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A risk analysis framework for aquatic animal health management in marine stock enhancement programmes

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Abstract

In light of limited supplies of fish from natural populations, stock enhancement is being considered as one means of helping to meet the demand for seafood products from an ever-increasing human population. The technology to produce large numbers of early-life stage aquatic organisms in hatcheries is well-developed, and the use of alien species, although controversial, has also created new fisheries in some countries. Stock enhancement often requires technical interventions in the rearing process of aquatic organisms that may substantially change how an organism interacts with pathogens. Aquatic animal health risk analysis in stock enhancement programmes involves consideration of: the source of animals to be released, the populations to be managed, hazard identification, risk assessment, risk management, quarantine, diagnostic and treatment procedures, mitigation measures, monitoring, reporting the disease status of hatchery and wild populations, and the establishment of aquatic animal health standards. Information and guidelines to assist in aquatic animal health management include the FAO Conduct for Responsible Fisheries, the ICES code of practice on introductions, the OIE aquatic animal health standards, the Asian regional guidelines on health management for the responsible movement of aquatic animals and the WTO's Sanitary and Phytosanitary Agreement.

Keywords: Marine stock enhancement; Aquatic animal health; Quarantine; Risk assessment; Risk management

1. Introduction

Stock enhancement within marine and coastal areas through release of aquatic animals raised in hatcheries is a potential management tool for increasing production and profitability of marine fisheries and meeting the demand for seafood from an ever-increasing human population. The technology to produce large numbers of early-life stage aquatic organisms in hatcheries is well-developed in many areas of the world. However, these practices require technical interventions in the rearing process that may substantially change how an organism interacts with the natural environment, the culture environment, and with other species. These changes also influence how an organism interacts with pathogens. The use of alien species to create new fisheries brings special concerns—there is potential to transfer new pathogens, or for the introduced animals to be susceptible to pathogens that do not affect native species. In short, certain viruses, bacteria, fungi, parasites and other organisms that may not be pathogenic under normal environmental conditions for native species can become problematic in stock enhancement programmes.

The importance of aquatic animal health management in responsible stock enhancement has been recognized by the scientific and international communities (Blankenship and Leber, 1995) and is embodied in articles in the FAO Code of Conduct for Responsible Fisheries (FAO, 1995). The World Trade Organization's (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) also applies to issues relating to trade of fish and fish products (WTO, 1994). Under the SPS Agreement, the Office International des Epizooties (OIE) (World Organization for Animal Health) is recognized as the international organization responsible for the development and promotion of international animal health standards, guidelines and recommendations affecting trade in live terrestrial and aquatic animals and their products.

Stock enhancement programmes present special problems in health management in that organisms must survive in two very different environments: animals are cultured in

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Table 1
Common factors in emerging infectious diseases of wildlife (after Daszak et al., 2001)

Factor	Mechanism	Examples
Increased pollution and degradation of marine environment	Many pollutants are immunotoxic and compromise immune system; terrestrial pathogens enter marine environment	Diseases and resulting mortality of corals, sea urchins, and other marine invertebrates near Florida coast (USA); increased parasite load in oysters
Introduction of alien species or non-quarantined food products	New hosts and new pathogens enter area	Herpes virus mass mortality of pilchards in Australia from non-quarantined frozen fish; mass mortalities of wild Norwegian salmon from *G. salaris*, accidentally introduced from Norway
Increased host density	Easier transmission of pathogens	Losses to California abalone farms due to sabellid worm parasite that spread quickly in high density culture environment; skin peeling disease of sea cucumbers
Climate change	Shift in host and pathogen range; new conditions favor pathogen or hurt host	Mexican oyster pathogen outbreak and range extension of other oyster disease agents in New England
Change in distribution of host due to human activities and contact with terrestrial animals	Host encounters environment and pathogens for which it is not well adapted	Phocine distemper virus in European harbor seals and other viruses of domesticated terrestrial animals appearing in marine animals

hatcheries and must survive in that controlled system, but are then released into the wild where natural selection and fishing effort determine survival. In nature, there is less control, and reduced ability to monitor health status.

