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Understanding and applying risk analysis in aquaculture

Cover photos:
Left column, top to bottom: Fish farmers administering antibiotic treatment
to a suspected viral infection of fish, courtesy of M.B. Reantaso.
Middle column, top: Suminoe oyster (*Crassostrea ariakensis*), courtesy of E. Hallerman;
bottom: Mortalities of common carp in Indonesia due to koi herpes virus, courtesy of A. Sunarto.
Right column: Women sorting shrimp post-larvae at an Indian shrimp nursery, courtesy of M.J. Phillips.

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Preparation of this document

A project "Application of risk analysis to aquaculture production" was undertaken in 2007 through a desk study and an expert workshop held in Rayong, Thailand, from 7 to 11 June 2007. The project culminated in the publication of this document, which is presented in two parts.

Part 1 contains 12 technical papers presented during the expert workshop, contributed by 23 specialists and peer-reviewed by nine experts. These include seven commissioned sectoral review papers addressing the seven identified major risk sectors of aquaculture production: pathogen risks, food safety and public health risks, genetic risks, ecological risk assessment and management of exotic organisms, environmental risks, financial risks and social risks, as well as an additional five contributed papers addressing the following topics: general principles of risk analysis, introduced marine species risk assessment, guidelines for ecological risk assessment of marine fish aquaculture, the aquaculture insurance industry risk analysis process and risk analysis experiences from small-scale shrimp farmers in India. Part 2 of this document contains the highlights of the FAO/NACA Expert Workshop on Understanding and Applying Risk Analysis in Aquaculture, with 42 experts participating.

The commissioned review papers and expert workshop were technically supervised by Dr Melba B. Reantaso, Fishery Resources Officer and Dr Rohana P. Subasinghe, Senior Fishery Resources Officer of the Aquaculture Management and Conservation Service, Fisheries and Aquaculture Management Division of the FAO Fisheries and Aquaculture Department.

The study, workshop and publication were made possible with financial assistance through the Programme Cooperation Agreement of Norway under B.1 and D.1 objectives administered through the FishCode Programme of the FAO Fisheries and Aquaculture Department and the Nutrition and Consumer Protection Division of the FAO Agriculture and Consumer Protection Department, respectively.

Abstract

As a food-producing sector, aquaculture has surpassed both capture fisheries and the terrestrial farmed meat production systems in terms of average annual growth rate. However, it has a number of *biosecurity concerns* that pose risks and hazards to both its development and management, and to the aquatic environment and society. Aquaculture faces risks similar to those of the agriculture sector. However, as aquaculture is very diverse (in terms of species, environments, systems and practices), the range of hazards and the perceived risks are complex. Multiple objectives are driving the application of risk analysis to aquaculture. Foremost is for *resource protection* (human, animal and plant health; aquaculture; wild fisheries and the general environment) as embodied in international agreements and responsibilities. The other drivers of risk analysis are: (i) food security, (ii) trade, (iii) consumer preference for high quality and safe products, (iv) production profitability and (v) other investment and development objectives.

The expert workshop, using a series of seven review papers commissioned by the desk study, focused on the importance and application of risk analysis to seven major risk sectors of aquaculture production: pathogen risks, food safety and public health risks, ecological (pests) risks, genetic risks, environmental risks, financial risks and social risks. Part 1 of the document consists of 12 peer-reviewed technical papers relative to the application of risk analysis to aquaculture that were prepared by 23 specialists papers on: general principles of risk analysis, food safety and public health risks associated with products of aquaculture, pathogen risk analysis, application of risk analysis to genetic issues in aquaculture ecological risk assessment and management of exotic organisms, introduced marine species risk assessment, guidelines for ecological risk assessment of marine fish aquaculture, the aquaculture insurance industry risk analysis process and risk analysis experiences from small-scale shrimp farmers in India. Part 2 contains the detailed outcomes of the deliberations of 42 experts who developed the contents of a Manual on the Application of Risk Analysis to Aquaculture, discussed in great length the seven risk sectors and reached general conclusions and specific recommendations to enhance the application of the risk analysis process to aquaculture production.

