whose culture requirements are not well known. Although it is beyond the scope of this book to deal with development of methods for "new" organisms, much of the information in this chapter will be helpful in suggesting "what to look for" when selecting and observing them.

'No Fish Is an Island'

Aquaculturists use the term "monoculture" to mean the growing of only one "species," or type, of organism in a system. Keeping more than one species in a system is called "polyculture." Since different species, even closely related ones, have different requirements, monoculture systems are easier to understand. A successful polyculture system must meet the requirements of all the living things in it.

It might seem, then, that this book should recommend only monoculture systems for beginning aquaculturists. However, two facts of nature impact the choice between mono and polyculture. First, even the best-managed monoculture system will have living things in it other than the animal one wishes to grow. The water will always contain bacteria, and if it is exposed to the air, it may soon contain microscopic plants and animals. This situation is not necessarily a problem, but the culturist will need to be aware that the cultured animals are not alone. Also, all living things take in energy and materials (for example, sunlight and water for plants, and food and oxygen for animals), and they put out wastes. In a monoculture, the culturist must provide all the "inputs," and arrange for the removal of wastes (for example, by providing water exchange) to keep them from accumulating. Polycultures consist of plants and animals chosen to perform some of these functions for each other.

Polycultures try to imitate natural systems, such as ponds and lakes, in part. In such natural systems, called "ecosystems" by biologists, culturists are not available to feed the animals and remove the wastes, yet the systems remain in balance (are "stable") for many years at a time. Animals and plants are produced, they grow and are eaten - or die of other causes, and their wastes are removed or changed back into natural fertilizers for the plants.

Polycultures aren't designed to be completely independent of human management, but they can have advantages even for a beginning aquaculturist. If the collection (called the "community") of plants and animals is well chosen, a system may produce more than it would with a monoculture, given the same amount of feed and effort by the culturist. Also, polycultures can be more stable. Plants can use the liquid waste materials from fish, as many keepers of houseplants and aquariums know, reducing the need for new water in the system. Some types of fish will eat some of the plants in the system, keeping the plants from growing excessively. Other fish will live entirely by eating the solid wastes of other fish, so that the bottom of the system will not need frequent cleaning.

Management of a polyculture system may be easier, in terms of physical effort, than caring for a monoculture in the same body of water, but the culturist must understand the relationships among the organisms and observe carefully and frequently for any signs of developing problems. As mentioned above, polycultures may produce a certain amount of animal growth with less feed than a monoculture would need, and may require less frequent removal of bottom debris or exchange of water. This situation is possible because plants and animals of different but well-matched habits are performing some of the activities that otherwise would be required of the culturist. However, because many interactions are going on, the system must be watched carefully and adjusted if necessary, like a machine with several moving parts.

In the following descriptions, some animals will be identified as appropriate for polyculture. You may find it fascinating, as other aquaculturists do, to see and learn about the community in an aquaculture system.

‘Names and Faces’

This section provides names, drawings, and brief descriptions of the plants and animals recommended for use in small-scale aquaculture systems in Hawaii. Most of the organisms have been studied and described well enough that you can find information in greater detail in library sources.

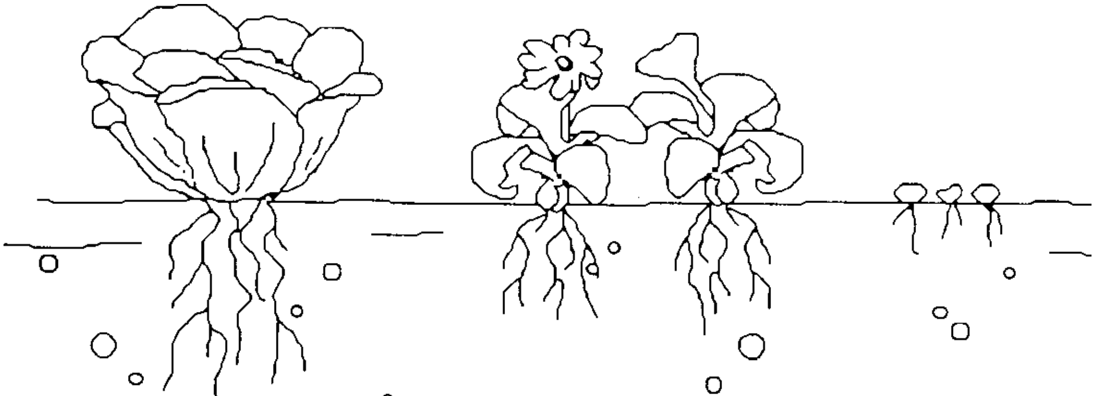
Two kinds of names are given, the “common” names in English, and the Latin biological names. Common names sometimes vary in different parts of the country or world, but usually only one common name will be listed here, with an alternative in parentheses when it is likely that you will see it in some sources. Biological names consist of two words: the first is the “genus,” and the second word, the “species.” A genus is a name for a general type of organism, which applies to several different specific types or species included in the genus. Often, the difference among species is fairly small in terms of appearance, but is important to the organism’s properties for aquaculture.

Genus and species names, because they come from a foreign language, are supposed to be underlined or italicized in print. Also, biologists always capitalize the genus name, but do not capitalize the species name, even if it resembles a person’s name. Many publications routinely fail to keep this system strictly, but once you become familiar with some of the names you will recognize them no matter how they are printed. Don’t be concerned if you find the biological names strange or difficult to pronounce. Biologists, not being Latin scholars, don’t all pronounce the names in the same way, and in any case, the common names will do perfectly well for most of our purposes.

The following short descriptions include comments on properties of the plants and animals that pertain to their suitability for small-scale aquaculture in Hawaii. Such properties include temperature requirements, growth rates, and general hardiness and resistance to disease. Other factors to consider are: how densely the organisms may be stocked in a system, the percentage of original juvenile stock that may be expected to survive until harvest, and the general availability of the organisms in Hawaii. The first few descriptions contain detailed explanations of these items where necessary, and the later descriptions are shorter.

Plants

WATER HYACINTH, *Eichornia crassipes,* is a floating plant with rounded, deep green leaves several inches wide, and bushy “roots” that hang into the water. The plant produces beautiful violet flowers that do not last long if picked, but it is known as a pest that clogs waterways around the world. Several species of fish love to eat the roots as either their main or a supplemental food. The water hyacinth can provide shade to help control temperature in a pond, and shelter for animals that do not like exposure to direct sun. The plant can completely cover a pond in two weeks, starting from 50 percent cover, earthen ponds at Windward CC are usually kept at 40 to 60 percent. The plant takes up animal wastes as its fertilizer, and it is highly prized by some gardeners as mulch that adds potassium and other materials to soil. The water hyacinth is easily obtained from streams in Hawaii. Wild plants should be manipulated and rinsed carefully, and for good measure dipped in a copper sulfate solution (available in aquarium stores), to remove any possible parasites.



Water Lettuce
Pistia stratiotes

Water hyacinth
Eichornia sp.

Water Fern
Azolla sp.

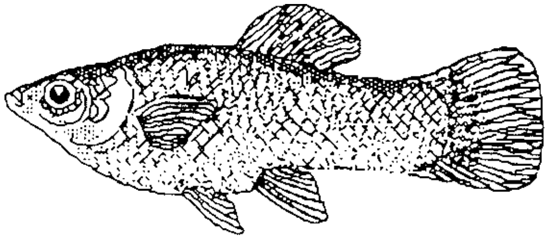
WATER LETTUCE, *Pistia stratiotes,* is a floating plant similar to the water hyacinth, but with larger, irregular, pale green leaves resembling the outer leaves of cabbage. It has bushy roots like the hyacinth, and provides the benefits to ponds described above. It also is readily available in some streams and ponds in Hawaii.

AZOLLA (WATER FERN), *Azolla sp.,* is a small (about 1" diameter) floating fern (though it doesn't look like larger ferns), with dangling roots like the water hyacinth and water lettuce, but proportionally smaller. Azolla also is eaten by some fishes, and it has a relatively high protein content. It provides the benefits to ponds described above, and it can completely cover a pond surface more rapidly than the other plants. It can be found in natural waters in Hawaii.

PHYTOPLANKTON are microscopic plants (too small to be seen as individual cells) of many different species. They live throughout the water, are eaten by only a few fish species, but provide food for tiny animals (zooplankton) that can be eaten by many fish. They take up wastes as fertilizer, add oxygen to the water during daylight hours, and when they "bloom" (become abundant), provide a shaded environment in deeper parts of a pond. They may introduce themselves to a pond naturally, carried by wind or water, blooms are often encouraged by fertilizing a pond, but must be managed to prevent excessive growth.

Animals

TOPMINNOWS, *Poecilia* spp. (spp. means "several species of the genus"), are small fish (up to about four inches long) that give birth to live young, like their relatives the aquarium mollies. Their natural diet includes plant parts, zooplankton, and insect larvae; they readily ac-

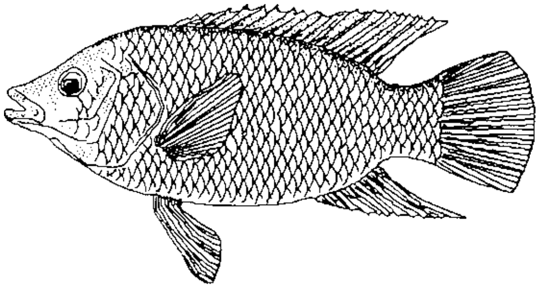


Topminnow *Poecilia* spp.

cept scrap or prepared feeds. Because they help to control mosquitos, they should be seriously considered for any backyard aquaculture system. Some fishes will eat the fry (young) of the topminnows, controlling the population; they are excellent fishing bait, and have been cultured commercially in Hawaii for that purpose. They tolerate a wide range of temperatures, can adjust to salt water, and can easily be cultured as feed for fish that require live food, such as largemouth bass. Topminnows can be obtained from any commercial or research facility that may be growing them at present.

MOSQUITOFISH, *Gambusia affinis,* also are live-bearing relatives of the mollies. They are similar to the topminnows, and can be caught easily in fresh waters in Hawaii. Mosquitofish are an excellent alternative to topminnows for mosquito control in small-scale aquaculture systems. As was mentioned for wild plants, wild animals should be introduced into culture systems only after separate holding for a time to see that they have no disease symptoms, and should be treated with copper sulfate before introduction.

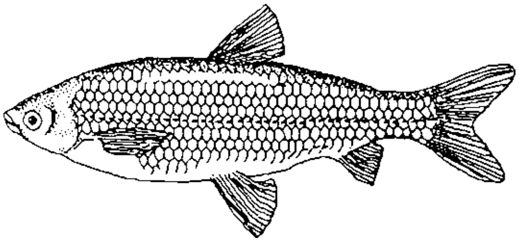
COMMON TILAPIA (JAVA TILAPIA), *Oreochromis mossambicus,* are drab-colored fish that can grow to a foot long or more and several pounds. They are related to the piranha and the aquarium angelfish, but are not aggressive and can be cultured at high densities. They are tolerant of a wide range of temperatures and can adjust to some degree of salinity; they can tolerate low levels of dissolved oxygen, are very hardy and disease-resistant, and grow rapidly. They eat plant parts, zooplankton, fry of their own and other fishes, and almost any scrap or prepared feed offered. Several types of tilapias are available in Hawaii, and they are, without doubt, the best choice of a food fish for the beginning small-scale aquaculturist. They are one of the most widely and abundantly cultured food fishes in the world. A strong and persistent prejudice against tilapia as food is prevalent among some people in Hawaii because of the muddy or waste-enriched environments in which they are found naturally, the dark color and the odd-looking mouth of the larger ones, and the availability of many types of traditionally more highly desired ocean fishes. Tilapia grown in fairly clean culture systems, or held in clean water for a time before use, are good tasting. They are cultured successfully and sold commercially here.


Common Tilapia (Java Tilapia)
Oreochromis mossambicus

RED TILAPIA (GOLDEN TILAPIA, “HAWAIIAN SUNFISH”), *Oreochromis mossambicus,* are a true-breeding variety (red ones produce red young) of the common tilapia. This fish is largely responsible for the commercial success of tilapia in Hawaii. Tilapia reproduce naturally in culture systems; fry can easily be obtained from commercial growers and grown to bait size. At high densities, they may overpopulate a system and stop growing at a small size, a condition which can be controlled by polyculturing them, if the culturist wishes, with a fish that will eat the young.

BLACK-CHINNED TILAPIA, *Sarotherodon melanotheron,* resemble the tilapias discussed above, but do not have their distinctive mouth shape. They have an attractive blue and yellow body color, and have black markings on the white underside of the lower jaw. They share the other tilapia characteristics, and like the others are available from commercial facilities.

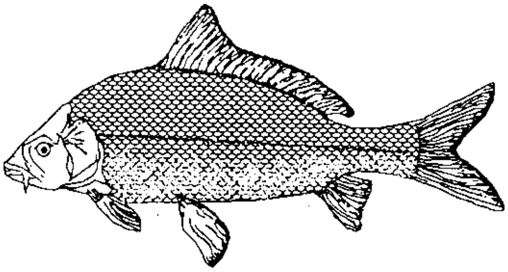
GRASS CARP (WHITE AMUR), *Ctenopharyngodon idellus,* are "standard-looking," large-scaled fish related to other carps, and are members of a group called Chinese carps. Grass carp are fast-growing fish that can reach well over 10 pounds. In nature they eat zooplankton as young, and later eat other animals and small fish, but they are not carnivorous after reaching six inches in length, when the natural diet switches to plant materials exclusively. They are best known for their ability, as they become adults, to eat plant parts, including floating plants and rooted vegetation at pond edges, a behavior that makes them valuable for weed control in earthen ponds. They readily accept prepared feeds, live well with other pond animals, and tolerate a wide range of temperatures, but they are sensitive to low levels of dissolved oxygen. The flesh of the white amur, as commercial growers and Hawaii's government agencies prefer to call it, is somewhat bony like that of other carps, but is of excellent taste and texture. The ability of the fish to control weeds and subsist on yard or garden trimmings makes it a good member of a beginner's small-scale culture community. Grass carp have been spawned in Hawaii by injecting hormones into mature fish, but fry usually are not available locally. Many mainland suppliers will ship fry to Hawaii; bringing them in requires a permit from the state Department of Agriculture.



Grass Carp (White Amur)
Ctenopharyngodon idellus

SILVER CARP, *Hypopthalmichthys molitrix,* are small-scaled Chinese carp that eat phytoplankton, and for this reason are often used in polyculture systems, where their presence contributes to the stability and increased productivity of the community. They do not grow as large as the grass carp, but otherwise share many of its characteristics, including their limited availability in Hawaii.

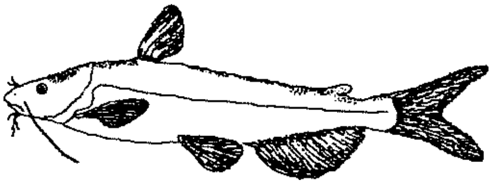
COMMON CARP and ORNAMENTAL CARP (KOI), *Cyprinus carpio,* are, along with the tilapias, one of the world's most cultured food fishes. Koi are the result of selective breeding by professionals and hobbyists, and are available as "fingerlings" (finger-sized fish too large to be called fry) in aquarium stores. Common carp and koi are tolerant of wide temperature ranges and low dissolved oxygen levels; they grow to several pounds, but not as rapidly as



Common Carp *Cyprinus carpio*

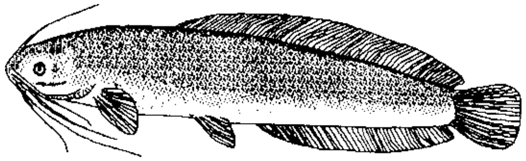
the Chinese carps. In nature, they feed on bottom animals they extract from the sediment; they also eat plant parts and prepared feeds readily. Their bottom-feeding habit makes them desirable as members of polyculture systems. A prejudice against common carp has been noted among some freshwater fishermen in North America, but they are of good quality when cultured. They can spawn naturally in ponds, but, like the Chinese carp, are most often spawned artificially, and they are of similar availability.

CHANNEL CATFISH, *Ictalurus punctatus*, are dark, white-bellied, smooth-skinned, odd-looking fish which are the most important commercially-cultured fish in the United States. They are relatively hardy, disease-resistant, and tolerant of moderately low dissolved oxygen levels. They are temperature tolerant, but they grow best at higher temperatures and can reach “table” size of 1/2 to 1 pound within a year in Hawaii. They tend to live near bottoms, but feed on a great variety of plant and animal material all through the water, including insect larvae and the fry of other fishes. Prepared feeds are readily available and highly developed because of the magnitude of the commercial catfish culture industry. Channel catfish are excellent members of polyculture systems (though dangerous to young prawns), and they are fun to catch from culture systems by hook and line (if you are careful about your pool liner). ‘Me catfish spawn naturally in waters that have suitable natural or artificial shelters, and can be spawned artificially. Fry or fingerlings can be imported from the U.S. mainland under permit, like the grass carp. Channel catfish are excellent food, and worth the effort for the small-scale culturist.

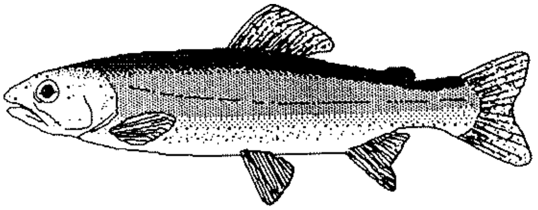


Channel Catfish *Ictalurus punctatus*

CHINESE CATFISH, *Clarias spp.*, are smooth-skinned, white-bellied fish that are not closely related to, and only slightly resemble, channel catfish. Chinese catfish are much faster-growing, however, and are also good-tasting. An additional attractive feature for small-scale culture is that the Chinese catfish can live in water that contains no dissolved oxygen, breathing air from the surface as needed. Such behavior is a sign of major distress in other fishes, but this ability permits Clarias to be cultured at high density without expensive measures to keep the water high in oxygen. Chinese catfish will eat the fry of other fishes, and therefore are considered a good prospect for polyculture with tilapia, which they would keep from overpopulating the pond. At least three commercial growers are culturing Chinese catfish at the time of this writing, and some research projects also are in progress in Hawaii, making fry potentially available to the beginning culturist. These fish, like the tilapias, are extremely hardy.



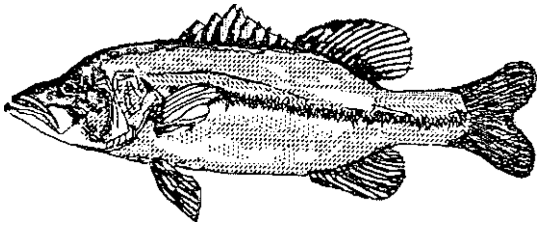
Chinese Catfish *Clarias* spp.



Rainbow Trout *Oncorhyncus mykiss*

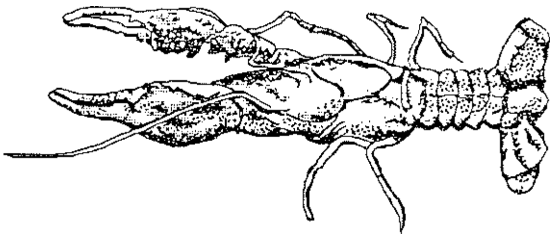
RAINBOW TROUT, *Oncorhyncus mykiss* (formerly *Salmo gairdneri),* are colorful, pink-sided fish which are the United States' major cultured cool-water species, second only to channel catfish in production. They survive and grow best at temperatures between 10 and 20 °C (50 to 68 °F), and have been cultured commercially in Hawaii. In nature they eat mainly insects, along with zooplankton, small fish, and fish eggs. The culture industry has produced special prepared feeds that meet their requirements. Trout can grow to table size (1/2 to 1 pound) within a year in Hawaii, and are of excellent taste and texture. They require cool, clear water with high oxygen content; eggs can be readily obtained from mainland suppliers under permit.