Inappropriate culture environments or conditions, such as overcrowding or poor nutrition, as well as a degraded or unsuitable wild habitat, can promote disease outbreaks (Rodgers and Barlow, 1987). Species introductions have the potential to introduce new pathogens and hosts to an area that does not have natural immunity to the pathogens. Furthermore, Daszak et al. (2001) indicate that there appears to be an increase in emerging infectious diseases (EIDs) in both humans and wildlife. They list some common underlying factors in the emergence of infectious diseases in wildlife (Table 1) and suggest "that human environmental modification drives the emergence of . . . wildlife EIDs".

Because disease outbreaks are dependent on the complex interaction of environment, pathogen, and host (Snieszko, 1974), in both culture and natural environments, a holistic systems approach to aquatic animal health is required (Subasinghe et al., 2001). In this paper, we present a framework for health management in marine stock enhancement programmes which includes pathogen risk analysis and risk management from a systems perspective.

2. Risk analysis framework

Hazard identification, risk assessment and risk management form the core of a risk analysis framework for responsible aquatic animal health management in stock enhancement programmes (Fig. 1). Throughout the entire risk procedure, risk communication is essential and insures awareness, and understanding and consensus among stakeholders with differing priorities and development goals. The system approach advocated here is therefore interactive and adaptive as information increases and lessons are learned.

The risk analysis process will allow wise decisions to be made about stock enhancement based on release of hatchery-reared juveniles, including species selection, site selection, hatchery protocols, culture conditions, and monitoring and surveillance. Hazards may always exist, but the probability

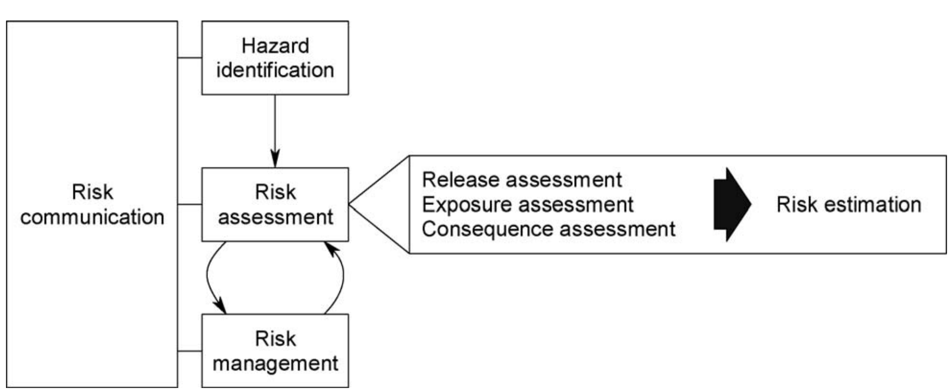


Fig. 1. The four components of risk analysis (from Subasinghe et al., 2004).

and severity of their impact as well as mitigation or management options will differ depending on circumstances and resources. A significant difficulty is deciding what constitutes an 'acceptable risk' or 'appropriate level of protection' (ALOP). The Sanitary and Phytosanitary Agreement (SPS) of the Word Trade Organization defines the appropriate level of protection as that level deemed appropriate by the member establishing a sanitary or phytosanitary measure to protect human, animal or plant life or health within its territory. Determination of a country's ALOP is more of a political rather than a scientific decision which a government needs to take in consultation with the community. The ALOP reflects government policy based on community expectations; it is a societal value judgement to which informed agencies or experts contribute by providing technical information and advice (Arthur et al., 2004).

2.1. Hazard identification

A hazard is any pathogen that could produce adverse impacts on cultured species or on species in the wild. Two steps are involved in the hazard identification process: (1) a preliminary hazard identification, in which all pathogens reported from the commodity (host) are considered; (2) a focused hazard identification which considers only those pathogens which are determined to be serious hazards. It is necessary to set up criteria for both steps. The preliminary hazard identification is an important step because it will help determine what type of risk analysis (e.g., routine or full-scale, qualitative or quantitative) is required based on various issues associated with stock enhancement of a certain species (e.g., availability of information, aquatic animal health services, facilities and expertise from trading countries). For example, in a risk analysis for the introduction of juvenile yellowtail kingfish (*Seriola lalandi*) from Australia to New Zealand, Diggles (unpublished) identified 11 serious hazards from a list of 43 potential hazards identified during the preliminary hazard identification.

