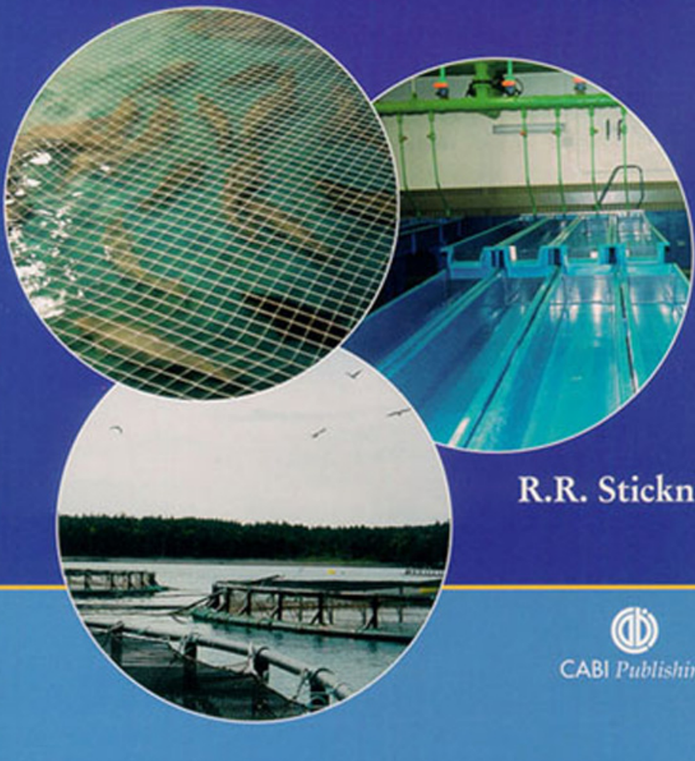
aquaculture

AN INTRODUCTORY TEXT



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an Introductory Text

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This book is dedicated to four important young people, my grandchildren Amanda, Trey, Ryan and Hannah. I hope you find as much joy in the professions you will choose as I have in mine.

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Preface

A Chinese proverb says something like the following:

Give a man a fish and he will have food for a day,
Teach a man how to fish and he will have food for a lifetime.

To that we might add:

Teach a man how to grow fish and he can feed the world.

As we shall see, the production of aquatic plants and animals – a subject we call aquaculture – takes a variety of forms, including items that enter the human food supply. That is the primary type of aquaculture discussed in this book, but it is far from the only type that is practised as you will see in Chapter 1.

The purpose of this book is to introduce you to the subject of aquaculture and to acquaint you with some of the techniques involved in aquatic organism – primarily aquatic animal – production. The emphasis is placed on shellfish – such things as oysters, scallops, mussels and shrimp – as well as on finfish. Both fresh- and saltwater culture are included.

Many books on aquaculture look at details on how to produce a particular type of animal: shrimp or salmon, for example. That approach is excellent for the student or practitioner who has decided on a particular species or species group upon which to concentrate. For the general reader who wants to gain some knowledge of the breadth of aquaculture, a different approach is required. Here, we discuss all aspects of aquaculture, from business planning through site and water system selection, to management of the system once it is in operation.

Aquaculture is a combination of natural science, business management and tradecraft. The successful aquaculturist needs to have many tools in his or her toolbox, or lacking those tools, needs to be a member of a team that brings all the proper tools to the enterprise. Increasingly, individuals who select aquaculture as a profession have received some formal education in the field. This is particularly true of practitioners from developed countries, whether they work in one of those countries or in a developing nation. Whereas there were very few aquaculture and related courses available at the college level 35 years ago, many colleges and universities now offer degrees in the subject. Increasingly, there are also aquaculture classes or at least some aquaculture activity available in high schools as well.

Over the past several years, strong opposition to certain types of aquaculture and to aquaculture in certain environments has developed due to concern about environmental degradation as a result of aquaculture practices. Aquaculturists, who once saw themselves as doing good by producing aquatic plants and animals to feed people (I like to think of them as the cowboys in the white hats), suddenly became villains in the eyes of critics (cowboys in the black hats). The perception that aquaculture is a bad thing, whether supported by the facts or not, became reality after being repeated over and over and after being picked up by the various forms of media: print and electronic. The response of the aquaculture community to the critics has received much less attention, though it has been significant. The topic has taken up an incredible amount of time over the past couple of decades and is discussed in some detail in this book. Tiersch and Hargreaves (2002) discussed how the aquaculture community can respond sensibly to the controversy that surrounds their profession.