LARGEMOUTH BASS, *Micropterus salmoides,* are highly prized game fish in the United States, and are often stocked in "farm ponds" for both their food value and their ability to control overpopulation by other fishes. Their carnivorous habit and voracious appetite restrict their polyculture possibilities, but they can be stocked as fingerlings with other fishes of larger sizes, and would be effective at preventing tilapia from filling a pond with undersize fish. Largemouth bass may reproduce naturally in ponds; literature indicates that reproduction can be encouraged by provision of proper cover artificially. Live feeds are preferred at all life stages, but the fish can be trained to accept prepared feeds, particularly if the process is begun at an early age. Temperature tolerance is good, with the native range of the fish extending from Mexico to the Great Lakes. Clear water with soft bottom and weedy shelter is preferred, but the fish can do well in covered tanks if fed properly. Fingerlings may be imported from mainland suppliers under permit; the "Florida strain" will not be allowed into Hawaii.

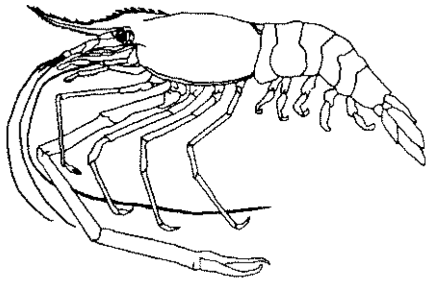


Largemouth Bass *Micropterus salmoides*

RED CRAYFISH (RED SWAMP CRAWFISH, CRAWDAD), *Procambarus clarkii,* are crustaceans related to lobsters (which they resemble, but are smaller) and shrimps. Tens of millions of pounds are produced in the southeastern United States each year. Crayfish may be eaten whole, using a variety of preparation methods, or may be shelled for the tail meat, which is similar to lobster. They reproduce naturally in earthen ponds, if they can burrow into



Red crayfish (Red Swamp Crawfish, Crawdad) *Procambarus clarkii*



Freshwater Prawn (Malaysian Prawn)
Macrobrachium rosenbergii

the banks, which can cause problems with the pond's ability to hold water. Crayfish are considered pests in Hawaii, where they do considerable damage to taro ponds (lo'i) by burrowing into banks and causing leaks. Their natural diet is very diverse. Crayfish are often cultured in rice fields, where they eat the leftover plant parts. They can be captured in streams or in standing water in Hawaii. A backyard culturist who likes them, and is not attempting to grow prawns for production (since the two species may compete for food and space), could consider stocking some crayfish with fishes, and regard them a "bonus" of the pond's production.

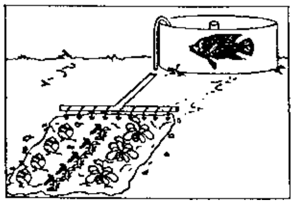
FRESHWATER PRAWN (MALAYSIAN PRAWN), *Macrobrachium rosenber*gii, is a shrimp (with grasping front legs) which has been Hawaii's major commercial aquaculture crop for some years. Its environmental and feed requirements have been well-re searched; prawns are usually fed commercial feeds, but can grow on natural pond production alone, feeding on bottom materials, or on table or garden scraps. They grow best in warm waters, and may stop growing at temperatures below 20 ^{o}C (68 ^{o}F) during Hawaii winters. Young "postlarvae" 1/2 to 1 inch long can be obtained from commercial growers who operate hatcheries. As they grow, the prawns require and defend bottom areas, and may yield one animal for each one or two square feet of pond bottom at harvest. For this reason, it may be difficult to produce a large crop in a small pond, but their excellence as food, and their compatibility with many fishes, make them a good polyculture prospect.

BULLFROGS, *Rana catesbeiana*, are familiar amphibians that can be recognized by their large, greenish tadpoles (young), and by the large eardrums visible behind the eyes of the adults. They differ from toads in having four fingers or toes on each leg, while toads have three. Bullfrogs are widely cultured commercially, including in Hawaii. Tadpoles eat mainly soft plant material and dead animals; adults eat moving prey, such as insects, small fishes, and sometimes small crayfish. They are fed prepared feeds by commercial growers. The bullfrogs reach their market size of 1/4 to 1/2 pound in one to two years, and are famous for their goodtasting leg meat. They can be captured near

Bullfrog *Rana catesbeiana*

ponds or lakes.

This list will provide you with ideas and information to help you select the species you wish to grow. When you design your system, you will need to be sure that it meets the requirements of your plants and animals. As mentioned, these animals are recommended for their ability to tolerate the range of environmental conditions found in Hawaii, as well as conditions likely to be prevalent in small-scale culture systems. Additional detail on requirements can be found in the publication, “Aquaculture Development for Hawaii,” which is listed in Chapter 12.



Chapter 6

Basic System Design

Culture Systems

A "system," to an aquaculturist, means the water container and everything that goes with it to make it a useful place to keep plants or animals for whatever purpose the culturist has in mind. Most systems include some means of water supply and drainage. In addition, aeration, shade, and a number of other factors may add parts to a system. In this book, the term "system" refers to the container and items installed in or attached to it. Considerations such as storage of tools, replacement parts, and feeds will be left to Chapter 9. The present chapter provides guidelines for choosing a system, and describes the two major systems in use at Windward CC. This chapter stops short of giving step-by-step instructions for actually constructing a system; such instructions are found in Chapter 11.

Many other systems are possible for backyard aquaculture, and HBAP can provide help in evaluating, options not discussed in this book. The systems used at Windward CC include small earthen ponds excavated below ground level, and above-ground cylindrical "Ponds," more commonly called tanks, made with plywood walls and commercially available swimming pool liners.

How to Choose a System

Whether you use one of the systems described here, some modification of one of these systems, or something totally different, you should consider some important factors in making the choice. Your system should be one in which your goals, projected earlier, can be most readily achieved. It should also be within your present (or near-future) ability to understand and maintain. You probably will be much more satisfied with your early aquaculture experiences if you begin with a smaller, simpler system in which your goals, for the most part, can be attained. When you are ready for further challenge and expansion, you will know it, and you will have the expertise and confidence to go on.

Your choice among systems, and indeed your reasonable goals themselves, will be determined by properties of your site, applicable public rules and regulations, and the requirements of your plants or animals, discussed in preceding chapters. All this information (including this chapter's) should allow you to make a reasonable preliminary design of a system. After reading this chapter, you should sketch a system you would like to build, and add the sketch to your diagrams of your site (see Figure 3. 1). Since any step in your analysis of systems and their operation may bring out new information that could suggest a change or improvement in your plan, you should review all your collected information and decisions from time to time, and finalize your design only when your analysis of the venture is complete.

The First Decision: Pond or Tank?

All the plants and animals discussed in Chapter 5 will survive and grow in either earthen ponds or above-ground tanks, which is part of the reason they have been selected as amenable species for small-scale aquaculture. However, if your goals include efficient production of a crop in definite amounts, one system type may have advantages over another, as would also be true with some other specific goals. Some of the information in Chapter 5, the suggested background readings (see Chapter 12), as well as personal experience with the animals, will help you to make these determinations.

- General advantages of earthen ponds over above-ground tanks include the following:

1) They require fewer materials to build, and so may be cheaper, (not considering the costs, if any, of earth-moving).

2) They are less visible above ground and from a distance, and create less disturbance to the property's appearance.

3) They more closely resemble the natural habitats of living things, therefore allowing the organisms to grow or behave more naturally.

4) Factor 3) may increase the recreational and educational value of harvest and management activities.

- Some potential disadvantages of earthen ponds include:

1) Earth must be moved by digging or grading to build one, or to remove one from a property.

2) Factor 1) may involve permits and consents. A lessor, for example, may require removal upon a sale.

3) An earthen pond may require control of emergent vegetation.

4) If the land has little slope, draining may be difficult.

5) Some soil types may require effort to seal the pond against excessive leakage.

6) If draining is difficult or impossible, pond management and harvesting of the crop may be more difficult.

- The general advantages of aboveground tanks include:

1) They are easily removed from a property without lasting effects.

2) They are easily drained.

3) The water environment and its properties (for example, depth, aeration, and bottom character) are more easily controlled and maintained.

4) Animals are more easily seen and harvested.

5) Emergent vegetation is not a factor.

- Some potential disadvantages of above-ground tanks are:

1) They require more materials, and may be more expensive, to build.

2) They are more visible on a property, and do not look "natural."

3) They require more maintenance and periodic replacement of some materials.

4) If the land has too much slope, earth-moving will be necessary to produce a level footing.

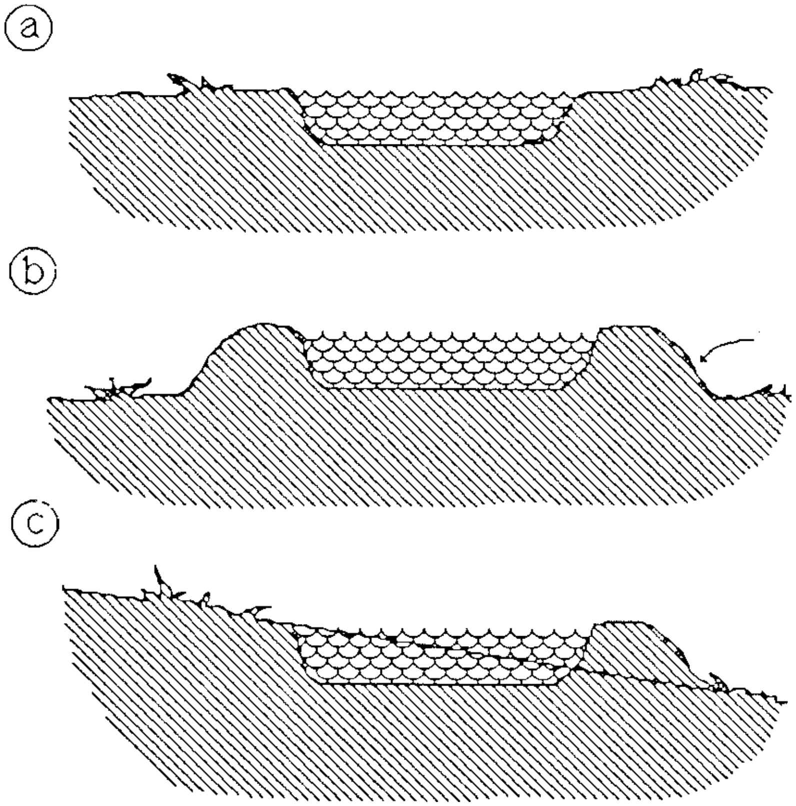


Figure 6.1 Three basic strategies for construction of an earthen pong: (a) excavation below ground level; (b) impoundment of water partly or entirely above ground level with berms; (c) a combination of (a) and (b) on sloping land

Small-Scale Earthen Ponds

Earthen ponds may be made by excavating a hole of appropriate size either by hand labor or with an earth-moving machine, such as a back-hoe, by building earthen walls (berms) above ground level, or by a combination of the two methods. Land of moderate slope is ideal for the combination approach, as shown in Figure 6.1 (c), because the excavated earth can be used to build the berms, and because the slope will permit easy drainage of the finished pond. Slopes greater than 5 percent, however, will present difficulties for earthen pond construction.

Soil texture, as well as slope, must be considered in evaluation of a site for an earthen pond. Table 6.1 presents an easy method for testing soil texture. Soils of the 44 clay-loam” grade are ideal for ponds; coarser soils may require more effort for sealing. Rocky soils (or even a few very large rocks) may present difficulty or at least require additional labor.

The acidity or “pH” of the soil can be an important factor in selecting a site for an earthen pond, because excessively acid soils can make pond water uninhabitable not a common problem in Hawaii, however. Test kits may be purchased from garden shops, or borrowed from

Table 6.1 Evaluation of Soil Texture

Texture	Properties		Sultability for Ponds
	DRY	MOIST	
Clay	forms a cast which can be handled without breaking; feels loke flour when crushed	forms a cast which can be handled without breaking	very good
Clay-Loam	forms a cast which can be handled without breaking; feels like flour when crushed	forms a cast which can be handled without breaking	very good
Slit	forms a cast which can be handled without breaking; feels like flour when crushed	forms a cast which can be handled; puddles if excessively wet	good
Slit-Loam	forms a cast which can be handled; feels like flour when crushed	forms a cast which can be handled; puddles if excessively wet	possible
Loam	forms a cast which can be handled carefully; feels slightly gritty	forms a cast which can can be handled	possible
Sandy Loam	forms a cast fragile to light touch; feels gritty; grains visible	forms a cast which can be handled carefully	poor
Sand	will not form a cast; flos; grains visible	forms a cast fragile to light touch	poor

some research organizations. Even when soil is not excessively acidic, it is worthwhile to apply lime to the pond bottom when construction is complete, and before filling, at approximately 0.05 pounds per square foot. Unless the test of soil texture indicates that a pond will need special effort for sealing, it is probably best to simply fill a new pond, stop the water supply, and watch for significant loss of the water through the soil. If the loss is relatively small (less than about 10 percent per day), the seepage will probably decrease with time (possibly to near zero), as the pond life adds fine debris to the bottom. Large ponds may be compacted before filling. At WCC an engine-driven tamper has been used to pack pond sides and bottoms; such machines can be rented. Although sealing a large pond containing porous soil can be expensive and troublesome, several options for small ponds are readily available to the small-scale culturist. One of the Windward CC earthen ponds is lined entirely with rubber sheets glued together at the seams. With other ponds, water slurries of bentonite clay (available from pottery-supply distributors) have been applied to filled ponds to let the water-absorbing fine particles settle and fill pores in the soil. Finally, it may be feasible to apply concrete to the bottom and sides of small ponds.

Although some of the world's large commercial earthen ponds are managed with very little plumbing, you will probably find it convenient to use some combination of pipe, hoses, and tubing to carry water to and away from your small-scale pond. If you use tap water as your source, good-quality garden hose may be the best choice for a supply line. Fittings are available in garden, hardware, and even food and drug stores. Other water sources (stream or rainwater) will be less expensive for the water itself, but will require some initial construction either to divert some of the stream water or to catch and hold the rainwater. Water supply may also be carried in plastic pipes, which can be buried underground like those of a sprinkler system. However, these possibilities may involve permits and consents from others.

Figure 6.2 shows some easy ways to carry overflow and drainage water out of earthen ponds. Exit pipes should be relatively large; at least 3 inches i.d. (inside diameter) is recommended. If you build an earthen pond entirely below ground level where the land has little slope, as was done at Windward CC, overflow can be handled with a standpipe draining to a sidearm leading to lower drainage, as shown in Figure 6.3. Complete drainage, however, may be slow if water is siphoned to lower ground, or may require pumping.

Properly-managed earthen ponds with moderate stocks of animals usually don't need to be

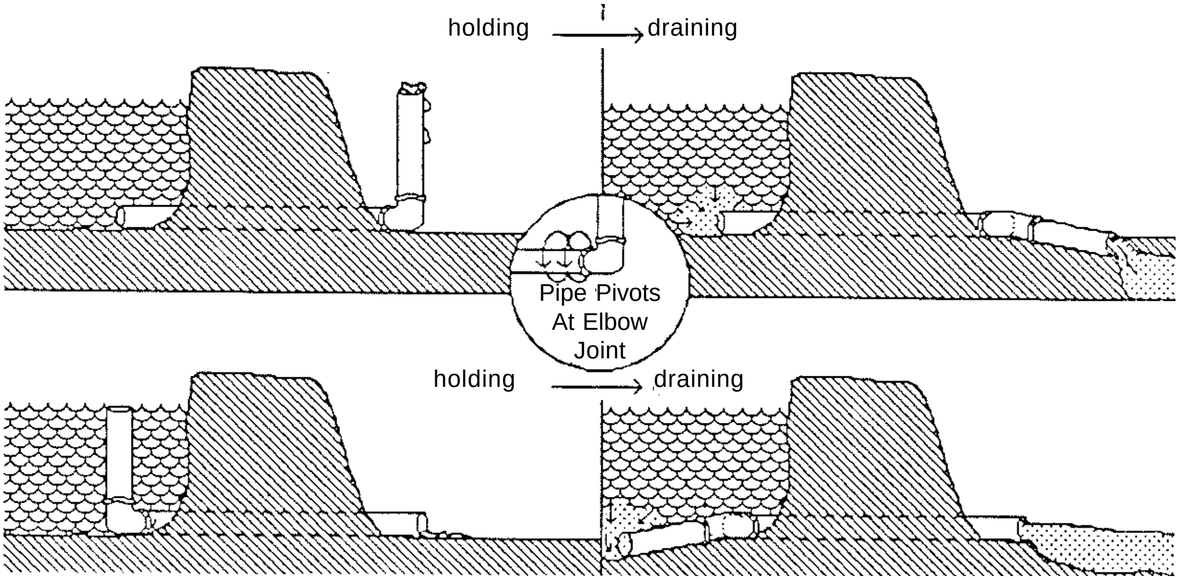


Figure 6.2 Examples of two simple overflow and drainage systems for earthen ponds, using plastic standpipes attached to rotating elbow joints. The top two frames show the use of an outside standpipe; the bottom frames show an inside standpipe.

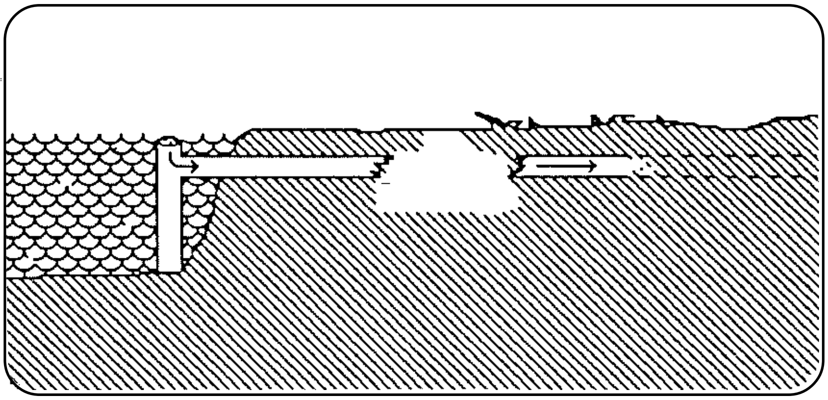


Figure 6.3
A workable plastic-pipe overflow system for "undrainable" earthen ponds

aerated for the survival of the animals. Small ponds, however, are not as easily mixed by the wind as larger ones, and a pond of any size may require artificial mixing during periods of no wind. Commercial ponds are sometimes mixed by machine to avoid the problems of calm weather (low oxygen at the bottom), or to increase production. You may find it advantageous to aerate a small pond with bubbles pumped through a single large airstone. The rising bubbles carry bottom water to the surface, and prevent low-oxygen layers from forming. An airstone in an earthen pond will clog easily, and will need periodic replacement. The stone may be glued to an old plate or bowl cover to keep it from sinking into soft sediment.

An earthen pond is easy to maintain, but after a time, depending on how heavily the pond is stocked and fed, and on whether soil and leaves enter the pond, soft sediment will need to be removed from the bottom. Care should be taken not to disturb the water-retaining "seal" of the pond when sediments are removed with hand tools. The surroundings of the pond can be maintained as the owner wishes, considering the appearance of the yard and avoiding the creation of muddy areas. Table 6.2 provides a list of materials and their estimated costs for construction of a square earthen pond 13 feet x 13 feet (4 x 4 meters) like the ones at Windward CC.