Risk analysis methods as applied to the seven risk sectors have many commonalities but also many differences. An overriding feature is a firm foundation in drawing upon the results of scientific studies, the use of logic or deductive reasoning and the application of common sense in assessing risk and applying risk management measures. General principles that apply to risk analysis for aquaculture include application of the precautionary approach when dealing with uncertainty, transparency of the process, consistency in methodolody, use of stakeholder consultation, application of high level of stringency, use of minimal risk management interventions needed to achieve an acceptable level of risk, the concept of unacceptable risk and recognition that some "risky" actions cannot be managed and therefore should not be permitted under any circumstance, and the concept of equivalence where alternative risk management measures achieving the required level of protection are equally acceptable.

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Acronyms and abbreviations

AAPQIS	Aquatic Animal Pathogen and Quarantine Information System
ADB	Asian Development Bank
ADCP	acoustic doppler current profiler
AHP	analytic hierarchy process
AIDS	Auto-immune deficiency syndrome
ALARA	as low as reasonably achieved
ALOP	appropriate level of protection
ALOR	acceptable level of risk
APEC	Asia-Pacific Economic Cooperation
ANP	Analytic Network Process
ANS	Aquatic Nuisance Species
AQIS	Australian Quarantine Inspection Service
ASFA	Aquatic Science and Fisheries Abstracts
ASP	amnesic shellfish poisoning
BDNs	Bayesian decision networks
BMPs	better management practices
BP	*Baculovirus penaei*
CAB	Commonwealth Agricultural Bureau
CAC	Codex Alimentarius Commission
CART	categorical and regression tree analysis
CBD	Convention on Biological Diversity
CCFH	Codex Committee on Food Hygiene
CCRF	Code of Conduct for Responsible Fisheries
CDFs	cumulative distributions functions
CE	consequence of establishment
CRS	corporate social responsibility
DAFF	Department of Agriculture, Fisheries and Forestry
DFA	discriminant function analysis
DIAS	Database on Introductions of Aquatic Species
DNA	deoxyribonucleic acid
DO	dissolved oxygen
DSP	diarrhetic shellfish poisoning
DTs	decision trees
Eh	redox potential
EIA	environmental impact assessment
EIFAC	European Inland Fisheries Advisory Commission
ER	economic rent
ERA	ecological risk assessment
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FCR	food conversion ratio
FCS	frozen commodity shrimp
FEAP	Federation of European Aquaculture Producers
FSO	Food Safety Objective
GAP	good aquaculture practices
GATT	General Agreement on Tariffs and Trade

GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GIS	geographic information system
GMOs	genetically modified organisms
HACCP	Hazard Analysis and Critical Control Point
HPV	hepatopancreatic parvo-like virus
HSNO	hazardous substances and new organisms
IAEA	International Atomic Energy Agency
ICAO	International Civil Aviation Organization
ICES	International Council for the Exploration of the Sea
IHHNV	infectious hypodermal and haematopoietic necrosis virus
IMO	International Maritime Organization
IRA	import risk analysis
IRR	internal rate of return
ISI	Institute for Science Information
ISSG	Invasive Species Specialist Group
IUCN	International Union for the Conservation of Nature
KSh	Keynan shillings
LOVV	lymphoid organ vacuolization virus
LP	linear program
MCDM	multicriteria decision making
MFF	Ministry of Fisheries and Forestry (Fiji)
MOP	multiple objective programming
MOTAD	minimization of total absolute deviations
MPEDA	Marine Products Export Development Authority
MrNV	*Macrobrachium rosenbergii* nodavirus
NAAHP	National Aquatic Animal Health Programme
NACA	Network of Aquaculture Centres in Asia and the Pacific
NaCSA	National Center for Sustainable Aquaculture
NBCR	net benefit-cost ratio
NGO	non-governmental organization
NHP	necrotising hepatopancreatitis
NOAA	National Oceanic and Atmospheric Administration
NPV	net present value
NRC	National Research Council
OIA	organism impact assessment
OIE	World Organisation for Animal Health (formerly Office international des epizooties)
ORP	organism risk potential
PCBs	polychlorinated biphenyls
PCR	polymerase chain reaction
PE	Probability of Establishment
PICTs	Pacific Island Countries and Territories
PL	postlarvae
PRA	pathogen risk analysis
PRP	pathway risk potential
PSP	paralytic shellfish poisoning
RA	risk analysis
RAS	recirculating aquaculture systems
RPS	rhabdovirus of penaeid shrimp
SEAFDEC	Southeast Asian Fisheries Development Center
SGS	sediment grain size
SPC	Secretariat of the Pacific Community

