
CHAPTER 8

FISH HEALTH MANAGEMENT FOR OFFSHORE AQUACULTURE IN THE GULF OF MEXICO

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ABSTRACT

Since its inception, aquaculture has developed into a major industrial complex, a major component of which is cage culture. Along with the growth, however, problems arose. Translocations of animals and diseases, as well as concerns over environmental effects limited the growth of the industry. The concept of fish health management whereby the host, pathogen, and environment are proactively managed to maximize the optimal conditions for sustained growth and health of both the fish and the environment was developed to facilitate the movement of animals and the growth of the industry. Fish Health Management Plans typically include requirements for training of personnel; protocols for site selection, maintenance, feeding, water quality, containment, and biosecurity; techniques for routine monitoring and assessment; maintenance of records; protocols for diagnosing and treating illness; and, protocols for demonstrating or reporting the health status of the stock. Implementation of the concept requires a regulatory framework, coordination by the government, and active participation by producers and user groups. In the Gulf of Mexico (GOM), no cage culture industry exists. If an industry is to develop, federal and state regulations must be developed and coordinated, the framework for fish health management specific to the disease issues relevant in the GOM must be developed, and issues specific to the physical environment in the GOM must be explored. In the context of the potential risk to aquaculture operations dealing with the most likely candidate species—red snapper (*Lutjanus campechanus*), red drum (*Sciaenops ocellatus*), and cobia (*Rachycentron canadum*)—we review the state of knowledge on potential disease-causing organisms in the GOM and comment on some GOM-specific physical parameters with the potential to impact fish health in an aquaculture operation. A template for a process of developing an aquaculture operation in the GOM within the context of fish health management is presented.

INTRODUCTION AND DEVELOPMENT OF AQUACULTURE

Originally conceived in the mid-1800s as a way to apply centuries-old subsistence techniques to the support of collapsing wild fisheries, modern aquaculture, driven by the increased demand for fish products from a growing population and technological

advances, has developed into a major industrial complex. By 1995, aquaculture operations worldwide were producing approximately 28 million metric tons of product worth in excess of U.S. \$40 billion (Subasinghe et al. 1998; Stickney 2000). Over the last decade, facilitated by intensification in existing facilities, expansion into new facilities/areas, and diversification into new products, aquaculture has

been the fastest growing sector of food production (Subasinghe et al. 2001). Such record growth, however, has come with a price. Non-indigenous animals have been translocated, diseases have been transported along with the animals, and new diseases requiring new diagnostic techniques have emerged.

Massive mortalities in wild Australian pilchards in 1995 and 1998 were linked to a herpesvirus in imported frozen fish used to feed southern bluefin tuna and other fishes held in netpens (Ward et al. 2001a, b). Whirling disease was introduced to North America through frozen fish imported from Europe (Markiw 1992). Infectious Salmon Anemia emerged as a significant pathogen in the mid-1980s in Norway and has subsequently caused mortalities throughout the North Atlantic basin. Indeed, in many parts of the world disease has become the primary constraint to the sustainability and growth of the industry (Subasinghe et al. 1998). China, traditionally the world's largest aquaculture producer, for example, lost almost its entire shrimp farming industry to viral diseases in the early 1990s (Lotz 1997). In addition, the impacts of waste feed, overuse of chemicals, and excretory effluent have become a major concern not only because of their effects on the environment but also because of their effects on the culture animals themselves. However, concomitant with the emergence of problems and concerns, sophisticated diagnostic techniques and increased scientific rigor has been brought to bear to deal with these issues.

Realizing the potential of the industry and the importance of moving animals for the continued development of the industry and the demonstrated risks, scientists, government officials, fishers, aquaculturists and businesspeople began to appreciate the need for coher-

ent regulation and management. Beginning in the 1970s, the risks were becoming apparent. As such, Canada, for example, designated the Department of Fisheries and Oceans (DFO) as the agency solely responsible for managing and regulating aquaculture. In 1977, DFO implemented a set of Fish Health Protection Regulations. Those regulations, originally developed specifically for salmonids, were intended to prevent the spread of known infectious diseases through controlling the movement of live fish, eggs, and fish products. Under the regulations presently in effect, transfer is permitted only from sources with a history of inspections demonstrating the absence of the specified pathogens. Briefly, this is accomplished through ministry-appointed officials (public or private) qualified to certify, via a Fish Health Certificate, facilities or animals free of the specified pathogens. Fish Health Certificates are issued only if facilities are inspected in accordance with a Manual of Compliance produced as part of the regulations. The Manual specifies, among other things, the diseases that must be inspected for and the appropriate diagnostic procedures. Local Fish Health Officers, also appointed by the ministry, issue the appropriate Import Permits based on the presence of a valid Fish Health Certificate from the source and other data provided by the importer and exporter (DFO 2003). Various revisions since 1977 have incorporated information on new diseases and advances in procedures, as well as amendments to deal with other finfish species and the emergence of new diseases. Since their implementation, the standards have successfully prevented the introduction of previously undetected diseases and confined those known to limited geographical areas. Presently, a proposal to develop a National Aquatic Animal Health Partnership is underway to facilitate the involvement of local and private authorities that would allow

the regulations to more easily keep pace with advancements in surveillance, biosecurity, international trade, and introduction and transfer requirements. As a result, the Canadian approach is widely respected and provides an excellent working model. In 1995, the Office International des Epizooties (OIE), an international intergovernmental organization of representatives from more than 150 countries aimed at promoting world animal health, began publishing the International Aquatic Animal Health Code and the Diagnostic Manual for Aquatic Animal Diseases based on the same principles enshrined in the Canadian regulations and designed to define the minimum health standards required of international trading partners to avoid the risk of spreading aquatic animal diseases. Among the developments facilitated through the OIE is the movement toward the establishment of scientifically based objective aquatic risk assessment criteria and the Aquatic Animal Health Code (OIE 2003). Also in 1995, the Food and Agriculture Organization of the United Nations developed the Code of Conduct for Responsible Fisheries, which included recommendations to ensure the coexistence of aquaculture with sound environmental, economic, and human health policy.

In the United States, regulations are less centralized and less comprehensive. The framework for aquaculture in the United States is established in the Aquaculture Act of 1980 (and subsequent amendments); however, the Act creates at least two concerns with respect to fish health. First, it specifies no central decision-making authority, and second, it does not explicitly deal with trade issues from a biological perspective. Thus, several federal agencies, in addition to regional and state agencies, with responsibilities in animal health are left to independently operate with

perhaps conflicting priorities. To complicate matters, the United States' membership in OIE requires certain procedures and actions. Without some centralized authority, insuring compliance becomes difficult, potentially redundant and, therefore, unnecessarily restrictive.

In 2001, recognizing the maze of conflicting regulations and priorities, the National Aquatic Animal Health Task Force, consisting of representatives from the departments of Agriculture, Interior, and Commerce, was charged with developing procedures for safe, efficient, and effective national and international commerce of aquatic animals and protection of cultured and wild aquatic animals from foreign pests and diseases. Some clarification was provided in 2002 when the Secretary of Agriculture was given the authority to protect and control the health of all livestock including imports and exports of aquatic animals. As of May 2004, however, only the introductory chapters for the National Aquatic Animal Health Plan (NAAHP) have been written and details of the implementation of the Secretary's authority are still being worked out (Amos 2004). In the interim, The American Fisheries Society's Bluebook, first published in 1975, and the OIE's Diagnostic Manual for Aquatic Animal Diseases, first published in 1995 and now in its 3rd edition, have provided a way of standardizing the procedures required to certify the presence or absence of particular pathogens. In addition, some state, local or regional groups have attempted to coordinate activities. The Pacific Northwest Fish Health Protection Committee (2004), for example, coordinates activities of government, academia, and user groups to prevent the importation or transfer of serious salmonid pathogens, as well as promote biosecurity and mitigation of factors conducive to the development of diseases (<http://pnfhpc.fws.gov/>).

For the Gulf of Mexico (GOM) region, no coordinating organization exists. Most jurisdictions, including Mississippi, provide for the protection and conservation of resources (some even name aquaculture as a permissible activity), but few specifically indicate how fish health issues should be handled. Some jurisdictions, particularly Florida, have adopted basic fish health guidelines that focus on maintaining cultured fish for use in stock enhancement programs at or below the levels of disease organisms found in their wild counterparts (Florida Fish and Wildlife Conservation Commission 2004). At the Gulf Coast Research Laboratory (GCRL), we have adopted the basic Florida guidelines. However, the Florida approach fails to elucidate a mechanism for dealing with emerging diseases or large-scale, intensive culture of organisms in the offshore from seed that may require transport from different facilities, localities, and environments.

In this paper, we will review the concept of fish health management and discuss the components of a Fish Health Management Plan. We will then review fish health issues for the GOM, and speculate on how those issues could be incorporated into a comprehensive strategy for managing large-scale, offshore culture of marine organisms in the GOM.

FISH HEALTH MANAGEMENT

Traditionally, fish health focused on treating the diseases that occurred; however, such an approach requires accepting a high degree of risk. In any outbreak, a certain number of fish will die before the disease is detected and treated (assuming a treatment is available). Even if a treatment is available, unchecked disease progression may lead to a decreased appetite in the stock and reduce the efficacy of

available in-feed oral treatments. Profit-making entities cannot always afford to assume a high risk. Thus, approaches to maximizing growth and health have been developed.