Above-Ground Tanks

A backyard tank can be constructed from five sheets of 1/4-inch plywood, joined with bolts and formed into a cylinder. Such a cylinder (12 feet in diameter) can be built in small backyard areas, and carried by three people to its final site. The cylinder is lined with a commercially-available swimming pool liner. The 4- x 8-foot plywood sheets may be used at their full size, or cut to 3 feet or other heights before the cylinder is joined.

A level footing must be prepared for a tank of this type. Suitable materials for the footing are sand and gravel, asphalt, or concrete. Detailed instructions for preparation of a sand-and-gravel footing are in Chapter 11, and Table 6.3 lists the materials and estimated costs for a 12-foot diameter tank on a sand-and-gravel footing pad.

Water supply may be provided with the same options discussed above for earthen ponds. It should be noted here that if the water supply contains sediment (as diverted stream water can),

Table 6.2 Materials and Approximate Costs for Construction of Earthen Ponds of 16 to 225 Square Meters Surface Area

I. Excavation	
A. back hoe rental, 0.5 days @ $____/day	$________
OR	
B. hand labor, no charge	
II. PVC Schedule 40	
A. Drain and Standpipe	
1. 3” pipe, 10 ft @ $3.00/ft	30
2. 3” el-90, 1 ea	15
B. Water Supply Lines	
1. 3/4” pipe, (est) 40’ @ $0.50/ft)	20
2. 3/4” ball valves, 2 ea	20
3. 3/4” unions & elbows, misc.	10
C. Ruber Liner (if needed)	$100
Estimated Total	$195 (without backhoe)

it may be desirable to collect the water in a container of some sort where the sediment can settle out before the water is supplied to the tank or pond. How ever, most of the animals recommended for small-scale culture can tolerate water containing some natural sediment.

A major advantage of an above-ground tank is that it is easy to drain rapidly, using any of the overflow-and-drainage arrangements shown in Figure 6.4. If an outside standpipe is used, the drain opening inside the tank should be covered with a coarse screen to prevent animals from exploring the drainage system and being lost from the tank. Such a screen is, of course, even more important when the tank is being drained. If an inside standpipe is used, a large diameter (6-inch i.d.) pipe can be stood over the standpipe itself, and openings cut at or near the bottom as shown in the figure. This procedure prevents loss of animals through the standpipe near the surface, and also causes bottom rather than surface water to leave the system.

A tank, if properly managed, will support a stable community of living things much as an earthen pond does, without requiring extensive maintenance efforts. Because the bottom of a tank is easily accessible with or without draining the tank, it can be cleaned regularly to avoid buildup of sediment and wastes. This practice, along with other measures discussed in Chapter 7, can permit the keeping of some animals at high densities. Such "intensive" culture can greatly increase the production of a culture system without expanding its size.

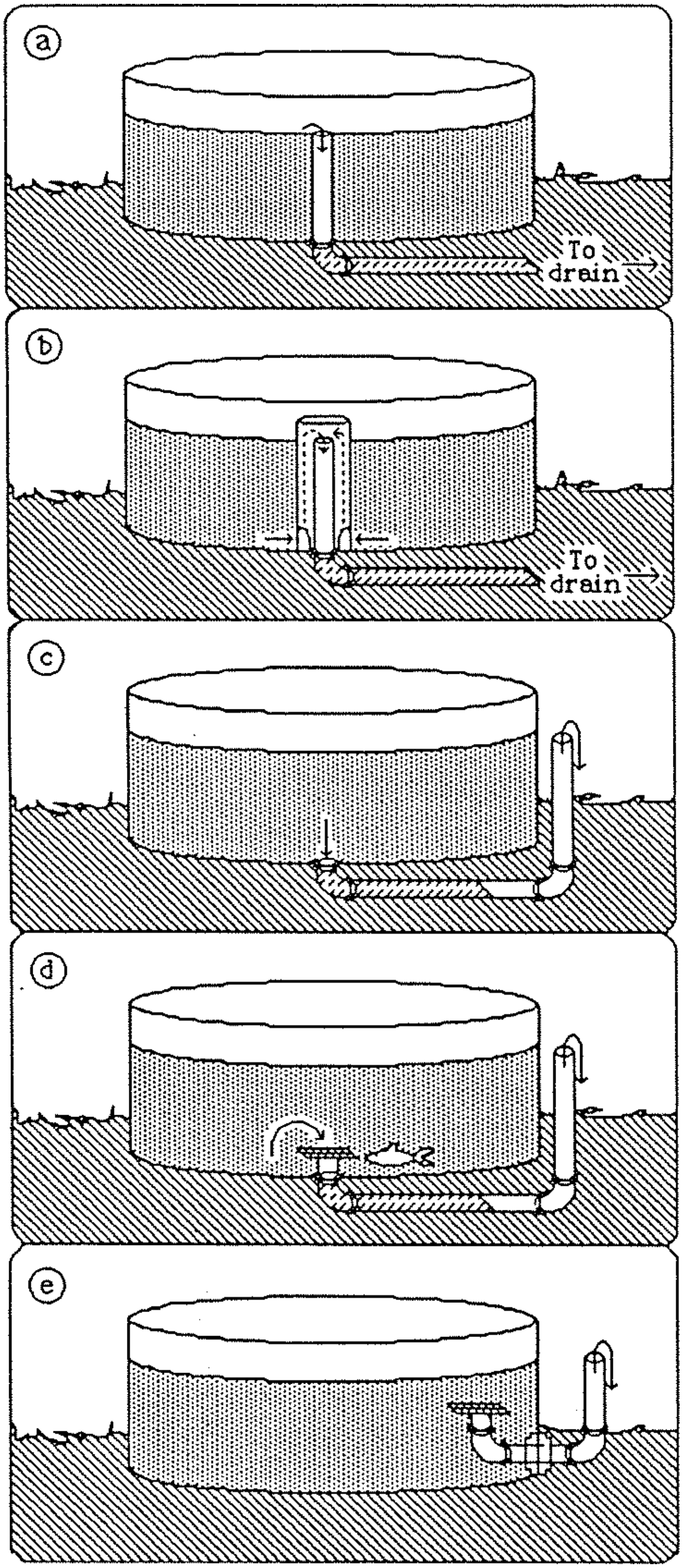
Above-ground tanks should be aerated for the same reasons that apply to small earthen ponds. Most small systems can be aerated at reasonable cost with electric air pumps.

Several approaches are possible, in addition to simply inserting one or more airstones into a pond or tank. If air is being pumped, an air-lift arrangement (Figure 6.5) can be highly effective at moving near-bottom water to the surface and aerating the water. Alternatively, if the water supply has enough pressure behind it, the incoming water can be sprayed slightly downward onto the water surface (also shown in Figure 6.5), which will create effective aeration, though it

Table 6.3 Materials and Approximate Costs for Construction of an Above-Ground Tank of 12 ft. (3.66 m) Diameter

I. Plywood, exterior grade A/C, 8'x4'x1/4", 5 sheets @ $13.00/sheet	$65
II. Sealers	
A. Water-seal wash, 1 gal	12
B. Asphalt emulsion, 1 gal	9
III. Fasteners, Banding	
A. Stainless carriage bolts, 3/8" x 1 1/4", w. flat washers, lock washers, hex nuts, .50 ea	12
B. Stainless shipping band, 1/2", approx. 120' @ $0.50/ft	60
IV. Liner, 16 mil, 12'x4'	80
V. PVC, Schedule 40	
A. 3" pipe, 16 ft @ $3.00/ft	48
B. 3" el-90, 2 ea @ $15	30
C. 3" union, thr male, slipe female	15
D. 3/4" pipe, (est) 40' @ $0.50/ft	20
E. 3/4" ball valves, 2 ea	20
F. 3/4" unions & elbows, misc.	10
VI. Footing Pad	
A. bricks, 24 ea @ $1.50	36
B. pea gravel, 60 cu ft	50
C. sand, 30 cu ft	25
Estimated Total	$492

Figure 6.4 Overflow and drainage systems for above-ground tanks



(a)
simple inside
standpipe

(b)
inside standpipe with
unattached larger
pipe over it, with
outout ports for exit of
bottom water

(c)
simple outside
standpipe

(d)
outside standpipe with
screened inner drain to
prevent loss of animals

(e)
outside standpipe, with
screened inner drain
through side of tank

does not lift bottom water.

Because a tank consists of artificial materials exposed to air and water, it will require maintenance and replacement of parts. Breaks in liners can be repaired easily with patch kits available in hardware stores. Liners should not be exposed to the sun without water in them for longer than absolutely necessary, because they may become brittle and tear when refilled. Plywood walls will last for several years, but eventually they become weak through drying out. Windward CC has some approaching six years of age, while four years is a reasonable life. The main factor limiting the life of the plywood walls has been long-term wetness near the bottom, either from slow leaks in liners or from contact between walls and standing water on footing pads, both of which can be minimized with care.

With the information provided in this and earlier chapters, you should be able to select the system appropriate for your site, consider the regulatory requirements, decide upon your preferred plants and animals, and update your personal goals. Now you are ready to learn about managing your system.

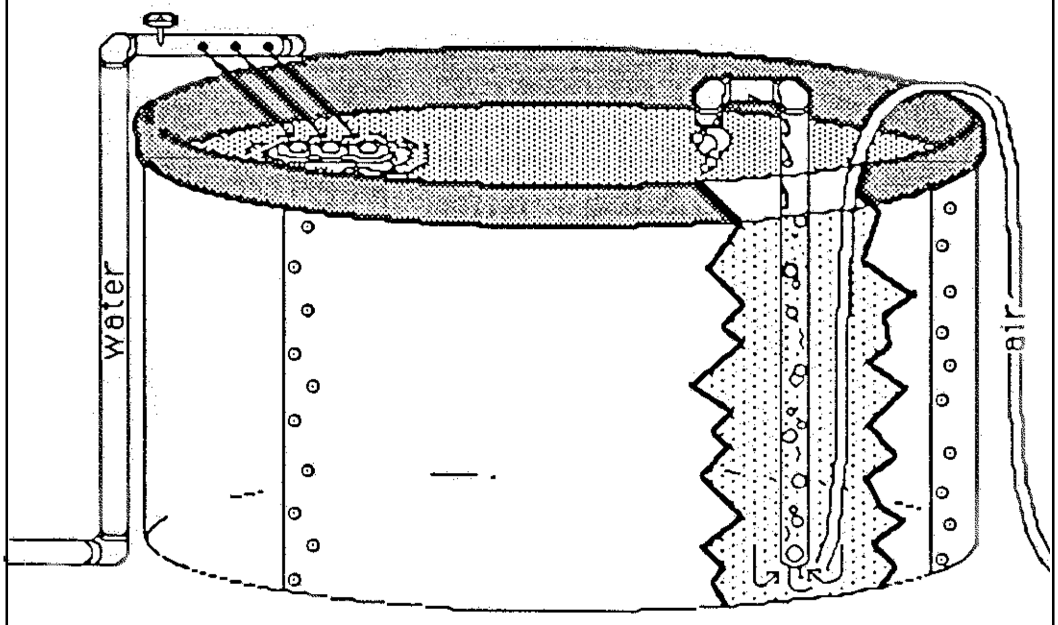
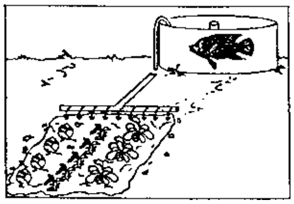


Figure 6.5 Two methods for aeration of tank water: “spray bar” method (left) forces small streams of water through small openings and mixes air and water at the surface; “air lift” (right) mixes pumped air with bottom water in pipe and lifts mixture to the surface.



Chapter 7

Keeping Your Animals Alive, Well, and Growing

You'll Learn to 'Know What You're Seeing'

Learning to manage your system so the plants and animals you keep will "do well," that is, live and grow according to your goals, can be the most satisfying part of your experience with small-scale aquaculture. The information here can help give you a start, and provide some answers when questions arise, but much of the learning will consist of your increasing experience at managing your system "hands-on." This chapter provides a framework of general rules and guidelines for managing the system. You may find, however, that your system does best with some variations from these guidelines, which would be quite natural because your system will be unique. As its frequent observer, you will come to be the best judge of what may be needed. Your confidence in the knowledge you gain by personal observations probably will increase rapidly.

Wanted: a Low-Stress Environment

The animals in your system will live and grow best if the system is set up and managed so that it meets their needs. For some animals, many of the requirements are well known, as you learned in Chapter 5. However, few animals have been studied enough for culturists to know all their needs. The species recommended in this book for small-scale aquaculture are reasonably well studied, and they are among the hardiest, that is, they are able to tolerate conditions that are not perfect, or "optimal." Such "suboptimal" conditions, even if they seem to have no obvious effects, can weaken the animals, keep them from growing or reproducing, or leave them more susceptible to disease.

The general effect of suboptimal conditions is called "stress." The medical profession has been gaining an ever greater appreciation of the relationship between stress and disease in humans. Despite great progress in the identification and treatment of both human and animal diseases, it is not well understood why some living things "catch" diseases, while others, seemingly exposed to the same causes, do not. In many cases, however, a clear connection can be shown between stress and disease. This section offers some basic information to help you provide your animals with as stress-free an environment as possible.

Chapter 5 related the selected animals' requirements; this chapter will discuss avoidance of stress. These ideas are two sides of the same coin. Biologists speak of animals' required conditions in terms of an "optimum" (best) condition for growth or survival, and a "tolerance range," the conditions between the optimum and harmful extreme conditions. Figure 7.1 shows that, although an animal grows best at its optimum temperature, and will fail to grow, or may

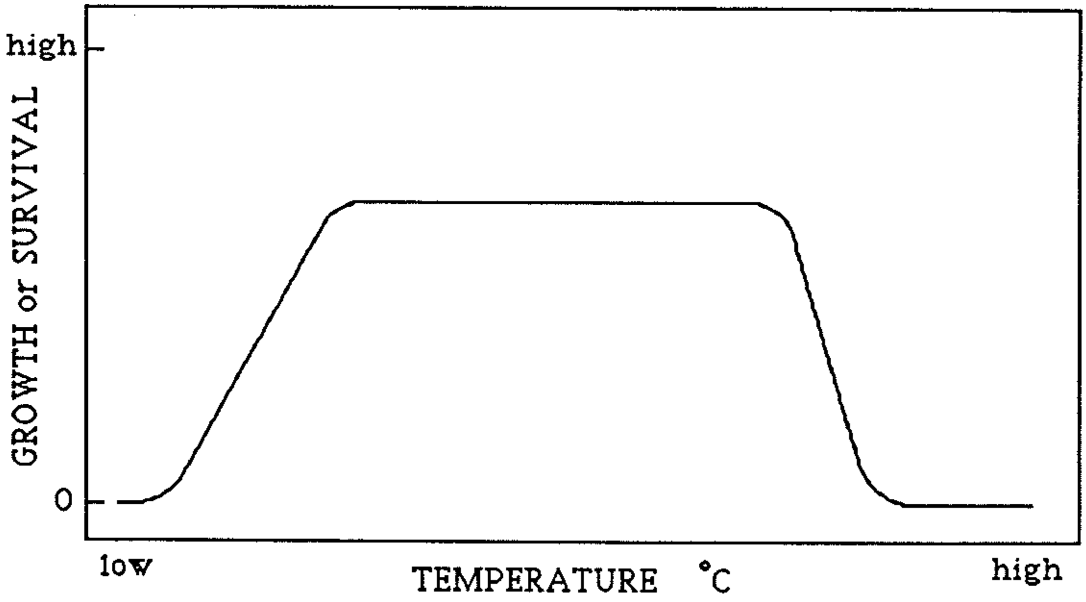


Figure 7.1 Example of a typical pattern of temperature tolerance for aquatic animals. The flat central part of the line shows 'optimum' growth or survival within the range of temperatures shown on the scale directly below it. The sloping parts of the line show that animals are stressed or limited in growth or survival, at temperatures outside the optimum range. At extremely high or low temperatures, animals cannot survive and grow.

even die, under extreme heat or cold. At some intermediate temperatures to either side of the optimum, some lesser rate of growth takes place. Such temperatures are said to "limit" the animal's growth, or, stated another way, the animal is stressed by the temperature. The picture in Figure 7.1 will have a similar shape for many different "factors," but the numbers on the scales will be different for each animal and factor.

Environmental Factors

It is convenient to divide the list of an animal's environmental requirements into "physical," "chemical," and "biological" factor (Table 7.1). You will soon see how these terms are used, but it is more important to recognize that these factors often interact with each other. For example, temperature, a physical factor, affects animals' need for oxygen in the water because the animals will use more oxygen at higher temperatures. Temperature also affects the ability of the water to keep oxygen dissolved and available to the animals, since warm water holds less oxygen than cold water can. These clearly sound like chemical and biological matters. Physical and chemical properties of the water in a system often are referred to in aquaculture literature as the "water quality."

To control a factor, an aquaculturist must be able to estimate the value of the factor, and be able to correct the value if needed. Factors can be measured with various tools, instruments, and chemical test kits, or can sometimes be estimated fairly accurately with out such tools by the senses of an aquaculturist who has gained some experience with direct measurement. Some factors need not be measured often, but are generally controlled by addition of new water or by "biological filtration" of the culture waters (explained below). This section discusses major environmental factors in terms of how they are measured and how they can be controlled.

Table 7.1 Important environmental factors in small-scale aquaculture systems. Each of these factors is discussed in the text.

A. Physical Factors
1. water temperature
2. salinity
3. light intensity
4. water motion
5. turbidity

B. Chemical Factors
1. dissolved oxygen content
2. pH and alkalinity
3. content of plant nutrients
phosphate
ammonia
nitrite
nitrate
4. dissolved organic matter

C. Biological Factors
1. biomass
2. species present
3. interactions among species
oxygen consumption
infection by disease agents
predation
competition for food or space
beneficial processing of waste

- Physical factors include temperature, salt content, light intensity, water motion, and turbidity (cloudiness due to small particles such as sediments).

1. **Temperature** is easily measured with a thermometer, available in stores carrying household goods or aquarium supplies. It is easy, with a little experience, to make reasonable temperature estimates with one's hand in the water, and even easier to compare the temperatures of two bodies of water (say, a bucket and a culture tank). Air temperature, however, is not as easily estimated. Thermometers are not expensive, and any serious culturist should obtain one. Temperature in a culture system may be adjusted or controlled by adding new water, or by covering or uncovering the water to reduce or increase exposure to the air and sunlight. Most animals and plants suitable for small-scale aquaculture are tolerant of a fairly wide range of temperatures, but they can be stressed by sudden changes, as, for example, when animals in a bucket or plastic bag are added to a tank or pond. This type of stress is easily avoided by floating the bag or bucket in the pond water until the water temperatures are the same.

2. **Salt content** (salinity) is not supposed to be a factor in freshwater systems, but some culturists may have an abundant source of "brackish," or partly-salty water. Although human taste is quite sensitive to salt, salinity should be measured directly if it is a factor in your system. The most convenient method is to use a small, hand-held instrument called a "refractometer," which can be purchased from aquaculture and laboratory supply companies ($150 and up). If the salinity of a water source does not change much through time, occasional measurements should provide enough information for management of the system.