The Commonwealth of Australia (2002) established criteria which need to be satisfied for a potential hazard to be given full consideration. The hazard:

- must be appropriate to the animal to be imported, or to the receiving environment;
- must produce adverse consequences in the importing country, including impact on related host species;
- may be present in the source of material to be stocked, the exporting country, or the feeds used in the stock enhancement programme;
- should not be present in the importing country-if present, the pathogenic agent should be associated with a notifiable disease, or should be subject to control or eradication measures;
- be an OIE notifiable disease;
- or be identified by some other additional criteria by the importing country.

2.2. Risk assessment

Risk assessment determines the likelihood of a particular pathogen entering, establishing and spreading in an importing country, or the receiving environment, and the consequences. There are four components to this process: release assessment, exposure assessment, consequence assessment and risk estimation.

2.2.1. Release assessment

A release assessment consists of describing the pathways necessary for a pathogen to be 'released' or introduced into a particular environment and estimates the probability of that process occurring (OIE, 2003). White spot syndrome virus (WSSV) of *Penaeus monodon*, for example, has a very broad geographic range of at least 22 countries and has numerous hosts, e.g., shrimp, crab, lobster, freshwater crayfish, krill, and Artemia (Hill, 2002). Thus, there is a high probability that WSSV would survive release into the wild. Biological factors such as means of transmission, route of infection, infectivity, virulence and stability of the pathogen; factors associated with the country such as aquatic animal health services of exporting countries, disease prevalence, farming and husbandry practices, and geographical and environmental characteristics; commodity factors such as ease of contamination, other relevant processing and production methods, and quantity of the commodity to be imported, need to be considered during the release assessment.

2.2.2. Exposure assessment

An exposure assessment consists of a description of the biological pathways that would expose animals in the hatchery or wild to a pathogen from a given risk source, and estimates the probability of exposure occurring. The biological, country and commodity factors that need to be considered are the same as for the release assessment. Additional biological pathways include transmission mechanisms (e.g., horizontal or vertical transmission), presence of intermediate hosts in the case of complex parasite life cycles, and effects of processing and susceptibility of different life stages of the host. Other considerations include: use of biosecurity measures to prevent potential escapes of infected stocks or prevent entry of potential carriers or vectors, disinfection procedures, discharge of effluents from infected areas, and disposal of infected animals.

Release of hatchery-reared juveniles may promote pathogens via a variety of pathways (Table 2). Live or fresh foods, i.e. non-pelletized or processed, are often used in hatchery-based stock enhancement programmes to precondition fish for life in the wild. However, disease organisms, including viral hemorrhagic septicemia virus (VHSV) (AQIS, 1999; Gaughan, 2002) and the pilchard herpes virus, have been associated with frozen pilchard and sardine fed to tuna (Harvell et al., 1999). Many species of marine forage and pelagic fishes are sold live or frozen as bait; analysis of these fishes revealed presence of an aquareovirus, VHSV,

