Part I

Health Maintenance

Fish health maintenance emphasizes many areas that affect the health of cultured fishes. It requires continuous efforts, which include the following: the location and construction of a culture facility; selection and introduction of culture species; and reproduction, culture, and harvesting of the final product. The aquatic habitat—a dynamic and continuously changing environment—is affected by structural material, facility design, soil quality and type, volume, and quality of water, fish species present, amount and quality of nutrients introduced into the system, climate, and daily human activities.

Health maintenance involves a series of principles that apply to most farm-raised animals. However, fish tend to react more quickly to environmental change than terrestrial farm animals. Because of their homeothermic nature, most terrestrial farm animals respond comparatively slowly to unfavorable environmental conditions, whereas fish—being poikilothermic—respond quickly and often fatally to handling, temperature change, excessive or insufficient dissolved gasses in the water, metabolites, or chemical additives, and so forth, to which they are un-

able to adapt. These factors also increase fish susceptibility to infectious agents and compromise their immune response.

Specific areas of concern addressed in this book include principles of health or health maintenance, epizootiology and pathology of fish diseases, disease recognition, basic concepts in disease diagnosis, and prevention and control of infectious fish diseases. Aquatic animal health management encompasses the entire production process, including disease diagnosis and treatment.

The objective of health maintenance is to help control environmental fluctuations through management practices, thus reducing the magnitude of change and producing a more economical, healthier, and better quality product. The ultimate goals of health management are (1) disease prevention, (2) reduction of infectious disease incidence, and (3) reduction of disease severity when it occurs. Successful health maintenance and disease prevention or control do not depend on any single procedure but are the culmination of the application of integrated concepts and exercising management options.

Chapter 1

Principles of health maintenance

"An ounce of prevention is worth a pound of cure" is a familiar phrase that describes one approach to the culture of food animal resources. Health maintenance is a concept in which animals are reared under conditions that optimize the growth rate, feed conversion efficiency, reproduction, and survival while minimizing problems related to infectious, nutritional, and environmental diseases, all within an economical context. "Health maintenance" encompasses the entire production management plan for food animals, whether they are swine, cattle, poultry, or fish. Aquaculture involves man's intervention in the growth process of fish and other organisms in an aquatic environment. The degree of intervention is progressive, ranging from extensive (few fish per unit of water volume) to increasingly intensive (comparatively greater numbers/weight of fish per unit of water volume) in ponds, raceways, cages, and recirculating systems where higher fish densities are maintained. As culture becomes more intensive, need for intervention increases accordingly, and principles of health maintenance become of greater importance. These principles apply to aquaculture around the world, regardless of fish species, culture method, or climate.

Fish health management is not a new approach to aquaculture. Snieszko (1958) recognized the need for health maintenance in fish culture when he stated, "We are beginning to realize that among animals (including fish) there are populations, strains, or individuals that are not susceptible all of the time, or even temporarily, to some of the infectious diseases." He theorized that fish possess a certain level of natural resistance to infectious diseases that can be enhanced through proper management, and that environmental stressors and/or fish cultural practices can adversely affect that natural resistance. Another contributor to a health maintenance concept for aquatic animals is Klontz (1973), who established a fish health management course at Texas A & M University that combined fish culture and infectious diseases into health management. The Great Lakes Fishery Commission published a *Guide to Integrated Fish Health Management in the Great Lakes Basin,* which was a regional concept for fish health management (Meyer *et al.* 1983). These references deal with the improvement of aquatic animal health through management. The most in-depth contribution to maintaining health of domestic (cultured) animals was Schnurrenberger and Sharman (1983), who set forth a series of principles for animal health maintenance, which apply in a general sense to all domesticated food animals.

In the following pages these principles are applied to aquaculture. Theoretically, if these principles are utilized in daily, monthly, yearly, and long-term management of an aquatic culture facility, there will be fewer environmental and disease problems and optimum production will be more readily obtained.

Biosecurity is the term recently applied to fish health management (Bebak-Williams *et al.* 2007) in which biosecurity is aimed at reducing the risk of pathogens being introduced to a facility, reducing the risk of pathogens being spread throughout the facility, and alleviating conditions that increase susceptibility to infections. It is emphasized that biosecurity cannot completely prevent entry of or eliminate all pathogens from the culture facility but emphasizes reduction of pathogens rather than their complete elimination. Biosecurity begins with selection of the aquaculture site and continues throughout production with complete control of water and human access.

Health maintenance

In an aquatic environment, there is a profound and inverse relationship between environmental quality and disease status of fish. As environmental conditions deteriorate, severity of infectious diseases increases; therefore, sound health maintenance practices can play a major role in maintaining a suitable environment where healthy fish can be grown. The aquatic environment is a dynamic ecosystem that changes over a 24-hour period and seasonally, particularly in ponds with limited water exchange. Tucker and Van der Pflog (1993) noted that in static catfish ponds, periods of poorest water quality occurred during summer months when feeding, temperature, and standing crops were at a maximum, but rainfall and available water were at a minimum, thus producing a higher potential for stressful conditions requiring health management.

Fish health management is a positive concept that aids in disease prevention, empha-

sizes interruption of a disease cycle, deals with multiple segments of health maintenance, and results in more efficient production. Health maintenance does not simply target infectious diseases, but emphasizes proper utilization of physical facilities; use of genetically improved fish and certified "specific pathogen free" (SPF) stocks whenever available and/or feasible; environmental control; prophylactic therapy; feed quality and quantity, pond, cage, raceway, tank, or recirculating system management; control of vegetation; aeration and use of other water quality maintenance practices; and a management commitment to provide an optimum habitat in terms of water quality for fish being cultured. Its goal is to improve the health and well-being of animals that appear to be generally healthy. If sound health maintenance principles are followed, production will be more efficient and result in a healthier product. Obviously, all activities, policies, and improvements must be based on sound economic criteria.

Stress

"Stress" is difficult to define because it is used to describe many adverse situations that affect the well being of individuals, but generally it is the reaction of an animal to a physical, physiological, or chemical insult (Barton 1997). Stress may also produce a nonspecific response to factors that are perceived as harmful; however, stress in fish is usually related to handling, transport, environmental quality, or fright. For clarification in this text, "stressors" are factors that cause a "stress response," which is the sum of physiological changes that occur as fish react to physical, chemical, or biological stressors as the fish attempt to compensate for changes that result from these stressors (Wedemeyer 1996). The corticosteroid level in plasma is the usual quantitative measure for stress; however, amounts of glucose, lactic acid, and ions will also increase during stressful conditions (McDonald and Milligan 1997).

The aquatic environment is in a continuous state of flux, and because fish are poikilotherms and body functions are controlled by temperature, oxygen concentration, and many other water quality parameters, they must continually adapt physiologically to environmental changes. An inability to adjust to these changes may be manifested in lower productivity, reduced weight gain, poor feed conversion, decreased immunity, reduced natural disease resistance, increase in infectious disease, lowered hardiness in general, death, reduced profits for the commercial fish farmer, and reduced production.

Some commonly known stressors in the aquatic environment are unionized ammonia, nitrite, chronic exposure to low concentrations of pesticides or heavy metals, insufficient oxygen, high concentrations of carbon dioxide (CO_2), rapidly changing or extremes in pH or water temperature, external salinities, nutrition, and fish density (Barton 1997). Low alkalinity and hardness are also not conducive to good fish health or performance (Boyd 1990). Many of these factors are exacerbated by type, quality, and quantity of feed put in a pond, and by waste accumulation. Sensitivity to these conditions will vary with fish species. Successful and efficient health maintenance programs for aquaculture facilities will include measures to reduce and modify stressful conditions that may be present in a fish population.

Hazard reduction by management

Experience has shown that a wide variety of viral, bacterial, parasitic, and other fish diseases will cause mortality if cultured fish are held in unfavorable environmental conditions (Wedemeyer 1996). Health and environmental management decisions are not independent and a change in one area should not be made without evaluating its effect in other areas. Notable stressor-related fish diseases that result from a culmination of management and biological factors are furunculosis, enteric redmouth, motile *Aeromonas* septicemia, columnaris, vibriosis, bacterial gill disease, streptococcus, external fungal infections, and some protozoan parasites (Table 1.1).

Stress on fish increases when environmental conditions approach the host's limit of tolerance (Snieszko 1973). For example, if water temperature is critically high and oxygen

Table 1.1 Microbial diseases of fish commonly considered stress *mediated*.

Disease	Predisposing Environmental Factor
Spring viremia of carp	Handling after over wintering
Bacterial gill disease	Crowding, poor water quality, elevated presence of causative bacteria
Columnaris	Crowding, poor water quality, handling, seining, adverse temperature, physical injury
Cold-water disease	Temperature decrease from >10°C to <10°C
Enteric redmouth	High stocking density, elevated water temperature, handling, transport, poor water quality
Furunculosis	Low oxygen, handling, environmental stress
Motile *Aeromonas* septicemia	Injury to skin, transport, improper handling, temperature stress, poor water quality, other parasites
Ulcer disease of winter or goldfish and carp erythrodermatitis	Handling and stocking in late early spring
Vibriosis	Handling, poor environmental conditions, moving from freshwater to salt water
Streptococcicosis	Handling, poor water quality, parasites

Source: Walters and Plumb (1980), Piper *et al.* (1982), Roberts (1989), Wedemeyer (1996).

concentration is adequate, fish may survive, and if oxygen is critically low and water temperature is normal, fish may also adjust and survive. Multiple stressful parameters have a compounding synergistic effect on the fish, and even though the fish may be able to handle the stressors individually, the combined effect can be lethal. An example of environmental stressors and their synergistic effect on fish involves dissolved oxygen (DO) and CO_2 concentrations. Channel catfish can adapt to an elevated level of CO_2 (20–30 mg/L) if the DO concentration is optimal (Boyd 1990). However, if the CO_2 level is critically high and DO is critically low, fish cannot eliminate CO_2 and will become listless (narcotized) and may die. If fish do adapt to these environmental stressors and survive, pathogen resistance is often compromised. Although salmonids require cooler water and higher oxygen concentrations, these factors are often offset in salmonid culture because in most instances the fish are reared in flowing water from springs or streams. These waters have more consistent temperatures and higher oxygen concentrations and lack high organic loads.

