lakes, oceans, and seas has not diminished. New technology will only enable, not reduce, the need for man's presence in these hostile environments.

See also

Deep Submergence, Science of. Manned Submersibles, Deep Water. Remotely Operated Vehicles (ROVs).

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MARICULTURE DISEASES AND HEALTH

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Introduction

As with all forms of intensive culture where a single species is reared at high population densities, infectious disease agents are able to transmit easily between host individuals and large economic losses can result from disease outbreaks. Husbandry methods are designed to minimize these losses by employing a variety of strategies, but central to all of these is providing the cultured animal with an optimal environment that does not jeopardize the animal's health and well-being. All animals have innate and acquired defenses against infectious agents and when environmental conditions are good for the host, these defense mechanisms will provide protection against most infections. However, animals under stress have less energy available to combat infections and are therefore more prone to disease. Although some facilities on a farm may be able to exclude the entry of pathogens, for example hatcheries with disinfected water supplies, it is impossible to exclude pathogens in an open marine situation. Under these conditions, stress management is paramount in maintaining the health of cultured animals. Even then, because of the close proximity of individuals in a farm, if certain pathogens do gain entry they are able to spread and multiply extremely rapidly and such massive infectious burdens can overcome the defenses of even healthy animals. In such cases some form of treatment, or even better, prophylaxis, is required to prevent crippling losses. This article describes some of the management strategies available to fish and shellfish farmers in avoiding or reducing the losses from infectious diseases and some of the prophylactic measures and treatments. The most important diseases encountered in mariculture are summarized in **Table 1**.

Health Management

Facility Design

Farms and husbandry practices can be designed in such a way as to avoid the introduction of pathogens and to restrict their spread within a farm in a variety of ways.

Isolate the hatchery Infectious agents can be excluded from hatcheries by disinfecting the incoming water using filters, ultraviolet lamps or ozone treatments. It is also important not to introduce infections from other parts of the farm that may be contaminated. The hatchery then should stand apart and strict hygiene standards applied to equipment and personnel entering the hatchery. Some diseases cause major mortalities in young fry while older fish are more resistant. For example, infectious pancreatic necrosis virus (IPNV) causes mass mortality in halibut fry, but juveniles are much more resistant. It is vitally important therefore, to exclude the entry of IPNV into the halibut hatchery and as this virus has a widespread distribution in the marine environment, disinfection of the water supply may be necessary.

Hygiene practice Limiting the spread of disease agents on a farm include having hand nets for each

Table 1 Principal diseases of fish and shellfish in mariculture

Disease agent	*Host*	*Prevention/treatment*
Shellfish pathogens		
Protozoa		
Bonamia ostreae	European flat oyster	Exclusion
Marteilia refringens	Oyster, mussel	Exclusion
Bacteria:		
Aerococcus viridans (Gaffkaemia).	Lobsters	Improve husbandry
Fin-fish pathogens		
Viruses		
Infectious pancreatic necrosis	Salmon, turbot, halibut, cod, sea bass, yellowtail	Sanitary precautions, vaccinate
Infectious salmon anemia	Atlantic salmon	Sanitary precautions, eradicate
Pancreas disease	Atlantic salmon	Avoid stressors, vaccinate
Viral hemorrhagic septicemia	Turbot	Sanitary precautions
Viral nervous necrosis	Stripped jack, Japanese flounder, barramundi, sea bass, sea bream, turbot, halibut	Sanitary precautions
Bacteria		
Vibriosis (*Vibrio anguillarum*)	All marine species	Vaccinate, antibiotics
Cold water vibriosis (*Vibrio salmonicida*)	Salmon, trout, cod	Vaccinate, antibiotics
Winter ulcers (*Vibrio viscosus*)	Salmon	Avoid stress, vaccinate
Typical furunculosis (*Aeromonas salmonicida*)	Salmon	Vaccinate, antibiotics
Atypical furunculosis (*Aeromonas salmonicida achromogenes*)	Turbot, halibut, flounder, salmon	Vaccinate, antibiotics, avoid stress
Flexibacter maritimus	Sole, flounder, turbot, salmon, sea bass	Avoid stress, antibiotics
Enteric redmouth (*Yersinia ruckeri*)	Atlantic salmon	Vaccinate
Bacterial kidney disease (*Renibacterium salmoninarum*)	Pacific salmon	Exclude
Mycobacteriosis (*Mycobacterium marinum*)	Salmonids, sea bass, sea bream, stripped bass, cod, red drum, tilapia	Sanitary
Pseudotuberculosis (*Photobacterium damselae piscicida*)	Yellowtail, sea bass, sea bream	Vaccinate, sanitary
Piscirickettsiosis (*Piscirickettsia salmonis*)	Salmonids	Sanitary
Parasites		
Protozoan: many species; *Amyloodinium, Cryptobia, Ichthyobodo, Cryptocaryon, Tricodina*	Most species	Avoid stress, sanitary, chemical baths, e.g., formalin
Paramebic gill disease	Salmonids	Low salinity bath, H_2O_2
Crustacea: Sea lice	Salmonids, sea bass, sea bream	In-feed insecticides, H_2O_2, cleaner fish