Lists of additional sources of information can be found at the end of each chapter. Those of you who have caught or will catch the aquaculture fever and would like to delve more deeply into the complex and very interesting world of aquatic plant and animal production are encouraged to look at the wealth of additional, and often much more technical, material that exists. The sources listed under the Additional Reading sections at the end of the chapters are mostly books, since they are readily available in many libraries and from booksellers, particularly booksellers who have internet sites. The books contain thousands of additional references to the scientific literature.

Aquaculture is a risky business. Some who have been involved with the subject for a number of years have indicated that commercial aquaculturists should include, in their balance sheets, plans for a total crop failure once every six or seven years. In addition, the aquaculturist is, in most cases, at the mercy of the marketplace in terms of how much money will be obtained upon sale of the product.

While risky and requiring a lot of hard work, aquaculture can also be highly satisfying. It is often a family activity as well. Salmon fishermen in Norway are commonly also salmon farmers. While one spouse is off on a commercial fishing boat, the other spouse and children tend the fish cages.

Speaking of family involvement, when I was a graduate student conducting research on channel catfish, there were many nights when thunderstorms caused power failures. You would find my wife, Carolan, standing with me splashing water with paddles in fish tanks to help maintain the oxygen level until the power was restored: hard work lasting into the wee hours of the morning, yes. But we also have looked back on such experiences with fond memories, particularly since we were able to save the fish upon which my doctoral degree depended.

Fish farming may mean the occasional vehicle in a pond, tractor stuck in the mud, getting grabbed on the thumbs by an aggressive crab or getting spined by a fingerling catfish. Frustrating, and sometimes costly or painful when such things happen, at least some of them are looked back on as humorous incidents months or years later. My experience with aquaculture has involved teaching, research and providing advice. I have never had to raise a crop for a profit, but I fully understand the difficulties involved and also the pride when one sees the crop on the truck headed for the market. My hat is off to those who are commercial aquaculturists. To those who read this book, my intention is to provide you with some insight into the complexity of this discipline we call aquaculture.

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1 The Who, What, When and Where of Aquaculture

Definitions

Many definitions of aquaculture have been proposed. The one I have used is as follows: *Aquaculture is the rearing of aquatic organisms under controlled or semi-controlled conditions*. This is a fairly simple definition, but it can be boiled down even more to simply *underwater agriculture*.

Let us break down the longer of the two definitions of aquaculture into its components. The term 'aquatic' refers to a variety of water environments, including freshwater, brackish water and marine.[1] 'Aquatic organisms' that are of interest with regard to human food include a wide variety of plants, invertebrates and vertebrates. Mariculture is a term reserved for the culture of organisms in saltwater (from brackish to full strength seawater).

While the above definitions are fairly simple, they embrace an extremely broad and complex topic that involves a broad array of scientific disciplines along with engineering, economics, business management and trade skills. The serious student of aquaculture should have experience (and preferably have taken formal courses) in mathematics, chemistry through at least organic chemistry, physics, biology, business management and economics, and if possible, some basic engineering. The practising aquaculturist also needs to be able to drive trucks, tractors and have skills in plumbing, electrical wiring, welding, painting and carpentry. Experience in pouring concrete will also come in handy. As you read on, the reasons for having knowledge and skills in the areas mentioned should become apparent.

One-person or one-family operations are becoming much less common as the field develops, so it is not always necessary for an individual to have all the background and skills mentioned. As long as all those components exist within the staff, the enterprise should be able to function effectively.

[1]The amount of salt in the water is known as its salinity. Freshwater is nearly salt free, while full seawater contains about 3.5% (35 parts per thousand or 35 ppt) of salt. Brackish water has salinities intermediate between freshwater and full seawater.