A theory of host/pathogen/environment relationship was applied to fish with regard to development of infectious diseases by Snieszko (1973) (Figure 1.1). This theory is based on the premise that to have an infectious disease, a host and pathogen are required but an unfavorable environmental condition often acts as a trigger for disease to develop. Potential pathogens are often endemic in surface waters, especially in warm-water fish culture, and only environmental conditions and/or the hosts natural resistance can dictate onset of the disease process. The interaction of these factors is expressed in the equation:

$$H(A + S^2) = D,$$

where:

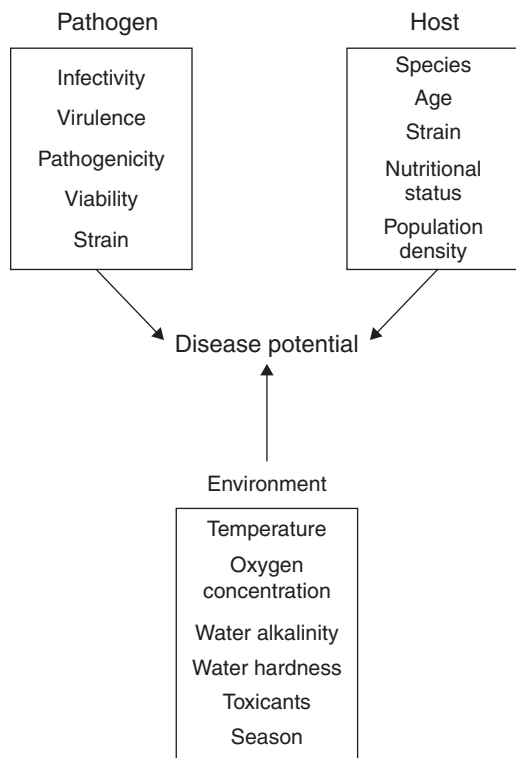H = Species or strain of host (natural resistance)

Figure 1.1 Variables of infectious agents, host, and environment that influences disease occurrence. (Adapted from Snieszko (1973) and Schnurrenberger (1983a).)

A = Etiological agent
S = Environmental stressors
D = Disease

Environmental stressors are squared because as fish approach adaptation limits, stressors increase accumulatively rather than additively. Also, when more than one stressor is involved (oxygen, ammonia, CO_2, temperature, etc.), detrimental factors act synergistically.

There is a relationship between water quality deterioration and bacterial infection. A sudden die-off of cyanobacteria (blue-green algae) in a channel catfish pond was followed by reduced DO production, decreased pH, and increased CO_2 and NH_4 (Plumb *et al.* 1976). These water quality changes in the pond resulted in "oxygen depletion" and
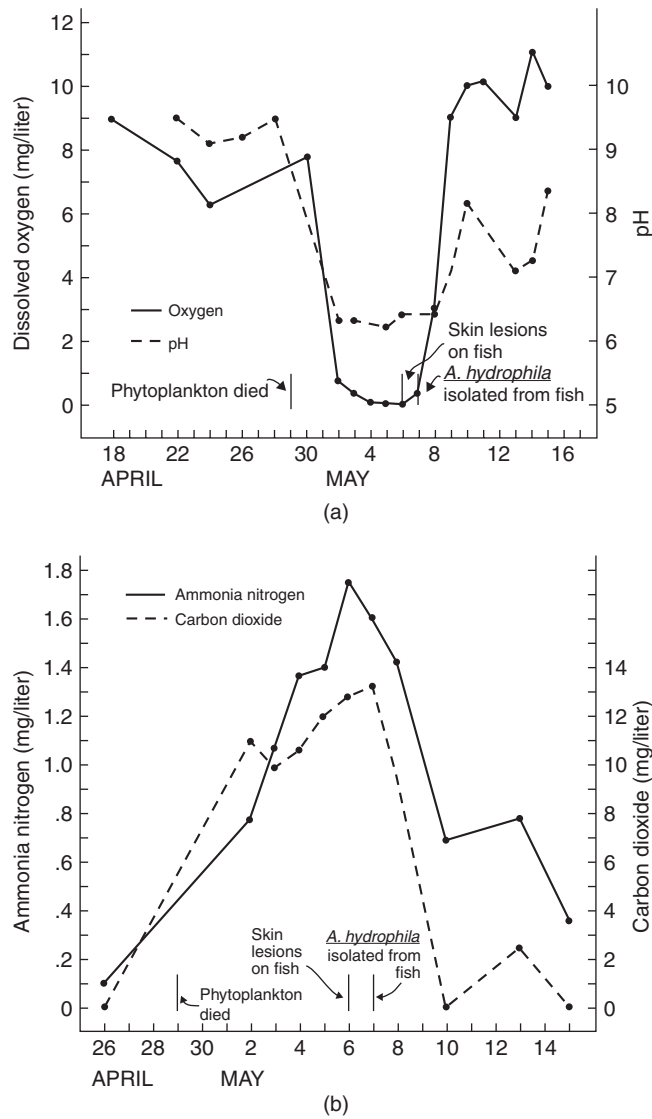
Figure 1.2 Water quality parameters before, during, and after a channel catfish mortality and subsequent *Aeromonas hydrophila* infection (Plumb *et al.* 1976). (Printed with permission of *Journal of Wildlife Diseases*.)

a fish kill (Figure 1.2). This phenomenon has since been described by R. Schmittou (Department of Fisheries and Allied Aquacultures, Auburn University, Alabama, personal communication) as "low dissolved oxygen syndrome" (LODOS), which refers to the fact that low DO is part of an environmental condition that includes a variety of separate but interrelated elements. When fish first

began to die as DO dropped below 1 mg/L, no bacteria or other significant pathogens were found during necropsy. However, 4 days after oxygen depletion, channel catfish were found with hemorrhaged and depigmented skin and muscle lesions (Figure 1.3). When first observed, no bacteria were isolated from internal organs or skin–muscle lesions of these fish, but 2 days later and for several days thereafter,

Figure 1.3 Channel catfish with depigmented, hemorrhaged, and necrotic lesions that appeared 6 days after oxygen depletion (Plumb *et al.* 1976). (Printed with permission of *Journal of Wildlife Diseases*.)

Aeromonas hydrophila was isolated from both. When freshwater was added to the pond and remedial aeration provided, mortality ceased and clinical signs of infectious disease abated. It was theorized that while the water had low oxygen concentrations, some muscle areas in the fish became hypoxic, which led to tissue necrosis, hemorrhaging, and skin depigmentation. When protective epithelium integrity was lost, naturally occurring opportunistic *A. hydrophila* invaded the muscle beneath areas where skin had been injured and focal infections were established, which progressed into septicemia. Walters and Plumb (1980) demonstrated that low oxygen, low pH, high ammonia, or high CO_2 alone was not particularly stressful and did not lead to bacterial disease. However, if two or more of these adverse environmental conditions occurred simultaneously, infection was much more likely to occur (Figure 1.4).

Intensive fish culture causes unique but manageable environmental problems for the aquaculturist (Piper *et al.* 1982; Boyd 1990; Wedemeyer 1996). All fish require adequate water maintained at a suitable temperature and oxygen concentration level for proper growth and reproduction. Water temperature
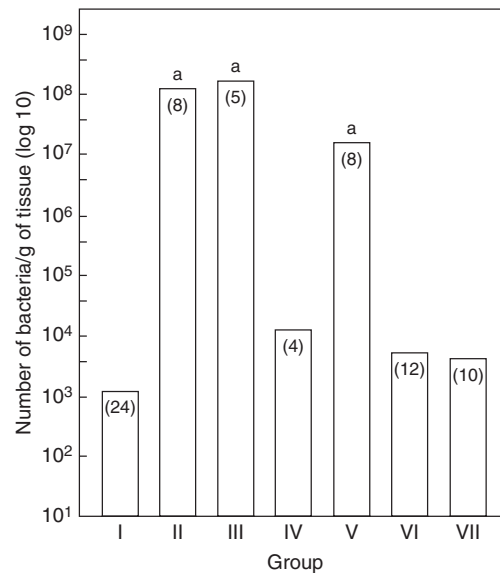

Figure 1.4 Number (CFU) of bacteria per gram of trunk kidney from channel catfish held in various environmental conditions. (i) Low dissolved oxygen (DO) only; (ii) Low DO, fish injected with *A. hydrophila*; (iii) Low DO, fish injected with *A. hydrophila*, NH_3 added; (iv) Low DO, fish injected with *A. hydrophila*, NH_3, and CO_2 added; (v) Low DO, fish injected with *A. hydrophila*, CO_2 added; (vi) Aeration, fish injected with *A. hydrophila*; (vii) Noninjected fish in aerated water. Number of fish samples in parentheses; significantly higher numbers of bacteria are designated by "a" (Walters and Plumb 1980). (Printed with permission of the *Fisheries Society of the British Isles*.)

Table 1.2 Range of temperature tolerance, optimum temperature for growth, and spawning temperature of selected cultured fishes.