SPF	specific pathogen free
SPS Agreement	Agreement on the Application of Sanitary and Phytosanitary Measures
STDF	Standards and Trade Development Facility
TCP	Technical Cooperation Project
TDH	thermostable direct hemolysin
TMDL	total maximum daily loads
TOTALPOLL	total pollution
TRH	TDH-related hemolysin
TSV	Taura syndrome virus
TVS	total volatile solids
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UNESCO-IOC	United Nations Educational, Scientific and Cultural Organization-Intergovernmental Oceanographic Commission
USA	United States of America
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
VOI	value of information
YHV	yellow head virus
WB	World Bank
WHO	World Health Organization
WMO	World Meteorological Organization
WSD	white spot disease
WSSV	white spot syndrome virus
WTD	white tail disease
WTO	World Trade Organization
XG	foreign exchange earnings
XSV	extra small virus

PART 1

CONTRIBUTED PAPERS ON UNDERSTANDING AND APPLYING RISK ANALYSIS IN AQUACULTURE

General principles of the risk analysis process and its application to aquaculture

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ABSTRACT

Governments and the private sector must often make decisions based on incomplete knowledge and a high degree of uncertainty and where such decisions may have far-reaching social, environmental and economic consequences. Risk analysis is a process that provides a flexible framework within which the risks of adverse consequences resulting from a course of action can be evaluated in a systematic science-based manner. It permits a defendable decision to be made on whether a particular risk is acceptable or not, and the means to evaluate possible ways to reduce a risk from an unacceptable level to one that is acceptable.

Risk analysis is now widely applied in many fields, for example, in decisions about risks due to chemical and physical stressors (natural disasters, climate change, contaminants in food and water, pollution, etc.); biological stressors (human, plant and animal pathogens; plant and animal pests; invasive species, invasive genetic material); social and economic stressors (public security (including risk of terrorism), construction and engineering (building safety, fire safety, military applications), and business (project operations, insurance, litigation, credit, cost risk maintenance, etc.).

The general framework for risk analysis consists of four major components:

- Hazard identification – the process of identifying hazards that could potentially produce consequences.
- Risk assessment – the process of evaluating the likelihood that a potential hazard will be realized and estimating the biological, social and/or economic consequences of its realization.
- Risk management – the seeking of means to reduce either the likelihood or the consequences of it going wrong; and
- Risk communication – the process by which stakeholders are consulted, information and opinions gathered and risk analysis results and management measures communicated.

Some basic principles that appear to be common to all types of risk analysis include those of common sense, uncertainty, precaution, objectivity, transparency, consistency, scientific validation, stakeholder consultation, stringency, minimal risk management, unacceptable risk and equivalence.

Risk analysis has wide applicability to aquaculture. It has mainly been applied in assessing risks to society and the environment posed by hazards created by or associated with aquaculture development. These include the risks of environmental degradation; introduction and spread of pathogens, pests and invasive species; genetic impacts; unsafe foods; and negative social and economic impacts. The use of risk analysis can provide insights and assist in making decisions that will help to avoid such negative impacts, thus helping aquaculture development to proceed in a more socially and environmentally responsible manner.