Fish Health Management is the concept of proactively regulating the host, pathogen, and environment to maximize the optimal conditions for sustained growth and health. It is based on Snieszko's premise that disease becomes a problem only under the confluence of proper conditions (Snieszko 1974). Pathogens must gain entry into the fish to cause disease or death; therefore, prevention is an important component of a fish health management program. But, pathogens are a normal part of the environment and may exist in a variety of habitats and host organisms. Thus, mitigation of further risk factors such as stress, nutritional or environmental problems that could directly kill fish, impair immune status, or trigger the outbreak of clinical disease is crucial in a health management protocol. Mitigation also includes the development of an understanding of the disease profiles a stock may encounter such that present technology in vaccine development such as genomics and proteomics can be brought to bear to improve preventative aquatic animal health. Ultimately, however, diseases or problems will occur as demonstrated historically with human and agricultural livestock health. As such, a fish health management plan must provide for containing the outbreak or problem in as few fish as possible and reducing the occurrence in the affected fish through the mitigation of offending environmental or husbandry factors, the judicious use of chemotherapeutants, preventative health protocol management, and combinations thereof. Finally, fish health management must balance the risk of the disease and treatment with public health, the environment, and farm economics including risks from and to wild fish.

A TEMPLATE FOR A HEALTH MANAGEMENT PLAN

To achieve these ends, many producers and regulators are requiring that detailed policies and procedures must be established in writing and understood by all involved parties. British Columbia, for example, requires an individualized Fish Health Management Plan for all private and public fish culture facilities in the province as a term and condition of the license (BC MAFF 2004a). As such, standard Fish Health Management Programs typically include requirements for training of personnel; protocols for site maintenance, feeding, water quality, containment, and biosecurity; techniques for routine monitoring and assessment that will identify signs or risks of morbidity and disease at the earliest stage; maintenance of records sufficient to track changes in health and environmental quality; protocols for diagnosing and treating illness; and, protocols for demonstrating or reporting the health status of a stock in accordance with relevant statutes or agreements. Said statutes or agreements may specify certain diseases whose presence or absence must be disclosed. If those diseases are present, continued operation may be contingent upon completion of specified procedures designed to eradicate or contain the disease. Some Fish Health Management Programs also advocate the use of crop insurance to indemnify against loss due to disease.

THE PRACTICE OF FISH HEALTH MANAGEMENT

Fish health management requires knowledge of the source and complete history of each group of animals in the facility/marine site including diagnostic sampling history, feeding records, dive records, environmental

and water quality data records, management history, and records of performance, along with some mechanism to convey that information in a timely manner. Routine maintenance includes standard inspection and/or repair of tanks, netpens, pumps, filters, air supply, or any other life support equipment to ensure the containment and well being of the animals. Routine monitoring includes a regular program for testing water quality, inspecting fish (both cultured fish from the netpen and wild animals from adjacent waters) for signs of disease, and periodically collecting samples of moribund fish or random samples of asymptomatic fish for routine diagnostic procedures in certified laboratories in accordance with specified protocols and statistical sampling requirements. Routine husbandry practices include day-to-day management of animals including feeding, cleaning, and removal/disposal of dead or moribund animals. Procedures for the removal and disposal of waste including the bodies of mortalities from the netpens must be specified. Open ocean disposal from facilities, processing plants, and marine cage sites is not acceptable. Adherence to hygiene and biosecurity protocols that limit contact among groups of animals, workers, and equipment, as well as prescribed disinfection/decontamination procedures are required. For operations that use different facilities for different stages in the production process, it is crucial that some quarantine/isolation or disinfection procedure be specified to reduce the risk of translocation of pathogens. Alternatively, single-year-class protocols in which all fish in a facility come simultaneously from the same stock can be implemented. An "all in-all out" agriculture model may be implemented in which all the stock is removed from the facility or contained portion of the facility followed by disinfection of the area prior to introduction of the new or naïve stock.

In preparation for the inevitable, protocols for diagnosis and treatment should be in place. Plans must specify either the party or the qualifications of the party who will diagnose, what procedures will be used, which accredited laboratories will perform the analyses, and who has decision-making authority. Plans must provide access to necessary and allowable chemotherapeutants, as well as instructions on how to use them. Details of treatments must be documented to certify compliance with public health, environmental, and safety standards. In well-established industries or in operations using animals with long culture histories, vaccine administration and/or the use of certified Specific Pathogen Free (SPF) or High Health animals, including the isolation of broodstock in biosecure land-based facilities, may be part of routine protocols. However, the use of vaccines or SPF stocks for animals to be grown in open systems such as netpens guarantees only that the animals exhibit decreased susceptibility to or are uninfected by a particular agent when they are introduced into the netpens. For SPF stock progeny, this may lead to decreased tolerance to endemic watershed pathogens. Thus, standard biosecurity and monitoring protocols are still required.

REGULATORY FRAMEWORK IN THE GULF OF MEXICO

Offshore, open ocean, netpen aquaculture is an emergent industry in the GOM; thus, no regulatory framework or regional body of knowledge on which to base fish health decisions exists. In one sense, this is an advantage. Designing a program from its inception allows for the incorporation of the expertise accrued through the development of similar industries in other places. In another sense,

predictability is low and any plan must accept a fair amount of adaptive management.

First and foremost, the regulatory environment must be established. Because the bulk of the operations will be in federal waters, a federal agency must have regulatory authority. The Department of Commerce/National Oceanic and Atmospheric Administration (NOAA)/National Marine Fisheries Service (NMFS) and the Department of Agriculture/Animal and Plant Health Inspection Service may be the most directly impacted agencies, although the United States Coast Guard, the U.S. Army Corps of Engineers, and the Environmental Protection Agency are affected as well. In Canada the lead aquaculture agency is the Department of Fisheries and Oceans via the Aquaculture Management Directorate, but the role of the Atlantic Canada Opportunities Agency and other federal agencies has been instrumental to the existence of aquaculture in Canada. The NAAHP, when completed, should delineate these roles and set a minimum standard. A regional committee, consisting of representatives from the five GOM states, could collate the regulations of each state and the federal agencies and propose modifications to streamline the regulatory framework and insure compliance with the minimum standards. The participation of and coordination with states is critical because the hatcheries that provide the fish for growout in the netpens are likely to be land-based and in multiple jurisdictions.

As experience with disease issues in the new industry develops, the development of a list of important pathogens, some of which may already be listed as important or notifiable by the OIE, can be developed. This could lead to the development of SPF animals, if considered desirable, through further research

by academia and the producers. Also, along with routine monitoring, the temporal and geographic patterns of diseases will become evident. Using this information, a classification system similar to that used by OIE can be established which certifies the absence of certain pathogens in facilities, zones, and regions, thus facilitating the monitored movement of cultured animals.

DISEASE ISSUES IN THE GULF OF MEXICO

Critical to the establishment of feasible regulations and operating procedures is an understanding of disease issues relevant to the GOM. Because the history of culture in the GOM is limited in scope (i.e., mostly for stock enhancement rather than production aquaculture) and geography (only in select localities/jurisdictions supported by public money), the risks associated with disease in large-scale culture must be extrapolated from essentially incidental observations in culture and background knowledge of the diseases known in wild fisheries and in culture facilities in sub-tropical regions around the world. Some of the disease issues are related to the choice of culture organisms. In the GOM, the red snapper (*Lutjanus campechanus*), the red drum (*Sciaenops ocellatus*), and the cobia (*Rachycentron canadum*) are the most often discussed candidate species; however, species such as the greater amberjack (*Seriola dumerili*) and spotted seatrout (*Cynoscion nebulosus*) also are possibilities. We do not consider the use of non-indigenous species.

The parasites of the likely candidates for culture in the GOM are relatively well known (Overstreet 1978; Shaffer and Nakamura 1989; Blaylock and Overstreet 2003; Blaylock unpublished data). We, however,

take a broad view of disease and discuss not only the disease-causing organisms but also other factors that may impair normal function in culture organisms. Further, we will include disease problems that have had major impacts on culture in other sub-tropical areas to expand the baseline understanding of potential problems.

Not all diseases and parasites pose equal risk to an aquaculture operation. Many disease-causing organisms have complicated life cycles requiring more than a single host species. Others have simple life cycles requiring only a single species. Still other diseases are caused by non-infectious agents. Those organisms with simple, direct life cycles are the most likely to cause difficulty in culture operations because the density of animals facilitates close contact and transmission. Thus, most of the concern in aquaculture is typically focused on these organisms. In open ocean netpens, however, complex life cycles can be operating because of the ingress and egress of organisms with water flow and the inhabitation of the netpen itself by ancillary organisms such as resident or migrating fish stocks. Further, the flow of water may expose fish to non-infectious agents. Thus, some disease organisms are known to predictably cause problems. Some problems will arise from known organisms that do not normally cause disease in the wild. Other problems will arise from organisms previously unknown in the wild. In the absence of non-indigenous culture organisms, non-indigenous pathogens should not be problematic unless introduced independently of aquaculture operations (e.g., ballast water).