Commmon Name	Temperature		
	Range	Optimum	Spawning
Atlantic salmon	1–24	10–17	7–10
Brook trout	1–22	8–13	8–13
Brown trout	1–25	9–17	9–13
Channel catfish	4–35	28–30	25–27
Chinook salmon	1–25	10–14	8–13
Coho salmon	1–25	9–14	8–13
Common carp	4–35	23–30	13–27
Eel	4–35	25–28	16–17
Grass carp	4–35	22–30	22–27
Lake trout	1–21	7–14	9–11
Largemouth bass	4–35	13–27	16–20
Milkfish	10–35	25–35	23–32
Northern pike	1–27	4–18	4–9
Rainbow trout	1–25	10–17	10–13
Sockeye salmon	1–21	10–15	8–12
Striped bass	2–32	13–24	13–22
Tilapias	15–35	23–32	23–32
Walleye	1–27	8–16	9–13
Walking catfish	13–38	20–30	20–30

Source: Ney (1978), Piper *et al.* (1982).

requirements will vary from species to species (Table 1.2). For example, channel catfish require a water temperature of 20–30°C for growth (optimum of 28°C), and they spawn at 27°C. They prefer oxygen concentrations above 5 mg/L. They will survive at 1–5 mg/L of oxygen, but prolonged exposure below 1 mg/L is lethal. If oxygen levels drop below a critical concentration, supplemental aeration is necessary as either a routine practice or as emergency management (Figure 1.5). For comparison, rainbow trout require water temperatures of 8–18°C for growth, spawn at temperatures as low as 6°C, and require oxygen concentrations above 5 mg/L. At the other extreme, walking catfish of Southeast Asia can survive water temperatures above 35°C and very low oxygen concentrations. However, these fish have an auxiliary gill that allows them to extract oxygen directly from the air. Extreme high or low water temperatures may result in greater fish susceptibility to viral, bacterial, and parasitic diseases (Austin and Austin 1987).

For a fisheries manager, biologist, or diagnostician to understand infectious fish diseases, he/she must also understand how and to what extent the environment affects the host and disease. It is not enough to simply identify a pathogen or parasite; it is equally important to identify and understand environmental stressors that predispose fish to disease. When stressors are known, corrective and preventive measures can often be initiated to help prevent or minimize a reoccurrence of the condition. In the aquatic world, maintaining an optimal environment is essential to good animal health. Extreme deviations will result in stress manifested by reduced feeding, higher feed conversions, poor growth, disease, or death.

Location, soil, and water

Choosing a proper site for an aquaculture facility is paramount to its success. Land topography, soil quality, water quality and abundance, and proximity to market are primary
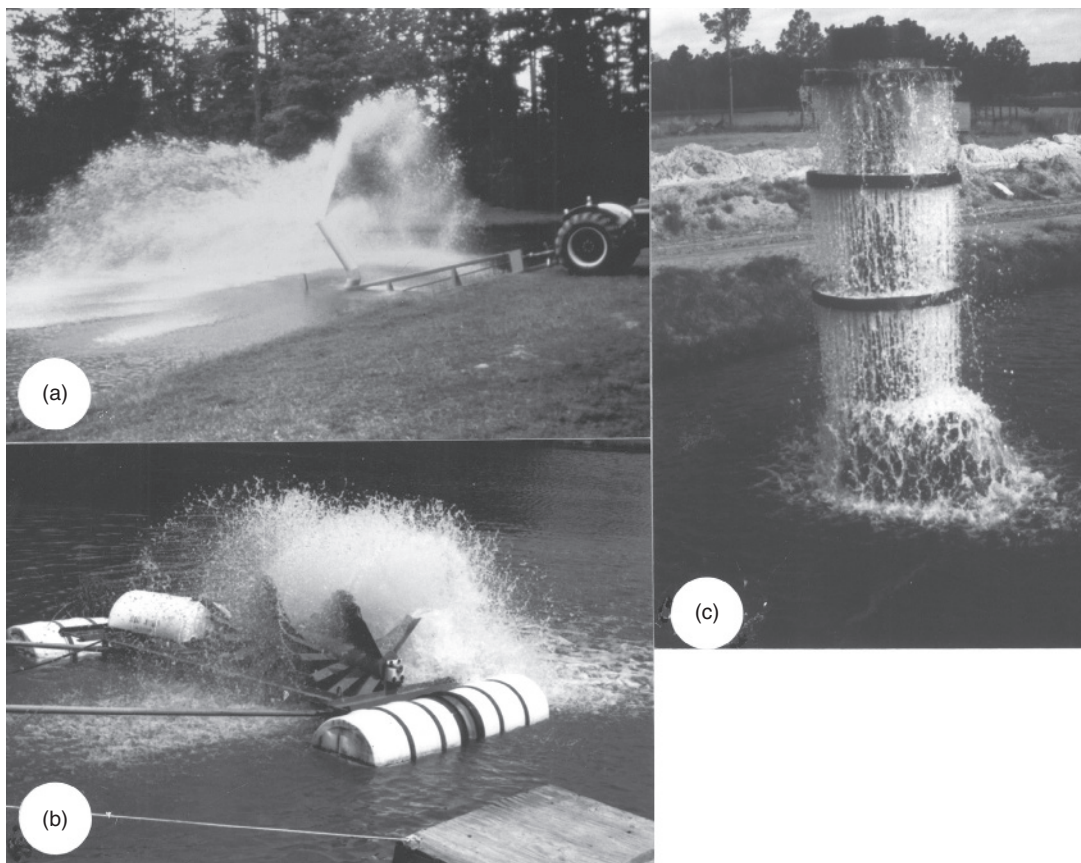
Figure 1.5 Routine and emergency aeration with (a) water pump attached to tractor power takeoff, (b) electric paddle wheel in a catfish pond (could also be powered by tractor power takeoff), and (c) aeration by flowing water over a column of perforated plates.

factors to be considered when choosing a location. To maintain healthy fish populations, soil, water, and fish species to be grown must be compatible. Sometimes environmental modifications can be made to accommodate a species not indigenous to a specific area but these modifications must be cost effective. For example, channel catfish are not normally grown in northern latitudes of the United States because of a short growing season and lack of warm water. However, if artificially heated water from power plants or geothermal supplies are available, channel catfish or other warm-water species can be grown successfully, although seldom economically. Another example of culturing fish species out-

side of their normal geographical range are tilapia, which require water temperatures of over 18°C for survival and over 24°C for optimum growth. However where adequate volumes of artificially heated water is available these fish can be successfully grown in temperate and cool regions.

Some soil requirements for culture ponds are very specific. Soil must have a high clay content to prevent ponds from leaking; leaky ponds are unstable, do not retain a suitable plankton bloom to shade out rooted vegetation, and require continuous water replenishment. Conversely, in an analysis of chemicals naturally present in soil, Boyd (1990) stated that it is possible to rear fish in ponds built

Table 1.3 Water quality criteria for optimum fish health management of warm water and cold water species of fish (mg/L except for pH).

Characteristic	Cold Water	Warm Water
Oxygen	5-saturation	5-saturation
pH	6.5–8	6.5–9
Ammonia (un-ionized)	0–0.0125	0–0.02
Calcium	4–160	10–160
Carbon dioxide	0–10	0–15
Hydrogen sulfide	0–0.002	0–0.002
Iron (total)	0–0.15	0–0.5
Manganese	0–0.01	0–0.01
Nitrate	0–3.0	0–3.0
Phosphorus	0.01–3.0	0.01–3.0
Zinc	0–0.05	0–0.05
Total hardness ($CaCO_3$)	10–400	10–200
Total alkalinity ($CaCO_3$)	10–400	10–400
Nitrogen (gas saturation)	<100%	<100%
Total solids	0–80	50–500

Source: Piper *et al.* (1982), Boyd (1990), Hajek and Boyd (1994).

on soils that have wide ranges of chemical properties.

Certain regions have acid-sulfate soils containing high levels of iron pyrite (Boyd 1995). As long as these soils are submerged, the iron pyrite is stable and usually causes no problem. However, when the pond is drained and the bottom exposed to air, iron pyrite is oxidized and upon dehydration sulfuric acid is produced. Upon refilling the pond, the water becomes highly acid (pH may be as low as 3.5), rendering an unproductive environment. Generally, such areas should be avoided for aquaculture sites, but the acidity level can be corrected to some degree by addition of huge quantities of lime.

It is important that pond soil is free of chemical and pesticide residues. If toxicants, usually of anthropogenic origin, are present, they can leach into the water and kill fish. Concern is not only with soil used in pond construction but also with soil in the watershed; therefore, prior to construction of a culture facility, watersheds should be inspected for toxicants that could contaminate the water supply.

The most important ingredient in successful fish health management is water quality and its availability. Water quality as described by Boyd (1990) varies, but most water can be made suitable for aquaculture, except under unusual circumstances. Water hardness, alkalinity, pH, presence of toxicants, or dissolved gases are important in aquaculture (Table 1.3). Before construction of a fish farm, water quality, volume, and reliability of the water source must be determined.

Water sources for aquaculture may be lakes, rivers, springs, pumped or artesian wells, surface runoff, or irrigation canals. From a fish disease management standpoint, springs or wells are preferred because these sources are free of wild fish that may be carriers of infectious disease agents. However, from a water quality standpoint, these sources may not be usable without modification because of acidity, low DO, and/or high concentrations of CO_2 or nitrogen gases, which require removal. These waters may be very soft (less than 50 mg/L $CaCO_3$) or contain high concentrations of iron, sulfur, or manganese (Table 1.3). Although well and spring water may have a constant temperature, it may not be optimum for the aquaculture species to be cultured, thus requiring heating or cooling in the case of

geothermal sources. If pumping is necessary to utilize a water source, it can be expensive and prone to mechanical breakdowns and interrupted water flow. However, most water quality problems can be overcome by proper planning and management.