The amount of control that is exerted by the aquaculturist can vary significantly. Spreading oyster shell on the bottom of a bay to provide a surface for the settlement of larval oysters is at one extreme, while operation of an indoor hatchery for fish that incorporates a water reuse system (see Chapter 2) is at the other. The oyster example would fit the definition of extensive aquaculture where the culturist has little control over the system but merely provides a more suitable environment for the animals. When operating a recirculation system, the aquaculturist exerts a high level of control and the system is called intensive. There are a number of other approaches that lie somewhere in between those two extremes, so we can view aquaculture approaches as ranging broadly from very simple to highly complex, or perhaps more precisely, as ranging from systems that employ little technology to those that rely heavily upon the very latest in technology. It can be argued that as the amount of technology involved in the culture system increases, so does the amount of control that the culturist has over the system. One can also argue that as the level of technology employed increases, so does probability of system failure.

Aquaculture organisms tend to be classified as having a preference for warm, cool or cold water. While not absolute, warmwater species tend to grow optimally at or above 25°C (for example, catfish and tilapia), while coldwater species exhibit optimum growth at temperatures below 20°C (trout, salmon, halibut). Coolwater species grow best at temperatures between 20°C and 25°C (walleye, yellow perch). Most commercially cultured species are either of the warmwater or coldwater variety, while some sport fish, as mentioned in the examples, fall into the mid-range group.

Culture systems may involve the production of one species (monoculture) or they may contain two or more species (polyculture). The latter approach is perhaps best exemplified by Chinese carp culture in which several species of carp are produced in the same pond, with each species using a different food source. Grass carp would eat higher plants, silver carp and bighead carp would consume plankton,[2] with silver carp eating phytoplankton and bighead targeting zooplankton. Other carp could feed on organisms living in the mud or may be provided with feed by the farmer. Fertilization is used to promote the growth of the plankton and other communities that are used as food.

Many terrestrial plants can be grown by immersing their roots directly into water or planting them in soils through which water flows. That method of growing plants is called hydroponics. If the water is used for growing both plants and aquatic animals, the technique has been called aquaponics, which is a form of polyculture.

[2]Planktonic organisms are those that are suspended in the water column and have limited ability to swim, so they are at the mercy of currents. The plant component of the plankton is the phytoplankton community, which is comprised of small, often microscopic, single-celled and multi-cellular algae. The animal component of the plankton is referred to as zooplankton.

Why Aquaculture?

You have undoubtedly seen stories on television or in magazines and newspapers or heard them on the radio about the fact that many of the world's capture fisheries are in decline. Some, like the New England cod fishery and the North Atlantic halibut fishery, have collapsed. It was estimated many years ago that the world's oceans can produce sufficient amounts of fish and shellfish to allow for about 100 million metric tonnes[3] to be harvested annually. In fact, that level of harvest was reached in the 1990s and has not increased since then. As fisheries have declined, new species have been targeted. Squid, popularly sold as calamari today, were not available in many western hemisphere markets until about the 1980s as there was no market for them, though historically, a market has existed, particularly in parts of Asia. Only by finding new target species was the annual harvest from the sea maintained.

Today, we are in a situation where the capture fisheries are being fully exploited or overharvested in nearly every case, yet the demand for seafood continues to rise. That increase in demand is fuelled in part by the increasing human population but also by rising *per capita* consumption of seafood. We have all heard about studies that seem to show certain health benefits from eating fish. One recent recommendation was that everyone should eat at least two fish meals a week. So, demand is increasing, while the supplies of fish are not increasing. How can we resolve this dilemma?

The answer that has been widely touted is aquaculture. The average consumer does not see any reduction in the availability of seafood in restaurants or supermarkets and the overall amount of seafood in the markets of the world continues to increase, despite the fact that capture fishery volumes are not increasing. This is because aquaculture has been able to fill the gap. Currently, at least 20% of the fish and shellfish marketed globally are produced by aquaculturists and that percentage can only be expected to grow.

While the demand for aquacultured products is increasing, opposition to aquaculture, or at least to many aquaculture practices, is also increasing and is so strong in at least a few countries that it has curtailed some forms of aquaculture development. That issue is explored in more detail later in this chapter.