Algal Blooms

Harmful algal blooms (HABs) generally refer to dense patches of pigmented phytoplankton carried in the current that can

mechanically damage fish gills, produce anoxia or oxygen supersaturation in the water column, or produce toxins that affect various organ systems. HABs have become a major economic threat to wild and cultured fishes, which are, of course, confined and cannot escape (Kent and Whyte 1997). A variety of taxonomic groups of algae contain genera and species known to be associated with disease in fish including dinoflagellates, green algae, cyanobacteria, yellow-green algae, blue-green algae, yellow-green algae, prymnesiophytes, raphidophyceans, and diatoms (Noga 1995; Kent and Whyte 1997). Mortalities in netpen-reared salmonids around the world have been attributed to at least one representative of each of the listed groups of organisms, and some are known to kill wild and pond-cultured fish of other species or invertebrates in various localities around the world (Noga 1995).

Representatives of all the groups are present in the GOM. Although “red tides,” as HABs are often called, occur around the world due to periodic and often unexplained blooms of algae, the warm, relatively shallow water in the northern GOM may be particularly vulnerable to blooms. Some blooms in the GOM, in fact, have been attributed to normally benthic organisms that because of the relatively shallow water were easily suspended into the water column (C. Moncreiff, personal communication). The “dead zone” in the GOM also attests to this vulnerability. Each summer, algae in the warm GOM water bloom in response to the high nutrient input from the Mississippi River and in the process of decaying consume all available oxygen rendering a vast expanse of the GOM relatively uninhabitable. The “dead zone” can cover more than 20,000 km² and vary somewhat in its location from year to year (Rabalais et al. 2002). Further, it is possible that nutrient input from netpens could facilitate smaller scale blooms.

In addition, oil platforms/rigs and netpens in the GOM could provide habitat that would not normally be available for microorganisms (C. Moncreiff, personal communication). Those organisms would be available to bloom under proper conditions.

Non-infectious Disorders

Non-infectious disorders in the context of this paper include degenerative, metabolic, neoplastic, and behavioral conditions. Fish production operations require handling and transport of fish for the purposes of stocking, grading, treating and vaccinating. Such activities invariably result in some degree of injury and stress, which contributes to the loss of some animals and increases the susceptibility of the fish to pathogens through the physical damage that creates portals of entry. In well-established industries, such as salmonid culture, technology has provided systems with the potential to minimize those risks. In a newly developing industry, those advantages do not exist. Some technology may be transferable or easily adapted from well-established industries, but, initially, producers should expect losses associated with these activities. Each culture species has its own suite of behavioral characteristics. Atlantic salmon, for example, are territorial and will attack their tank or cagemates resulting in injuries that can directly lead to death or facilitate the establishment of pathogens (Speare 1998). Tank-held red snapper also are known for their aggressive tendencies (R. Blaylock, personal observations). For Atlantic salmon, increased density was found to suppress the territorial behavior (but decreased biomass per tank or cage system is desirable from a health viewpoint). Research and trial and error will be required to establish protocols for a new industry.

Environmentally-induced Diseases

Environmentally-induced disorders include problems associated with water chemistry/quality, toxic compounds, and weather. Problems related to oxygen levels in the context of algal blooms already have been discussed. Temperature affects oxygen levels as well, but also affects metabolic rate and the quality of the immune response, both of which may affect the toxicity or pathogenicity of an agent. Further, the reproductive rate of disease organisms generally increases as temperature increases. In the GOM, water temperatures can easily exceed 32°C, and because of the shallow continental shelf, these temperatures can penetrate significantly into the water column. In cooler climates and in deeper water, fish can escape warm surface water by moving to the bottom of the cage, by the lowering of the cage in the water column, or by using deeper nets (Pepper et al. 2003). In such a warm shallow basin that exists in the GOM, the margin for manipulation is narrow.

Toxic compounds can include chemicals used for treatment of diseases, parasites or environmental pollutants, although therapeutic margins for many chemotherapeutants are relatively well known. Petrochemical pollution in the GOM is a possibility given the presence of numerous oil and gas operations. Hydrocarbons are known to cause mortality and affect parasite loads in marine fish (Overstreet 1993 and references therein). Toxicants in crude oil and water-soluble fractions of crude oil are known to induce histopathological changes in fishes from the GOM (Solangi et al. 1982). Stress related to pollutants and toxicants may increase the susceptibility of organisms to secondary infections. Overstreet and Howse (1977) demonstrated that fish stressed by organic waste and already infected with the ciliate *Epistylis* sp. were more likely to suffer from secondary

bacterial infections. Water quality issues such as turbidity are important as well because it can result in fouled gills, which can in turn precipitate other disease problems.

Nutritional Diseases

Food-related disorders are common in aquaculture. Fatty livers are common in many farmed fish, though not always pathological, and can be caused by several factors including rancid food, overfeeding, and inappropriate food formulations (Speare 1998). Overfeeding also can promote outbreaks of diseases such as vibriosis, presumably through nutrient loading (Speare 1998). Fast-growing, fat Atlantic salmon in sea cages are more prone to cardiomyopathy and “water belly,” a condition characterized by a stomach distended by saltwater and a thin tunica muscularis and serosa (Speare 1998). Vitamin or other nutrient deficiencies are widely known to cause a variety of physical, behavioral, or growth deformities (Halver 1989; Lasee 1995). In established industries such as salmonid culture, proper food formulations and food conversion ratios are well known, but in fledgling industries those issues must be researched and developed. In the case of the likely candidates for netpen culture in the GOM, standard marine grower feeds are typically used. The information required for feed formulations specific to the likely candidates generally is not available, though more may be known about the nutritional requirements of red drum than the other candidate species (see Gatlin 2000 and references therein).

Neoplasia

Neoplasia is an uncommon but sometimes important issue in fish culture. Neoplasia is a condition in which genetically altered cells “escape” from normal growth regulation and produce some type of abnormal mass independent of normal tissue that persists after the

removal of the stimulus that evoked the lesion (Grizzle and Goodwin 1998). Neoplasias occur spontaneously or can be induced by exposure to chemical pollutants or oncogenic viruses. Spontaneous neoplasias are not likely to be problematic for fish culturists. Chemically induced neoplasias, although known to be induced by halogenated compounds and polycyclic aromatic hydrocarbons in wild fish (Grizzle and Goodwin 1998), are not common in commercially cultured fish. However, there is substantial use of cultured fish for laboratory experiments in carcinogenesis. A variety of neoplastic lesions are known from the GOM, including a schwannoma in lutjanids from Florida (see Overstreet 1988 and references therein), but their role as disease-causing organisms in aquaculture in the GOM is unknown. Oncogenic viruses are known to cause problems in commercial fish culture in some instances. Plasmacytoid leukaemia, caused by a retroviral agent, can cause high mortality in netpen-reared chinook salmon (Kent 1997a), and *Oncorhynchus masou* virus causes typically nonlethal cutaneous lesions on a variety of salmonids (Grizzle and Goodwin 1998). Any cutaneous abnormalities could affect the marketability of fish.

Viruses

Viruses have had a major impact on aquaculture and are among the most difficult diseases with which to deal because of the difficulty in recognizing and diagnosing an infection, the ease with which they are transmitted, and the lack of effective treatments. Viral diseases in penaeid shrimp are considered one of the largest obstacles to the growth of shrimp aquaculture (Lotz 1997). Likewise, viruses such as Infectious Salmon Anemia Virus and Nervous Necrosis Virus (Nodaviridae) have had substantial impacts on finfish aquaculture (ARDF 2002; Miller and Cipriano 2003).

With the exception of lymphocystis, a chronic and typically benign condition caused by Lymphocystis Virus (Iridoviridae), and an unnamed DNA virus known to cause mortalities in hardhead catfish (*Arius felis*), no fish viruses are known from marine fishes in the GOM. Viruses certainly exist in the GOM; therefore, any aquaculture operation should be prepared for viral diseases. Unfortunately, because we cannot reasonably predict which viruses will cause problems, aquaculture pioneers in the GOM must assume a high degree of risk. Viruses such as Nervous Necrosis Virus (Nodaviridae) have caused problems in a variety of cultured species around the world, including cobia (Chi et al. 2003) and red drum (Oh et al. 2002), and are likely to be problematic in the GOM. Other iridoviruses that have been reported from more than twenty species of marine fish (Leong and Colorni 2002), as well as members of the Togaviridae family and aquareoviruses, could become problematic.