When streams or reservoirs are used as a water supply, there are inherent problems involved. Wild fish, including fry and eggs that harbor parasites, pathogenic bacteria, or viruses may be indigenous to these sources. These waters can be disinfected with ozone or ultraviolet light, but the efficacy of treatment depends on the physical nature of the water. For example, ultraviolet treatment is ineffective in silt or particulate-laden water. Also, surface waters including streams, reservoirs, and irrigation canals may be prone to wide seasonal temperature fluctuations, variable oxygen levels, silt loads, increased organic loads, volume fluctuations, or contamination with pollutants from municipal, industrial, or agricultural sources. Installation of sand and gravel filters or use of porous (saran) socks on inlet pipes are some options to prevent fish contamination.

Avoiding exposure

The ideal way to control infectious fish disease is to prevent exposure to pathogenic agents whenever possible, thus avoiding most devastating health problems through biosecurity (Bebak-Williams *et al.* 2007). However, when dealing with the aquatic environment, it is virtually impossible to define all disease-causing agents and to keep them isolated from the fish host. Water provides an excellent medium for transfer of many communicable agents from fish to fish or from locality to locality. Moreover, many disease-causing organisms are endemic to the aquatic environment and are opportunistic, facultative pathogens that remain viable under various conditions.

Since the mid-1960s some governments, fish hatcheries, and privately owned fish farms have made great strides in avoiding fish exposure to certain infectious diseases by using fish certified as specific pathogen free (SPF), quarantine, routine water disinfection, and by destroying populations that have become infected with specific pathogens. The pros and cons of the latter approach should be carefully weighed before making a decision to destroy or treat the fish. Paraphrasing a statement by Snieszko, "A disease management practice should not destroy more than it saves."

The earliest attempt to prevent fish exposure to infectious pathogens was when trout stocks known to be positive for infectious pancreatic necrosis virus (IPNV) were not used as egg sources; a practice that is now applied to other diseases. It is impossible to declare a fish group, or population, simply "disease free," implying they are free of all disease agents; therefore, the term "disease free" is limited to a specific pathogen. Currently, Specific Pathogen Free (SPF) certification is the best way to prevent introduction of unwanted pathogens into a "clean" facility, but it must be understood that testing procedures are not infallible because they are based on a statistically determined sample number of individuals taken from a larger population (AFS-FHS 2007). To detect a given pathogen with 95% confidence, the appropriate sample number for a 2% prevalence is 120 fish per 100,000 and for a 5% prevalence, 60 fish per 100,000 (Simon and Schill 1984). However, Thorburn (1996) indicated that these numbers may not be uniform for all diseases and all fish species. In some instances a larger number than recommended should be sampled to improve accuracy. Fish pathogen detection methods for determining SPF populations are discussed further in Chapter 3.

Many states have now established fish health protection programs that specify that incoming fish must be accompanied by a document certifying them SPF. California has one of the oldest and most rigorous fish health regulatory programs in the United States. Regional fish health plans have also been

established to prevent introduction of unwanted pathogens into geographically defined fish populations. The Colorado River Basin Council has a strong inspection program to prevent introduction of fish that are infected with certain disease agents into natural and/or hatchery waters. The Great Lakes Fisheries Commission initiated a regional fish health protection program for the states and Canadian provinces contiguous to the Great Lakes. The major problem with state and/or regional fish health regulations is statutory inconsistency and degree of implementation. However, they are a step in the right direction to prevent the spread of some fish diseases.

All Nordic countries have established coordinated surveillance and monitoring systems for fish diseases of concern to the fish farming industry (Hastein *et al.* 2001). The ultimate goal of the program is to eradicate or keep the level of disease to a minimum. According to the authors, due to these surveillance systems coupled with good management practices the fish disease situation in the Nordic countries is generally good compared to other countries of the world. Diseases included in the surveillance are viral hemorrhagic septicemia, infectious hematopoietic necrosis, infectious pancreatic necrosis, viral nervous necrosis, bacterial kidney disease, and furunculosis. However, remedial measures to be taken when a disease is found depend on the country in which it is found.

International fish disease control concepts are gaining support to keep pace with a growing, world-wide aquaculture industry. An increasing number of countries now require health certificates of some type verifying that certain imported fish products (alive or dead) are free of specific diseases. While not fool proof, these methods have generally been successful in inhibiting the spread of many infectious disease agents. Great Britain, the European Economic Union, Canada, and the United States all have regulations limiting fish movement with emphasis on fish health. Great Britain probably introduced the first fish health

regulation by passing the Diseases of Fish Act 1937 (Hill 1996) with several subsequent amendments. It is believed that it's continuous implementation has had a positive effect on the United Kingdom's fish industry. In the United States, Title 50 applies to Injurious Wildlife and requires that fish and/or fish eggs imported into the United States be certified free of certain pathogens. The European Union has directives that provide guidelines that must be met before aquaculture products are shipped into their sovereign territories to insure protection against introduction of exotic diseases (Daelman 1996). The European Union also has an operative fish disease control service that requires that all aquaculture facilities be inspected and registered. However, some countries such as Japan, consider aquaculture practices to be too diverse and extensive for implementation of an effective national disease control program (Wakabayashi 1996).

Quarantine is an approach to disease avoidance when fish are moved from one area to another. Fish should be isolated for a specific period of time before contact with a resident population. If disease develops in newly arrived animals, it can be dealt with more effectively and without exposing resident stocks.

Drastic measures such as eradication of an entire fish population from an aquaculture facility are sometimes necessary to avoid exposing healthy fish to highly infectious, nonendemic disease agents. When contemplating the eradication of a fish population, the economic, environmental, and biological significance of the disease should be considered. Is the disease indigenous to the area? Can it be adequately controlled through management or chemotherapeutics? In other words, is eradication worth the long-term potential savings in fish and can the facility be maintained free of the disease organism?

In 1989, an attempt was made to prevent establishment of viral hemorrhagic septicemia virus (VHSV) in the United States by destroying adult salmonids as they returned to spawn at two sites in the Pacific Northwest where

the virus had been found (Hooper 1989). This constituted the first confirmed VHSV occurrence outside Europe and so these drastic measures appeared to be justified. However, in subsequent years, the virus was found in different areas of northwestern United States, so eradication did not solve the problem (Winton *et al.* 1991). Viral hemorrhagic septicemia was detected in the Great Lakes region of Canada and the United States in 2005 (Paul R. Bowser, Cornell University, personal communication).

Destruction of lake trout and disinfection of contaminated hatcheries in the Great Lakes region of the United States and Canada in the late 1980s was apparently successful in eliminating epidermal epitheliotropic disease, a severe herpesvirus infection of juvenile lake trout (R. Horner, Illinois Department of Natural resources, personal communication); however, the disease eventually showed up in other locations. Also, a second fish eradication occurred in 1990 when salmonid brood stock at Jackson National Fish Hatchery (Wyoming) (Anderson 1991) and White Sulfur Springs National Fish Hatchery (West Virginia) (Cipriano *et al.* 1991) were killed because they were subclinically infected with *Renibacterium salmoninarum* (bacterial kidney disease, BKD). These two facilities were major egg suppliers for many federal and state agencies and could potentially contribute to the spread of BKD by egg distribution. Therefore, an administrative decision was made to destroy large numbers of valuable rainbow, lake, cutthroat, and brook trout. This decision was based on a highly sensitive ELISA method for detecting very low numbers of *R. salmoninarum*. The fish were killed in spite of the fact that neither facility demonstrated any evidence of clinical BKD. Snieszko's theory on the application of fish health management practices comes to mind: "Was the cost and consequence of implementation greater than the value of what was saved?"

Although infectious disease prevention is best accomplished through avoidance whenever possible, there are times when one must look beyond the host for a disease source. Some disease agents (helminths, for example) have complex life cycles that involve fish-eating birds, snails, or copepods, and the pathogen life cycle is broken by controlling non-fish vectors, a nearly impossible task. Another example of a disease agent that may have a non-fish vector is IPNV. This virus has been shown to be infectious after passing through the intestines of fish-eating birds (Peters and Neukirch 1986). It would be extremely difficult to prevent exposure of fish to these contamination sources in an endemic area.

Each disease outbreak must be considered individually and rarely will a general policy be applicable; therefore, "avoiding exposure" decisions must be made using biological facts and common sense, with an eye to the overall good of the aquatic environment.

Exposing dose

As previously noted, total avoidance of infectious agents is the desirable approach to disease prevention; however, this is not always possible or practical because many organisms that infect fish are normally free-living, facultative, and opportunistic pathogens. Fish and some pathogens can coexist without disease unless the fish's immune system or other defensive mechanisms are compromised.

Aeromonas hydrophila, the bacterial agent of motile *Aeromonas* septicemia (MAS), is a ubiquitous organism that occurs naturally in most freshwaters of the world. It is capable of living and proliferating in any water containing organic enrichment. The bacterium usually causes disease only after a fish's resistance has been compromised by environmental stressors, or when fish have suffered some mechanical or biophysical injury. Thus, the best approach to prevent MAS is to reduce organic load and bacterial numbers in the water and to keep fish at a high state of resistance by environmental management. Prophylactic treatments after fish are handled will aid in

healing superficial wounds and in reducing bacterial populations on the skin. In a normal, healthy fish population, a certain percentage of fish may possess systemic *A. hydrophila*; however, disease occurs only when bacterial numbers overwhelm the fish's resistance.

Many fish, wild or cultured, normally have some parasites present on their gills or skin. As long as these parasites, either protozoa or monogenetic trematodes, are present in low numbers, there generally is no health problem; however, if water quality deteriorates to a point that fish are stressed, parasite numbers will increase. Parasite populations can be reduced with prophylactic chemotherapy and good health reestablished with restoration of environmental quality.