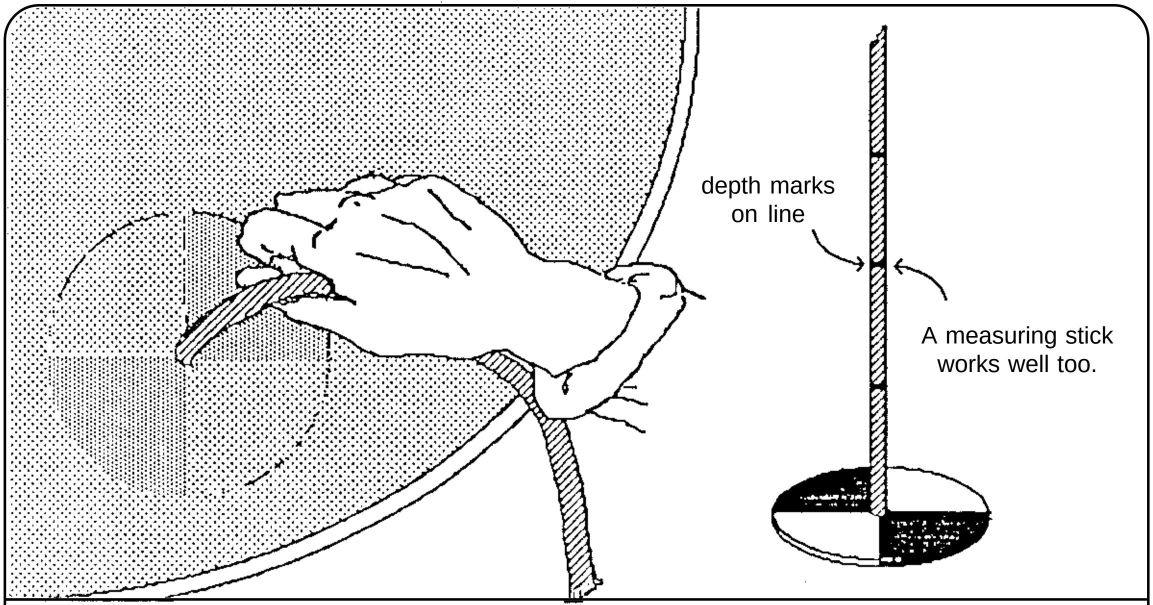


Figure 7.2 Water turbidity is measured by lowering a Secchi disk on a line or stick marked at measured distances. The depth of the disk is recorded when the slowly-lowered disk just disappears from sight. This depth is averaged with the depth at which the disk just reappears when raised from a greater depth.

3. **Light intensity** varies greatly during the course of a day, and rapidly during a partly-cloudy one. It may be measured by a photographers' light meter, but measuring is usually not necessary for most small-scale systems, unless controlled production of plants is the major goal. Light reaching the water may be controlled by garden shadecloth or by floating plants, as described in Chapter 5.

4. **Water motion** is not usually measured in small-scale systems, but may be important to control. If the water in a tank or pond is allowed to remain still while heated by the sun from above, the lighter warm water at the surface will isolate the deeper cooler water from contact with the air. When animals, or plant and bacteria cells, use up the oxygen in this deeper isolated water, oxygen cannot be replenished by contact with the air, and the animals may be stressed or killed.

Small bodies of water are especially sensitive to this effect, because light wind does not stir them as easily as it does large ponds. Bottom water may be brought to the surface with air bubbles injected at the bottom, or the incoming water may be sprayed downward onto the surface. Such a "spray bar" (shown in Figure 6.5) can also be used to create a horizontal stirring or current in the water, which may keep some animals happier in being able to orient themselves in the flow.

5. **Turbidity** is easily measured by dipping a "Secchi ('seck-ee') disk" (Figure 7.2) slowly into the water, and recording the depth at which it disappears from view. Turbidity in a culture system may consist of a bloom of phytoplankton cells, of mineral particles in the water source, or of waste materials produced in the system. The last two of these may stress the animals by

interfering with vision, impairing the functioning of the gills, or, if excessive, providing food for undesirable bacteria and other parasites. Turbidity can be controlled in a tank by stopping the water motion, allowing the particles to settle, and removing settled material through a siphon tube easily made from garden hose. Earthen ponds are less sensitive to problems from these materials because bacteria and other living things in the bottom sediment process them naturally. Even in an earthen pond, however, excessive sediment may have to be removed from time to time, as pointed out in Chapter 6. Phytoplankton blooms may be controlled by increasing water flow, or by restricting light. Bloom turbidity is generally considered excessive, and may endanger the animals by depleting the oxygen at night, if the Secchi disk disappears at a depth of 20 centimeters or less. This amount of turbidity is roughly equivalent to being unable to see one's hand when the arm is immersed up to the elbow.

- **Chemical factors** include content of dissolved oxygen, pH and alkalinity, and content of plant nutrients and dissolved organic matter.

1. **Dissolved oxygen (DO),** as you probably realize by now, is one of the most important factors in a culture system. Oxygen dissolves very poorly in water, with the maximum, or saturation, level in warm waters at about 8 parts per million (ppm). No more than about 8 grams (about 1/4 ounce) of oxygen gas can dissolve in a cubic meter (260 gallons) of water. This concentration is much lower than exists in the air, where a cubic meter contains 300 grams (about 2/3 pound) of oxygen gas. Aquatic animals must have very efficient gills, if they can extract and live on this amount. It is easy, however, for oxygen in water to be depleted to near zero by the activity of the even more efficient bacteria and other small cells found in every culture system.

DO can be measured with expensive electronic instruments, or with less expensive chemical test kits (about $50) that can be ordered from supply companies. It may be advisable in some cases for the small-scale culturist to buy or borrow materials required to measure dissolved oxygen concentrations, at least until experience with managing a system can be gained. The best course of action for all culturists, however, is to try to ensure that near-saturation levels of DO are maintained in a system, which can be done by using pumps to force air bubbles into the water, or stirring devices which either splash water into the air or at least bring bottom water to the surface frequently.

Unless the cultured animals are kept in very high densities, "microbial" activity (done by microbes, such as bacteria and phytoplankton), is the major source of oxygen demand (depletion) in a culture system. If phytoplankton are present, they produce oxygen during the daytime when they "photosynthesize" (produce food molecules using light energy). This oxygen takes care of their own needs, and usually those of all other living things in the system during the day. At night, however, photosynthesis stops, and oxygen levels are depleted by all living things in the system, including the phytoplankton.

In a well-managed system, the day's excess oxygen is sufficient to prevent stress or death of animals during the nighttime depletion. If a system has too much microbial activity, or if insufficient oxygen is produced during a cloudy day, nighttime levels may fall dangerously low. Aeration strategies can prevent such problems, but they require apparatus and attention by the culturist. Addition of water to the system can also replenish oxygen, but at possibly high cost. Maintenance of oxygen levels is a serious problem faced by most commercial aquafarmers, and much research has been done to solve it.

2. **pH and alkalinity** are measures of the condition of the water with regard to its acid content. pH is a measure of the water's acid/base balance; alkalinity is a measure of the water's total capability to neutralize acids because of the presence of several different materials in the water. These factors can be measured with chemical kits (costing under $50), available from supply companies, or in the case of pH, where swimming pool supplies are sold. Extremes of acidity make water unfit for living things, but such extremes are not usually produced by biological activity.

Some soils (not found frequently in Hawaii) can make an earthen pond acidic, unless measures are taken to prevent it, such as addition of lime. It would be advisable for a culturist about to dig a new earthen pond to have the soil tested by the University of Hawaii's Agricultural Extension Service, and perhaps to lime the pond upon construction, as suggested in Chapter 6. Dense phytoplankton blooms can produce highly alkaline conditions, but dense blooms should be controlled by shading or by addition of new water, for the more immediate reason that nighttime oxygen depletion may be excessive with a dense bloom present.

3. **Plant nutrients** are materials commonly used as fertilizers for terrestrial plants. They are important to aquaculture systems not only because they fertilize phytoplankton and floating plants, but also because some of them are produced by animals as waste products, and are toxic to animals at excessively high levels. They can be measured with kits available from supply companies.

Phosphate is an animal waste product required by plants, which rarely if ever causes problems of excess. It is a component of garden fertilizer. If plants are being grown as a major goal, it is necessary to be sure that phosphate (along with the other nutrients) is not completely depleted. More important are the nutrients that contain nitrogen: ammonia, nitrite, and nitrate. Ammonia is an animal waste product, and nitrite and nitrate are produced by bacteria from ammonia and from other wastes. Ammonia is the most toxic of the three materials, and nitrate the least toxic.

Aquarium "biological" filters work by providing a place for beneficial bacteria to grow and change ammonia to the less toxic materials. This process goes on in the sediment of earthen ponds, and could take place in tanks with sufficient sediment. It is possible, however, that if animals are kept at high density and fed large amounts of feed, the production of ammonia waste could build up to toxic levels. This condition can be controlled by addition of new water, or by the presence of sufficient plant material to take up the ammonia as fertilizer. It is also possible for a small-scale aquaculturist to build a filtration system that works as an aquarium biological filter does to remove ammonia, which would also reduce the need to add large amounts of new water to the system. A simple design for such a filter is described in Chapter 8.

4. **Dissolved organic matter (DOM)** refers to large, sometimes complex molecules containing carbon, that animals add to culture waters as wastes, or that are released from solid wastes by dissolving or by the action of bacteria. These materials do not usually build up to levels toxic

for animals, but may encourage the growth of harmful bacteria and other parasites if present in excessive amounts. DOM is not easily measured, but large amounts may be smelled or seen as color in clear water, it is best controlled by dilution with increased water exchange or by use of biological filters.

- **Biological factors** include the number, total weight (called “biomass”), and kinds of plants and animals in the system and their interactions with one another. The activity of bacteria in pond waters, and its effect on dissolved oxygen, have already been discussed. Since all living things in the system require and use oxygen, the system’s total oxygen demand is the result of the activity of all of them taken together. Although microbial activity usually accounts for most of a pond’s oxygen demand, it is possible to stock and grow some animals so densely that the cultured animals become a significant factor in the oxygen demand. If this is the case in your system, it will be necessary to give special attention to provision of oxygen and removal of wastes. The “stocking density” (number or weight of animals in a given amount of water or pond area) is an important biological factor. Each animal has its optimal stocking density, based on its needs and habits.

Polyculture was discussed in Chapter 5 in terms of its possible benefits to your system and your goals. In a smoothly working polyculture system, the plants and animals not only “get along” with one another, but fill important roles in the ecosystem, to the benefit of all. If food is scarce, however, or if other stresses disturb the organisms their roles, undesirable interactions may take place. Members of the same, or even of different species, may compete for food, even to the point of fighting for it. Animals which typically defend territories in nature may become more aggressive when crowded in a tank, but some become less so! It takes some time and experience to become skillful at interpreting the relationships among living things in your system, but it is well worth the effort, both for the success of your system, and for the fascinating knowledge to be gained.

Finally, some organisms may harm others directly, and should not be kept in the same system. This is true for the obvious case of disease-causing bacteria, though it is worth noting that most bacteria are beneficial if not allowed to consume oxygen excessively. Some animals may prey on others, all through life or only at some life stages. Channel catfish and freshwater prawns, for example, have been successfully grown together, but very small postlarval prawns must not be stocked with large catfish, which would eat them.

Healthy Animals Grow

If your plants and animals are generally free of stresses, and are fed correctly (discussed below), they will grow well. However, since the animals listed are quite tolerant of different temperatures, you should remember that they will probably grow more rapidly at higher temperatures within their range, and more slowly at lower temperatures. Prawns grow much better at temperatures in the high 20s (C) or 80s (F) than at lower temperatures, and can stop growing completely during periods when water temperatures decrease to 20 ^{o}C (68 ^{o}F) or lower. If your goals include reliable or maximum production of food, you need to consider ways to maintain higher temperatures during the cooler seasons. Covering the surface of tanks or ponds, insulating tank walls, and warming the water with solar collector panels are all possible solutions.

Aquatic animals tend to grow at different rates during different stages of their lives. Young animals grow more rapidly than older ones, as shown in Figure 7.3. Many aquatic animals, however, can continue to grow all their lives, and can reach surprisingly large sizes if they live long enough. You may find it interesting, depending on your goals, to keep a few animals of species that may not be your primary interest, in hopes of producing a few large ones for very little extra effort. On the other hand, knowing the expected growth pattern can help you to plan the best time to harvest animals to be used as food regularly. Commercial aquafarmers rarely keep and feed animals into the ages of slower growth, because the cost of producing each added unit of body weight increases with the animals' age. Female aquatic animals often grow more slowly or stop growing entirely when they produce eggs. Commercial tilapia. growers sometimes choose to grow only males for this reason. They either select males from mixed groups, or sometimes breed parent fish of two different species, chosen to produce only male offspring for growout.

Although plants grow by making their own food out of carbon dioxide, water, and plant nutrients during photosynthesis, animals can grow only by processing food already made by plants or other animals. Some food energy and materials are used up or discarded as waste during feeding, digestion, and growth, and do not contribute to weight gain or growth. Growth is not perfectly "efficient," that is, an animal cannot produce a pound of new growth from a pound of food.

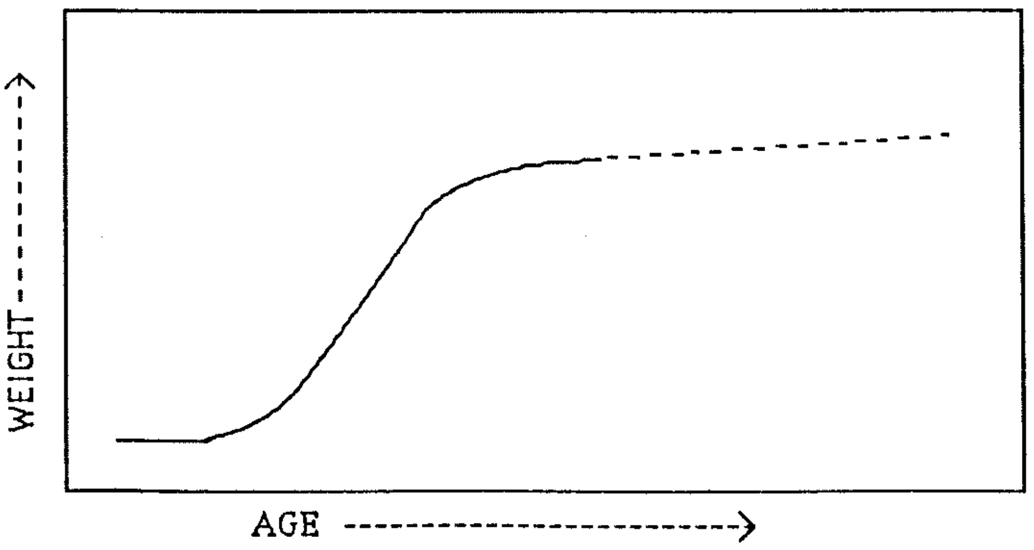


Figure 7.3 Typical pattern of fish growth at different ages. Weight increases rapidly from hatching to pre-adult stages (left protion of curve); later growth is progressively slower (center portion), but slow growth may continue if the animal lives a long time (right protion).

Aquaculturists usually think about this feeding efficiency in terms of a "Food Conversion Ratio," or FCR. If an animal must eat three pounds of food to add one pound of body weight (a typical figure), the FCR is stated as 3: 1. This ratio usually means that the weight of the food and the weight of the animal are both taken just as they come. The food may be fresh animal material (pieces of cut-up fish, for example), or dry prepared feed; the animal weight is taken "fresh," or "wet." If an animal is given one pound of dry feed, it may sometimes be able to produce a pound or more of body weight with it, because its body weight will consist of about 70 to 80 percent water, which it obtains from the pond. For this reason, you may read that some animals have FCR's of 1: 1 or even 0.9:1! This does not mean that the animal has made something out of nothing, but it does mean that one must read carefully about FCR's. Researchers are generally careful to state which materials were wet or dry in their studies, but news articles and informal reports may not provide all the details.

For "holding" purposes, or as a starting point with animals whose growth rates are not known, they can be fed 3 to 5 percent of their body weight per day, or about 1/2 to 1 ounce for each pound. If maximum growth of small animals is a goal, the feeding rate may need to be higher. If some of the animals are weighed each week, the feeding rate can be adjusted carefully upward to produce the desired growth. Some trial-and-error will be involved for most animals; however, it Is important not to contaminate a pond or tank by overfeeding.

Finally, it is not uncommon for aquatic animals, like others, to "go off feed" as farmers say, and be uninterested in food at times. The culturist should watch them carefully at such times, because this reaction may indicate stress. Other times, they soon resume feeding normally, with no cause of the stoppage ever becoming evident.

What's in a Feed?

Animals in nature can be classified as herbivores (plant eaters), carnivores (flesh eaters, preying on other live animals), omnivores (eating both plants and animals), or detritovores (eating "detritus," dead plant or animal material). Because aquacultured animals must be fed cheaply and conveniently, they are not usually fed their natural diets. Trout, for example, eat zooplankton (microscopic animals) in nature, but are fed dry commercial feeds in culture. Some of the recommended animals can be fed garden and table scraps; but some, like prawns, will obtain part of their diet from materials in the pond other than their feed.

No matter what the source of the feed, all animals must obtain energy (measured in calories) and certain specific materials from their feed if they are to survive and grow. As is true for environmental factors, the feed requirements of a few animals are known in great detail, but they are known or assumed only in very basic terms for others. Trout, as important commercially-grown fish, are well-studied, and a number of competing feeds claim to offer minor advantages over others. The recommended animals are quite flexible with regard to diet, but like all animals they must take in proteins, carbohydrates, fats, and vitamins and minerals.

Commercial prepared feeds such as catfish and trout chows, and even some feeds intended for farm animals, such as chickens, contain most of the required materials, and are basically suitable for the animals recommended here. If your goals include maximum growth, however, you may wish to look at the percentage breakdown of various materials in feeds in order to make the best choice. Also, if you feed scraps to animals in an environment (such as a tank) that grows no natural supplements for them, you will need to take care that they have all the required materials.

1. **Proteins,** large molecules containing nitrogen, are the basic building materials of all living things. Plants require nitrogencontaining nutrients because they use the nitrogen to build proteins. Animals must eat ready-made proteins in their diets of plant and animal materials. Commercial fish feeds contain 30-40 percent protein by weight and, as mentioned, all of the selected animals will do well on them. However, such high protein content is not strictly necessary for some fishes, particularly herbivores, which are adapted to “tract protein from plants that are poor in protein. Carnivores generally require feeds of high protein content, because their natural diets, animals, are rich in protein. Detritovores, such as prawns and shrimps, are like herbivores in being able to extract protein from “poor” sources.

2. **Carbohydrates** are large molecules, but do not contain nitrogen. They include sugars of many types and starches; plants make, use, and store them during photosysthesis, while animals must eat them ready-made. Carbohydrates provide fuel for life and growth, and may be important in aquaculture diets in a subtle way. Feed formulas aim to have just the right amount of carbohydrate calories in a feed so that the animals will not have to use the more expensive protein-containing ingredients for fuel, which they can and will do, if necessary.

Herbivores are accustomed to obtaining more of their calories from carbohydrates (because plants are a rich source) than are carnivores (because their prey do not contain them). Trout, however, and some other carnivores, do well on prepared feeds that contain some carbohydrates. Commercial feeds contain 20 to 50 percent carbohydrates, some of which may not be digestible. The seed coats of grains (such as wheat) used in feeds contain cellulose, a large carbohydrate molecule which most animals cannot digest. Such materials are known as “fiber.”

3. **Fats** are richer energy (calorie) sources than either proteins or carbohydrates, and are particularly important as fuel for carnivores, which are not well adapted to use carbohydrates. Fats are important in feeds for other reasons as well. Fats are needed to carry some vitamins around in the body, and for the formation of certain cell and tissue components. Commercial feeds contain 5 to 15 percent fats. The level in a diet is important in permitting the animal to use all the protein for maintenance and growth rather than for energy. Also, the taste of the animal may be affected by the fat level in its diet.

4. **Vitamins and minerals** are. materials required in small amounts by cultured aquatic animals, just as they are by humans. Prepared feeds contain additions of these materials according to what is known of the requirements of the target animals, but most fishes are assumed to have similar basic needs in this regard. If your animals are accepting a fairly diverse diet of non-commercial foods, they may well be getting all that they need. If your goals include maximum growth or long-term keeping, however, it might be wise to mix standard pet vitamins into double-strength gelatin, cut the cooled gelatin into pieces, and feed this to the animals once every week or two.