Bacteria

Bacteria also can be devastating in aquaculture both as primary infectious agents and as secondary infectious agents. Vibriosis, furunculosis (*Aeromonas*), Edwardsiellosis, columnaris, and others including rickettsial and chlamydial organisms are well known in fish culture. Commonly cultured fish species in sub-tropical waters of southeast Asia including groupers, lutjanids, carangids, and sciaenids are regularly lost to outbreaks. Representatives of all these types of bacteria and others are known in warmwater marine fish culture and from fish in the GOM. Representatives of *Acinetobacter*, *Aeromonas*, *Photobacterium*, *Pseudomonas*, *Shewanella*, and *Vibrio* as either primary or secondary pathogens from a variety of wild and cultured fishes including red snapper, red drum, and cobia are readily isolated (Overstreet 1978; Florida Fish and Wildlife Conservation

Commission 2004; R. Blaylock, unpublished data). Most respond well to antibiotic treatment if the outbreak is detected early; however, our experience at GCRL is with bath treatments, which, for obvious reasons, would be difficult in netpen aquaculture. Administration of antibiotics through food or intraperitoneal injection are widely accepted techniques. Vaccines for furunculosis and vibriosis in salmonids and cod are now available; therefore, development for use in other fishes is possible. Others are being refined to account for the variability expressed in some disease organisms. *Mycobacterium marinum*, *Streptococcus* spp., and chlamydia-/rickettsia-like organisms are also known from the GOM, but we have not seen evidence of them in our marine fish culture system at GCRL. Their potential role as disease-causing organisms in netpen culture is unknown.

Fungi and Fungi-like Organisms

Fungal infections in fish typically refer to infections by a variety of organisms with a variety of life cycles that are not necessarily related systematically. Historically, however, they have been referred to as fungi; therefore, we consider them together for convenience. Species of *Ichthyophonus* (now classified as a protist) occur in temperate to tropical waters around the world and systemically infect a variety of marine fishes causing severe mortalities both in the wild and in culture (McVicar 1999). Members of *Saprolegnia*, *Aphanomyces* (water mold—now classified as a protist), and other oomycetes infect a variety of fishes and are known to cause ulcerative mycosis, a serious disease in a range of estuarine species (Bruno and Wood 1999). Various deuteromycetes also have been reported to cause disease in wild and cultured fishes (Bruno 1989; Lehmann et al. 1999; Blaylock et al. 2001). In many cases, however, the disease associated with the fungus is assumed to

be secondary to an injury or another compromising factor (Blaylock et al. 2001). That assumption may be valid in many cases, particularly in salmonids; but, Noga et al. (1988) and Dykstra and Kane (2000) show how *Aphanomyces* sp. produces primary disease in an estuarine fish. Representatives of all these groups are present in the GOM, but their role as potential pathogens in netpen culture in the GOM is unknown.

Microspora

Members of the phylum Microspora are widely known from fishes but are typically regarded as parasites of invertebrates. In the GOM, microsporidians are known from blue crabs and grass shrimp and less so from fishes (Overstreet 1978). Microsporidians are small, single-celled, intracellular parasites characterized by spores that contain a sporoplasm that extrudes through an everted polar tube into a host cell. Development of the spores of some species, such as those of *Pleistophora*, occurs in groups within a sporophorous vesicle. A host “cyst,” making an infection apparent to the naked eye, encapsulates large numbers of spores that may be directly infective (Blaylock and Overstreet 2003).

Those species that infect fish can cause severe diseases in culture facilities (e.g., *Glugea stephani* in flatfishes, *Microsporidium seriola* in *Seriola quinqueradiata*, *Loma salmoneae* and *Nucleospora salmonis* in salmonids, *Loma morhua* and *Loma branchialis* in cod (Rodriguez-Tovar et al. 2003)); however, they are typically associated with temperate waters (Overstreet 1978; Dyková 1995). In the GOM, microsporidians (mostly unnamed) are known from sciaenids (drums, croaker, spot, and seatrout) and red snapper; but, in the wild, the cysts appear to be relatively innocuous (Overstreet 1978).

Their potential role as pathogens in netpen culture in the GOM is not known. Dyková (1995) believed that young fish suffered more than adults from microsporidians. This is probably especially true for cultured fish, but primarily hypothesized for wild ones.

Apicomplexa

The phylum Apicomplexa includes the coccidians, haemogregarinids, and piroplasmorids. All have representatives in fishes, though coccidians, typically intestinal parasites that can have either direct or indirect life cycles depending on the species, are the most common. Members of *Goussia* and *Eimeria* are known to cause mortality in cultured marine fishes such as cod, haddock, and red drum (Molnár 1995; Johnson 2000). Several species of *Eimeria* and *Calyptospora funduli* from the Gulf killifish are known from the GOM. *Haemogregarina platessa*, a blood parasite requiring a leech, isopod, or argulid vector, is known from the blood of southern flounder and mullet, among others (Becker and Overstreet 1979; Overstreet 1978). The potential role of these parasites as pathogens in netpen aquaculture in the GOM is unknown.

Sarcomastigophora

Sarcomastigophorans, such as members of *Hexamita*, typically occur in the intestines of a wide variety of marine fishes, have a direct life cycle, and are known to kill juvenile, salt-water reared salmonids (Woo and Poynton 1995). *Ichthyobodo*, an ectoparasite that alternates between a free-living stage and a stage parasitic on the epithelial cells, is known to kill flounders in hatcheries in Japan (Urawa et al. 1991). Species of *Cryptobia*/*Trypanoplasma* are well-known flagellate pathogens of fishes (hatchery-reared salmonids and wild summer flounders). There is debate, however, on the taxonomy of the

group. *Cryptobia* (subgenus *Cryptobia*) are typically ectoparasites or intestinal parasites with direct life cycles. *Cryptobia* (subgenus *Trypanoplasma*), typically containing the pathogenic species, are haematozoic with indirect life cycles requiring a leech vector (Woo and Poynton 1995). *Cryptobia* (*T.*) *salmositica* causes mortalities in salmonids both in culture and in the wild (Woo and Poynton 1995). In the GOM, *Cryptobia* (*T.*) *bullocki* is known from the southern flounder and Atlantic croaker (Overstreet 1978; Becker and Overstreet 1979). The parasite is known to kill experimentally infected summer flounder, *Paralichthys dentatus* (Overstreet 1993). The potential role of these parasites as pathogens in netpen aquaculture in the GOM is unknown. Trypanosomes such as *Trypanosoma murmanensis* are known to kill experimentally infected cod (Woo and Poynton 1995). Trypanosomes such as *T. mugilicola* are known from mullets and other fishes in the GOM (Becker and Overstreet 1979), but their potential role as disease-causing organisms in aquaculture in the GOM is unknown. Amoebae such as *Paramoeba pemaquidensis* cause mortalities in salmonids in sea cages (Kent 1997b), but their status as disease-causing organisms in the GOM is unknown.

Sarcomastigophora (Dinoflagellida)

One of the most problematic parasites culturists in the GOM must face is the dinoflagellate *Amyloodinium ocellatum*, often considered the single most consequential pathogen in warm water fish culture (Paperna et al. 1981). The parasite alternates between an obligate feeding trophont on the gills and skin and an encysted reproductive tomont in the sediment, on surfaces of nets and tanks, or in the water column. Trophonts attach to epithelial cells and feed on surrounding cells causing hyperplasia, inflammation, and necrosis that disrupts gas exchange in the gills. Species

are differentially susceptible to infection, but most fishes are susceptible (Lawler 1980). Wild-caught fishes are infested at a relatively low level that typically does not harm the host in the wild (Blaylock and Overstreet 2003), although mass mortalities in a variety of fishes have been associated with the parasite (Overstreet 1993). However, because each encysted tomont produces 256 infectious dinospores, populations of the parasite can build to dangerous levels if a fish experiences a stress event, which can stimulate the trophonts to drop off and produce the dinospores. This is particularly important for captive fishes because the tank, pond, or net-pen concentrates the infective dinospores in proximity to the fish hosts. Red snapper, cobia, and red drum are susceptible. Survivors, although few in our experience if left untreated, can develop some level of resistance to reinfection, and serum from fish immunized with dinospore fractions kills the parasite in cell culture (Noga and Levy 1995); thus, vaccine development may be possible.

Myxozoa

Myxozoans are pluricellular, spore-producing protists, arguably related to cnidarians, that typically alternate between an actinosporean stage in oligochaetes/polychaetes or other invertebrates and a myxosporean stage in teleost hosts. The parasites can be either intercellular or intracellular in a variety of tissues, and they develop in a variety of patterns, often occurring in “cysts” containing many spores or packets of spores that are infective to the alternate host.

Myxozoans are among the most devastating pathogens of cultured fishes. *Kudoa thyr-sites* myoliquefies the flesh of infected fish, and may render it unsightly and unmarketable. *Myxobolus cerebralis* infects the cartilage and is responsible for whirling disease in trout.

Ceratomyxa shasta infects the gall bladder and causes serious mortality in cultured and wild salmonids. Species of *Henneguya*, *Myxidium*, and *Tetracapsula* also are well-known pathogens of fishes. Species of *Myxidium*, *Sphaerospora*, *Ceratomyxa*, *Myxobolus*, and *Kudoa* are known to debilitate and kill sparids, groupers, mullets, seabass, and cobia in culture (Alvarez-Pellitero and Sitjà-Bobadilla 1993; Leong and Colorni 2002). In the GOM, representatives of *Kudoa*, *Myxobolus*, *Henneguya*, and *Myxidium* are known, but their potential role as pathogens in netpen aquaculture is unknown.