Culling old brood stock and using younger fish for reproduction before they become heavily parasitized can reduce the effects of metazoan parasites. Using young largemouth bass as brood stock has proved successful in the southeastern United States where bass tapeworm (*Proteocephalus ambloplitis*) larvae can be a problem. This parasite can damage the ovaries of adult fish if the parasite is present in large numbers. The damage can cause a reduction in egg production that is cumulative with age (W. A. Rogers, Auburn University, Alabama, personal communication).

Most infectious agents require specific levels of infective units before adversely affecting a host's health status. Therefore, if infectious organisms can be maintained at levels below disease threshold, losses will be reduced.

Extent of contact

Diseases that involve opportunistic (facultative) organisms are not germane to this particular discussion; therefore, the following remarks pertain to obligate pathogen-induced fish diseases (viruses, some bacteria, and most parasites). In managing such diseases, initial consideration is given to the pathogen source in the culture system.
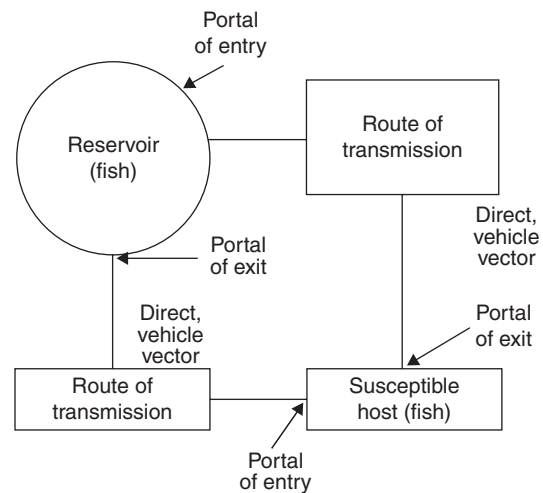

Figure 1.6 Typical transmission cycle for communicable disease agents. The direct vehicle vector may be water, food, contaminated equipment, eggs, etc. (Adapted from Swan (1983).)

Pathogens must have a route of transmission from source to susceptible host, which may be by direct contact from fish to fish, via the food chain, through water, on nets, buckets, and other gear, or via reproductive products (Figure 1.6). Infected fish that survive can become pathogen carriers and a reservoir for disease agents. There are numerous examples of fish diseases (particularly viruses) where epizootics are associated with a reservoir host. A pathogen must have a way to escape the host; in fish this can be accomplished by shedding virus or bacteria across the gill membranes, through skin mucus, from skin lesions, in feces, urine, or via reproductive products. Internal metazoan parasites often must wait until the host fish is eaten by an intermediate or final host to complete its life cycle. Nematode and trematode parasite larvae that live in the eyes of some fish are released when the eye is destroyed.

Some pathogens, especially viruses, are released from a reservoir host during spawning via eggs, ovarian fluid, or milt. In some viral diseases, the number of virus-shedding fish actually increases during spawning time (infectious hematopoietic necrosis virus, IHNV),

which aids transmission (Mulcahy and Pascho 1985).

Bacteria and parasites can be transmitted to cultured fish populations through feed that contains raw wild fish flesh. Marine fish are an especially good source for these pathogens. Mycobacteria (acid fast staining bacteria) are transmitted to uninfected fish when uncooked fish flesh or viscera is incorporated into their feed. Transmission of mycobacteria was common in Pacific salmon hatcheries in the 1950s and 1960s when ground raw marine fish was incorporated into hatchery feeds. Another example of a parasite being transmitted by feeding contaminated fish flesh occurred in Florida when chopped Atlantic menhaden, infected with *Goezia* (a nematode that inhabits the stomach and intestinal wall), was fed to cultured striped bass fingerlings (W. A. Rogers, Auburn University, personal communication). The infected striped bass were then stocked into Florida's inland lakes where the parasite was transmitted to resident tilapia and largemouth bass. Although virus transmission resulting from feeding raw fish has not been reported, most virulent fish viruses have been transmitted orally under laboratory conditions.

While infectious disease-induced mortalities in wild fish populations are rare, high losses are much more common in cultured fish populations. Like other animals, fish are more susceptible to infection when crowded. As fish density increases, rate of contact and pathogen transmission increases accordingly. Therefore, in high-density fish populations, many epizootics have a potential for reaching catastrophic proportions. Many fish disease organisms do not cause clinical disease until infected fish are placed in stressful conditions.

Pathogens can be introduced into an aquaculture facility by humans, either staff or visitors. In order to prevent this mode of transmission fish hauling trucks should be disinfected before entering a facility (Bebak-Williams *et al.* 2007). Also footbaths containing disinfectant placed between fish holding areas should be available to kill any pathogens on boots, etc.

Protection by segregation

Segregating fish according to species and age can reduce transmission of disease-producing agents because some of these organisms are not equally pathogenic to all fish species, or all strains or ages within a susceptible species. Some fish disease-producing organisms lack host specificity, while others are more host specific. Nonhost-specific, opportunistic free-living bacteria are generally facultative. Some diseases, such as furunculosis (*Aeromonas salmonicida*) and most viral agents are generally more host specific. Brook trout are considered highly susceptible to *A. salmonicida* and should be reared completely segregated from carrier populations. Rainbow trout and brown trout are also susceptible to *A. salmonicida*, but to a lesser degree than brook trout, and may be considered for culture where this disease is endemic. Rainbow trout and some species of Pacific salmon are highly susceptible to IHNV; therefore, culture of a less susceptible salmonid species should be considered where this virus occurs.

Channel catfish are the most susceptible species to channel catfish virus disease (CCVD). However, within channel catfish stocks, inbred strains are more susceptible to CCVD than are "out-bred" strains (Plumb *et al.* 1975). In areas where CCVD is endemic, less susceptible catfish species, blue catfish for example, can be cultured even though they are not totally CCV resistant. The same catfish susceptibility pattern exists for *Edwardsiella ictaluri*, the bacterial causative agent of enteric septicemia of catfish (ESC) (Wolters *et al.* 1996).

Generally, young fish have greater pathogen susceptibility than do older fish, particularly with regard to viruses and some parasites. In the case of IPNV and IHNV of salmonids and CCV of catfish, fish less than 3 months old

are highly susceptible, but disease effects diminish with increasing age. If these fish species can be reared in noncontaminated water until past the critical age of susceptibility, severe losses can be avoided. The same is true with *Myxobolus cerebralis* (whirling disease), a parasite that infects young trout before the cartilage has matured into bone. Susceptible fish should be reared in well or spring water free of wild fish, but after fish have grown past a susceptible size or age, they can be transferred to less protected waters.

Segregation for disease avoidance may also take into account water temperature because it affects the disease-causing ability of some fish pathogens. Infectious hematopoietic necrosis virus normally occurs at a temperature of 10–17°C; thus, if fish can be reared in water above 17°C, effects of disease is minimized. However, at elevated temperatures, trout may be more susceptible to other disease organisms and growth rate will be reduced. Channel catfish virus is most severe at temperatures above 25°C, therefore, if catfish are held at cooler temperatures, CCV can be avoided but growth rate will be reduced because of the suboptimal temperature. Unfortunately in most instances, optimum temperature for pathogens is also optimum for hosts. However, a combination of susceptible age and optimum temperature may be factors that are used to determine when strict segregation of young fish from the rest of the stock can be modified.

Temporal segregation can also be an important factor in reducing disease-associated losses. This involves depopulating fish holding facilities between batches to prevent the transmission of pathogens carried by one crop to the next. Current channel catfish culture involves a continuous production system where fish are partially harvested for market (graded according to size) and then fingerlings are added to the pond to replace the number of fish harvested. This type of system perpetuates endemic pathogens and the newly arriving fish will bring their own pathogens (and strains) that may exacerbate disease problems. The use

of batch systems (all in from one source and all out at one time) greatly reduces the opportunity for pathogen accumulation in a production system. To be effective, all fish must be removed from the production system and water source and the system disinfected before restocking.

Problem of new arrivals

Newly arrived fish may bring pathogens with them, either in an active or carrier state, to which the resident population has not been exposed. Therefore, no new animals should be introduced into an existing population until reasonably certain they will not be detrimental. This rule applies to home aquaria, movement of fish from farm to farm, and to interstate and international live fish shipments. Even if the new arrivals carry the same pathogens as the farm population, there can be substantial differences in strains of the pathogen. The new strains may have different ability to cause disease or different host ranges, allowing more severe disease outbreaks to occur or they may have different antibiotic-resistance profiles, making treatment more difficult. Furthermore, new pathogen strains may have different antigen profiles that can allow the pathogen to infect fish that have developed immunity to the endemic strains of pathogen or to infect and cause more severe disease in fish vaccinated against the endemic strain.

Several precautions to reduce potential for introducing disease with new arrivals are use of SPF eggs or be familiar with health history of fish to be introduced, know if any serious disease problems occurred, and if so what type of treatment, if any, was given. If not treated before transport, newly arrived fish or eggs should be given a prophylactic treatment with appropriate drugs to remove any external pathogens. When possible, new fish should be segregated (quarantined) from the resident population until shown to be disease free. Fish farmers must be extremely careful

when replenishing brood stocks with outside sources to insure that no new pathogens are introduced into their facility. This danger is especially prevalent if fish from wild populations with unknown disease histories are used to replace brood stocks.