Risk analysis is less commonly used to achieve successful and sustainable aquaculture by assessing the risks to aquaculture posed by the physical, social and economic environment in which it takes place. These include reduction of environmental risks (e.g. due to poor siting or severe weather events), biological risks (infection by pathogens via transfer from native stocks, predation by seals and sharks; red tides, etc.), operational risks (poor planning, work-related injuries), financial risks (e.g. market changes, currency fluctuations, emergence of new competitors, etc.) and social risks (negative image and resulting product boycott, lack of skilled manpower, competition from other sectors).

There exists, therefore, considerable scope to develop and expand the use of risk analysis for the benefit of aquaculture and the social and physical environments in which it takes place.

INTRODUCTION

Governments and the private sector must often make decisions based on incomplete knowledge and a high degree of uncertainty. Such decisions may have far-reaching social, environmental and economic consequences. Risk analysis is a process that provides a flexible framework within which the risks of adverse consequences resulting from a course of action can be evaluated in a systematic, science-based manner. The risk analysis approach permits a defendable decision to be made on whether the risk posed by a particular action or "hazard" is acceptable or not, and provides the means to evaluate possible ways to reduce the risk from an unacceptable level to one that is acceptable.

Risk analysis is now widely applied in many fields that touch our daily lives. These include decisions about risks due to chemical and physical stressors (natural disasters, climate change, contaminants in food and water, pollution etc.), biological stressors (human, plant and animal pathogens; plant and animal pests; invasive species, invasive genetic material), social and economic stressors (unemployment, financial losses, public security, including risk of terrorism), construction and engineering (building safety, fire safety, military applications) and business (project operations, insurance, litigation, credit, cost risk maintenance etc.). Risk analysis is thus a pervasive but often unnoticed component of modern society that is used by governments, private sector and individuals in the political, scientific, business, financial, social sciences and other communities.

THE CONCEPT OF RISK

The definition of "risk" varies somewhat depending on the sector. Most definitions incorporate the concepts of:

- uncertainty of outcome (of an action or situation),
- probability or likelihood (of an unwanted event occurring), and
- consequence or impact (if the unwanted event happens).

Thus "risk" is the potential for realization of unwanted, adverse consequences to human life, health, property or the environment. Its estimation involves both the likelihood (probability) of a negative event occurring as the result of a proposed action and the consequences that will result if it does happen. As an example, taken from pathogen risk analysis, the *Aquatic Animal Health Code* (OIE, 2007) defines risk as:

"Risk – means the likelihood of the occurrence and the likely magnitude of the consequences of an adverse event to public, aquatic animal or terrestrial animal health in the importing country during a specified time period."

While some sectors incorporate consideration of potential benefits that may result from a "risk" being realized (e.g. financial risk analysis), others specifically exclude benefits from being taken into account (e.g. pathogen risk analysis).

WHAT IS RISK ANALYSIS?

"Risk analysis" is usually defined either by its components and/or its processes. The Society for Risk Analysis www.sera.org offers the following definitions of "risk analysis":

- a detailed examination including risk assessment, risk evaluation and risk management alternatives, performed to understand the nature of unwanted, negative consequences to human life, health, property or the environment;
- an analytical process to provide information regarding undesirable events;
- the process of quantification of the probabilities and expected consequences for identified risks.

In can also be defined as *an objective, systematic, standardized and defensible method of assessing the likelihood of negative consequences occurring due to a proposed action or activity and the likely magnitude of those consequences*, or, simply put, it is "*science-based decision-making*".

The risk analysis process

In simple terms, a risk analysis typically seeks to answer four questions:

- What can go wrong?
- How likely is it to go wrong?
- What would be the consequences of its going wrong?
- What can be done to reduce either the likelihood or the consequences of its going wrong? (see MacDiarmid, 1997; Rodgers, 2004; Arthur *et al*., 2004).