Research has revealed detailed requirements for vitamins and minerals, and even for specific kinds of protein and fat materials, for some fishes. Most of this information pertains to commercial culture success, for which maximum growth, efficiency, or minimum costs are critical. The small-scale culturist should begin with a simple approach to feeding, as outlined here, and gain experience with the particular animals in the system.

How Can You Be Sure They're Healthy?

Like nutrition, disease in cultured animals is the subject of much active research, and the results are important mainly to commercial aquafarmers. The small-scale culturist does not have large amounts of money invested in the crop, and so would probably not be prepared to spend large amounts of time or money on prevention or treatment of disease, unless learning about such matters is one of the primary goals.

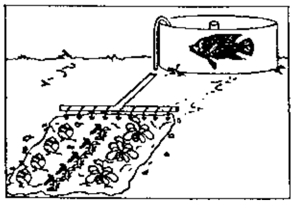
The best preventive measures against disease, whether in commercial or small-scale aquaculture, are acquiring disease-free stock and minimizing stress to the animals. Minimizing stress is best done by maintaining a stable environment within the animals' requirements, as discussed above. If symptoms of disease develop, the small-scale culturist should consult sources of information about treatment, if possible.

Books about aquarium- keeping may provide a useful introduction to common diseases in aquarium fishes, some of which can occur in culture systems. Operators of aquarium stores are often very knowledgeable because their business depends on their ability to recognize and sometimes treat problems. Finally, commercial farmers and government organizations whose mission is to help them, such as the state's Aquaculture Development Program, may be able to refer you to experts about your particular animals or problem.

It is worthwhile for you to be able to recognize the existence of possible stress or disease in your system, and to have some information about possible causes. If stresses are recognized early, they often can be corrected before animals are lost. If you do consult with expert sources, some knowledge of symptoms to look for will help you to communicate with them effectively. Stress or actual diseased conditions can be indicated by certain behaviors, some of which (such as going off feed), have already been mentioned. In addition, it is sometimes reasonable to suspect causes of death from the pattern in which the deaths occur.

Any clearly unusual behavior of fish may indicate stress or disease. Mouth-opening ("piping") at the surface of the water indicates oxygen deficiency, either because the oxygen concentration is low, or because parasites on the gills are keeping the oxygen from getting to the blood of the fish. Absence of the usual motion pattern, or the presence of unusual patterns, often indicates infection by internal or external parasites. Unusual patterns include resting at the surface or near the bottom, "flashing" (rolling over and showing the more reflective sides or bellies), scraping sides on rocks or bottom, or other swimming patterns not characteristic of the particular fish.

If you find animals dead in your system, you should keep careful notes on the number and the times they were found, and any observations you can make about the condition of the rest of the system. Continuous deaths for more than a day or two, at a constant number per day, suggest parasitic infection. Increasing numbers of deaths per day, which eventually decline sharply or stop, suggest infection by microbes (viruses and bacteria). A sudden death of large numbers, particularly if they are found in the morning, and if more large than small fish have died, indicates oxygen depletion. Sudden deaths not necessarily overnight, particularly if accompanied by unusual behaviors and the death of more small than large fish, suggest the possible presence of toxic materials. With care and luck, you can hope to avoid losing animals to stress or disease. This chapter's information is provided to help you keep such losses to a minimum, or better yet, to prevent them entirely.



Chapter 8

Aquaculture and the Rest of Your Backyard

Everything's Connected

You've been working hard at making and revising a plan for your system. The primary focus until now has been on how to get your new culture system planned and started. But the system won't be out there in your yard all by itself. You have planned its location in relationship to the rest of your property, and considered some of the effects of the system on people and things around it. With the information you now have, you can consider how your developing system can work with other parts of your home and property, and how you can operate the system more easily and efficiently.

"Integrated aquaculture" means the connection of aquaculture facilities and activities with others, such as agriculture (gardening) or the keeping of farm animals, to the mutual benefit of both. If you already have, or would like to have, such activities on your property, this chapter will offer some ideas for how your aquaculture system could work as part of an integrated, or unified, system.

"Appropriate technology" means applying scientific or technical knowledge at just the right level to achieve a goal or solve a problem. This entire book attempts to use this concept, which implies careful selection of the degree of complexity of hardware, machinery, and scientific ideas involved in the project. This chapter offers ideas on additional appropriate technology that could be used to enhance a small-scale aquaculture system.

Better Lawns and Gardens

The most obvious integration of an aquaculture system with other backyard activities involves getting more use from the water. Chapter 10 will explain how a simple financial analysis of your system can help you calculate the cost of providing water to the system, and compare the costs with the value of the product. If the water leaving the system is used to water lawns, shrubbery, and gardens, its value is obviously much greater. The animals in the culture system actually improve the water for such further use because some of their waste products are the same as the ingredients of lawn and garden fertilizers, as discussed in the last chapter. This fact is well-known to people who keep aquariums and house plants; you will simply be using the idea on a larger scale.

Water may be dipped from a pond or tank and carried to its next use, or, with a little more thought and work, made to flow by gravity or pumping down to the planted areas. One possible convenient arrangement is shown in Figure 8.1. The plastic pipe system, either exposed or partially buried, is connected to a removable,

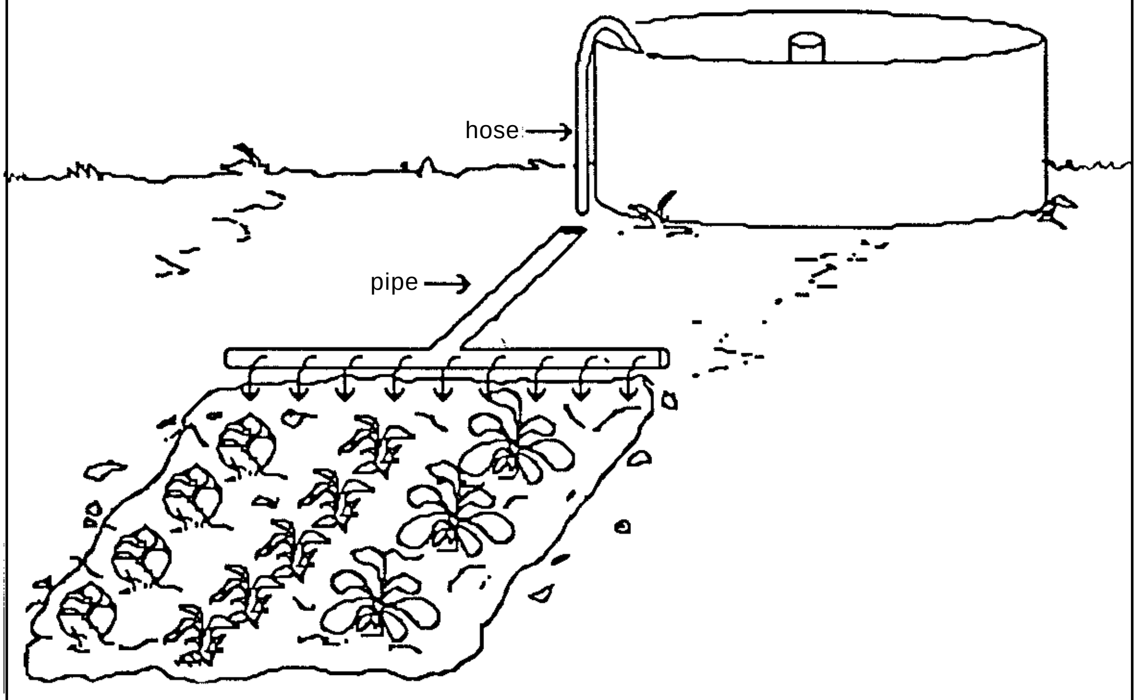


Figure 8.1 A simple arrangement for use of culture tank water for garden irrigation. A flexible siphon hose is used when needed to supply water to a plastic pipe leading to a garden plot.

flexible siphon hose for delivery of the water.

Tank and pond ecosystems also produce solid waste, which is excellent for conditioning lawn and garden soils. Earthen pond bottoms collect solid animal waste, along with decaying plant material from pond plants or debris that falls into the pond, and they develop a collection of bacteria and very small animals that feed on this resource. After a time, pond sediment builds up to a point where it must be removed to make the pond manageable. Sediment from a drained pond can be tilled into, or simply laid upon, lawn and garden soil, where it will fertilize and add texture. Similar materials collect on tank bottoms, but as noted in the last chapter, should be removed more frequently than from earthen ponds. These materials may be added to planted areas with regular waterings, particularly if you remove them by siphoning, or they may be saved to make larger amounts.

Gardens are usually thought of as producing products for people, but they also produce scraps and cuttings that may serve as feeds for some pond animals. Prawns are rather non-selective bottom feeders that will eat a variety of materials, including vegetable tops and trimmings, if they sink when added to ponds. Tilapias will also eat such materials. Grass carp will subsist on lawn trimmings. Although these feeds will not produce maximum growth, such growth is usually not a primary goal for small-scale culture, and their price is certainly right.

Of course, you must be sure that your particular animals will eat the feed you offer them, and you would be wise to provide some fraction of their diet in the form of prepared feeds containing needed nutrients that may be absent from the scraps. In addition, table scraps, including leftover meats, and fish parts, should be included in your potential resources. Feeds and water are near the top of the list of costs for commercial aquafarms. Backyard culturists have abundant opportunities to reduce these costs dramatically.

Other Backyard Feeds

Your culture system and the rest of your yard may well produce even more materials that can be used to feed the animals you are growing. Many people, for example, have electric insect-killers that attract and destroy flying insects. Such a device placed over a pond or tank can remove the pests and contribute significantly to feeding a tank. Trout, bass, and many other animals will eat insects added to a system in this way, or insects may be collected and added to compost piles or to backyard feeds as described below.

If you add floating aquatic plants and fish that eat mosquito larvae to your system (see Chapter 5), the plants and fish will grow and multiply, and require periodic removal. Plants and fish, in the form of grains and fish meal, are the major components of commercial prepared feeds. Your system's "free" production of plant and fish material could be used as a major part of the feed for your major cultured animals. The plants and topminnows can be dried, ground in a food grinder, and re-combined into a high-quality feed. Drying can be done on window screens or cookie sheets, outdoors on sunny days, in an oven at low temperature, or even in an automobile left in the sun!

Commercial feeds are held together in pellets with binder materials, and you could experiment with materials such as cornstarch, mixing it with the ground feed material and some water, passing it through the grinder screen again without using the cutter, and re-drying the product. It is possible, however, that your animals may be perfectly happy to take lumps of the combined feed materials (a 50-50 combination could be tried as a starting point), moistened with a little water if necessary and without any binder. Such feeds could be completely or nearly adequate for the animals recommended here for small-scale systems, in terms of the composition of the feed. The amount you produce, however, will depend on your particular system and your own ingenuity. You have a unique and exciting opportunity to experiment, learn something new, and reduce your feed costs.

Manure-based Pond Culture

The scientific study of cultured animals and pond ecology is a relatively recent development. Aquaculture has been practiced successfully since long before the beginnings of science as we know it today. Even today, pond culture is practiced in many places by 44extensive" strategies, that is, without feeding the pond or exchanging much water. The cultured animals live and grow as part of the total pond ecosystem, feeding on other plants, animals and waste materials, and fertilizing the phytoplankton with their own wastes in turn.

A common strategy is to fertilize a pond with the manure of farm animals, which stimulates the growth of phytoplankton and other microbes in the pond, and finally, stocking the aquatic animals to be cultured. Studies have shown that many animals will grow in such ponds, and will produce crops of significant size, sometimes half (or more) significant size, sometimes half (or more) the crops of fed ponds. This practice is usually not done in the United States, because the costs of land and labor require greater yield from land use to make ventures profitable, and because regulations may restrict the use of manures with commerciallysold food crops. It is generally agreed, however, that thorough cooking of the cultured animals, which is necessary with all freshwater animals in any case, renders them safe for consumption.

Since this book is aimed primarily at people with properties too small to permit much livestock , strategies for using manure for fertilization will not be discussed in detail. However, this approach may be a possibility for people with properties of sufficient size on which animal keeping is permitted. Backyard culturists should NOT attempt such strategies with pet wastes (to avoid diseases), and others should obtain expert advice on these practices before attempting non-commercial operation.

Water Recycling

An alternative to simple re-use of water from culture systems on lawns and gardens is to clean the water and return it to the culture system itself, which is what aquarium filter systems do. The wastes added to system waters by the cultured animals are taken up by beneficial bacteria, and changed into less toxic materials, as discussed in the last chapter.

A simple system for this “biological filtration” of water is shown in Figure 8.2. Water is removed from the tank by air-lift, and deposited in the bottom portion of the filtration tank. In this design, the tube entering the filter must be carefully located a few inches above the bottom, to prevent back siphoning of the sediment if the air supply fails. Solids which will settle out of the water accumulate at the bottom and are periodically removed through a valve. Constant addition of water near the bottom pushes water slowly upward through the “filtration medium,” a layer of finely-divided material (such as crushed coral) which provides a large surface area for growth of the beneficial bacteria. The water emerging from the top of this layer is allowed to flow back to the culture tank.

A tremendous amount of research and engineering has been done on biological filtration, and the resulting literature describes many possible systems and designs. The system presented here is inexpensive, and in preliminary tests, appeared to be adequate for a 12-foot diameter plywood tank stocked with several hundred red tilapia at WCC.

Requirements for a filtration system are: 1) a means to remove solids, 2) a bacterial medium or “substrate,” 3) a means to keep the water in the system and filter aerated, and 4) a means to move the water through the pathway. Some systems separate the settling function from the filter in separate tanks, use different bacterial substrates, and use various means of moving water, such as siphoning and pumping. It will still be necessary to add some new water to a culture system, even with a filter operating. Some loss will occur from evaporation, and some undesirable materials, including the less-toxic nitrate, will eventually build up. A workable beginning guideline would be replacement of about 10 percent of the system water with new water each week.

A new system should be monitored with chemical test kits upon startup, because it takes time for the bacteria to become numerous enough to stabilize the system, and you will want to be sure a stable condition is eventually reached. Some aquarium stores and aquaculture supply catalogs offer dried starter cultures of the appropriate bacteria, which can speed up the conditioning of a new filter system.

The water coming out of the biological filter will be clear, low in dissolved organic matter and ammonia, but still high in nitrate and phosphate content. Although these materials are not highly toxic to the cultured animals, they will build up over time and must be diluted with new water or otherwise removed eventually. If you use crushed coral (commonly available from building supply stores) or shells as the filtration medium, those materials will control the pH of the water passing through the biological filter system. If you use a synthetic material, such as pieces of plastic pipe, the pH of the water should be monitored, and may need to be adjusted by addition of lime to the filter.

Chapter 12 lists readings on biological filters, which will give you detailed guidance if you decide to use one. Many ideas and designs for systems that will remove nitrate and phosphate materials have been published. One intriguing possibility for backyard culturists is to use the materials to fertilize a “hydroponic” (soil-free) system for growing vegetables or or-

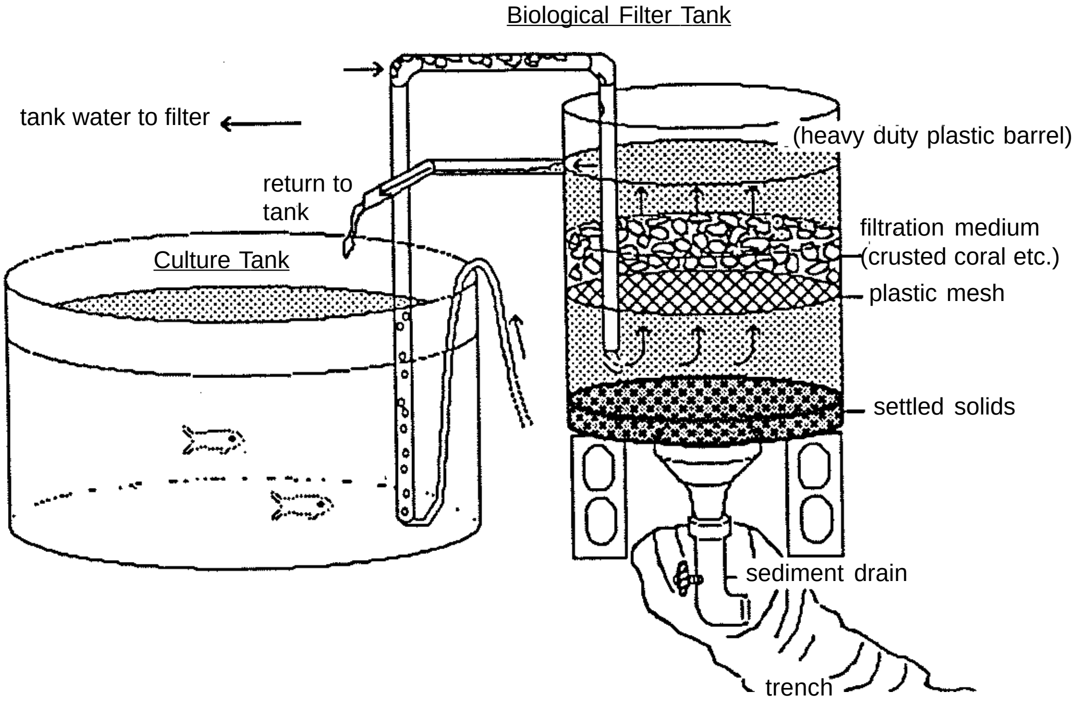


Figure 8.2 Diagram of major parts and functions in a simple biological filter suitable for a small-scale culture tank. Pumped air lifts water from bottom of culture tank to filter tank, where it enters below the fitration medium. This water pushes the old water up through the medium, with solids trapped in the lower portion to settle later. Bacterial activity on the medium processes wastes as water goes through it. Processed water at top of ifltraion tank returns to culture tank through a simple overflow outlet.

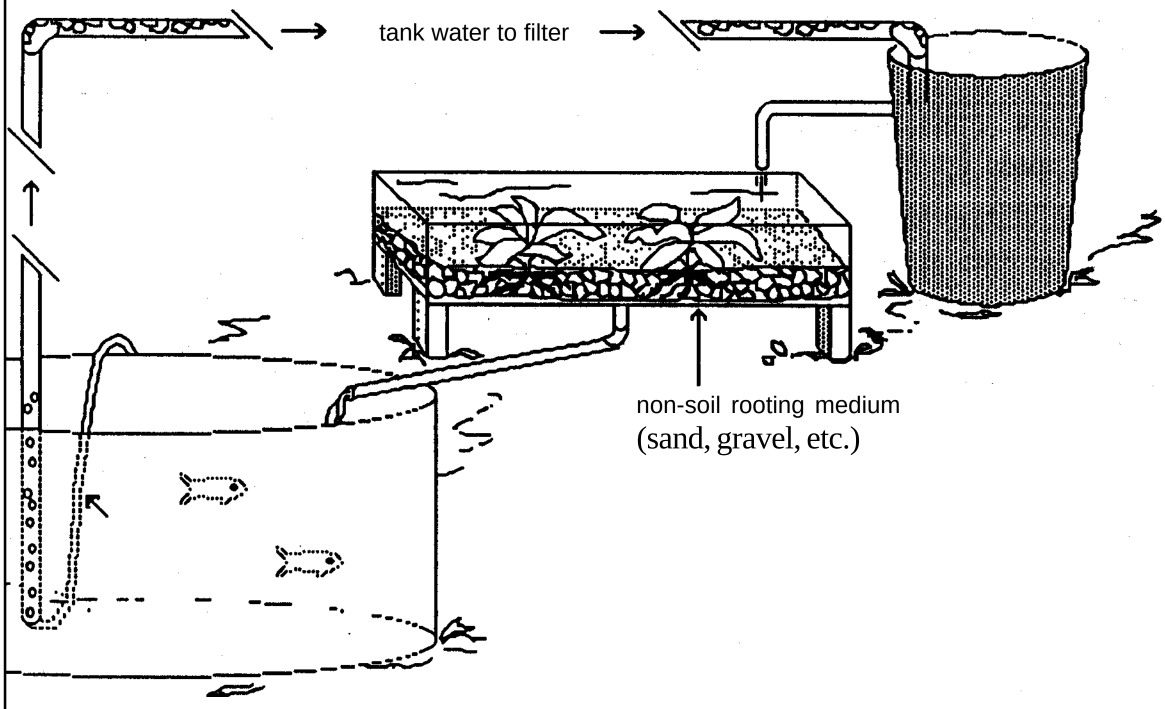


Figure 8.3 Integration of a hydroponic (soil-free) garden with a small-scale culture tank and biological filter. When processed water leaves the filter tank (see Figure 8.2), it goes to the garden box rather than directly back to the culture tank. Plants (garden vegetables, flowers) in the garden box are fertilized by the nutrients remaining in the water, before the water, now even cleaner, returns to the culture tank.

namental plants. The hydroponic system is placed between the overflow of the biological filter and the return to the culture tank, as shown in Figure 8.3. The plants, with their roots in sand, gravel, or other medium, take up the nitrate and phosphate, with the water passing through to be returned to the culture tank. This idea combines water recycling with garden integration, and represents a highly efficient use of all materials in the system.