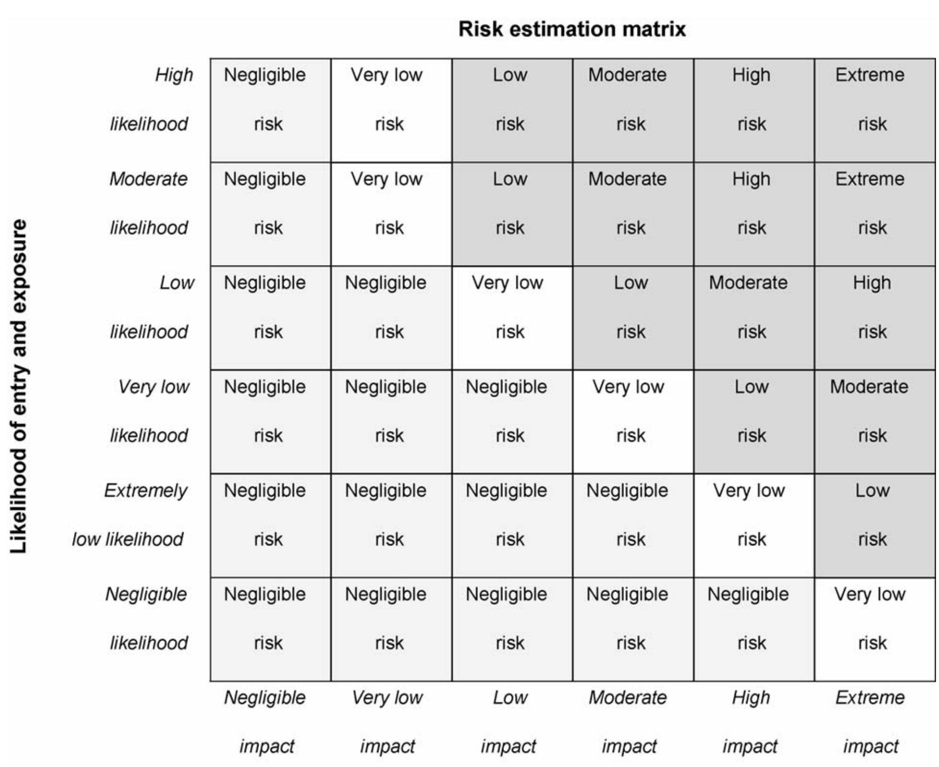
Table 2
Mechanisms promoting disease outbreak in marine stock enhancement programmes

	Hatchery environment	Natural environment
Pathogen pathways	Live or fresh food	Escaped or released fish from hatchery
	Horizontal transmission from infected fish in hatchery	Hatchery effluents
	Vertical transmission from infected parent to offspring	Alien species
	Contaminated facilities	Ballast water and fouling organisms
	Natural environment	Naturally occurring pathogens/hosts
	Blood transfers by blood feeding vectors such as copepods, leeches or monogenean parasites	
Environmental pathways	Poor nutrition	Climate change, short term: El nino, long term: global warming
	Over-crowding	Habitat degradation
	Poor genetic "environment", e.g., inbreeding.	Poor genetic "environment", e.g., loss of genetic diversity

viral enthrocytic necrosis virus, VENV, infectious salmon anemia virus, ISAV, and other viruses affecting freshwater species (Yashiro et al., unpublished; Goodwin et al., 2004). Indeed, Goodwin et al. (2004) concluded that "until proven otherwise, marine forage fish should be highly suspect as potential sources of the virus (ISAV)".

2.2.3. Consequence assessment

A consequence assessment is conducted when exposure assessments and analysis of pathways determine that there is more than a negligible risk of introducing a disease agent into cultured or wild organisms. Consequence assessments consider the possible effects on the productivity of the culture facility, the environment, and on the economy if a disease agent is released into the marine environment. The consequences of disease outbreaks can be severe in direct economic loss, as in the case of the loss of AUS$ 12 million as a result of the pilchard disease outbreak (Gaut, 2001). The re-introduction of European flat oysters, *Ostrea edulis*, to Europe from North America also introduced the blood parasite, *Bonamia*, which subsequently destroyed the majority of the European flat oyster industry (Chew, 1990). The presence of new pathogens in a country can change trade relationships or import/export privileges and lead to reduced market



(a)

Fig. 2. (a) Risk estimation matrix (from Commonwealth of Australia, 2002), and (b) composite risk estimation matrix, including risk evaluation decision and risk management measures for different hypothetical potential hazards.