The general framework for risk analysis typically consists of four major components:

- Hazard identification – the process of identifying hazards that could potentially produce consequences;
- Risk assessment – the process of evaluating the likelihood that a potential hazard will be realized and estimating the biological, social and/or economic consequences of its realization;
- Risk management – the seeking of means to reduce either the likelihood or the consequences of it going wrong; and
- Risk communication – the process by which stakeholders are consulted, information and opinions gathered and risk analysis results and management measures communicated.

The risk analysis process is quite flexible. Its structure and components will vary considerably depending on the sector (e.g. technical, social or financial), the user (e.g. government, company or individual), the scale (e.g. international, local or entity-level) and the purpose (e.g. to gain understanding of the processes that determine risk or to form the basis for legal measures). It can be qualitative (probabilities of events happening expressed, for example, as high, medium or low) or quantitative (numerical probabilities).

THE CONCEPT OF "HAZARD"

All risk analysis sectors involve the assessment of risk posed by a threat or "hazard". The definition of "hazard" depends on the sector and the perspective from which risk is viewed (e.g. risks **to** aquaculture or risks **from** aquaculture). A hazard thus can be:

- a physical agent having the potential to cause harm, for example:
  - a biological pathogen (pathogen risk analysis);
  - an aquatic organism that is being introduced or transferred (genetic risk analysis, ecological risk analysis, invasive alien species risk analysis);
  - a chemical, heavy metal or biological contaminant (human health and food safety risk analysis, environmental risk analysis); or
- the inherent capacity or property of a physical agent or situation to cause adverse affects, as in
- social risk analysis,
- financial risk analysis, and
- environmental risk analysis.

Risk analysis terminology

The terminology used by some risk analysis sectors is well established (e.g. pathogen risk analysis, food safety, environmental risk analysis), and there is often considerable differences in how individual terms are defined. An attempt at cross-sectoral standardization of terms is thus probably futile, and it is thus important that that terms used by the various risk analysis sectors be fully defined at the outset.

SOME GENERAL PRINCIPLES

Some basic principles that appear to be common to all types of risk analysis are presented below. These involve the broader concepts of common sense, uncertainty, precaution, objectivity, transparency, consistency, scientific validation, stakeholder consultation, stringency, minimal risk management, unacceptable risk and equivalence.

- **The Principle of Common Sense** – In assessing risks, the use of "common sense" should prevail. In many cases, the outcomes of a risk analysis are obvious and uncontroversial, and a decision can be made without resulting to a full risk analysis, which can be a lengthy and expensive process.
- **The Principle of Uncertainty** – All risk analyses contain an element of uncertainty. A good risk analysis will seek to reduce uncertainty to the extent possible.
- **The Principle of Precaution** – Those involved in the aquaculture sector have a responsibility to err on the side of caution, particularly if the outcomes of a given action may be irreversible. If the level of uncertainty is high, the Precautionary Principle can be applied to delay a decision until key information is obtained. However, steps must be taken to obtain the information in a timely manner.
- **The Principle of Objectivity** – Risk analyses should be conducted in the most objective way possible. However, due to uncertainty and human nature, a high degree of subjectivity may be present in some risk analyses. A risk analysis should clearly indicate where subjective decisions have been made.
- **The Principle of Transparency** – Risk analyses, particularly those conducted by public sector agencies, should be fully transparent, so that all stakeholders can see how decisions were reached. This includes full documentation of all data, sources of information, assumptions, methods, results, constraints, discussions and conclusions.
- **The Principle of Consistency** – Although risk analysis methodology continues to evolve, it is important that decisions, particularly those made by government, are reached via standardized methods and procedures. In theory, two risk analysts independently conducting the same risk analysis should reach roughly similar conclusions.
- **The Principle of Scientific Validation** – The scientific basis of a risk analysis and the conclusions drawn should be validated by independent expert review.
- **The Principle of Stakeholder Consultation** – If the results of a risk analysis are likely to be of interest to, or impact upon others, then stakeholder consultations

should be held. This is accomplished by risk communication, the interactive exchange of information on risk among risk assessors, risk managers and other interested parties. Ideally, stakeholders should be informed/involved throughout the entire risk analysis process, particularly for potentially contentious risk analyses (e.g. ecological, genetic and pathogen risk analyses for the introduction of new aquatic species).