Other Appropriate Technologies

The above ideas are the most likely instances of integration and appropriate technology to be used by the backyard aquaculturist. However, many other creative ideas and devices could in some way be applied to backyard aquaculture. They were becoming better and better known to the general public during the oil crisis of the early-mid 1970s, when alternative energy sources were being studied intensively. Although petroleum prices dropped, depletion of the earth’s total petroleum resource has continued, and alternatives will be used more and more. A brief review of some of these ideas follows.

1. **Solar Energy:** The use of solar energy for water heating has become common. Hot water from systems that produce more than is needed for the home could be diverted to warm a small-scale culture system during winter

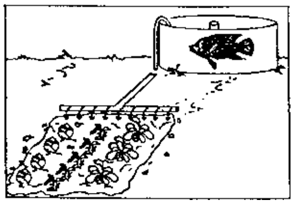
months, at no cost, increasing the growth rates of the animals. Solar energy can produce electricity directly in photovoltaic cells, which could be used to drive water and air pumps in a culture system. The cells are inexpensive enough that a culturist could consider using them, but it would not at present be cheaper than using electrical power from the home for pumps. However, an advantage would be that the culture system would be independent of the costs of keeping the home, and of the failures of public power systems.

2. **Wind Energy:** Windmills are a centuries-old technology, and are particularly appropriate in Hawaii with its tradewinds. Wind energy can generate electricity, or drive pumps directly.

3. **Energy of Moving Water:** Although this source applies to relatively few situations, stream flows also can drive generators

4. **Biomass Energy:** In addition to providing opportunities for integrating culture systems and agriculture, plant and animal waste material (sugar cane waste or "bagasse"; manures) can be digested or fermented to make fuels such as methane and alcohol, which can in turn run generators and pumps.

In summary, the small-scale culturist can profit in many ways from awareness of the potentials for integration and appropriate technology. But now it's time to return to the specifics of planning the system.



Chapter 9

It's Easy When You're Organized

How to 'Find the Time'

By now, you may have a very clear mental picture (and some pictures on paper as well) of your system as a finished product. If you have planned and completed home projects before, you'll probably have a good idea about the amount of time and effort it will take to build your system. However, if this project is your first try at something of this kind you may wonder how long the road leading to " operations" will be. This chapter will help you plan the building and maintenance of your system in some detail.

Just as this book suggests and illustrates a step-by-step approach to the whole idea of small-scale aquaculture, this chapter offers specific techniques for planning and organizing the actual construction, and then the routine maintenance, of a small-scale system.

Writing Things Down

The next step for a well-organized construction effort should be to make a list of tools and materials, similar to those given for the sample systems in Chapter 11. Your list should include the names of the suppliers and the costs. As noted in the introduction, this book does not suggest specific sources for tools and materials. Many competing hardware and building supply sources do business on Oahu and the other islands, and you should have no trouble finding common items. Aquarium stores, of which you will also find many, carry nets, air pumps, plastic tubing, and the like.

Materials more specialized for aquaculture are widely advertised in trade publications found in public and college libraries. Examples are Aquaculture Magazine (which produces an Annual Buyers' Guide) and Water Farming Journal. These publications also advertise sources for animals that may be imported to Hawaii under permit. HBAP at Windward CC and the state Aquaculture Development Program's information specialists will be able to help you with specific items. Finally, ADP and the UH Sea Grant College Program are in the process of producing a directory of aquaculture-related businesses and other organizations on Oahu. That work should be available soon after the publication of this book.

As you develop your list of materials, you will collect other important information. For example, you may find that some items will not be available immediately. Whether or not this happens, the next consideration will be time. You'll need to plan when each step in construction is to take place, and to try to have everything needed on hand for each step. One aid to thinking about the timing is a schedule like the one in Table 9. 1, which is simply a list of steps or activities, with projected start and completion dates, and a short list of the items required for each activity. The required items may be tools and materials, or they may be previously listed

Table 9.1 Sample Schedule for Development of a Small-Scale Aquaculture System

Activity	Start Date	Completion	Requirements
1. Discuss with family	1 Jan	7 Jan	Mom returns from travel
2. Discuss with neighbors	8 Jan	14 Jan	Family says OK
3. Write to lessor	15 Jan	30 Jan	Neighbors say OK
4. Prepare site sketches	15 Jan	15 Feb	Buy tape measure
5. Request permits	1 Feb	15 Feb	Lessor says OK
6. Purchase materials	15 Feb	28 Feb	Permits seem OK Payday is Feb. 15
7. Remove mango tree	15 Feb	28 Feb	Helpers are available
8. Clean out tool shed	15 Feb	28 Feb	
9. Construct system	1 Mar	31 Mar	
10. Stock animals	1 Apr	7 Apr	Permits OK System is operational

tasks that must be completed before another activity can begin. Because some people work more naturally with pictorial information than with words, the schedule can be done in "time-line" style, as shown in Figure 9. 1. Calendar dates appear at the top; the lines connect the start and completion dates for each activity.

This kind of planning takes a little time' but it has many benefits. Most obvious is that it can help avoid the frustration of having to delay some step because something necessary has been overlooked. While this can be financially critical for businesses, it is 'helpful for small-scale efforts, too. Friends and family members who may be involved will probably enjoy their participation more if they see that the project is well-organized and that success is likely.

The Big Day and Beyond

Once your system is built, stocked, and operating (a perfect reason for a party), it will need regular attention, which also will require time and materials. The list of supplies (see the example in Chapter 11) will depend on the specifics of your system, and may change as time goes on and you gain experience. The same is true for the maintenance activities, but it is easy to make a preliminary estimate of the time that will be needed.

To help you with this estimate, make a list of all the maintenance activities you can think of that your system will need, and organize it like the one in Table 9.2. For each activity, make an estimate of the time you expect it to take, and enter this amount in the proper column, depending on whether it has to be done daily, weekly, monthly, or at some other interval. Some activities will be done "as needed," but at this point you should try to fit each into some column.

Experience will quickly help you to revise this management plan to make it as realistic as possible. You might want to make a table more detailed than Table 9.2 at first, including such detail as the time required for each measurement you would make at item 3. Temperature, for example, can be taken very quickly, while using chemical kits requires 10 to 15 minutes for each measurement.

When the table is complete, you will be able to add up the times entered in each column to get the estimate of how much time it will take to maintain your system during any particular period. Note that the "1 hr 50 min" total shown for weekly activities does not include the 30 minutes a day required for daily tasks, which means that each week, 1 hour and 50 minutes more time is required. Similarly, the 3-hour monthly total means 3 hours each month in addition to daily and weekly activities.

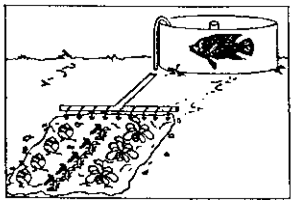
Of course, these times are only guesses taken to show how the table can be used, and they don't necessarily apply to your system. The estimates of the maintenance time, even if not perfect at first, can be valuable information for re-evaluation of your goals, system design, and projected financial outcome, which will be discussed in Chapter 10.

Figure 9.1 Example of a Time-Line Schedule for Development of a Small-Scale Aquaculture System

Month	Jan	Feb	Mar	Apr	May
Activity					
1. Dicuss with family	—				
2. Discuss with neighbors	—				
3. Write to lessor	—				
4. Prepare site sketches	—				
5. Request permits		—			
6. Purchase materials		—			
7. Remove mango tree		—			
8. Clean out tool shed		—			
9. Conduct system			—		
10. Stock animals				—	

Table 9.2 Maintenance Time for a Small-Scale Aquaculture System

	Estimated Time Required				
Frequency	Daily	Weekly	Monthly	>Month	Notes
Activity					
1. Feed and observe animals	10 min				
2. Check, adjust air and water	5 min				
3. Measure and and record temperature, etc.	5 min	30 min			
4. Maintain pond/tank system (replace airlines, etc.)		20 min			
5. Maintain yard or grounds		30 min			
6. Integrate garden (pond water to garden; collect scrap feeds)	10 min				
7. Measure growth, check for disease			1 hr		
8. Review records		10 min	½ hr		
9. Take inventory				½ hr/2 mo	
10. Buy supplies			½ hr		
11. Harvest crop		20 min		2 hr/6 mo	
12. Re-stock new crop				1 hr/6 mo	
13. Call/write other culturists			1 hr		
14. More?					
TOTALS	3 min	1 hr 50 min	3 hr	4 hr/yr	



Chapter 10

Will It All Be Worth It? (and How You Can Tell)

'There's No Such Thing as a Free (Fish) Lunch'

You have probably noticed by now that, unless you inherit an aquafarm, it will take at least a little money to start a small-scale aquaculture project. This book has mentioned some specific dollar amounts as estimates of the costs of some items, and as you develop your system, you will obtain more precise estimates, and pay real bills. It is also clear that you will need to invest personal time and effort, in addition to the money.

The word "invest" is used in everyday speech in nearly the same way that it is used by people who work with money as a profession. The word means "to expend with the expectation of return," with technical details added to the definition for special purposes. Sooner or later you will, naturally, consider what you expect to get for your monetary and personal investment in your system. Some of the answers should be in your list of goals.

If you developed your goals before planning the system itself, as this book has suggested, you wrote them down having less appreciation of the required investment than you have now. The book also suggests that you revise your goals as you go along, knowing more about the investment and about the possible returns at each step. This chapter offers some thoughts and techniques for evaluating your investment and return in monetary terms.

Money Isn't Everything

Most people recognize the necessity of money in modem society, and in fact, have to spend a major portion of their waking hours obtaining money to support their lives. However, many hesitate to analyze pastimes, well being, or other human values in terms of money. Medical professionals, insurance companies, courtroom juries, and government officials experience difficulties when required to associate dollar amounts with the value of human life and health.

It has become important, however, to be able to gauge such things as whether government spending to enhance citizens' recreational opportunities actually provides enough benefits to justify their costs. Other government programs often are analyzed in this way, but the value of recreation seems to be a problem. Recreation often is seen as optional, or less than truly necessary, because individuals are free to choose whether or not to engage in any particular activity.

One study tried to estimate the value of boat trips for recreational fishing by offering fishermen at a public boat ramp various sums of money to forget the fishing trip and go home! The offer was not strictly serious, but the idea was a creative one, and the study showed that the fishermen placed high values on this activity.

If you have small-scale aquaculture goals including human values that are usually not evaluated in dollars, such as “recreation” or “more time with the family,” you may wonder if a money-related analysis will be valuable. Only you can be the judge of whether your benefits from small-scale aquaculture are worth the costs. This kind of activity will almost surely not return monetary rewards equal to the monetary costs. It will, however, return rewards that are not easily evaluated, but which could be large. Many people spend considerable amounts of money for recreation, personal learning, and other goals, quite apart from aquaculture. The “bottom line” will be determined by the value of the rewards to you.

The rest of this chapter presents a basic economic analysis of small-scale aquaculture projects. It does not ask you to place dollar values on strictly human, intangible benefits, but does provide you the option to include or exclude the value of labor to be applied to the project. Whether or not you are interested in a bottom-line estimate of “profit” ‘or “loss,” the analysis provides you with an opportunity to make estimates of the money it will take to develop and operate your system. With this information, your personal judgment of the value of the project will be as well informed as possible.

Some Basic Ideas

This analysis attempts to compare “income” (or estimated value of the product) and costs, and then to use this information to calculate a few simple quantities that should be very informative. It will be easiest to understand the steps by looking at two examples, starting on page 62. In the first example, analysis is made of a simple case, a monoculture, in which only one species, the freshwater prawn, is grown. Later, you may apply the ideas to the second example, which deals with two species. The prices used in the examples do not necessarily apply to any particular place and time. If you decide to analyze your system in this way, you will need updated and specific information.

The analysis sheets contain four major categories of information. The first section, I. “Production and Revenues,” takes an estimate of annual production of the crop (210 pounds of prawns), places an estimated value on each pound ($5), and by simple multiplication estimates the value of the annual crop at $1,050. The estimate of 210 pounds annual production is made from the number of animals stocked in the system, their projected survival rate (for prawns, usually 50 percent of the young postlarvae or “PLY’ stocked), and the estimated final weight of individuals (the initial weight of the postlarvae can be taken as zero).

For example, if a culturist stocks 8,000 PL’s, and 4,000 survive and grow to weigh a total of 210 pounds (each weighing about 1/19 pound), a wholesale market price of $5 per pound produces an estimated annual revenue, or income, of $1,050. This starting point assumes that the crop has that value to you, even if, as is likely, you don’t plan to sell it. Any such analysis has its set of assumptions, which will be identified as you continue. A crop of this size, discussed here purely to illustrate the analysis, might be produced with good “beginner’s luck” in a square earthen pond about 90 feet on each side.

In this first example, section H. “Annual Operating Costs,” details the costs of producing the crop, and includes costs that must be paid during any period of time that a system is in operation. It does not include start-up costs, which are covered in section III. Operating costs are divided into two types, "variable" and "fixed."

Variable costs (ILA) are those directly associated with raising the crop, as is obvious from looking at the items on the sheet. At this point, you can decide whether or not to include a monetary evaluation of the "labor" input, that is, the time you and others spend raising the crop. A simple list of possible items is shown and totaled ($725).

Fixed costs in section II.B are those that must be taken into account whether or not a crop is actually in the water; they include depreciation (die loss in value of facilities and equipment through time), rents, and interest on loans. The estimate of annual depreciation cost is based on information in sections III and IV. Depreciation is estimated as the cost of major facility and equipment items, divided by their useful life. For example, if a $100 seine net will last five years, its depreciation is $20 per year. You can estimate total depreciation by doing this calculation for all appropriate items you listed in section III. The formal definition, explained above, is found in formula form in section IV, item A.4. Rents and interest may not apply to most small-scale culturists (though a system might be constructed with a "home improvement" loan); however, these costs are very important to commercial farmers.

With sections I and II completed, you can jump ahead and fill in one of the calculated quantities needed for section IV, "Operational and Investment Analysis." Item IV.A. 1 calculates "Net Annual Returns," equal to the annual income minus the operating costs. In this example, $1,050 - $925 = $125, showing that the crop did have more value than the costs of producing it, which is a good start!

Section III, "Capital Costs" looks at the "start-up" costs of the building and equipping of the system. These costs are the basis for estimating depreciation in section IV. Depreciation applies to both the pond or tank facility, and to equipment items needed to support it. Depreciation is a "cost" because, if the system is to continue to exist, funds must either be saved to replace worn-out items, or be applied to maintenance. The costs of pond or tank construction are easy to understand. "Equipment" is different from "expendable supplies" in that equipment should refer to longer-lasting and more expensive items of "gear" than those that are classed as supplies. Different people and organizations have different definitions of equipment. Here, items are placed into equipment if they are expected to last longer than one year.

Section IV, "Operational and Investment Analysis" organizes the information from the other sections so that you can calculate a few simple figures that are useful for thinking about the monetary situation in this project. The subsection A, "Quantities Needed for Other Calculations" shows how to calculate Net Annual Returns (A. 1, discussed above), Average Price (A.2, which is the same as the price per pound in section 1), and Average Variable Costs (A.3), the variable costs for each pound produced, calculated by a simple division as shown, and Depreciation (AA also discussed above).

Subsections IV. B through D are the quantities you have been working for. "Simple Return on Investment" compares the net annual returns to the capital (start-up) costs. Since this system cost $800 to start up, and the annual returns are $125, the Simple Return on Investment (IV.B) is 15.6 percent. Many assumptions have gone into the analysis to produce this figure, but if the assumptions are accepted, the 15.6 percent can be compared with other possible uses of $800. Questions could be asked about the figure, such as, “Could I obtain a greater percent of return by placing the $800 in a savings account?,” or “Would I and my family derive more value from a vacation costing $800?”

The “Break-even Production Quantity” (IV.C) is the amount of production needed to make income exactly equal to operating costs. If your analysis, for example, showed that your estimates of all these numbers would lead to a loss (costs greater than income), this quantity shows you how much production would have to increase to remove the loss. You could then decide how to adjust your plans (increasing income or decreasing costs) to avoid such loss. Similarly, the “Break-even Average Price” (IV.D) shows what the average price per pound for your crop would have to be to make income exactly equal to costs. You can decide whether to place a -higher value on your crop (or the total of all your benefits), or whether to grow something of higher value.

This analysis, as mentioned, is intended as an aid to thinking about your goals and your system. It is based on principles found in some of the references, but you probably know that accountants regard their work as start” (involving skill, experience, judgment, and human values) as much as “science” (collecting information about the world and drawing conclusions according to accepted rules). More sophisticated economic analyses could be done by a professional accountant on an aquaculture project. On the other hand, it may be better in some cases to reject some of the assumptions used here, and take a simpler view. Many aquaculturists find that the total small-scale aquaculture experience is a highly valuable one.

Examples

The following examples are frameworks, with sample dollar amounts filled in to illustrate how to analyze your projected financial position during operation of a small-scale aquaculture system.