Pathogen[1]	Likelihood of Release	Likelihood of Escape	Probable Consequence	Mitigated Risk Estimate	Risk Evaluation Decision[2]	Examples of Management Measures
Virus						
WSSV (shrimp)	High	moderate	moderate	high	reject	None
IHHNV (shrimp)	moderate	moderate	moderate	moderate	approve	Import only SPF or 'high health' stocks; Pre-border (separation of stocks; screening or testing; health certificates) and post-border (e.g. quarantine, health monitoring, supervised movement); contingency plans in case of a disease outbreak; implementation of HACCP in processing plants
Parasite						
Callotetrarhynchus japonica (cestode)	moderate	moderate	low	moderate	approve	Health certificate; Use frozen food instead of live fish
Bacteria						
Vibrio penaeicida	low	low	low	low	approve	Chemical treatment

[1] White spot syndrome virus (WSSV), Infectious hypodermal and haematopoietic necrosis virus (IHHNV)

[2] The risk evaluation decision is based on 'moderate'' as the appropriate level of protection (ALOP).

(b)

Fig. 2. (*Continued*).

access or market share when "disease free" status is lost. The recent incursion of Koi herpes virus (KHV) in Indonesia and Japan has prompted both governments to restrict domestic movements of Koi and common carps. Singapore requires compulsory inspection, testing and quarantine of all Koi consignments imported from Japan and Indonesia.

2.2.4. *Risk estimation*

A matrix of pathogen risk estimation can be created using the information above (Fig. 2a). Very low risk could represent a country's ALOP or "acceptable" risk. A composite risk matrix can be developed (Fig. 2b) that quickly presents a summary of important pathogens, risk estimates, and the type of risk management needed.

2.3. *Risk management*

Risk management mitigates the potential risk of disease introduction, spread and establishment. In the event of a disease outbreak, it provides containment or eradication measures. There is a wide range of potential mitigating measures in culture facilities that can promote responsible health management in stock enhancement programmes. However, there are less options for risk management once the animals are released in the wild. Record keeping and maintaining health profiles of species, from both source and receiving environments/facilities, will establish a clinical history of occurrence and impacts of pathogens, assist with accurate diagnosis and further help with risk communication and evaluation of different mitigation actions.

2.3.1. Culture environment

Strategies for aquatic animal health management in the culture environment are well-developed and include implementation of international codes, regionally oriented guidelines, national programmes and legislation on aquatic animal health with emphasis on: (a) disease prevention, biosecurity, import controls, and risk analysis, (b) disease control, e.g., isolation, quarantine, movement restrictions or containment, sanitation measures, hygienic practices, chemotherapy, eradication, and elimination of intermediate hosts, and (c) disease management, e.g., enhancing the host's defense mechanism or its innate ability to suppress progression of an infection to a disease condition through maintenance of good environmental conditions (FAO/NACA, 2000, 2001; Subasinghe et al., 2001; Bondad-Reantaso et al., 2001; OIE, 2003; Mushiake and Muroga, 2004).

Quarantine measures include many aspects of aquatic animal health management. They are a primary form of mitigation required by many aquatic animal health programmes and countries before import of animals, or products derived from them, is allowed. The International Council for the Exploration of the Sea (ICES, 2003) code of practice recommends isolating broodstock, breeding them, and then stocking only their progeny. Visual inspection provides useful information to hatchery managers and aquatic animal health inspectors. For example, risk mitigation measures could consider only batches of fish with low mortality rates (<5%) for use in stock enhancement, and rejection of any batches of animals containing dermal lesions and/or ectoparasitic infections. Diseased stocks are often destroyed and appropriate disposal is essential. Testing and diagnosis can be considered part of the quarantine process. For example, to reduce the risk of introducing *Aermonas salmonicida* into New Zealand with imports of kingfish, B.K. Diggles (unpublished) recommended that 150 fish from each batch of juvenile kingfish destined for export to New Zealand should be tested for the presence of the bacteria by a competent authority in Australia. The risks of introduction of strains of *A. salmonicida* into the New Zealand marine environment appear likely to be increased above natural levels only if injured, unhealthy juvenile kingfish with external lesions and/or ectoparasitic infections were imported.

Recently, the use of 'high health', 'specific pathogen free' (SPF) or 'specific pathogen resistant' (SPR) stocks is becoming widely practiced. However, once the host animals leave the original facility, the health status becomes uncertain. The receiving facility should have a proven track record of adherence to strict biosecurity protocols, an overall health management plan and a documented history of pathogen surveillance.