Certain fish production facilities produce certified disease-free fish or eggs (certified to be free of known obligate pathogens). Disease free salmonid eggs have been extensively marketed (certified free of IPNV, IHNV, VHSV, and some salmonid bacterial diseases), but this is not 100% reliable. Because of the production systems, lack of legal restraints to shipping and limited number of pathogens to target, no facilities currently market disease-free eggs or fry for warm-water aquaculture systems. Specific disease-free certification requires certification by an external authority. Sampling and diagnostic tests used are specified by the most current edition of "*FHS Blue Book: Suggested Procedures for the Detection and Identification of Certain Finfish and Shellfish Pathogens*" (AFS-FHS 2007), the "OIE Manual of Diagnostic Tests for Aquatic Animals" (OIE 2009) or must conform to "Code of Federal Regulations—Title 50: Wildlife and Fisheries". In order to stop movement of disease agents, one must stop movement of infected animals. The prudent fish farmer must take every precaution available when acquiring new stock.

Breeding and culling

Domestication of wild animals has been the foundation of successful animal husbandry throughout the ages. Selection, culling, and crossbreeding has been vital in developing today's herds and flocks of domesticated animals. Culturing fish for food has been practiced for thousands of years in some areas of the world, especially in China. However, comparatively few studies have dealt with development of disease-resistant fish through selective breeding and genetic manipulation. In most genetic fish improvement experiments, objectives have been to increase growth rates and fecundity or to improve feed conversions; therefore, any disease-resistance traits have resulted from happenstance.

Different strains of channel catfish express different susceptibility to channel catfish virus disease and ESC (Plumb *et al.* 1975; Wolters and Johnson 1994; Bilodeau-Bourgeois *et al.* 2007). But few studies have investigated genetic selection or genetic manipulation in order to develop strains of fish with improved disease resistance. Peterson *et al.* (2008) demonstrated that certain selected strains of channel catfish not only had superior growth performance but also were more resistant to *Edwardsiella ictaluri* (ESC). Recently, transgenics has shown the potential to improve disease resistance. Dunham *et al.* (2002) enhanced disease resistance of transgenic channel catfish into which cecropin B gene from the cercropia moth had been inserted. In a pond epizootic of *Flavobacterium columnare* (columnaris) infection, 40.7% of the transgenic fish expressing the cecropin B gene survived compared to only 14.8% of the controls. Furthermore, 100% of the transgenic survivors possessed the cecropin B gene. Bilodeau-Bourgeois *et al.* (2007) points out that there is a variation in ESC susceptibility between strains and results from experiments in aquaria may not hold true in the pond environment.

Lack of available scientifically developed disease-resistant brood fish should not prevent the aquaculturist from improving his stocks by gradually selecting fish that are less affected by specific disease outbreaks. If a particular lot of brood fish routinely produces offspring that develop a specific disease year after year (i.e., CCVD), then replacing those brood fish should be strongly considered; however, antidotal evidence of this practice suggests that success has been mixed. Routine culling of inferior individual brood fish will also improve performance.

Nutritional basis of health maintenance

Proper nutrition is essential for survival, growth, and reproduction of any animal species, and nutrient requirements of fish are similar to those of other animals (Lovell 1989). This applies to wild or cultured fish populations although nutritional management in the two systems is entirely different. In aquaculture, the fish's nutrition is generally dependent on the quality and quantity of feed provide to the fish, but in wild fish populations, proper nutrition is dependent upon the natural food chain and availability of primary nutrients. Nutrients can be supplemented in these populations by addition of organic or inorganic fertilizers to stimulate growth of macroflora (vascular plants), microflora (phytoplankton), zooplankton, and other invertebrate fish food organisms. In some parts of the world, traditional aquaculturists continue to use manure and/or ingredient-based nutrient sources to feed cultured fish. This practice causes increased levels of organic matter in semiliquid layers of unoxygenated sediments, greater water quality problems, poor fish growth, higher feed conversion ratios, and higher incidences of infectious disease, especially stress-induced epizootics. More advanced aquaculture management practices advocate the use of manufactured feeds that contain proteins, fats, carbohydrates, fiber, vitamins, amino acids, and minerals. A deficiency in any one of these nutrients can result in nutritionally related disease or lowered disease resistance. The amount of each nutrient needed for proper growth depends upon species and age of fish being fed and intensity of the culture system. Fresh feed of the highest quality available should always be used.

It has been shown that certain nutritional deficiencies can result in specific pathological conditions (Halver 1972). Injury to the spinal column of channel catfish (broken-back syndrome) results from a vitamin C deficiency.

Lack of sufficient riboflavin can cause eye cataracts in rainbow trout and possibly in channel catfish. A niacin deficiency increases sensitivity to ultraviolet irradiation and "sun burn" on fish in clear water. Nutritional gill disease of trout is caused by a pantothenic acid deficiency and can progress into bacterial gill disease if the deficiency is not corrected. Also, severe anemia in channel catfish is linked to dietary deficiency of folic acid or presence of the folic acid antagonist pteroic acid (Butterworth *et al.* 1986).

Several researchers have shown that a deficiency of specific elements in a fish's diet can increase disease susceptibility and megadoses may increase immune response. Channel catfish fed a vitamin C-deficient diet were more susceptible to *Edwardsiella tarda* and *E. ictaluri* (Durve and Lovell 1982) and megadoses of vitamin C (five times the recommended 60 mg/kg of diet per day) enhanced immune response (Li and Lovell 1985). However, these studies were conducted in aquaria and when the same principles were applied to pond-reared channel catfish, vitamin C-deficient diets did not affect susceptibility nor did megadoses of the vitamin enhance immunity (Liu *et al.* 1989).

The attributes of organic zinc sulfate vs. inorganic zinc sulfate in a fish diet has received significant attention. Paripatananont and Lovell (1995) reported that channel catfish required less organic than inorganic zinc sulfate and that resistance to *Edwardsiella ictaluri* increased with addition of organic zinc sulfate in the diet. Contrastingly Lim *et al.* (1996) reported that the zinc source was unimportant and did not change disease resistance of channel catfish.

Fish in poor nutritional condition (starved or lightly fed) may be more resistant to some infectious agents than are well-fed fish. Antidotal observations indicate that channel catfish susceptibility to CCV is decreased following starvation for 2 weeks (unpublished). More recently Kim and Lovell (1995) showed that

channel catfish that were not fed at all during winter were significantly less susceptible to *E. ictaluri* in the spring than fish fed everyday or less frequently during the winter. Taking channel catfish off feed when ESC occurs has been practiced throughout the catfish industry. Fish that continue to be fed suffer higher mortality than do either medicated or nonfed populations (Wise and Johnson 1998). To what degree nutrition affects disease resistance in fish remains unclear.

Subtle effects of a nutritionally deficient diet are reduced growth and poorer feed conversion; reduced fecundity and all dietary factors have the potential to affect health status and disease susceptibility of fish (Lovell 1989). When water quality becomes critical with high organic fertility and low DO, reduced feeding can hasten a reversal of this trend; therefore, flexibility in feeding can be a valuable tool in aquaculture management.

Eradication, prevention, control

The terms eradication, prevention, or control are defined as follows: *Eradication* is the complete elimination of a disease-causing agent from a facility or specific geographical region, while practical eradication is elimination of an agent from its reservoir of practical importance. *Prevention* is avoiding introduction of a disease-producing agent into a region or facility and/or stopping a disease process before it becomes a problem. *Control* involves reduction of a problem to a level that is economically and biologically manageable, and/or confinement of a problem to a defined area.

Eradication of a fish disease from a facility, watershed, or region is desirable but difficult to accomplish. To date, there are no reported examples of a fish disease agent being totally eradicated from a large geographical region. Practical eradication of IPNV, furunculosis, and bacterial kidney disease from individual fish hatcheries and farms in the United States

has been accomplished by removal of all fish and sterilization of facilities with chlorine or formaldehyde gas. These select facilities had closed water supplies with no indigenous fish populations to serve as disease reservoirs and precautions were taken to prevent reintroduction of disease. Only SPF eggs were used to repopulate the facilities and strict sanitation was established, which included disinfection of equipment and fish transport trucks that accessed the culture area. A commitment to eradicate a specific disease must be balanced with an equal commitment to keep the facility disease free.

Eradication of a disease is much more difficult in warm water than cold-water aquaculture because most warm-water facilities do not have closed water supplies and use large ponds, which are more difficult to sterilize. They are more susceptible to animals (birds, snakes, muskrats, etc.) that may mechanically carry pathogens from one pond or farm to another. Additionally, there are no applicable SPF certification procedures that apply to warm-water fish pathogens.

Disease prevention is primarily a farm management approach and should begin with construction of a culture facility. Disease prevention considerations should include site selection, development of water supply, and selection of fish to be stocked. Original fish stocks, as well as any subsequent fish brought onto the facility, should come from populations known to be free of obligate pathogens. When available, vaccination should be considered as a disease prevention tool. Sanitation practices are extremely important and disinfection of nets, buckets, boots, and other equipment should be a routine practice whenever used in different culture units. These precautions will also help prevent spread of disease within a facility once it occurs.

Control is appropriate when obligate or nonobligate pathogens are involved or when effective chemotherapeutic and management practices are available to combat the disease. The objective of control is to reduce pathogen

levels in an environment or host so that overt disease will not occur. This approach dictates that some fish will die while attempting to keep losses at a minimum. Chemotherapeutics are most successful when used in conjunction with elimination of environmental stressors and applying good health management practices.

Biological and economic constraints usually dictate what approach will be employed when dealing with fish disease problems. Eradication may be the best approach when isolated cases of obligate pathogen infections are involved; however, destruction of entire animal populations remains controversial. Eradication vs. control should be determined on a case-by-case basis with strong consideration being given to economic consequences. Eradication is only feasible if a facility can be maintained free of a specific disease agent after sterilization.