Ciliophora

Representatives of the phylum Ciliophora parasitic in fishes are typically commensals or opportunistic parasites. These organisms include *Trichodina*, *Epistylis*, *Tetrahymana*, and *Brooklynella*. Many fish harbor a few commensal organisms without effect; however, because the organisms are typically directly transmitted, the stress and confinement of captivity can result in the development of large numbers of commensals which can do extensive damage to the hosts through grazing on or anchoring on epithelial cells and by interfering with gas exchange in the gills (Overstreet 1978; Lom 1995).

Representatives of the cosmopolitan genus *Trichodina* are among the most common organisms found on fish in the GOM (Overstreet 1978). *Brooklynella* is commonly seen in captivity and typically on the gills where it can destroy the gill epithelium of most marine teleosts. Although we have never seen *Brooklynella* in our marine fish culture facilities at GCRL, lutjanids cultured in Martinique have suffered heavy infestations with the parasite (Gallet de Saint Aurin et al. 1990). *Cryptocaryon irritans* is a ciliate with an obligate parasitic feeding stage inhabiting

the basal layer of epithelial cells and a free-living, encysted reproductive stage that infests a wide variety of marine fishes producing vesicles on the skin, increased mucus production, and erosion of the gill epithelium. It is known to cause mass mortalities in closed systems such as ponds and aquaria (Overstreet 1993). Groupers and snappers in cage culture are susceptible (Leong 1994). We identified *C. irritans* on wild-caught, tank-held red snapper on one occasion. Colorni (1987) indicates that *C. irritans* in cage culture can be avoided by keeping cages at depths and currents sufficient to prevent contact with the infectious stage.

Monogenea

Monogeneans commonly occur as ectoparasites on the gills and body surfaces of fishes. The different species attach by means of a variety of hooks, anchors, suckers, and clamps located on a posteriorly located haptor. The life cycles of these parasites are typically direct. Some species lay eggs while others bear live young. Eggs hatch into infective oncomiracidia that invade the same or another individual of the host species. Some oncomiracidia are free swimming and some crawl. Viviparous species produce well-developed embryos that directly infest the host but can be passed on to other individuals. Monogeneans are of two general types: sanguiferous polyopisthocotyleans, usually with multiple attachment structures in the haptor, and tissue grazing monopisthocotyleans, usually with one or two relatively large pairs of anchors and very small marginal hooks in the haptor. Because of the direct life cycle, populations of monogeneans can build rapidly, producing detrimental effects particularly when the host occurs in confined areas.

Among the most devastating of monogeneans in culture conditions are the capsalids.

Amberjack, flounder, rockfish, and various groupers and lutjanids in culture in Asia have been seriously affected by several capsalid species (Leong and Colorni 2002). *Neobenedenia melleni*, a species reported from over 100 host species, including several from the GOM can also be devastating (Bullard et al. 2000, 2003). Other monogeneans, such as members of *Haliotrema*, are very common on lutjanids (Leong and Colorni 2002) including the red snapper (R. Blaylock, personal observation), but their role as disease-causing organisms is unclear (Leong and Colorni 2002). At GCRL, we have maintained wild-caught red snapper infested with a species of *Haliotrema* in captivity for extended periods of time without difficulty (R. Blaylock, personal observation).

Cestoidea

Cestodes, or tapeworms, are perhaps the most well known parasites. These flatworms, typically segmented as adults, generally live as adults in the intestinal tracts of a wide variety of animals including fishes and have intermediate stages in other hosts. Eggs of aquatic species develop into stages infective to invertebrates that are in turn consumed by fishes where the parasites can either develop into adults or encyst as metacestodes that are transmitted to other fishes, birds, or mammals. Most marine teleosts do not serve as a definitive host for tapeworms. Rather, in many cases involving fish tapeworms, the metacestode stage that can occur in the flesh is transferred from host to host many times before it develops further or enters the definitive host, a process known as paratenesis.

Juvenile tetraphyllideans inhabiting the cystic duct and intestinal tract comprise several commonly encountered species that belong in a group collectively termed "Scolex polymorphus." These organisms, while common,

probably cause little harm to the host (Blaylock and Overstreet 2003; Overstreet 1978). Other cestodes include the trypanorhynchean metacestodes. Trypanorhynchs are typically found encapsulated in the flesh or viscera and are characterized by four eversible, hook-bearing tentacles. The metacestodes of species of *Otobothrium* and the *Kotorella-Nybelinia* complex are relatively widespread in fishes and apparently cause little harm (Blaylock and Overstreet 2003). Probably the most well known cestode in the GOM is the trypanorhynch *Poecilancistrum caryophyllum*, a larval tapeworm that appears as a chalky, opaque, worm-like object twisted within the flesh of the spotted seatrout, *Cynoscion nebulosus* (Overstreet 1977). Because these parasites are not infective to humans, the greatest problem related to this parasite is an aesthetic issue (Overstreet 1983). The presence of plerocercoids in the flesh makes the fillets unsightly.

Digenea

Digeneans are the most abundant metazoans in marine fishes both in numbers of species and individuals. These parasites are among the most complex of parasitic organisms, requiring multiple hosts to complete their life cycles. Typically, eggs produce miracidia that enter molluscs where they, in turn, produce a sporocyst or in some cases a redia. After what can be several asexual generations in the mollusc, each sporocyst or redia produces many cercaria, which leave the mollusc, infect a second intermediate host, and often encyst as a metacercaria. Metacercariae, encysted, encapsulated, or free, are infective to appropriate definitive hosts. Marine fishes can act as both intermediate and definitive hosts for digeneans (Blaylock and Overstreet 2003).

Although infections by adult digeneans rarely harm the host, some metacercariae such as diplostome metacercariae, when present in high enough numbers, are known to impair or kill freshwater catfish in farms (Coblentz 2000; Overstreet and Curran 2004). An exception is the sanguinicolid digeneans whose adults and eggs inhabit and obstruct the circulatory system of fishes. These flukes are unusual with respect to most digeneans in that their life cycle may use a polychaete rather than a molluscan first intermediate host, lacks a second intermediate host altogether, and lacks an encapsulated metacercaria. Thus, the mere proximity to the intermediate host can facilitate infection (Bullard and Overstreet 2002). Cultured carangids, seabass, groupers, and snappers in Asia are commonly infected with several species, and mass mortalities have been reported in cultured amberjack (Ogawa and Fukudome 1994). In the GOM, several species of bloodflukes are known from a variety of inshore and pelagic fishes (Bullard and Overstreet 2002). Their potential as disease-causing organisms for fish in culture in the GOM is real.

Nematoda

Nematodes can be found in the intestinal tract, viscera, mesentery, and in the tissues. Marine fishes acquire the worms, depending on the species, by consumption of eggs, juveniles, or the intermediate host, often a copepod. Some species are acquired from a paratenic host, one in which development of the parasite does not occur. After one or two molts in the definitive host, nematodes mature and produce eggs or larvae that are in turn shed from the definitive host to infect the appropriate intermediate host where another series of molts occurs. Nematodes are typically dioecious and often markedly sexually dimorphic. In many species, females often

constitute the majority of worms observed (Blaylock and Overstreet 2003).

Some nematodes certainly cause pathology (e.g., abdominal adhesions in salmonids caused by species of *Philonema*; see Dick and Choudhury 1995), but few cause overt disease in either wild or cultured fish. Juvenile nematodes, if they are large relative to the size of the host, can kill juvenile fishes (Overstreet 1978). Some obvious exceptions result from infections in abnormal hosts such as the case of the introduction of the eel nematode *Anguillicola crassus* into the U.S. This is a nematode from East Asia where it is relatively non-pathogenic in native eels. When introduced, first into Europe and then into the United States (Fries et al. 1996), it caused mortalities in the native, naïve eel species. Heavy infections of other nematodes may affect fish condition or behavior. Nematodes (Anisakidae) in the liver of cod results in reduced liver size, weight, fat content, and overall fish condition (Margolis 1970). *Philonema oncorhynchi* affects the orientation of sockeye salmon smolts (Garnick and Margolis 1990). Even without direct physical effects, large numbers of worms, especially in the flesh, can affect the marketability of fish. Red snapper, red drum, and cobia are infected with both juvenile and adult nematodes. Among the most common nematodes in marine fishes from the GOM are juveniles of *Hysterothylacium* (Anisakidae) found in the mesentery. These worms, difficult to identify to species in the larval stages, mature in the intestinal tract of other fishes. Juveniles of *Contracaecum* have been reported as well. At least one larval nematode, a species of *Hysterothylacium*, can cause mucosal hemorrhaging and focal eosinophilia in the digestive tract of rhesus monkeys, and probably humans (Overstreet and Meyer 1981).

Acanthocephala

Acanthocephalans, also known as spiny-headed worms, are a small, unique group of parasites related to rotifers (Dunagan and Miller 1986). Acanthocephalans inhabit either the intestine as adults or the body cavity or tissues as juveniles (cystacanths) and typically have simple life cycles involving two hosts, a vertebrate and an “arthropod.” Shell-encased embryos (acanthors) are released from adult worms and passed in the vertebrate definitive host’s feces. In species infecting an aquatic vertebrate, a specific crustacean then consumes the acanthor, which develops into a juvenile in the crustacean. Definitive hosts are infected either by consumption of the arthropod intermediate host or, in cases of some species, by a vertebrate or invertebrate paratenic host. Fish may serve as paratenic or definitive hosts (Blaylock and Overstreet 2003). Epizootics of acanthocephalans are known from trout hatcheries (Bullock 1963) and wild populations (Schmidt et al. 1974), but are unusual. Several species are known from a variety of host species in the GOM. *Acanthocephalus* sp. is known from the red drum, and *Serrasentis sagittiferus* (both cystacanths and adults) is known from cobia and red snapper. Heavy infections could cause problems in culture, but the true role of acanthocephalans as primary disease-causing agents in culture in the GOM is unknown.