History

Aquaculture has been practised for millennia. Its origins appear to be rooted in China, perhaps as long ago as 2000 BC. The first known written record describing aquaculture and its benefits was a very short book in Chinese written by Fan Li in 460 BC. The Japanese reportedly began farming oysters intertidally about 3000 years ago, and pictographs from the tombs of the Pharaohs of Egypt show people fishing for tilapia in what appear to be culture ponds.

[3]A metric tonne is 1000 kg. Throughout this book use of the word 'tonne' implies metric tonne.

Oysters were cultured by the Romans nearly 2000 years ago (Beveridge and Little, 2002). Preceding that by a few hundred years was prototype aquaculture associated with the Etruscans who managed coastal ponds for fish production.

Native Hawaiians constructed hundreds of coastal ponds that were flooded as a means of stocking them with marine organisms, which were then allowed to grow to the desired size for harvest (Costa-Pierce, 2002). Pond construction preceded the discovery of the Hawaiian Islands by Captain Cook in 1778 by perhaps 500 years. Seaweed culture in Korea apparently dates back to the 15th century.

For literally thousands of years aquaculture was practised as an extensive form of agriculture by fish and shellfish farmers who shared techniques among themselves and also learned through trial and error. In the late 19th century, advances in aquaculture began to be associated with the development of new technology by naturalists and others who brought a more scientific approach to the discipline. The first applications of science to aquaculture can be attributed to workers in Europe and North America.

In 1871, Spencer F. Baird, then Secretary of the Smithsonian Institution in Washington, DC, convinced the US Congress that an agency was needed to develop methods to increase the supply of fish in the nation's waters. Some aquatic animal populations were already in decline due, in part, to overfishing. One of the first things Baird did once the US Fish and Fisheries Commission was established that year was to hire fish culturists to develop the technology required to mass produce, transport and stock various marine and freshwater fish and shellfish in the nation's waters. Several of the very few fish culturists of the time, including Seth Green, Charles Adkins and Livingston Stone, were recruited to work for the Commission. As a result of the activities of those men and their colleagues in the USA and abroad – particularly in Europe – much of the basic technology associated with modern fish culture was developed. As the 20th century dawned, fish and shellfish were being stocked by the hundreds of millions. I like to think that if those early fish culturists were alive today, they would be able to walk into a modern hatchery and recognize much of what is going on. Computer controls (Fig. 1.1) and modern materials would be baffling at first, but those men would quickly understand and relate to them.

In the early years, glass jars were used to incubate fish eggs, fry were being reared in raceways (see Chapter 2), devices had been developed to aerate water, and various species were being transported live, not only throughout the USA, but also across the world's oceans. Jars are still sometimes used to hatch fish eggs, though today they are likely to be made out of plastic or plexiglass (Fig. 1.2).

Brown trout were introduced to the USA from Europe and rainbow trout were sent to Europe and New Zealand from the USA. Chinook salmon from the Pacific Northwest of the USA were shipped to New Zealand, where they continue to thrive. European carp were established in the USA, largely with the strong support of Spencer F. Baird. Carp quickly became a nuisance species and its culture was discontinued. The species became established and appears to be with us to stay. Details of the development of aquaculture in the USA can be found

Fig. 1.1. Computers are often used to control water flow rates and collect data on water quality in modern aquaculture facilities.

Fig. 1.2. Plexiglass containers used to hatch marine fish eggs in a research laboratory.

in the book by Stickney (1996) which is on the additional reading list at the end of this chapter.

Interest in recreational fishing in both Europe and North America led to the establishment of hatcheries responsible for stocking fish of interest to anglers. Commercial aquaculture was a cottage industry during the first half of the 20th century and involved only a few trout farms. Most of the fish being raised – which included trout but also quite a number of other freshwater and marine species – were produced for stocking by government agencies at the state and federal levels. Parallel activities were underway in Europe. During the 1930s, tilapia were introduced from their native North Africa and the Middle East to tropical Asia where they quickly became established. The average Filipino, Malaysian or Indonesian undoubtedly thinks tilapia are native to their countries since they have been there for so long.

The decade of the 1960s represents the period when aquaculture began to capture the attention of entrepreneurs, university researchers and the public in the developed world. Trout farming was expanding in the USA; research in Great Britain on plaice was underway; aquaculturists in the southern USA attempted to produce buffalo fish, but soon turned their attention to channel catfish; research on tilapia had begun in various nations; various tilapia species were introduced to the Americas; and interest among researchers to develop even more culture species blossomed.