tank and disinfecting the net after each use, disinfectant foot-baths at the farm entrance and between buildings, and restricted movement of staff, their protective clothing and equipment. Prompt removal of dead and moribund stock is essential as large numbers of pathogens are shed into the water from such animals. In small tanks this can easily be done using a hand net. In large sea cages, lifting the net can be stressful to fish and divers are expensive. Special equipment such as air-lift pumps, or specially designed cages with socks fitted in the bottom in which dead fish collect and which can be hoisted out on a pulley are more practical. Proper disposal of dead animals is essential. Methods such as incineration, rendering, ensiling and, on a small scale, in lime pits are recommended.

Husbandry and Minimizing Stress

Animals under stress are more prone to infectious diseases. However, it is not possible to eliminate all the procedures that are known to induce stress in aquaculture animals, as many are integral parts of aquaculture, e.g., netting, grading, and transport. Nevertheless, it is possible for farming practices to minimize the effects of these stressors and others, e.g., overcrowding and poor water quality, can be avoided by farmers adhering to the recommended limits for stocking densities, water flow rates and feeding regimes. In cases where stressors are unavoidable, farmers can adopt certain strategies to minimize the stress.

Withdrawal of food prior to handling Following feeding the oxygen requirement of fish is increased. Withdrawal of food two or three days prior to handling the fish will therefore minimize respiratory stress. It also avoids fouling of the water during transportation with fecal material and regurgitated food.

Use of anesthesia Although anesthetics can disturb the physiology of fish, light anesthesia can have a calming effect on fish during handling and transport and so reduce the stress resulting from these procedures.

Avoidance of stressors at high temperatures High temperatures increase the oxygen demand of animals and stress-induced mortality can result from respiratory failure at high temperatures. It is therefore safer to carry out netting, grading and transport at low water temperatures.

Avoidance of multiple stressors and permitting recovery The effects of multiple stressors can be additive or even synergistic so, for instance, sudden changes of temperature should be avoided during or after transport. Where possible, recovery from stress should be facilitated. Generally, the duration of the recovery period is proportional to the duration of the stressor. Thus, reducing the time of netting, grading or transport will result in recovery in a shorter time. The duration required for recovery to occur may be from a few days to two weeks.

Selective breeding In salmonids, it is now established that the magnitude of the stress response is a heritable characteristic and programs now exist for selecting broodstock which have a low stress response to handling stressors. This accelerates the process of domestication to produce stocks, which are more tolerant of aquaculture procedures with resultant benefits in increased health, survival and productivity. Such breeding programs have been conducted in Norway for some years and have achieved improvements in resistance to furunculosis and infectious salmon anemia virus (ISAV) in Atlantic salmon.

Management of the Pathogen

Breaking the pathogen's life cycle If a disease is introduced on to a farm, it is important to restrict the horizontal spread especially to different year classes of fish/shellfish. Hence, before a new year class of animals is introduced to a part of the farm, all tanks, equipment etc. should be thoroughly cleaned and disinfected. In sea-cage sites it is a useful technique to physically separate year classes to break the infection cycle.