Crustacea

Crustaceans representing the Copepoda, Isopoda, Amphipoda, and Branchiura typically infest the skin, fins, gill filaments, gill rakers, and mouth and are among the most grossly noticeable of all fish parasites. Life cycles are generally direct and involve various numbers of molts progressing from nauplius to copepodid, chalimus, pre-adult, and adult stages. In copepods, there is great sexual dimorphism, and the majority of observed

specimens are female. Copepods associate with the host in a variety of ways ranging from no attachment (as in the caligid *Lepeophtheirus salmonis* which simply grazes along the surface of the host) to grasping onto the host using modified appendages (as in the ergasilids and lernanthropids) to elaborate holdfast organs (as in the pennellids *Lernaeenicus radiatus* and *Phrixocephalus cincinnatus*) which anchor the parasite deep within the tissue of the host. Copepods feed on blood, mucus, and epithelial cells or some combination thereof depending on the species. They can cause extensive physical damage, severe hemorrhage, hyperplasia, and inflammation in the tissue they infest, which can result in the blockage of blood and lymph vessels, loss of surface area for gas exchange (gill parasites), osmotic stress, hyperplasia of epithelium, and infiltration with various immune cells.

Lepeophtheirus salmonis, the sea louse, is well known for the damage it does to netpen-reared salmon (Johnson et al. 2004). Members of *Caligus*, of which there are many representatives in the GOM, also are responsible for disease outbreaks in netpen aquaculture (Johnson et al. 2004). Overstreet (1983) noted that larval seatrout (*Cynoscion nebulosus*) can be infested, and a single *Caligus* individual can kill a small fish. Members of *Ergasilus*, of which there also are many representatives in the GOM, are known to be important parasites of marine-reared salmonid and non-salmonid fishes (Paperna 1975; Johnson et al. 2004). A representative of *Thysanote* (Lernaeopodidae) is found in the nostrils of the red snapper (R. Blaylock, unpublished data). Lernaeopodids, which typically graze on mucus and epithelial cells, are known for their secure attachments to their hosts that can cause substantial physical damage. Representatives of *Cybicola* (Pseudocynidae) are known from the GOM

(Blaylock and Overstreet 2003). These copepods can cause major damage from host reaction at the attachment site; however, many individual copepods are probably necessary to cause serious harm to a host unless the host is a juvenile or otherwise compromised. Specifically which copepods are likely to cause problems in netpen aquaculture in the GOM is not known, but some are certain to cause difficulty.

Species of *Argulus*, sometimes known as fish-lice, and related branchiuran genera, comprise this distinct group of parasitic crustaceans. These organisms do not use an intermediate host, but long-lived, well-protected eggs are typically deposited on a hard substratum. A copepodid-like stage emerges from the egg and is immediately infective to the host, usually the same host species from which it came, where it will undergo a series of molts into the adult stage (Lester and Roubal 1995). Argulids feed through a tubular mouth equipped with a stylet that everts and pierces the host releasing hemorrhagic compounds (Overstreet et al. 1992). Thus, a heavy infection with an argulid can decimate hosts, particularly in confined areas (Lester and Roubal 1995). This group of organisms is well represented in the GOM and is likely to present some difficulty for aquaculture.

Isopods belong to a third group of crustaceans with representatives parasitic on fishes. Little is known concerning the complete life histories of parasitic forms. Typically free-swimming juveniles are released from brood pouches to infect either the same or another host. Cymothoids, the most common type of parasitic isopod, typically attach (sometimes in male-female pairs) to the mouth, in the branchial area, or near the base of the fins with their claw-like legs. With these legs and their piercing or sucking mouthparts,

some are capable of producing severe lesions, destroying gill filaments, and serving as vectors for other infectious organisms such as viruses (Blaylock and Overstreet 2003). *Lironeca ovalis* obstructs the gill chamber causing the opercula to flare out unnaturally, erodes the gills, and debilitates the host (Overstreet 1978). Further, Pearson (1929) and Overstreet (1983) both suggested that *L. ovalis* might contribute to significant morbidity and mortality among juvenile spotted seatrout and red drum through destruction of gill filaments. Cymothoids (*Ceratothoa oestroides*, *Nerocila orbignyi*, and *Emetha audouini*) kill and retard the growth of seabass in netpen culture in the Mediterranean Sea, and *Ceratothoa gaudichaudii* retards the growth of salmon in netpen culture in Chile (Horton and Okamura 2001). Gnathiid isopods, parasitic on fish only as juveniles, feed on blood and can cause losses in cage-held fishes, particularly in heavy infections (Bunkley-Williams and Williams 1998). Approximately 12 species of cymothoid isopods are known from the GOM, but each of these species may infest more than a single fish species, an important consideration for aquaculturists because wild fish surrounding netpens can transfer their isopods to fish in the netpens. Because juveniles of gnathiid isopods are difficult to identify to species, the number of species infesting fish in the GOM is unknown.

Annelida (Hirudinea)

Leeches are blood-feeding members of the phylum Annelida that live at least part of their lives parasitic on vertebrates. Mating occurs either on or off the vertebrate host. Cocoons are either deposited on hard substrates such as crustacean exoskeletons or brooded on the leech's ventral surface depending on the species and newly hatched leeches seek out the vertebrate host. Leeches serve

two roles in fish diseases. First, because leeches are blood feeders that attach to the host, they may act as direct pathogens. *Piscicola salmositica* has caused mortalities in salmon hatcheries, *Myzobdella lugubris* has heavily infested cultured striped bass, and *Johanssonia arctica* has caused severe lesions in cod (Burreson 1995). In addition, there is interesting evidence that leeches alter the energy balance that results in reduced growth or condition in infested fish (Burreson 1995). Second, leeches may serve as vectors for other disease organisms. Their role in the transmission of fish haematozoa is well established, but they are suspected vectors of lethal viral illnesses such as Spring Viraemia of carp and Infectious Haematopoietic Necrosis Virus of salmonids (Burreson 1995). Representatives of at least six genera are known from the GOM (Sawyer et al. 1975), but their potential role as pathogens in netpen culture is unknown.

DISEASE MANAGEMENT

Management of disease problems is accomplished through several avenues. Because netpens will typically be used only for growout, diseases in larviculture can be controlled through biosecurity and quarantine procedures in the hatchery as discussed earlier. Broodstock should be maintained in land-based sites, preferably in more than one biosecure facility to guard against failure at one facility. If fish introduced into netpens are known to be free of pathogens of concern, efforts can focus on managing the netpen to minimize the likelihood of infection. Health information on resident wild fish populations is crucial to managing the cultured fish and decrease the likelihood of disease transference from wild fish to the cultured fish. Further precautions such as single-year-class rearing

will reduce the risk of introducing new diseases with new fish as well as maintaining a minimum distance for site separation. Coherent management practices require knowledge of the subtleties of the environment in which you work. For the GOM, because there is no precedent for netpen culture, some of these subtleties will be understood only through trial and error. Some basic information on the physical nature of the environment in the GOM, however, may serve to facilitate the estimation of best management practices.

PHYSICAL ISSUES IN THE GULF OF MEXICO

Water flow is a significant issue in netpen management because sufficient flow can flush out infectious stages of organisms and maintain water quality. The proper choice of site for a netpen, therefore, is critical and can be regulated as part of the licensing process. British Columbia, for example, makes issuance of all new commercial finfish aquaculture licenses contingent on meeting 15 siting criteria that address biological, aesthetic, and legal issues (BC MAFF 2004b). Ordinance 13.001 of the Mississippi Commission on Marine Resources (2000) specifies the parameters for required site assessments and the requirements for placement of the facility in relation to the bottom and surrounding interests. Maximizing tidal flow in the GOM must consider that throughout most of the region, tidal range is usually around only 0.6 m (2 feet). In addition, a substantial portion of the GOM experiences diurnal tides (one high and one low tide per lunar day) or mixed diurnal tides (2 unequal highs and 2 unequal lows per lunar day) that for practical purposes are diurnal. Thus, use of nets that maximize water exchange and keep

the net clear of fouling organisms may be critical.