Variable causes require variable solutions

Epizootiology is the study of disease patterns in animals other than man and implies that the presence or absence of overt disease is not necessarily indicative of the presence or absence of a disease-causing agent. As previously discussed, many infectious fish diseases are caused by the complex interaction between host, pathogen, and environment. Although a host and pathogen must be present to cause infectious disease, environmental influences are often the trigger that elevates a subclinical infection to disease. Most pathogenic organisms can be identified, but environmental influences that precipitate disease are far more complex and difficult to detect. Each disease situation is different and must be evaluated and dealt with on an individual basis.

When a fish disease problem arises, an environmental evaluation prior to and during time of disease outbreak must be part of the diagnostic process (Schnurrenberger 1983a). Facts pertinent to establishing an accurate diagnosis are as follows: had there been a recent oxygen depletion or any other water quality problem noted, any color change in the water, had heavy rains occurred recently, did mortality occur suddenly or increase gradually, were other fish recently introduced, and what are current water quality characteristics? Answers to these questions will influence type of management procedures or treatments to be used.

At the time of disease outbreak, it is imperative that a complete disease examination (necropsy) be performed to determine if a single species of bacterium, parasite, or virus is involved or if multiple pathogens are present. It is emphasized that even after a pathogen is found, necropsy must be completed or other contributing pathogens may go undetected. Different disease organisms, requiring different treatments, can produce very similar clinical signs. Therefore, an incomplete necropsy may result in a premature and incorrect diagnosis and improper treatment. The key to treating multiple infections is to first identify and treat the primary disease-causing agent and then deal with lesser disease agents.

Don't just cure, prevent

A health maintenance program should be in place when an aquaculture facility begins production, and health management issues should be addressed on a daily basis, not just when disease outbreaks occur. When disease does occur, managers often expect an immediate diagnosis and treatment prescription from a fish disease specialist. This can put pressure on a diagnostician to recommend a treatment that will correct the immediate problem without addressing long-range problems. Often a chemical can be added to water and/or an antibiotic incorporated into feed, which will result in a positive response and cessation of mortality. However, the effect of these treatments may be temporary and disease may reoccur unless a commitment is made to seek and eliminate all predisposing disease factors. Even though a fish farmer is more likely to

accept chronic disease losses because they are not dramatic and occur over an extended period of time, these losses can be minimized through proper health maintenance. If a subacute disease occurs and large numbers of fish die in a few days, the farmer will be more inclined to implement preventive steps.

While preventive health maintenance is important in controlling fish diseases, it is not a "cure all." Some fish diseases are less preventable through environmental management than are others and some have no known prevention or treatment. No health maintenance program is perfect, but one that emphasizes biosecurity and disease prevention is well worth the effort economically, productively, and for the pure satisfaction of knowing that the best possible aquaculture techniques are being used.

Law of limiting factors

The law of limiting factors plays an important role in our ecology as well as in health management of fish. Schnurrenberger (1983b) compared this law to the concept that a "chain is no stronger than its weakest link." Also, each major link consists of its own set of limiting factors and a weak spot within a subset of factors can cause failure in the overall chain. If one considers the fish production cycle a chain, with one end being spawning adults and the other harvestable-size fish, many potential weak links exist, any of which could be considered a limiting factor. Components present in a given body of water or water supply make it either suitable or unsuitable to support a healthy fish population. Volume of water, temperature, pH, and other parameters must all be compatible with the fish species being cultured. If adequate water is available but its temperature is not suitable, temperature then becomes a weak link and water becomes a limiting factor in the production cycle.

Food quantity and quality is often a limiting factor in unmanaged fish ponds. With fertilization, the base of the food chain in these ponds can be extended to support an increased standing crop, but if culture procedures become too intensive, other limiting factors may become involved. As a standing crop increases, supplemental feeding is required so that food will not again become a limiting factor. Supplemental feeding will increase the organic water load, and pond fertility will increase as a result of uneaten feed and the accumulation of metabolic wastes (feces, urine, ammonia, etc.). Decomposition of dead plants and uneaten feed remove oxygen from the water, and this oxygen loss may become a limiting factor. Accumulation of ammonia, nitrite, and CO_2 may also become limiting factors.

The law of limiting factors becomes acute as a fish culture system becomes more intensive. As fish density increases more feed is required; more water is necessary to remove, dilute, and neutralize metabolic wastes; more efficient supplemental aeration is required; and fish stressors become more critical. At what point these limiting factors become detrimental to effective production must be determined and appropriate corrective measures taken. A limiting factor does not always have to be biological. It can be financial or dependant on a manager's ability to properly and effectively operate a facility.

Each fish species has its own set of factors that are necessary for survival, growth, and reproduction. Factors for fish survival lie between minimum requirements and maximum tolerances. Consideration must also be given to the synergistic effect one limiting factor has on another and how altering one factor to improve health may illuminate a previously unrecognized factor.

Staying on top of the operation

Many people go into aquaculture without fully understanding what is required to initiate and maintain a successful operation. Fish farming,

especially of warm-water species, is possibly the most demanding of all agricultural enterprises during certain seasons of the year. During critical periods in the production cycle, a 24-hour schedule must be maintained to stay on top of the operation. It is as important in aquaculture for a fish farmer to routinely observe and evaluate his culture procedures and facility as it is for cattle or swine farmers to inspect herds daily.

Although casual scrutiny of ponds, tanks, or raceways can be helpful in detecting possible health changes, specific aspects must also be considered. Operational procedures should be observed in such detail that any departure from good health management is immediately detected. The most obvious indicator of deteriorating fish health is a change (reduction) in feeding behavior, which can be affected by adverse environmental conditions and/or by infectious disease. If on a given day, fish are eating actively and the next day there is a noticeable reduction in feed consumption, the cause should be investigated. Water quality should be checked to determine DO, nitrite, or CO_2 concentrations and a sample of fish should be examined for presence of infectious or parasitic disease. Some fish, channel catfish for example, normally reduce feed consumption in autumn and throughout the winter as water temperatures drop, but when this happens at other times of the year, it may indicate a health problem.

Color changes in the water may indicate a potential water quality problem. When a pond turns from green (indicating a viable phytoplankton bloom) to dingy brown or suddenly clarifies, it could indicate algae are dying, or a pond "turn over" (good upper water mixes with unoxygenated deep water) is occurring and oxygen depletion is likely to ensue. If the cause can be detected and corrected while occurring, stress on fish can be minimized.

DO concentrations in ponds should be measured on a daily and nightly basis during critical periods, either by an individual or automatic DO recording device. Computerized oxygen monitoring systems will register oxygen concentrations 24 hours a day and automatically turn on aeration when needed. Monitoring oxygen concentration is particularly critical in heavily stocked ponds that are receiving large amounts of feed. If over a period of days and nights a downward trend in oxygen concentration becomes evident, the DO may be ready to "crash" as a result of pond respiration and nightly aeration should be initiated. Also, when fish swim erratically or lethargically just beneath the surface, gasp (pipe) at the surface, or move into shallow water, one should look for causes for this abnormal behavior, which could be attributed to poor water quality, toxicants, infectious disease, or parasitic infestation. When fish surface, aeration should be initiated or freshwater added as soon as possible because a delay may cause fish to become so stressed they will not move to the aerated water.

"Staying on top" can prevent catastrophes from occurring in a fish population, but it requires diligence and regularly scheduled visits to the entire culture facility. During critical times, if several days or nights are allowed to pass without checking water quality, high fish losses can occur in a very short period of time. Also, sublethal stressful conditions may lead to infectious disease.

Early diagnosis

An early, accurate diagnosis when disease occurs is important in maintaining healthy fish; therefore, it is imperative that an aquaculturist know what is normal. It is important to be able to recognize clinical signs of disease and to have affected fish examined as soon as possible. It is also important to be able to distinguish signs of oxygen depletion and chemical toxicants from those of infectious disease.

Few specific infectious fish diseases can be diagnosed solely upon clinical signs; therefore, whenever possible fish should be examined by a competent fish pathologist. In most cases,

only a few fish die during early stages of a disease outbreak followed by a gradual increase in the daily mortality rate. When the first sick or dead fish appear, suitable specimens consisting of moribund fish showing clinical signs typifying the condition should be examined.

Although an early and accurate diagnosis is important in nearly all infectious fish diseases it is absolutely crucial in bacterial infections when use of medicated feed is indicated or in parasitic infections requiring drug treatment. If infection progresses to a degree that fish are no longer feeding, oral treatment with antibiotics is no longer an option. In any disease situation, the earlier the diagnosis the sooner corrective measures or treatment can begin, thus reducing losses.

A dynamic team effort

A dynamic fish health maintenance program must be flexible and coordinated, not a mixture of unrelated, unchanging procedures. While objectives and principles for fish health maintenance programs can follow a general outline, each facility needs to design and implement a health plan that best meets its needs.

There are three principal times when an animal food resource producer is ready to discuss the establishment of a health maintenance program (Hudson 1983): (1) when experiencing a disease crisis, (2) when starting a new unit, and (3) when considering expansion with borrowed capital. The broad scope of basic knowledge and technology that applies to health maintenance of aquatic animals is usually beyond the expertise of any one individual. Therefore input from a variety of specialists is often indicated. In most geographical areas, State Cooperative Extension Services, or state, federal or university laboratories have qualified fishery specialists available to assist farm managers in developing a good health maintenance program that meets their specific needs.

Keeping current

Health management decisions should be based on the most current and accurate information available. Shell (1993) quoted an old folk saying "It's not what I don't know that hurts me. It's what I know that's not true that hurts me." In the past 40 years, major advances in aquaculture have been made in breeding, genetics, nutrition, disease identification, treatment, and processing. However, during this time, few new drugs or chemicals have been developed to aid in disease treatment and/or prevention. Because of constraints imposed by the U.S. Food and Drug Administration, there has actually been a reduction in number of drugs that can be used on food fish in the United States; a trend throughout many regions of the world. The reduction in approved chemotherapeutics is in part due to technological advances that have been made in identifying hazardous characteristics of drugs previously thought to be safe and their potential negative effects on efficacy for human medicine. It is, therefore, imperative that a producer stay current on which drugs and chemicals are approved for use on food fish.