Case I: MONOCULTURE of Freshwater Prawns

I. Production and Revenues (Income)

species	est. annual production lb	est. price $/lb	revenue
A. prawns	210	5.00	$1050
TOTAL PRODUCTION	210	TOTAL REVENUE	$1050

II. Annual Operating Costs

A. Variable Costs

feed (500 lb @ $0.30/lb)	$150
water (500 gal @ $0.13/gal)	65
labor (50 h @ $4.00/h)	200
electricity (600 kwh @ $0.10/kwh)	60
prawn juveniles (8000 @ $0.25 ea)	50
expandable supplies	50
total variable costs	$725

B. Fixed Costs

pond depreciation	$100
equipment depreciation	50
interest on borrowed funds	20
lease rent	30
total fixed costs	$200

C. TOTAL OPERATING COSTS (A. + B.)	$925

III. Capital (Start-Up) Costs

A. Pond Construction

concrete and lumber	$350
labor	100
liner	50
cement mixer rental	40
hardware	40
refreshments for helpers	20
total pond costs	$600

B. Equipment

meters, analytical kits, etc	$60
freezer	80
hoses and filters	30
nets	15
plastic bucket	15
total equipment costs	$200

C. TOTAL CAPITAL COSTS (A. + B.) $800

IV. Operational and Investment Analysis

A. Quantities Needed for Calculations

1. Net Annual Returns = total revenue - operating costs = $1050 - $925 = $125

2. Average price = $\frac{\text{total revenue (\$)}}{\text{total production (lb)}} = \frac{\$1050}{210\text{ lb}} = \$5.00/\text{lb}$

3. Average variable costs = $\frac{\text{total variable costs (\$)}}{\text{total production (lb)}} = \frac{\$702}{210\text{ lb}} = \$3.45/\text{lb}$

4. Depreciation = sum for all items: $\frac{\text{orig. cost - salvage value}}{\text{expected useful life (yr)}}$

   (Use equipment costs from III.B)

B. Simple Return on Investments (%) = $\frac{\text{net annual returns x 100}}{\text{total capital costs}}$ =

$$\frac{\$125 \text{ x } 100}{\$800} = 15.6\%$$

C. Break-even Production Quantity (lb) = $\frac{\text{total fixed costs (\$)}}{\text{avg. price (\$/lb) - avg. variable cost (\$/lb)}}$ =

$$\frac{\$200}{\$5.00/\text{lb} - \$3.45/\text{lb}} = 129 \text{ lb}$$

D. Break-even Average Price = Average Cost per Unit Production =

$$\frac{\text{total operating costs (\$)}}{\text{total production (lb)}} = \frac{\$925}{\$210/\text{lb}} = \$4.04/\text{lb}$$

Case II: POLYCULTURE - Tilapia and Prawns
(at the same costs and total revenue as in CASE I)

I. Production and Revenues (Income)

species	est. annual production lb	est. price $/lb	revenue
A. tilapia	300	2.00	$600
B. prawns	100	4.50	450
TOTAL PRODUCTION	400	TOTAL REVENUE	$1050

II. Annual Operating Costs

A. Variable Costs

feed (500 lb @ $0.30/lb)	$150
water (500 gal @ $0.13/gal)	65
labor (50 h @ $4.00/h)	200
electricity (600 kwh @ $0.10/kwh)	60
prawn juveniles (4800 @ 2.5 cents ea.)	120
tilapia juveniles (400 @ 20 cents ea.)	80
expandable supplies	50
total variable costs	$725

B. Fixed Costs

total fixed costs	$200

C. TOTAL OPERATING COSTS (A. + B.) $925

III. Capital (Start-Up) Costs

TOTAL CAPITAL COSTS $800

IV. Operational and Investment Analysis

A. Quantities Needed for Calculations

1. Net Annual Returns = total revenue - operating costs

2. Average price = $\frac{\text{total revenue (\$)}}{\text{total production (lb)}}$

3. Average variable costs = $\frac{\text{total variable costs (\$)}}{\text{total production (lb)}}$

4. Depreciation = $\frac{\text{sum for all items: orig. cost - salvage value}}{\text{expected useful life (yr)}}$

(estimates under II.B)

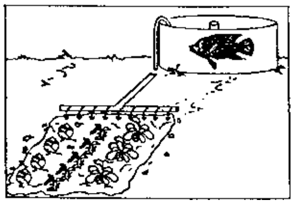
Polyculture Example (cont.)

B. Simple Return on Investments (%) = $\frac{\text{net annual returns} \times 100}{\text{total capital costs}}$ =

C. Break-even Production Quantity (lb) = $\frac{\text{total fixed costs (\$)}}{\text{avg. price (\$/lb)} - \text{avg. variable cost (\$/lb)}}$ =

D. Break-even Average Price = Average Cost per Unit Production =

$$\frac{\text{total operating costs (\$)}}{\text{total production (lb)}}$$



Chapter 11

A Sample System

A Basic Beginning

This chapter gives instructions for building an above-ground tank of the type discussed in Chapter 6. One workable small-scale system is presented in some detail, along with a number of hints acquired through experience. Although your specific system may be different, much of the information presented here should be helpful.

Every set of practical instructions is written with some assumptions about the previous knowledge or skill of the reader. Although this manual is aimed primarily toward people who have no prior experience with aquaculture, these instructions assume that the reader has a general familiarity with tools and materials at a basic household maintenance level. A person with less experience will probably be able to build this system, if a more experienced person is available for questions and other help. Construction people may find some of the methods informal, but an attempt has been made to keep to a basic level of cost and effort, and these methods have been successful at Windward CC.

This system consists of a 12-foot diameter tank on an earthen footing pad at ground level, with “less expensive” (but not always absolute minimum-cost) materials used when a choice is possible. This design may be expected to provide several years of low-maintenance use, possibly as many as five years, depending on specific location and other factors. The use of more elaborate or expensive strategies (e.g., concrete footing pad, external posts supporting the walls) could lead to greater lifetime of the system, but the experience at Windward CC does not support that notion.

Originally, Windward CC had three types of tank construction: minimum-cost, medium, and “luxury” level 12-foot tanks. Weakening of the tank walls almost always has been the first sign of age and fatigue in these tanks of all three types, with most problems appearing near the walls’ contact with the ground. The more expensive concrete pad could be advantageous over an earthen one if rainwater drains efficiently from the apron outside the walls, but detrimental if the water pools toward the walls. The design described here aims to keep the lower parts of the walls dry by allowing rain and runoff to drain away through the brick and gravel foundation.

Footing Pad and Drain

The first step is to prepare a level area large enough to hold a circle at least 14 feet in diameter. This space will accommodate the 12-foot tank with one foot of border area on all sides. If the land has no large mounds or dips, an initial idea of the effort needed to level the ground can be obtained by laying a 2 x 4 piece of lumber across the site, and placing a carpenter’s level on it. By surveying the site in this manner in several directions, one can easily see where to remove high areas. Large mounds or dips, or large sloping areas, may require the use of mechanical earth movers. Filled areas should be tamped or rolled if possible, so the earth does not move or settle under a full tank. The 2 x 4 and level will provide a sufficient check of the initial earth leveling, and can in fact be used to check the final leveling of the walls, which will be discussed later.

The location of the drain is chosen after the initial earth leveling. If the tank is to be operated with an outside standpipe as in this system (see options in Chapter 6), the interior drain should be in the center to allow the circular water flow (described below) to push sediment toward the slightly deeper center, and out of the system. If an inside standpipe is to be used, the culturist should consider the need for a person to enter the tank to remove a central standpipe. This requirement can be avoided by placing the drain 1 1/2 to 2 feet in from a wall, where it can be reached from outside the tank. In either case, the earth should be gently and smoothly sloped downward toward the drain, with the drain being 6 to 8 inches lower than the edges.

A trench to hold the drain pipe must be dug from the drain to a point at least 2 feet outside the tank (Figure 11. 1), where the outside standpipe and drainage away from the system will be. The trench must be deep enough for the drain pipe to be buried in gravel before being re-covered with earth, and should slope slightly downward to the outside. The outer end of the drain pipe may end with an upward-pointing elbow that will just emerge from the earth, or the entire final elbow may be exposed in a ditch alongside the site (Figure 11.2), into which the standpipe-and-elbow assembly may be lowered to drain the tank when necessary. At this time, one must consider where the water will go when it leaves the tank, either by continuous overflow (as in this system), or when the tank is drained.

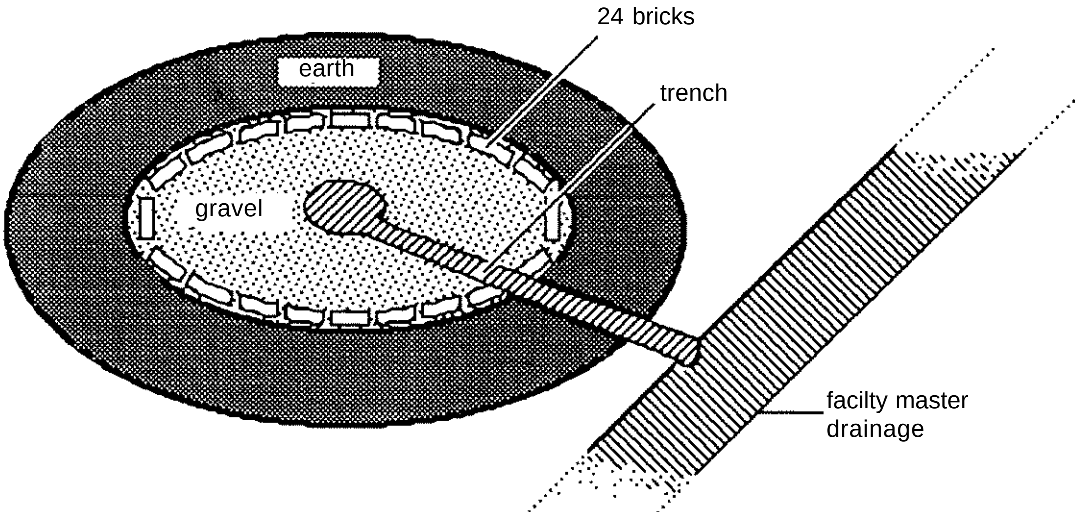


Figure 11.1 Basic site preparation for an above-ground culture tank. The level earthen area contains a circular level of gravel. Bricks are placed at even intervals around a circle 12 feet in diameter. A central hole is connected by a trench to the pipe or larger trench leading to drainage.

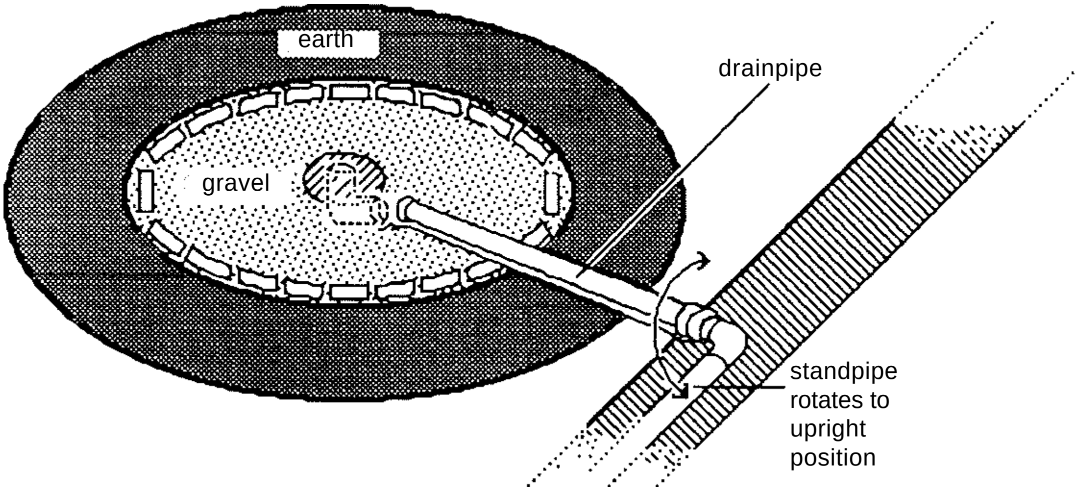


Figure 11.2 Installation of drain pipes. A 3-inch elbow is placed in the central hole so that its top edge is level with the top of the gravel; earth and gravel are filled in around the elbow. Three-inch pipe is laid in trench, connected to lower end of elbow, buried in the earth, and covered with gravel up to the edge of the gravel circle. The outside standpipe (see Figure 6.4c) is attached at the outside end of the drain pipe.

The ability to lower the standpipe is advantageous because it allows control of the rate of drainage, which is difficult or impossible if the pipe must be removed entirely from a partially-buried elbow.

The elbow at the center drain hole inside the tank should be glued to the drain pipe according to directions on the cans of PVC primer and glue. If a rotatable outer standpipe is desired, it is best to glue a malethreaded union on the outside end of the drain pipe, and obtain an outer elbow with one female-threaded opening for the rotating joint and one plain end for the standpipe itself (Figure 11.3).

The perimeter of the pad is now lined, partially or completely, with small bricks to provide solid support for tank walls, as shown in Figure 11. 1. Two dozen bricks will be sufficient; these must be carefully leveled across the perimeter in at least three directions. Small “pea” gravel is then laid to fill the perimeter to the level of the top of the bricks, also extending onto the outside apron.

Tank Walls and Bottom-Finishing

The tank walls are made from five 4 x 8-foot sheets of 1/4-inch plywood. Several grades of plywood have been used at Windward CC, but the inexpensive exterior grade “A/C” is recommended here. The designation A/C refers to the better, knot-free quality of one side of the sheet, which will face to the inside of the tank. Five 8-foot sheets provide 40 feet (480 inches) of length; the circumference of a 12-foot diameter tank is 12 x pi = 37.7 ft = 452.4 inches, which means that each sheet will overlap the one on either side of it by almost exactly 5 1/2 inches when the walls are bolted together.

The sheets are pre-treated before assembly with a liberal coat of water-seal brushed on all surfaces and, when dry, with a coat of asphalt emulsion, on both sides, along one long edge in a strip 12 to 18 inches wide. The latter material is to make the bottom edge of the wall as waterproof as possible. The system described here leaves the sheets in their original size, but the sheets could be trimmed to 3 feet x 8 feet for a shallower tank.

The sheets are carefully stacked atop each other for the drilling of bolt holes. A straight line 5 1/2 inches from one short side is drawn on the top sheet (Figure 11.4). Between this line and the edge, 10 holes are drilled through the entire stack with a 7/16- or 13/32-inch drill bit. The hole nearest the bottom (asphalt-coated) edge of the sheets is located about 1 inch from each edge at the comer. 'Me other holes are then located evenly up the edge in a staggered pattern as shown in Figure 11.4. It is not necessary to locate the holes more precisely than this, as long as they are within the line. When the first side of the stack has been drilled, the top sheet is pushed along the stack to the other end, and laid so that its drawn line is at the far edge as shown. The far end of the stack is now drilled through the existing holes in the top sheet, repeating the pattern exactly. Care must be taken to keep the stack as "squared-up" as possible. Finally, the second edge of the first sheet must be drilled, using one of the other sheets as a guide (not shown).

The walls are then laid out and bolted together (with nuts left finger-tight) in a long line with 50, 5/16-inch carriage bolts (1 1/2 inches long),

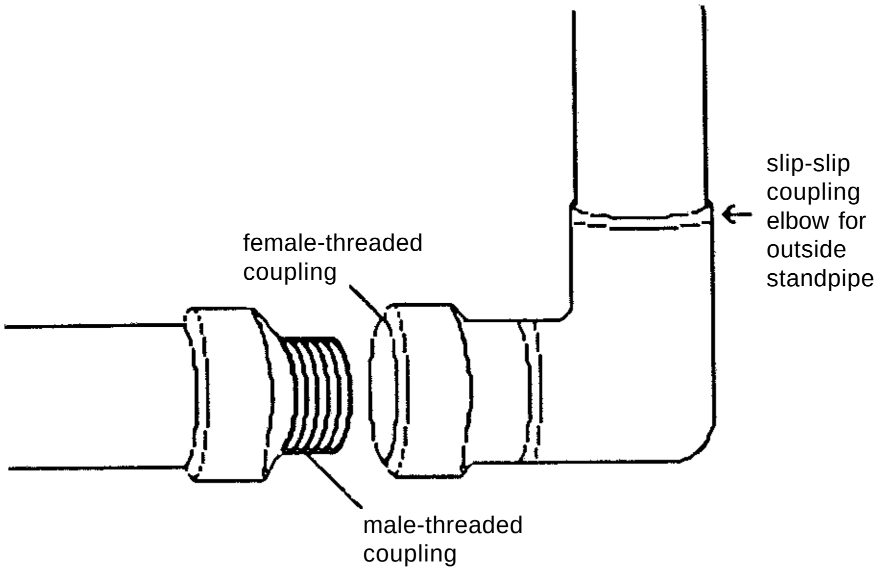


Figure 11.3 Detail of the outside standpipe connection. The elbow for the bottom of the standpipe (without the standpipe attached at top) is loosely threaded onto a threaded coupling attached to the end of hte drain pipe. The standpipe is then inserted into the upper end of the elbow. This arrangement allows the standpipe to be rotated between its upright and lower draining positions (see Figure 11.2).

with bolt heads to the inside of the tank, and flat and lock washers used with the nut on the outside. The plywood sheets should overlap the same way in each case, as shown in Figure 11.5. When the walls have been bolted together, the assembly is picked up and bent into nearly circular shape; it can be done by three or four persons, and may be done away from the pad to avoid disturbing the gravel, or at the pad with care.

The assembly will show considerable tension as it is bent into a circle, and a few small cracks may appear. These cracks have not proved to be serious problems, but can probably be avoided by going slowly at the end of the wall-forming operation. The last set of holes at the final seam may be difficult to align because plywood sheets are not perfectly regular. It is advisable to have an electric drill handy to correct such problems when assembling the final seam. The finished wall may now be placed on the bricks at the pad, and the nuts tightened to lock the washers.

The banding encircling the wall is installed with the walls on the pad. About 120 feet of 5/8-inch wide shipping-crate banding will be required for three bands, which are sufficient. The bottom band should be 3 to 6 inches above the ground between the first and second bolts. The banding tool may be borrowed from organizations that build such tanks, or may be rented. An experienced user should be consulted for instructions on fastening the ends of the bands, which should be made as tight as possible without undue damage to the wood. The second band should be 12 to 18 inches above the first, and the third the same height above that. This pattern provides greater reinforcement near the bottom, where the outward pressure of the water is greatest. The bands will be of level height

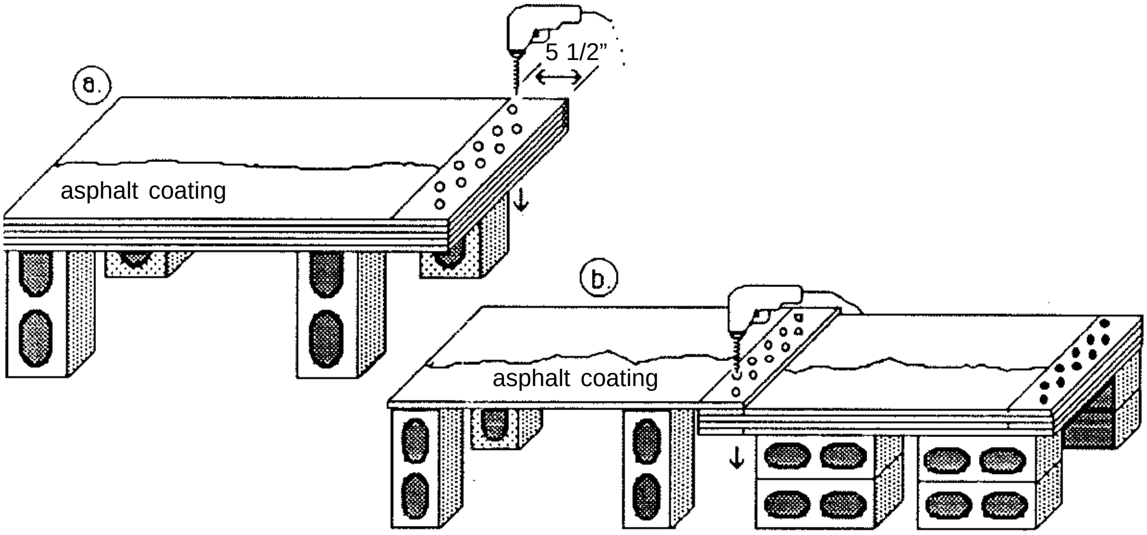


Figure 11.4 Method for drilling bolt-holes in tank wall panels. (a) Ten holes are drilled through all five sheets, staggered within 5 1/2 inches of the edge. (b) THe four remaining panels are aligned so that the "5 1/2-inch line" on the first sheet matches with the outer edge of the other sheets, and holes are drilled through the top sheet's holes to assure an accurate match. Finally, a second set of holes is drilled in the first sheet by using one of the others as a pattern (not shown).