Many pathogens do not survive for long periods of time away from their host and allowing a site to be fallow for a period of time may eliminate or drastically reduce the pathogen load. This practice has been very effective in controlling losses from furunculosis in marine salmon farms and also significantly reduces the salmon lice populations particularly in the first year after fallowing.

Eliminate vertical transmission Several pathogens may persist as an asymptomatic carrier state and be present in the gonadal fluids of infected broodstock and can infect the next generation of fry. In salmon farming IPNV may persist in or on the ova and disinfection of the eggs with iodine-based disinfectants (Iodophores) is recommended immediately after fertilization.

The testing of gonadal fluids for the presence of IPNV can also be carried out and batches of eggs from infected parents destroyed. IPNV has been associated with mass mortalities in salmon and halibut fry and has been isolated from a wide range of marine fish and shellfish, including sea bass, turbot, striped bass, cod, and yellowtail.

Avoid infected stock Many countries employ regulations to prevent the movement of eggs or fish that are infected with certain 'notifiable' diseases from an infected to a noninfected site. These policies are designed to limit the spread of the disease but require specialized sampling procedures and laboratory facilities to perform the diagnostic techniques. By testing the stock frequently they can be certified to be free from these diseases. Such certification is required for international trade in live fish and eggs but within a country it is widely practiced voluntarily because stock certified to be 'disease-free' command premium prices.

Eradication of infected stock Commercially this is a drastic step to take especially when state compensation is not usually available even when state regulations might require eradication of stock. This policy is usually only practiced rarely and when potential calamitous circumstances may result, for instance, the introduction of an important exotic pathogen into an area previously free of that disease. This has occurred in Scotland where the European Commission directives have required compulsory slaughter of turbot infected with viral hemorrhagic septicemia virus (VHSV) and Atlantic salmon infected with ISAV.

Treatments

Viral Diseases

There are no treatments available for viral diseases in aquaculture. These diseases must be controlled by husbandry and management strategies as described above, or by vaccination (see below).

Bacterial Diseases

Antibiotics can be used to treat many bacterial infections in aquaculture. They are usually mixed into the feed. Before the advent of vaccines against many bacterial diseases of fin fish, antibiotic treatments were commonly used. However, after a few years, the bacterial pathogens developed resistance to the antibiotics. Furthermore, there was a growing concern that the large amounts of antibiotics being used in aquaculture would have damaging effects on the environment and that antibiotic residues in fish flesh may have dangerous consequences for consumers by promoting the development of antibiotic resistant strains of human bacterial pathogens. These concerns have led to many restrictions on the use of antibiotics in aquaculture, especially in defining long withdrawal periods to ensure that carcasses for consumption are free of residues. These regulations have made the use of antibiotic treatments impractical for fish that are soon to be harvested for consumption but their use in the hatchery is still an important method of controlling losses from bacterial pathogens.

For most bacterial diseases of fish, vaccines have become the most important means of control (see below) and this has led to drastic reductions in the use of antibiotics in mariculture.

Parasite Diseases

Sea lice The most economically important parasitic disease in mariculture of fin fish is caused by sea lice infestation of salmon. These crustacean parasites normally infest wild fish and when they enter the salmon cages they rapidly multiply. The lice larvae and adults feed on the mucus and skin of the salmon and heavy infestations result in large haemorrhagic ulcers especially on the head and around the dorsal fin. These compromise the fish's osmoregulation and allow opportunistic bacterial pathogens to enter the tissues. Without treatment the fish will die.

A range of treatments are available and recently very effective and environmental friendly in-feed treatments such as 'Slice' and 'Calicide' have replaced the highly toxic organophosphate bath treatments. Hydrogen peroxide is also used. As a biological control method, cleaner fish are used but they are not a complete method of control.