The physical make-up of the environment is important. The GOM is a semi-enclosed, partially land-locked, intercontinental, marginal sea separated from the adjacent Atlantic Ocean and containing a water mass with movements that differ substantially from those in the ocean (Gore 1992). The GOM has a wide shallow continental shelf that slopes to a deep pit, but is interrupted by three relatively deep canyons. In general, however, the 182 m (100 fathom) isocline is well offshore. This physical environment also engenders an additional problem—waves and the associated turbulence. As opposed to deepwater swells typical of oceanic aquaculture sites, the shallow water increases swell height and superimposes shallow water chop on incoming swells in the GOM, creating an extremely high-energy environment. In addition, tropical weather systems regularly traverse the GOM creating severe conditions. Therefore, when one considers that an operation must be approximately 40 km offshore to reach water depths sufficient to achieve an economically feasible scale of operation using present technology, transport to and from the facility under normal conditions is a major endeavor. The additional difficulties superimposed by the weather magnify the problem. From a fish health standpoint, the feasibility of scheduled, regular monitoring and fast response in such an environment becomes questionable. A disease outbreak could be well underway by the time it is detected if weather conditions prohibit contact with the site.

Ocean currents are also an issue to be considered. The current in the GOM is characterized by the Loop Current system. Water driven by the Equatorial and Guiana currents enters the GOM through the Yucatan Channel

and moves in a generally north-northwestward direction spinning off series of gyres, particularly in the eastern GOM, along the way before exiting through the Florida Straight as a major component of the Gulf Stream (Gore 1992). The northward extent of the Loop Current varies according to season, extending further north during the summer. Circulation along the shelf is driven by winds, tides, and freshwater discharge sporadically interrupted by the intrusion of the gyres (Johnson et al., in press). The Loop Current, its associated gyres, and the interaction with shelf water are, at least in part, responsible for creating and maintaining the aggregations of nutrients and organisms that result in the high productivity of the region, and fishers are keenly aware of these fertile areas. The northern GOM, in fact, has been referred to as the “fertile fisheries crescent” (Gunther 1963). Indeed, the dispersal of several organisms including the exotic tropical jellyfish *Phyllorhiza punctata* into the northern GOM has been attributed to the gyres that spin off the Loop Current (Graham et al. 2003). Concomitant with these features that facilitate productivity is the abundance of intermediate hosts, vectors, and sources for parasites and diseases as well as animals that can clog nets. Thus, aquaculture operations in the northern GOM must be designed to deal with both the high background productivity and the unpredictability associated with periodic incursions of water potentially containing exotic flora and fauna.

TEMPLATE FOR FISH HEALTH MANAGEMENT IN THE GULF OF MEXICO

Philosophy

The development of an aquaculture industry in the GOM first requires the establishment of an enabling regulatory framework coordinated at the local, state and federal lev-

els (Mitchell and Stoskopf 1999). Chapter 3 in this volume reviews the specific legal and regulatory issues applicable to obtaining the necessary permits to site aquaculture facilities in the GOM. A complete regulatory framework to operate aquaculture facilities must be based on the concept of fish health management whereby all parties, ranging from all levels of government (i.e., local, regional, state, and federal authorities) to the producers and their individual employees, embrace the philosophy of minimizing adverse effects to cultured animals, wild animals, people, communities, and the environment. A proactive, scientifically robust risk assessment process to quantify and manage the relative risks for disease introductions/transfers and environmental impacts (see Arthur and Bondad-Reantaso 2004 and references therein) must be at the foundation of this framework. Based on the scientific risk analysis, the program must develop and enforce a Code of Practice, a Code of Containment, and a Code of Environmental Protection (see the Newfoundland Code of Practice for examples (NAIA 2004)). In addition, the regulatory framework must include mechanisms such as inspections to ensure adherence to the codes (see British Columbia Ministry of Agriculture, Food, and Fisheries—www.agf.gov.bc.ca/fisheries/compl/ce_main.htm). These mechanisms should provide for typical penal repercussions for violations, and facilitate the involvement of producer associations to advocate for the industry and peer review colleagues to implement a good neighbor policy that facilitates adherence to codes of practice such that due diligence is given to the prevention or mitigation of disease or environmental impacts. Finally, some mechanism must be implemented to indemnify producers much like is done in agricultural settings when something beyond the control of a producer, such as a

weather event, a disease outbreak, or a cull order, results in the loss of a crop.

Practice

Specific, fundamental questions about operational procedures must be addressed to maximize the likelihood of success in an operation. It is not our intent to speak for those who may eventually face designing an application procedure. Rather, we present these questions from the fish health management perspective espoused throughout this paper. Answers to these questions should be viewed as potentially legitimate information required for consideration of an application to establish an operation. Where possible, we comment on the manner in which those questions have been addressed in other jurisdictions. In other cases, we present only ideas about ways in which they could be addressed. We present these ideas through a series of some basic procedural questions that must be addressed when developing and implementing a regional fish health management plan for the GOM.

What permits are required? Who issues them?

The United States Army Corps of Engineers is responsible for maintaining navigational access to U.S. waters and must approve anything installed in navigable waters for its effect on water, wildlife, recreation, navigation, and pollution. The U.S. Coast Guard requires that installations meet marking and signaling requirements facilitating safe navigation. The Environmental Protection Agency must issue a wastewater discharge permit for any facility discharging wastewater into U.S. waters. The U.S. Fish and Wildlife Service requires review of any permit that impacts aquatic plants and animals and the Minerals Management Service has some jurisdiction over operations near oil, gas, or mineral leases (Fletcher, this volume). Additionally,

state agencies may be involved if the operation is within state waters.

What is the approval process?

The order of events must be known (see the Newfoundland Aquaculture Policy and Procedures Manual (NL DFA 2004a) as an example). Public comment and input from a variety of user groups should be encouraged.

What are the conditions of continuance once approved?

The issue of how to insure continued adherence to the conditions of approval should be addressed. Questions such as which inspections are required and at what intervals should be answered. British Columbia, for example, requires at least yearly inspections during which inspectors interview company officials and review the farm's operational procedures, management plans, and maintenance records for completeness and compliance with the regulation with respect to therapeutant use, stock inventory, net and equipment maintenance, mooring systems, containment systems, and predator control systems. The inspectors perform above-water visual examinations of the site, including a perimeter inspection of each containment pen and infrastructure including anchors, walkways and other associated hardware. Spot dive audits are also conducted at randomly selected sites where a dive team is contracted to review the underwater portion of the containment and anchoring system (British Columbia Aquaculture Code of Enforcement—www.agf.gov.bc.ca/fisheries/compl/ce_mainhtm).

Pursuant to the existence of a mechanism for issuing and regulating permits, questions related to the information required in an application must be addressed. We believe that a substantial amount of information should be required. Our view, however, is not that the

process should be prohibitive. Rather, we believe that the knowledge gained from this information will increase the likelihood of success.

What constitutes a site? Based on what information?

Hydrography, depth, temperature, oxygen profile, and tidal flow are among the important parameters that must be determined. A formal site assessment process must be developed (DFO 2002; NL DFA 2004b). Some states, including Mississippi, already specify some assessment and placement criteria for aquaculture sites (see Mississippi Commission on Marine Resources 2000); thus, coordination will be required. Certain failure of an aquaculture operation is expected if a decision is made to place a site in a suboptimal environment in relation to the animal's physiology and the seawater/seafloor dynamics.

Land and water ownership must be considered. In Canada, for example, aquaculture sites require the leasing of Crown land/water (see NL DFA 2004a; BC MAFF 2004b). If a lease is required, should there be a rental fee?

How many netpens per site? How much distance between sites is required to mitigate water quality/environmental issues and disease transmission?

One kilometer can be used as a minimum starting point for distance between sites based upon requirements in other jurisdictions (British Columbia and Newfoundland and Labrador, for example), but a mechanism for adjusting that to locally relevant conditions must be considered. Coordination with existing ordinances (Mississippi Commission on Marine Resources, Ordinance 13.001 for example) will be necessary. As well, the site distances should be assessed based on sound

epidemiological analysis (Hammell and Dohoo 1999) and marine hydrography. The issue of how many netpens constitute a site will be dependent on logistics, as well as environmental conditions. Because of the emergent nature of the industry in the GOM, the resolution of these issues will require research, the application of sound epidemiological analysis, and adaptive management.

Will sites be single year class sites? Single-species sites?

For optimal health, an "all in-all out" growout cycle is advocated for one stock species. For economic reasons, variances may be issued on a case-by-case basis. The timing and frequency of grading must be in conjunction with the environmental conditions.

In what will the animals be housed? How will food be administered? What is the optimum maintenance and feeding schedule?

Design and specifications of the netpen should be submitted for review to insure adequate engineering. Adequate nutrition based on scientifically derived data must be provided to the stock both for humane reasons and for optimizing performance.

How do you ensure the containment of the animals? How do you safely move and harvest animals?

Mooring systems must be regularly inspected. Adequate protection against rips must be required including net checks, inspection by ROV, and net tensile strength audits. Maximum allowable age for moorings, nets and containment equipment can be set. Plans for moving and harvesting should be disclosed. Specific plans for securing or moving the facility in the event of hurricanes are presently required by ordinance in Mississippi (Mississippi Commission on Marine Resources, Ordinance 13.001).

Who is the Fish Health Professional in charge?