A fish farmer can stay current in aquaculture management techniques by being active in professional or trade organizations on a local, regional, state, national, and international level and by reading literature published by these organizations. Extension fishery specialists and agricultural agents can provide pamphlets, brochures, and newsletters with accurate, up-to-date information. If modern fishery managers are to maximize production facilities, they must keep pace with technological advances being made in the field.

Maintaining a clean environment

Everyone recognizes the fact that an accumulation of trash, excrement, decaying animals, etc. in a terrestrial environment is associated

with unhealthy conditions. Why should we expect it to be different in the aquatic environment? Clearly it is not! Generally, when visiting private and governmental aquaculture facilities around the world, it is often possible to visually identify facilities that have the most disease problems based on appearance. This is not to say that a "spit and polish" facility will never have disease problems, but they tend to have fewer and less severe disease outbreaks. Water is an excellent medium for transmitting disease-producing agents; therefore, sick or dead fish should be removed to reduce pathogen reservoirs. For example, in *E. ictaluri*-infected catfish ponds, areas where dead fish were allowed to accumulate had significantly higher pathogen concentrations in the water than where carcasses had not accumulated (Earlix 1995). Maintaining clean areas around ponds and controlling vegetation at water's edge will not allow sick or dead fish to go unnoticed. If dead fish are allowed to remain in a culture unit, there is also the possibility that scavengers will carry infected carcasses to other ponds, thus spreading the disease. Accumulation of feces, uneaten feed, and other organic detritus is a major problem in ponds, raceways, and recirculating systems and contributes significantly to water quality degradation and can serve as a substrate for facultative pathogens. Removal of excreta and bottom detritus from the culture unit will help improve and maintain water quality. These problems can be avoided and/or corrected by improving feed quality, regular cleaning and periodic draining, drying, and when necessary disinfection of holding facilities. Removal of accumulated sediment is accelerated by drying the pond bottom, adding lime to the surface and tilling (Boyd and Pippopinyo 1994). Increasing soil pH to 7.5–8.0 with calcium hydroxide or calcium carbonate will enhance pond respiration and reduce pond sediment.

Cleaning and disinfection of seines, nets, buckets, tanks, and other equipment will reduce transmission of many pathogens. Maintaining a clean aquaculture facility will pay dividends by providing a safer work place, reduced disease incidence, increased production, and generally healthier fish, all of which translates into more efficient production.

High-risk concept

Aquaculture is a high-risk endeavor because of its dynamic relationship to environmental change. Since some aspects of fish culture present higher risk factors than others, management efforts should concentrate on areas that include production and financial losses, namely disease, growth rate, feed quality and conversion, water quality, and product marketability. Water quality is a major factor in rearing healthy fish and if not suitable, fish will not feed or grow well regardless of feed quality, and potential for disease becomes more prevalent. Consequently, major emphasis must be placed on water quality in any aquaculture health maintenance program.

Infectious disease can also be classified as a major risk factor, but risks will differ from farm to farm depending on water type and quality, species and strain of fish being reared, general management practices, etc. Disease problems also change from year to year. The aquaculturist should be aware of high-risk factors, practice preventive health maintenance that addresses these areas, and at the same time not lose sight of lesser risk factors and their potential for causing problems.

Record keeping and cost analysis

Well-organized records are basic to a successful aquaculture business. In addition to production records that include stocking and feeding rates, feed conversion, and harvest totals, each fish production facility should maintain a set of health records that include mortality patterns and dates, infectious disease incidences and treatments, and treatment results.
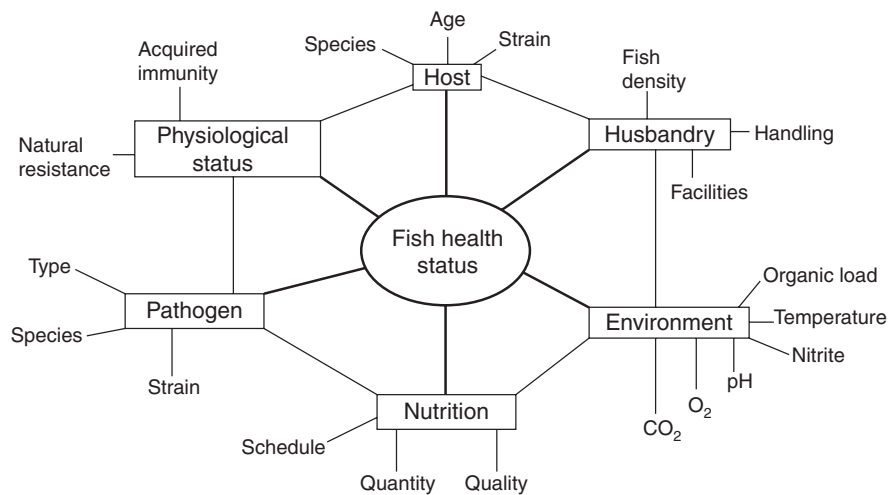
Figure 1.7 The relationship of environmental conditions, biological factors, and management practices in aquaculture that influence health and infectious diseases of fish.

Size, water volume, and water quality characteristics of each production unit should also be included in health records. After several growing seasons, a manager may be able to ascertain from these records if a certain disease is likely to occur and what conditions predispose fish to a specific disease. This information can help prevent disease outbreaks by timely prophylactic treatments or other remedial actions. Detail and extent of record keeping may vary with size and intensity of an operation; however, records should be kept by every facility regardless of size.

Accurate records are important when evaluating health maintenance procedures or a biosecurity program because without records, an economic feasibility and cost-effective evaluation is impossible. When considering the economic feasibility of a procedure cost, efficacy and benefits are considered and the most cost-effective (not necessarily the cheapest) procedure selected. Having to deal with greater pressure from imported fish products, domestic aquaculture must consider all aspects of the operation to maximize efficiency production and profit.

When initiating fish health management practices, a long range, cost-effective analysis

should be made. Initial financial outlay may be high, but over a period of time, good health management will pay for itself in reduced mortality and optimal growth. A cost/benefit ratio should be calculated for each health management procedure and benefits must outweigh cost except under unusual circumstances.

Fish health status

Health of fish depends on the interrelationship of six major components of the fish and the environment in which they live (Figure 1.7). The fish health matrix resembles a spider web in which if one satellite factor (host, husbandry, environment, etc.) is disrupted or diverge from the optimum, each of the other factors are also affected, thus impacting the health status of the fish. These components are such that one cannot be discussed without considering its relationship with or effect on each of the other components because of their interaction and their collective influence on fish health status. Overall physiological status of the fish host is determined by the husbandry practice, environmental quality, the fish's nutritional well being and the pathogen, all of which influence

the natural resistance and acquired immunity of the host. It is common knowledge that fish stressed by one of these factors are more susceptible to infection.

Maintaining good health of the fish is the primary concern because it is necessary for survival and good growth. Disease susceptibility depends on the culture species because all fish species are not equally susceptible to a specific pathogen and strains within a fish species may vary in their susceptibility. Age of the fish is important because many high impact diseases (i.e., channel catfish virus, infectious pancreatic necrosis virus of trout, and the parasite *Ichthyophthirius multifiliis)* affect juvenile fish more severely than older and adult fish.

Husbandry practices depend on the fish species being cultured. Stocking density of juvenile and grow out fish will vary because some species are more conducive to higher density than others; some species (salmonids) are adaptable to raceway culture but others (channel catfish) perform better in ponds. Generally, fish stocked at higher density are more prone to serious infectious disease than fish stocked at low or moderate density. Therefore higher stocking density requires more intense management. When and how fish are handled is an important consideration in disease susceptibility because the protective mucus layer that covers the skin serves as a barrier to ubiquitous invasive pathogens and if it is disturbed by improper handling, the fish becomes more susceptible to these pathogens. Also, moving fish when water temperatures are at the upper level of their tolerance is often stressful.

The environment may be the most critical component of the fish health matrix because environmental quality influences the fish's physiological well being, species cultured, feeding regimes, rate of growth, and ability to maintain natural and acquired resistance and immunity. Major environmental factors are temperature, organic load in the water, alkalinity and hardness, nitrite level, pH, oxygen and CO_2 concentration as well as other water quality parameters. Tolerance of these various factors is dependent on the host and in many cases the husbandry practices.

Nutrition is vital to health management, but feed quality and amount fed is related to husbandry practices. Good growth and maximum disease resistance is also dictated by the species of fish cultured. Some cultured species (i.e., salmonids and channel catfish) require complete manufactured feeds that contain complete vitamin packs, essential amino acids, and high protein content because they do not receive nutrients from their culture environment. In contrast, other species (i.e., tilapia or carp) feed extensively on water micro- and macroflora from which they receive essential nutrients. Quantity and quality of feed as well as feeding schedules are dictated by the fish species and age/size of the fish. The type of environment, whether it is a static water pond or flowing raceway, must be considered in the type of feeding program.

The type of pathogen is dependent on all previously discussed factors in the fish health status matrix. Within a specific pathogen, there may be virulent or avirulent strains. While many pathogens are not host specific, others are either host specific or fish group (i.e., salmonids, ictalurids, etc.) specific. Whether or not a particular pathogen is present in an environment may depend on whether it is an obligate or nonobligate (facultative) pathogen. All fish viruses are obligate pathogens, while bacteria and parasites may be either obligate or nonobligate pathogens. Whether or not a pathogen causes an overt disease is often dictated by the host, husbandry practice, environmental quality, nutritional status, and the physiological status of the fish.

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