Vaccination

Use of Vaccines

Vertebrates can be distinguished from invertebrates in their ability to respond immunologically in a specific manner to a pathogen or vaccine. Invertebrates, such as shellfish, only possess nonspecific defense mechanisms. In the strict definition, vaccines are used only as a prophylactic measure in vertebrates because a particular vaccine against a particular disease induces protection that is specific for that particular disease and does not protect against other diseases. Vaccines induce long-term protection and in aquaculture a single administration is usually sufficient to induce protection until the fish are harvested. However, vaccines also have nonspecific immunostimulatory properties that can also activate many nonspecific defense mechanisms. These can increase disease resistance levels but only for a short period of time. Thus, in their capacity to induce such responses they are also used in shellfish culture, especially of shrimps.

Current Status of Vaccination

In Atlantic salmon mariculture, vaccination has been very successful in controlling many bacterial diseases and has almost replaced the need for antibiotic treatments. In recent years vaccination of sea bass and sea bream has become common practice. Most of the commercial vaccines are against bacterial diseases because these are relatively cheap to produce. Obviously the cost per dose of vaccine for use in aquaculture must be very low and it is inexpensive to culture most bacteria in large fermenters and to inactivate the bacteria and their toxins chemically (usually with formalin). It is much more expensive to culture viruses in tissue culture and this has been a major obstacle in commercializing vaccines against virus diseases of fish. However, modern molecular biology techniques have made it possible to transfer viral genes to bacteria and yeasts, which are inexpensive to culture and produce large amounts of viral vaccine

Table 2 Vaccines available for fish species in mariculture

Vaccines against	*Maricultured species*
Bacterial diseases	
Vibriosis	Salmon, sea bass, sea bream, turbot, halibut
Winter ulcers	Salmon
Coldwater Vibriosis	Salmon
Enteric redmouth	Salmon
Furunculosis	Salmon
Pseudotuberculosis	Sea bass
Viral diseases	
Infectious pancreatic necrosis (IPNV)	Salmon
Pancreas disease	Salmon
Infectious salmon anemia (ISAV)	Salmon

cheaply. A number of vaccines against viral diseases of Atlantic salmon are now becoming available. Currently available commercial vaccines for use in mariculture are summarized in **Table 2**.

Methods of Vaccination

There are two methods of administering vaccines to fish: immersion in a dilute suspension of the vaccine or injection into the body cavity. For practical reasons the latter method requires the fish to be over about 15 g in weight.

Immersion vaccination is effective for some, but not all vaccines. The vaccine against the bacterial disease vibriosis is effective when administered by immersion. It is used widely in salmon and sea bass farming and probably could be administered by this route to most marine fish species. The vaccine against pseudotuberculosis can also be administered by immersion to sea bass. With the exception of the vaccine against enteric redmouth, which is delivered by immersion to fish in freshwater hatcheries, all the other vaccines must be delivered by injection in order to achieve effective protection.

Injection vaccination induces long-term protection and the cost per dose is very small. However, it is obviously very labor intensive. Atlantic salmon are usually vaccinated several months before transfer to sea water so that the protective immunity has time to develop before the stress of transportation to sea and exposure to the pathogens encountered in the marine environment.

Conclusions

It is axiomatic that intensive farming of animals goes hand in hand with culture of their pathogens. The mariculture of fish and shellfish has had severe problems from time to time as a consequence of infectious diseases. During the 1970s, *Bonamia* and *Marteilia* virtually eliminated the culture of the European flat oyster in France and growers turned to production of the more resistant Pacific oyster. In Atlantic salmon farming, Norway was initially plagued with vibriosis diseases and Scotland suffered badly from furunculosis in the late 1980s. These bacterial diseases have been very successfully brought under control by vaccines. However, there are still many diseases for which vaccines are not available and the susceptibility of Pacific salmon to bacterial kidney disease has markedly restricted the development of the culture of these fish species on the Pacific coast of North America. As new industries grow, new diseases come to the foreground, for instance pisciirikettsia in Chilean salmon culture, paramoebic gill disease in Tasmanian salmon culture, pseudotuberculosis in Mediterranean sea bass and sea bream and Japanese yellowtail culture. Old diseases find new hosts, for example IPNV long known to affect salmon hatcheries, has in recent years caused high mortality in salmon postsmolts and has devastated several halibut hatcheries.