Vaccination has become an established prophylactic method for controlling certain infectious diseases in cultured animals (mainly finfish). Many vaccines against bacterial pathogens, e.g., enteric red mouth, furunculosis, cold water vibrios, and *Streptococcus* are now commercially available. Vaccines for some other pathogens are under development. The numbers of doses of vaccines currently used in aquaculture range from ∼22 million in Canada to 150 million in Chile (M. Horne, Research Director, Novartis, 2004, personal communication). Vaccines not only reduce the impact of a disease but also reduce the need for antibiotics, leave no residues in the product or environment, and do not induce pathogen resistance. However, since vaccination prevents or reduces the effect of disease and cannot completely replace biosecurity control, they can also result in creation of farmed fish that are pathogen carriers and thus place wild fish stocks at risk (Alderman, 2002).

Vaccines are specific for certain diseases and their development requires considerable investment to research target diseases, careful planning, efficacy and cost evaluation. Vacination is one option for disease prevention but does not guarantee total exclusion of a particular disease. It has proved successful in programmes to release hatchery-reared juveniles, e.g., injection of dead *Vibrio anguillarum*, *Yersinia ruckeri* and *A. salmonicida* increased the return rate of Atlantic salmon in a sea ranching initiative (Buchmann et al., 2001); however, bath vaccinations did not increase the return rate.

Disease resistance has in part a genetic basis and maintenance of proper genetic diversity is necessary for aquatic animal health. Specific strains of fish may be resistant to certain pathogens as in the case of Atlantic salmon, where populations from the Baltic Sea are resistant to the salmon parasite, *Gyrodactylus salaris*, whereas Atlantic stocks in Norway are susceptible (Bakke et al., 1990). Allelic diversity appears to be correlated with general disease resistance (Beardmore and McConnell, 1998). Although breeding for disease resistance is an important part of many commercial aquaculture ventures, it may not be efficient in stock enhancement programmes because selection usually reduces overall genetic variability. In particular, selected genotypes may be fitter in hatcheries than in the wild, or stocked animals may breed with non-selected individuals in the wild, thus losing any advantage of the selected genotype from the hatchery. Choice of juveniles with high allelic diversity, adapted to the local receiving environment (see next section), may be a more practical means than selective breeding to improve disease resistance of cultured animals released in the wild.

Good husbandry and aquaculture practices, including proper nutrition, rearing densities, and broodstock management also reduce the incidence of disease outbreaks. Diseases arise in aquaculture primarily because of the high stocking densities used in many systems, especially salmonid culture systems (Håstein and Lindstad, 1991). Also, over-crowding of sea cucumbers led to an outbreak of skin peeling disease (Battaglene and Bell, 2004), and stocking densities of only 8 fingerlings m^{-2} were needed to minimize risk of disease during production of juvenile sturgeon for stock enhancement (Abdolhay, 2004). Disinfection of culture facilities is also common practice. For sturgeon stock enhancement programmes in Iran, disinfection procedures extend to ponds, facilities, and equipment, as well as to the sand used in egg de-adhesion and the live food used in rearing juveniles (Abdolhay, 2004).

Trash or forage fish to feed cultured juveniles can be a source of infection (see also Section 2.2.2). The larval cestode, *Callotetrarhynchus nipponica*, is a parasite of yellowtail, *Seriola quinqueridiata*, associated with feeding of raw anchovy, *Engraulis japonica* (Ogawa, 1996). The life cycle of this parasite involves an unknown first intermediate host, anchovy as the second intermediate host, yellowtail as the third and shark as the final host. The parasite disappeared from culture sites when frozen food was used as feed (Ogawa, 1996). However, culture and use of live food also present disease risks. Sako (1996) reported that food management to reduce disease in marine finfish includes immunostimulant supplementation of beta-carotene and a bath treatment of live food with nitrofuran derivatives and sodium nifurstyrenate to decrease the number of bacteria.