Establishing a relationship with an aquaculture veterinarian is crucial. This will enable access to individualized health management strategies, prescriptions, Investigational New Animal Drugs (INAD), [Experimental Studies Certificates (ESC), Emergency Drug Release (EDR) in Canada], chemotherapeutants, pesticides, and a tailored vaccination regimen. Fish farmers are required by law to seek the advice of a licensed veterinarian when administering prescription-only therapeutants. Veterinarians must develop and maintain a Veterinarian/Client/Patient Relationship (VCPR) in which the veterinarian has assumed the responsibility for making medical judgments regarding the health of the animals and the need for medical treatment, and the client (owner or caretaker) has agreed to follow the instructions of the veterinarian. A review of state legislation is required to determine the details of the Veterinary Medical Act that pertains to maintaining a valid VCPR and offering medical services to the aquaculture producers. There must be sufficient knowledge of the animals and/or appropriate and timely visits to the premises by the veterinarian to initiate at least a preliminary diagnosis of the medical condition of the animals. The veterinarian must be readily available for follow-up in the event of adverse reactions or failure of the regimen of therapy. Federal and state veterinarians are generally available, but someone must be designated as “in charge” and participating parties must understand the relationships. Also, the role of other fish health researchers in the diagnostic and treatment procedures should be established.

Which species will be grown?

This issue is dependent on technical issues to determine which organisms can be feasibly grown. Other critical issues include

the consideration of robust economic analyses (Posadas and Bridger, this volume).

How many fish will be stocked? In how many netpens? For how long?

The stocking density in netpens and the biomass in the region must be kept at recognized optimal levels. Research may be required to establish these limits.

Is fallowing considered in the long-term plan? How long will sites need to be fallowed? How many extra sites will be required to insure continuous production?

Standard protocols from other jurisdictions can be used as a starting point. Jurisdictional review must include consideration of the appropriate principles similar to those outlined in Australia that have been considered to manage the aquaculture industry in a sustainable manner to generate wealth for the country’s citizens (Aquaplan 2001).

Where will the fry come from? What is the source of the broodstock? Is a selective breeding regime for broodstock desired?

A comprehensive broodstock program to deliver disease tolerant stocks with low feed conversion ratio and optimal performance is required. To diversify risk, the broodstock should be housed in separate locales, buildings and water sources. Nurseries should be implemented to further house the progeny prior to seawater entry. A nursery would enable the stock to be vaccinated, assessed for health, and reach a minimal recognized size prior to seawater transfer. The issue of broodstock and fry genetics should be considered. Presently, the three main candidate species' are considered single unit stocks in the GOM, but a conservative approach requiring stocked fry to come from local broodstock may be desirable. Genetic tagging, such that individual progeny of specific broodstock can be

identified, is technically feasible and could be developed as part of a genetics management program.

What health standards must fry meet for transfer to netpens?

Is testing for the organisms specified in the AFS Bluebook, Canada Fish Health Protection Regulations, or the OIE Aquatic Animal Health Code sufficient or necessary?

What biosecurity/disinfection procedures will be in place for people and equipment at both the growout site and broodstock and hatchery facility?

Disinfection is required to minimize the build up and spread of infectious pathogens and parasites. Information is readily available for various disinfection agents, concentrations and appropriate application, neutralization, and disposal methods. The disease of concern must be suppressed by the disinfectant chosen—this requires strict adherence to appropriate application and contact time to allow the disinfectant to be effective. The environmental agency that regulates the use of disinfectants and seawater use must be consulted prior to usage. All organic debris (mucus, blood, tissue and detritus) must be physically brushed or hosed off the area where disinfectant will be applied. Disinfectant contact time on equipment and clothing should be maximized to ensure complete disinfection. For example, when an iodophore disinfectant is applied it should be at a concentration of 100–200 mg/l for a minimum of 10 min (Washburn and Gillis 1998; MLA 2000). Disinfectants containing potassium peroxomonosulphate sulphamic acid and sodium alkyl benzene sulphonate are being used in the aquaculture industry due to high success rates against viral pathogens. Every piece of equipment, including boats, should be either dedi-

cated to a single site or undergo routine disinfection procedures.

The flow of people must be regulated as well. When visiting finfish aquaculture sites, visitors must follow the necessary steps to ensure quality assurance, disease-free sites, and a positive working relationship with the industry.

The following is a recommended protocol to follow when visiting finfish sites. Visits should be appropriately scheduled with the site manager. The purpose is to monitor traffic and prevent unnecessary incursions on to the site. If disease is present or evidence of unknown mortality is detected on site then the visit should be postponed. It is recommended that visitors visit one marine cage site per day. In the spring and summer it is recommended that visitors wear a set of clean, disinfected gear over the life vest when walking on the cage system or housing. Rubber boots are required and must be disinfected prior to entering the boat to bring the visitors to the site. A footbath should be available on the boat with fresh disinfectant. If a footbath is available onsite then all visitors must step into the footbath prior to walking on the site system. The boots and lower pant legs (if rain gear is worn) should be scrubbed while standing in the footbath if it is safe to complete the action. Boots must be immersed in the disinfectant to a depth of 10 cm (4 in) for at least 2 min depending on the disinfectant. If multiple sites are to be visited, clean clothes or different rain gear must be worn to the additional sites. The previous rain gear is to be enclosed in a sealed bag and brought back to shore for disinfection. Routine cleaning of the site apparel must be performed to decrease levels of detritus or organic matter that may impede the activity of the disinfectant and harbor pathogens.

What are the disease monitoring protocols?

How often will samples be taken? Which fish will be sampled? Which tissues will be sampled? How will the samples be handled and processed? Consultation with a biostatistician or an epidemiologist is recommended.

Who will test the samples?

Which laboratories are approved for testing? Which tests do they use? Is your sampling scheme compatible with the test, both in terms of the collection/handling of samples and the sensitivity/specificity of the test. A relationship with those laboratories should be developed to maximize the reliability of the results.

How will pests/predators be controlled? How will chemotherapeutants be administered?

The procedure should not be adversarial. Government agencies (veterinarians, regulators, and other fish health professionals) and producers should cultivate a relationship to ensure the free flow of information. Once required information is reviewed and, at least conditionally, accepted, other pertinent issues critical to success will need to be addressed.

Is the business plan feasible?

See Chapter 7 in this volume for a discussion of business and economic issues.

Vaccination regimen?

Will fry be vaccinated? Against what? Is a SPF broodstock required? If so, which pathogens are to be excluded and why?

What disease issues are characteristic of wild fish at the chosen site? What wild fishes are typically encountered at the site?

Because wild fishes can be a major source of disease in netpen culture, routine monitoring should include observations of wild fishes around and within the site as well as periodic

sampling of those fishes for examination for diseases and parasites.

What is the procedure for the collection and disposal of mortalities?

Are divers used? Air lifts? Mortality rings? Some combination thereof? Are there site-specific incineration, composting, offal management or extraction processes? Secondary processing of the residual products can be constituents of tires, ice cream and pharmaceuticals (Goodlad 1999)?

What qualifications or training will be required of staff?

Lack of knowledge and training regarding aquatic species health has been identified to contribute to the failure of some aquaculture operations due to employee turnover or failure to schedule continuing education either in house or through outside agencies. Site workers are crucial to early detection of altered health conditions. Site workers need to be aware that presence of bacteria, viruses or parasites does not necessarily mean disease will occur. The presence of an agent in combination with other risk factors may lead to disease. Risk factors include weakened fish, poor water quality, and poor site selection. Disease is prevented or mitigated by controlling the associated risk factors.

There are a number of characteristics that producers may observe that would indicate a fish health problem initiating at a site. The swimming behavior may be altered and fish may exhibit erratic swimming, flashing/rubbing, jumping, or loner fish circling at the top of the cage. The feeding activity of the fish generally decreases in diseased fish. Skin lesions may become evident such as ulcers, red spots, white spots, or raised scales. Flared gills may be exhibited characterized by open or eroded opercula. Fin erosion may become

evident. Floating dead fish may be observed on the top of the water indicating that further mortalities will be found at the net bottom. Changes in water quality conditions may precipitate a health crisis or indicate that one is impending. Water conditions such as increased or decreased temperatures, supersaturation, hypoxia, anoxia, and algal or mussel set may be encountered. If these conditions are observed onsite then management and health personnel must be notified and disease diagnostics initiated.

What size should fry be to maximize survival when introduced into the netpen?

This will require research and may be specific to each species. Survival of released fish is related to size at release (Leber and Arce 1996), but that must be balanced with the economics of raising them to that size in land-based hatcheries/nurseries versus moving fingerlings offshore to cages at a smaller size.

What is the role of public relations in the operation?

An association among the various producers should be formed to facilitate and advocate common interests. An aquaculture liaison committee with local stakeholders should be initiated and dialogue begun with surrounding communities to communicate the farming practice to the public and allow a high degree of transparency. Also, interaction with the federal Joint Subcommittee on Aquaculture (JSA) is advisable because of its role in setting policy. Relationships with academia should be cultivated to facilitate research on challenging health or husbandry issues.

CONCLUSIONS

The history of aquaculture, as in agriculture, has proven that mistakes will be made and sometimes repeated. It is the intention of this chapter to show that when the proper questions are asked, a template for success can be created, implemented, and result in the delivery of a sustainable aquaculture industry from a fish health management perspective. With stakeholder cooperation, enabling regulation, and strong leadership at all levels of government, aquaculture can supply additional benefits from a common resource, such as offshore waters, providing an economic boost to coastal communities.

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