To combat these diseases and to ensure the sustainability of aquaculture great attention must be paid to sanitation and good husbandry (including nutrition). In some cases these are insufficient in themselves and the presence of certain enzootic diseases, or following their introduction, have made it impossible for certain species to be cultured, for example, the European flat oyster in France. The treatment of disease by chemotherapy, which was performed widely in the 1970s and 1980s, resulted in the induction of antibiotic-resistant strains of bacteria and chemoresistant lice. Furthermore, the growing concern for the environment and the consumer about the increasing usage of chemicals and antibiotics in aquaculture, led to increasing control and restrictions on their usage. This stimulated much research in the 1980s and 1990s into development of more environmentally and consumer friendly methods of control such as vaccines and immunostimulants. These have achieved remarkable success and the pace of current research in this area using biotechnology to produce vaccines more cheaply, suggests that this approach will allow continued growth and sustainability of fin-fish mariculture into the future.

See also

Crustacean Fisheries. Mariculture Overview. Molluskan Fisheries. Salmonids. Salmon Fisheries: Atlantic.

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MARICULTURE OF AQUARIUM FISHES

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Introduction

Marine fishes and invertebrates have been kept in aquaria for decades. However, attempts to maintain marine species in a captive environment have been dependent on trial and error for the most part but it has been mainly through the attention and care of aquarists that our knowledge about many marine species has been obtained. This is particularly true of the charismatic syngnathids, which includes at least 40 species of sea horses.

During the past 30 years, technological advances in corrosion resistant materials together with advances in aquaculture systems have brought about a rapid increase in demand for large public marine aquarium displays, oceanariums and hobby aquaria suitable for colorful and exotic ornamental species. These developments have led to the establishment of important export industries for live fishes, invertebrates and so-called 'living rocks'. Attempts to reduce dependence on wild harvesting through the development of marine fish and invertebrate hatcheries met with limited success.

The availability of equipment, which greatly assists in meeting the water quality requirements for popular marine organisms, has turned the attention of aquarists towards maintaining increasingly complex living marine ecosystems and more exotic species. A fundamental requirement for the success of such endeavors is the need to understand species biology and interspecific relationships within the tank community. Modern marine aquarists must draw increasingly on scientific knowledge and this is illustrated below with reference to sea horse and coral reef aquaria, respectively.

History

The first scientific and public aquarium was built in the London Zoological Gardens in 1853. This facility was closed within a few years and another attempt was not undertaken until 1924. By the 1930s several public aquaria were built in other European capitals but by the end of World War II only that of Berlin remained. During the 1970s the scene was set for a new generation of public aquaria, several specializing in marine displays, and others becoming more popularly known as oceanariums due to the presence of marine mammals, displays of large marine fish and interactive educational activities.

Themes have added to the public interest. For example, Monterey Bay Aquarium exhibits a spectacular kelp forest, a theme repeated by several world class aquaria and Osaka Aquarium sets out to recreate the diverse environments found around the Pacific Ocean. Some of these aquaria have found that exhibits of species native to their location alone are not successful in attracting visitor numbers. The New Jersey Aquarium, for example, has been forced to build new facilities and tanks housing over 1000 brightly colored marine tropical fish with other ventures having to rely on the lure of sharks and touch pools.

The history of public aquaria has evolved from stand alone tank exhibits to massive 2–3 million liter tanks through which pass viewing tunnels. Once, visitors were content to be mere observers of the fishes and invertebrates but by the end of the millennium the emphasis changed to ensuring the public became actual participants in the aquarium experience. The modern day visitors seek as near an interactive experience as possible and hope to be transformed into the marine environment and witness for themselves the marine underwater world.

The concept of modern marine aquarium-keeping in the home has its origins in the United Kingdom and Germany. The United States is now the world's most developed market in terms of households maintaining aquaria, especially those holding exotic marine species: there are about 2.5 million marine hobby aquariums in the USA. In Holland and Germany, the emphasis has been on reef culture, a hobby which is becoming more widespread. The manufacture of products designed specifically for the ornamental fish trade first began in 1954 and