This is not to say that aquaculture was not a prominent activity in other locations and with other species by the 1960s. In their landmark treatise on aquaculture, Bardach *et al.* (1972) chronicled the state of affairs around the world and presented detailed information on the methods used to produce a variety of seaweeds, fish and shellfish. At that time, production was largely for domestic consumption and was centred in Asia. International trade in aquaculture products had yet to be developed. Bardach described techniques associated with the production of common carp, Chinese carp, Indian carp, catfish, tilapia, milkfish, eel, trout, salmon, striped bass, yellowtail, flatfish, shrimp, crayfish, crabs, oysters, clams, cockles, scallops, mussels, seaweeds and others, including species of primarily recreational fishing interest. Some species were of local interest (e.g. yellowtail in Japan), while others, such as common carp, were being cultured in many nations. Carp culture was occurring in Europe (including eastern Europe), and had been for centuries. Other carp-producing countries were Haiti, India, Israel, Indonesia, Japan, Nigeria, the Philippines, the United Arab Emirates and the former USSR. In the USA, the channel catfish industry was growing rapidly but had only been in existence a little over a decade by 1972. Catfish quickly replaced buffalo fish as the warmwater species of choice by US aquaculturists.

There was some interest in developing economically viable culture techniques for such difficult-to-rear species as pompano and lobsters, but aquaculture of many species, particularly in the tropics, was largely a subsistence activity. That is, fish were being cultured by small farmers primarily for home or village consumption.

Compared with production levels in the early years of the 21st century, those of the 1960s tended to be very low. For example, channel catfish farmers in the USA produced from about 500 to 1000 kg/ha[4] in their ponds, compared with up to ten times those levels today. Feeds were primitive, diseases and their treatment were not well understood, and water quality requirements had not been well defined. Those problems were attacked with vigour during the 1970s and progress was rapid. There was a great deal of optimism surrounding the notion that aquaculture could fill the anticipated gap between supply and demand of fisheries products as the predicted peaking of the supply of products from the world's capture fisheries grew increasingly imminent.

In the USA, a few government laboratories and various academic institutions became interested in aquaculture before there was much of a commercial industry. Unlike the development of agricultural research, which came in response to the needs of farmers, aquaculture research actually was out in front of the industry's development in many instances. Part of the explanation for the difference lies in the fact that techniques associated with the culture of the few species that were commercially reared prior to the 1960s had been developed in government hatcheries for the purpose of stocking the nation's waters. Only a few farmers had adopted the techniques and begun commercial production. In most instances, researchers in universities evaluated new species that might be of commercial interest and developed the technology needed for successful farming before the commercial industry for those new species became established.

Most species of interest to terrestrial farmers – both plants and animals – were already being grown in the USA prior to recognition by producers of the need for research. Thus, farmers drove the impetus for agricultural research. The opposite was largely true for aquaculture, where researchers often developed the techniques required to rear new species before commercial culturists became interested. As a corollary, there are few, if any, new species being developed for agriculture (genetically engineered organisms aside), while aquaculture researchers continue to search for new species that might be adopted by producers.

Some desirable species have proved difficult to culture. Included are American and Florida lobsters, along with many species of crabs. Rearing of Florida lobsters is impeded by the fact that their larval stage is several months long. During those months the larvae are rather feathery in appearance and are very fragile. If two of them come into contact with one another, they will become intertwined and will die. American lobsters – the ones with the big claws or chelae – are highly cannibalistic. When one animal in a confined area such an aquaculture tank moults[5] it is vulnerable to attack by others that are present. Crabs typically exhibit the same behaviour as American lobsters. The result of stocking a large number of lobsters or crabs in a single container may

[4]kg/ha = kilograms per hectare. A hectare is 10,000 square metres.
[5]Moulting, or ecdysis, is a process by which lobsters and other crustaceans shed their hard shell (exoskeleton) and are very soft and vulnerable to predation for a few hours until the new exoskeleton forms. It is during this time that a good deal of water is taken up, thereby increasing the lobster's size. Water is traded for tissue as the lobster grows into its new exoskeleton.