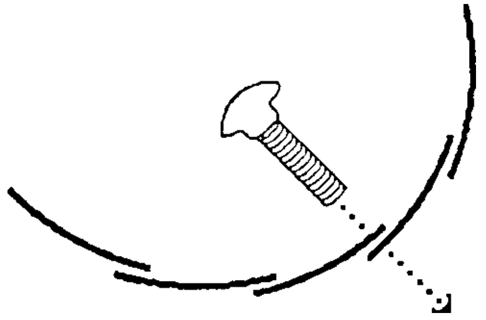


Figure 11.5 Diagram (not true to size scale) of overlapping pattern of tank walls and orientation of bolts (heads to inside of tank)

around the tank if they are placed between bolts of the same height all around. Care is needed to avoid trapping washers beneath the bands.

At this point, final leveling of the top perimeter of the walls is done, either with a 2 x 4, as described above, or with a perfectly taut string managed by two people at its ends. If the top perimeter of the walls is not level, the bricks on the downhill side should be raised by placing more gravel under them, with such adjustments continuing until the top perimeter is level and the bottom perimeter touches each brick. An additional layer of pea gravel 1 to 2 inches thick is now laid inside the walls, with extra gravel forming a wedge at the walls, and then the gravel is covered with a similar thickness of sand. This latter step is optional, but it helps to make the shape of the bottom regular. The sand is covered with a 1/2 to 3/4-inch layer of newspaper, which has been effective in preventing the intrusion of plants upward through tank bottoms. The paper layer should be about 1” thick if sand is omitted.

Liner and Drain-Finishing

The liner must be installed carefully, with the bottom as fully extended as possible, and the perimeter seam at a uniform location at the base of the walls all around the tank. The top of the liner is draped outside the walls, and pinned in place with pieces of PVC pipe or black irrigation pipe, cut as shown in Figure 11.6b. These cut pieces should be sanded to remove burrs and sharp edges, and then pressed into place carefully to avoid tearing the liner. For this 12-foot diameter tank, about 20 pieces will do the job. The process described here should be repeated and continued until the liner is spread as uniformly as possible.

Finishing the drain requires cutting a 1 -inch section from a 3-inch PVC pipe. This section may be slightly less than 1 inch wide, but not more. This piece is also carefully sanded, and rubbed with wet soap to make it slippery. Immediately over the drain, two slits are to be cut in the liner at right angles, as shown in Fig 11.6a. These cuts should extend fully to the edge of the elbow’s rim, or the liner will be pulled into the hole when the insert is gently tapped in with a hammer (a rubber mallet is helpful but not essential). Inserts can usually be tapped completely flush with the elbow rim, but because PVC may have irregularities, some cannot. If you can detect no further movement with moderate hammer strokes, hard strokes should not be used. A broken elbow is laborious to excavate from an earthen pad, and much more difficult from a concrete one.

Congratulations! You have built a plywood tank.

Tank Accessories

In this system, the depth of the water will be controlled by the height of the outside standpipe,

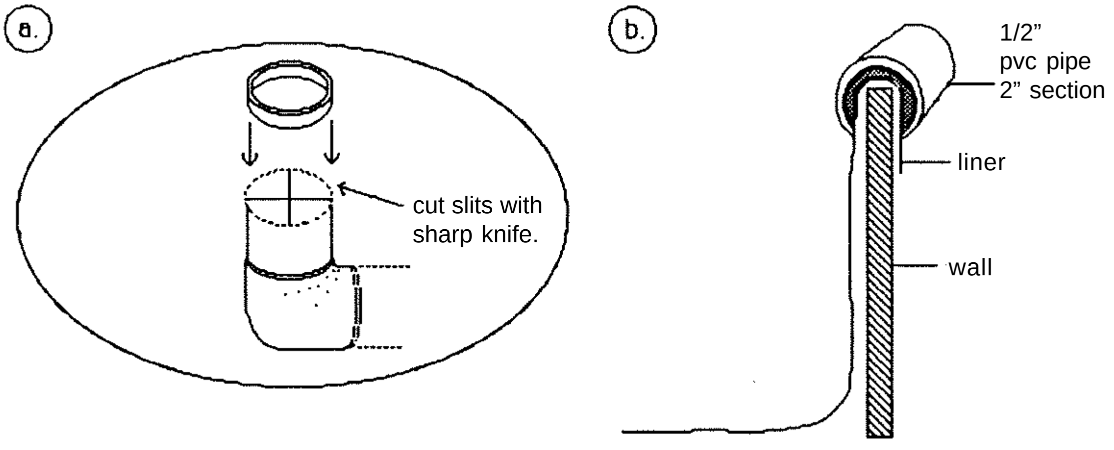


Figure 11.6 Details of tank liner installation. (a) Two perpendicular slits are cut in the liner directly over the top of the drain elbow. The 'insert' is then tapped into the hole. (b) The top edge of the liner overlaps the top of the tank walls, and is held in place with 2-inch sections of PVC or garden irrigation pipe which are slit along one edge to fit over the tank wall and liner.

which may be cut as desired. If the pipe has a rotatable joint, as in this system, it should be secured or supported at the proper height, to avoid accidental draining of the tank.

The interior drain is covered with a coarse screen, of sufficiently small mesh to retain the smallest animals in the tank, but otherwise as large as possible to permit sediment to enter the drain freely (see Figure 6.4). The screen may be made of plastic-coated wire mesh, or a plastic basket may be used. Bouyant screen materials may be held down on the drain with a brick.

This system is designed to be filled with tap water delivered by garden hose, and not aerated by air pumps. If the flow is to be continuous (the costs must be considered), the water should be sprayed in a fine stream, directed parallel to the walls (see Chapter 6), to create aeration and a continuous rotation of the tank water. This action, along with the slope of the bottom, will continuously cause sediment to move toward the drain.

Too vigorous a flow, however, will keep much of the sediment suspended. If periodic (rather than continuous) water exchange is practiced, the sediment may be removed before water additions by paddling the water until it rotates vigorously, allowing the motion to stop almost completely, which requires 5 to 10 minutes, and removing or lowering the outside standpipe for a few seconds, which will draw the collected sediment out of the drain.

Whether or not air-pump aeration is required depends upon the type and amount of animals stocked in the system. Specifics of management strategy can be decided by reference to the information in Chapters 6 and 9.

A tank may be covered with garden shade cloth or other materials, as mentioned in earlier chapters. A 12-foot tank is large enough, however, that many covering materials may sag into the tank upon stretching. Two perpendicular ropes stretched tightly across the tank may be sufficient to hold coverings in position neatly. Alternatively, two 1/2-inch PVC pipes greater than 12 feet in length may be attached at right angles across the tank, and lashed together in the center, as shown in Figure 11.7. Such a dome-like support permits easier access to the tank for feeding and maintenance.

This chapter has offered instructions for constructing one type of small-scale system. The next chapter offers a list of information sources on systems and many other aspects of small-scale aquaculture.

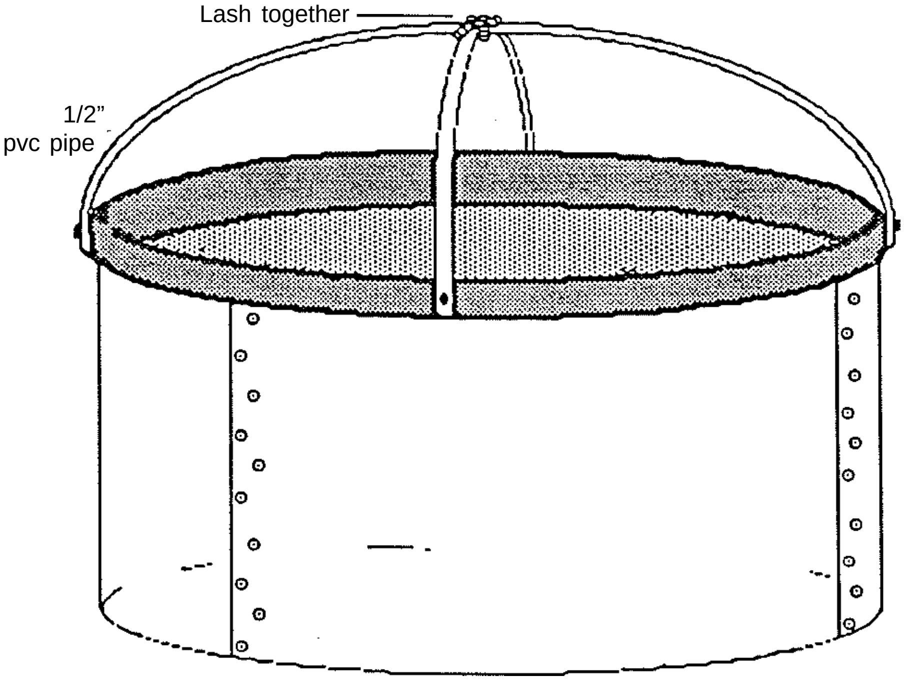


Figure 11.7 A simple frame to hold a cover (plastic, shade cloth) for a small-scale culture tank. Pipes are bolted to the upper part of the tank walls, and lashed together at the center.

Chapter 12

Background Reading and Reference Sources

Going Further

This manual has provided you with enough information to show you what backyard aquaculture involves and requires, to help you decide what you would like to do, and to prepare you to start up and enjoy small-scale aquaculture. Many readers may already have knowledge and experience that have prepared them to take a more advanced approach. Also, once beginners have gained knowledge and experience with a system, they may wish to refine or expand their efforts.

This chapter lists two types of further reading material. "Background Reading" consists of published material pertinent to small-scale aquaculture, with further details on specific items that have been discussed in this book. This list would be the first source of information for a person seeking an advanced approach to backyard aquaculture in Hawaii. Many of these sources were used in preparation of this work. "Other Reference Sources" lists the remaining materials used for this work, particularly those that would not be of as much general interest as the sources under "Background." Also included in the latter section are some materials not used directly in this book, but which make this listing more complete.

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Appendix A: Glossary

Part I List of Abbreviations

ADP	Aquaculture Development Program, Department of Land and Natural Resources, State of Hawaii.
DLNR	Department of land and Natural Resources, State of Hawaii.
DLU	Department of Land Utilization, City and County of Honolulu.
DO	Dissolved oxygen in water, which is required to support life functions of aquacultured animals.
DOM	Dissolved organic matter. An unspecified mixture of carbon containing molecules found in natural and aquaculture waters.
FCR	Food conversion ratio. The weight of food required to produce one unit of weight (a pound, for example) of an aquaculture product, usually expressed in the form “2: I,” meaning that two pounds of food produced one pound of animal product.
HBAP	**Hawaiian Backyard** Aquaculture Program, Windward Community College, University of Hawaii.
MOP	Marine Option Program, University of Hawaii.
PL	Postlarva (plural: postlarvae). A young juvenile stage of an animal (in aquaculture, usually a shrimp or prawn) immediately following the larva stage. A postlarva, unlike a larva, resembles the adult in appearance and living habits.
ppm	Parts per million. A unit use to express the “concentration” of a substance dissolved in water. A concentration of one ppm means that for every million units of weight of a solution (pond water, for example), one of those units consists of the dissolved material.
PVC	Polyvinyl chloride. A plastic polymer with many domestic and industrial uses; the material of which pipes and fittings commonly used in aquaculture systems are made.
TMK	Tax Map Key. The code for location of parcels of land in Hawaii.

Part 11 Glossary of Terms

acid	A material which releases hydrogen ions upon dissolution in water. Acids may enter aquaculture waters from some soil types or as a result of microbial activity; excessive amounts make water unfit for aquaculture, and would require chemical treatment.
aeration	Mixing of air and water.
airstone	A stone-like lump of cemented sandy material attached to the end of a plastic tube supplying pumped air to a container of water, for the purpose of finely dividing the bubbles.
alkalinity	The ability of water to neutralize acid, determined by a chemical test.
amphibian	Group of vertebrates (animals with backbones) including frogs, toads, and salamanders, that lives on both land and water.
aquaculture	According to Bardach et al. (See Chapter 12), “the farming and husbandry of freshwater and marine organisms.” aquatic Water-dwelling or water-based.
bacteria	A group of microscopic single-celled organisms important in aquaculture because of their ability to process wastes in water. Most species of bacteria are beneficial, but some are agents of infectious disease to cultured animals.
berm	Earthen margin of an aquaculture pond.
biological filtration	Processing of water by bacterial activity, usually by passing water over a bed of coarse particles on which the growth of bacteria has been permitted.
biomass	The weight of living things in a defined unit of space, such as a pond or tank.
bloom	Rapid and abundant growth of microscopic plant cells (phytoplankton) in an aquaculture pond or system, characterized by the appearance of green color and turbidity in the water.
brackish	The condition of water having some detectable salt content, half or less that of offshore sea water. Brackish water is unfit for drinking, but may be used for aquaculture with some animals.
carbohydrates	A class of biologically important molecules including starches, sugars, and cellulose, significant as caloric fuel in the diets of many organisms.

carnivore	An animal able or obliged to subsist on a diet of animal material, in contrast to a diet consisting solely of plants or a mixture of plant and animal material.
cellulose	a generally indigestible carbohydrate found in many plant materials; the main component of dietary “fiber.”
Celsius	Measurement scale for temperature used in science and with the metric system of measurement units. Zero degrees Celsius is the temperature of melting ice; 100 degrees is the temperature of boiling water at sea level.
chlorophyll	The green pigment of plants, which captures light energy for the process of photosynthesis.
community	The collection of plant and animal species found within a defined region of space, for example, in an aquaculture system.
covenant	A land-use agreement made between a buyer and seller of real estate, which is recorded with the official documents.
crustacean	Member of a group of organisms including shrimps, prawns, crayfish, and lobsters.
density	The property of matter relating the weight to the space taken up. Water has a density close to one gram (weight) per cubic centimeter (volume). Colder water is slightly denser than warm water, and tends to sink to the bottoms of containers.
detrivore	An animal able or obliged to subsist on a diet of non-living plant and animal material, such as leaf litter and fish wastes at the bottom of a pond. dissolved organic material See DOM above. dissolved oxygen See DO above.
ecosystem	The community of organisms inhabiting a well-defined space, plus the physical environment. A pond or tank used for aquaculture, with its community, is an example of an ecosystem.
Fahrenheit	Measurement scale for temperature in the United States, apart from scientific applications (which use the Celsius scale). The temperature of melting ice is 32 degrees F; that of boiling water at sea level is 212 degrees F.
fats	A class of biologically-important molecules required in the diets of animals as building blocks of some structures and as an energy source.
fee simple	Common real estate ownership arrangement in the U.S., including Hawaii, in which an owner receives tide to a parcel of land and rights to its use.

fiber	Undigestible portion of edible plant materials.
fingerling	Juvenile fish approximately the size of a human finger. Fingerlings generally resemble the adults in appearance and living habits.
filtration medium	Particulate material (for example, crushed coral, broken plastic pipe parts, etc.) in a biological filtration system which traps suspended waste particles from the water and provides surfaces on which bacteria can grow and process waste materials in the water.
flashing	Fish behavior in which reflective sides are turned upward, possibly indicative of stress or disease. food conversion ratio See FCR above.
fry	Life stage of fish from hatching to fingerling size. Early fry are also called "larvae," which generally differ from adults in appearance and living habits.
genus	The first of two words in the scientific name of an animal, designating a more general classification than the second word, the species.
growout	The final phase of life for an aquacultured organism, during which it attains its final size and is harvested. herbivore An animal able or obliged to subsist on a diet of plant material.
hydroponic	Without soil, referring to systems for growing rooted plants in inert materials such as sand or gravel, with nutrients being supplied in dissolved form in water.
integrated aquaculture	Aquaculture practiced in conjunction with agriculture in a broad sense, in which products of water- and landbased production systems are shared for mutual benefit.
light intensity	Any of several measures of the amount of visible light falling on a designated area, commonly measured with instruments such as a photographer's light meter.
medium	A material pervading an environment. For example, a "filtration medium" is a mass of particles through which water is passed to remove suspended matter; a "culture medium" (for bacteria or phytoplankton) is a water solution containing the nutrient materials necessary to support growth of the cells.
microbial	Referring to microbes, microscopic organisms, such as bacteria, phytoplankton, and other organisms too small to be seen without a microscope.

minerals	Class of materials required by plants and animals in small amounts for proper function. Minerals are found in natural waters as a result of dissolution of rocks by rain water, and are generally obtained by animals in the diet.
monoculture	Culture of a single species in a system.
omnivore	An animal able to subsist on a variety of food material, including both plants and animals.
optimum	The best value of an environmental factor (for example, temperature) for growth or survival of an aquacultured organism.
organism	An individual living thing, including common and easily seen plants and animals, single-celled bacteria, and single-celled algae called phytoplankton.
oxygen	A gas constituting about 20 percent of the atmosphere which is required by most living cells for life processes.
parasite	An organism which lives attached to or in close contact with another, from which it obtains nourishment at the other’s expense. Parasites may cause disease in cultured animals.
pH	Measurement scale for acidity in water, on which 7.0 is termed “neutral,” numbers below 7.0 indicate acidic conditions, and numbers greater than 7.0 indicate alkaline conditions.
photosythesis	Biological process in which chlorophyll-containing cells use light energy and simple dissolved materials to produce carbohydrates and oxygen.
photovoltaic cell	Electronic device able to convert light falling on it into electric current.
phytoplankton	Microscopic single-celled organisms capable of photosynthesis, which live suspended in water.
piping	Fish behavior in which the mouth is opened at the surface of the water in an attempt to obtain oxygen when its content in the water is insufficient.
plant nutrients	A class of dissolved materials required by plants during photsyntheses to produce cell components. The common plant nutrients are those supplied in garden fertilizers. polyculture Culture of more than one species in a system. postlarva See PL above.
protein	A class of biologically important molecules which are essential in animal diets as building blocks for all cells, and which may be used as an energy source if necessary.

refractometer	Instrument used to measure the salinity of water by means of its light-bending (refractive) properties.
salinity	Salt content of water. The salinity of open-ocean seawater is about 3.5 percent by weight.
Secchi disc	A white circular plate about one foot in diameter with black markings, used to make visual estimates of water turbidity.
siphoning	Process in which water moves from a higher level to a lower one through a tube under the influence of gravity.
slope	Measurement of rise or fall in the level of a land area, expressed as amount of height difference found within a specified horizontal distance, for example, “3 feet per 100 feet, or 3%.”
spawn	The reproductive process of an aquatic animal in which eggs are released.
species	The second word in the scientific name of an organism, indicating distinguishable or specific type. Members of a species are, in theory, able to interbreed readily, but not members of different species. Numerous exceptions exist.
spray bar	A tube having a sealed end and with several small holes through which water is supplied to a culture system with sufficient force to aerate the water by spraying action. stable Unchanging through time.
standpipe	A pipe in an aquaculture system through which water leaves the system, and whose height controls the height of the water in the system.
stocking density	The number or weight of organisms in a given amount of water in an aquaculture system, for example, “two prawns per square foot (of pond area)” or “one fish per ten gallons.”
stress	The result of environmental conditions which cause an organism to adjust its behavior or other functions to maintain adequate internal conditions.
suboptimal	Values of environmental conditions significantly different from those termed optimal or best for survival or growth. **terrestrial** Land-dwelling or land-based.
tolerance range	Range of values for an environmental factor, temperature for example, within which an organism is able to function without severe stress.
turbidity	Cloudiness in water due to the presence of suspended particles.
vitamins	A class of biologically important molecules required in small amounts by animals and some plants for proper function.

water quality	General term for the suitability of water for a particular purpose, such as aquaculture. Values of various environmental factors in the water constitute the water quality.
zooplankton	Aquatic animals which live suspended in water. Most are microscopic or nearly so.