2.3.2. *Natural environment*

The presence of a pathogen in a fish or in nature is not indicative of a disease condition. Disease is a result of the complex interaction between the host, the pathogen and the environment (Snieszko, 1974). For a disease to spread from either a cultured fish to a wild fish or vice versa, one or more of the following circumstances must occur: presence of the pathogen in both the animal and water source; presence of a susceptible host; viability of the pathogen in the environment, in terms of number and longevity; a viable infection route (Olivier, 2002). However, once a pathogen or disease agent is introduced and becomes established in the natural environment, there is little possibility for treatment or eradication. Therefore, management measures in the natural environment, and modified environments such as enclosed or semi-enclosed bays, should be aimed at avoidance of risk and monitoring.

Degraded habitats have been associated with increased disease outbreaks and increased incidence of emerging infectious diseases (Daszak et al., 2001) and should be avoided in stock enhancement programmes. Locating hatchery facilities away from sensitive areas, or areas with important and vulnerable fishery resources, can reduce the risk of transmitting pathogens from the culture environment to natural populations. Iceland and Norwegian stock enhancement of Atlantic salmon prohibits siting fish farms on rivers that have native salmon runs (Heggberget et al., 1993).

The introduction of alien species has been shown to be a leading threat to biological diversity and provides a means for the introduction for new pathogens (Stewart, 1991). Although guidelines exist, e.g., ICES code of practice (ICES, 2003), serious impacts on wild stocks have resulted from lack of adherence to proper aquatic animal health management. In Norway, domesticated Atlantic salmon stocks have had adverse impacts on native stocks, primarily through the introduction of disease organisms. In 1975 the monogenaen parasite, *G. salaris* was found in wild Atlantic salmon parr, probably introduced from infected and resistant Atlantic salmon from Sweden. The causative agent of furunculosis, *A. salmonicida*, was also introduced to Norwegian salmonid farming through infected stocks of rainbow trout from Denmark in 1966. The pathogen spread to over five hundred fish farms and to 66 salmon streams by 1991 (Heggberget et al., 1993). *A. salmonicida* has been found in seawater over 20 km from infected farms indicating its potential for dispersal. The spread of both *Gyrodactylus* and *A. salmonicida* was probably facilitated by stock enhancement programmes that inadvertently used infected fish. The problem of unknown pathogens is even greater with introductions of new species. The California abalone industry and several local species of gastropods were infected by a sabellid worm imported with abalone from South Africa. In its native range the sabellid worm did not cause significant impacts, however, it devastated the California abalone industry (Culver et al., 1997).

Surveys of pathogens or disease status of wild fish populations can help determine what species could be stocked in efforts to avoid species that would be susceptible to locally occurring pathogens. A pertinent example is *Kudoa amamiensis*, a myxosporean parasite endemic to coral fishes, e.g., species of *Abudefduf*, *Chromis* and *Chrysiptera*, in Amami and Okinawa prefectures, Japan (Ogawa, 1996). Amberjack and yellowtail that were introduced to these prefectures became heavily infected in the skeletal musculature with *K. amamiensis*. Surveys of the susceptibility of amberjack and yellowtail to the parasite and the parasites natural distribution might have allowed the identification of a better culture site, or implementation of more rigorous disease prevention actions.

3. Conclusions

Aquaculture is the fastest growing sector of the food producing industry and release of hatchery-reared individuals for restocking and stock enhancement is a potentially important application for this sector. To avoid incursions of pathogens, parasites, diseases or pests accompanying as a result of releases, disease control strategies must be an integral part of stock enhancement programmes. Disease control strategies encompassing the production of disease free stock in hatcheries, the implementation of risk analysis, risk management and risk communication procedures, and the monitoring of the environment receiving such stocks, must be considered. Information and support to assist in the development of aquatic animal health programmes for responsible stocking of marine waters are available from a number of sources and internationally accepted guidelines and protocols exist (AFFA, 1999, 2001; Kahn et al., 1999; Arthur, 2002; Biosecurity Australia, 2003; ICES, 2003; OIE, 2003;

Subasinghe et al., 2001; Arthur et al., 2004). With appropriate management, stocking the marine environment can be done with minimal losses due to disease and can contribute to the provision of quality seafood to a growing human population.

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