- **The Principle of Stringency** – The stringency of the risk management measures to be applied should be in direct proportion to the risk involved.
- **The Principle of Minimal Risk Management** – Risk management measures that impinge on the legitimate activities of others should be applied only to the extent necessary to reduce risk to an acceptable level.
- **The Principle of Unacceptable Risk** – If the level of risk is unacceptable and no effective or acceptable risk management measures are possible, then the activity should not take place.
- **The Principle of Equivalence** – Risk management measures proposed by trading partners that meet the acceptable level of risk should be accepted by the importing country.

APPLICATION OF RISK ANALYSIS TO AQUACULTURE

Risk analysis has wide applicability to aquaculture. So far, it has mainly been applied in assessing risks to society and the environment posed by hazards created by or associated with aquaculture development (Box 1). These include the risks of environmental degradation; introduction and spread of pathogens, pests and invasive species; genetic impacts; unsafe foods; and negative social and economic impacts. The use of risk analysis can provide insights and assist in making decisions that will help to avoid such negative impacts, thus helping aquaculture development to proceed in a more socially and environmentally responsible manner.

Risk analysis is less commonly used to achieve successful and sustainable aquaculture by assessing the risks to aquaculture posed by the physical, social and economic environment in which it takes place Box 2. These include reduction of environmental risks (e.g. due to poor siting or severe weather events), biological risks (infection by pathogens via transfer from native stocks, predation by seals and sharks; red tides etc.), operational risks (poor planning, work-related injuries), financial risks (e.g. market changes, currency fluctuations, emergence of new competitors, etc.) and social risks (negative image and resulting product boycott, lack of skilled manpower, competition from other sectors).

There exists, therefore, considerable scope to develop and expand the use of risk analysis for the benefit of aquaculture and the social and physical environments in which it takes place.

BOX 1

Examples of risks to society from aquaculture

Environmental risks
- pollution from feeds, drugs, chemicals, wastes
- alteration of water currents & flow patterns

Biological risks
- introduction of invasive alien species, exotic pests & pathogens
- genetic impacts on native stocks
- destruction/modification of ecosystems and agricultural lands (mangrove deforestation, salination of ricelands)

Financial risks
- failure of farming operations
- collapse of local industry/sector

Social risks
- displacement of artisanal fishers

Human health risks
- food safety issues

CONCLUSIONS

An integrated approach to risk analysis will assist the aquaculture sector in reducing risks to successful operations from both internal and external hazards and can similarly help

BOX 2

Examples of risks to aquaculture from society and the environment

Environmental risks
- severe weather patterns
- pollution (e.g. agricultural chemicals, oil spills)

Biological risks
- pathogen transfer from wild stocks
- local predators (seals, sharks etc.)
- toxic algal blooms, red tide

Operational risks
- poor planning
- poor design
- workplace injuries

Financial risks
- market changes
- inadequate financing
- currency fluctuations
- emergence of new competitors

Social risks
- negative image/press
- lack of skilled manpower
- competition for key resources from other sectors
- theft, vandalism

to protect the environment, society and other resource users from adverse and often unpredicted impacts. This could lead to improved profitability and sustainability of the sector, while at the same time improving the public's perception of aquaculture as a responsible, sustainable and environmentally friendly activity.

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Food safety and public health risks associated with products of aquaculture

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ABSTRACT

The Sanitary and Phytosanitary (SPS) Agreement within the framework of the World Trade Organization emphasizes the need to apply risk analysis as a basis for taking any SPS measure. With the adoption of the food-chain approach for food safety, the responsibility for the supply of safe food is shared along the entire food chain from primary production to final consumption. Thus the application of risk analysis to the aquaculture sector, which produces nearly half the fish that is consumed worldwide, has become very important. Guidelines for performing risk analysis have been brought out by the Codex Alimentarius Commission or Codex. Risk analysis is a process consisting of risk assessment, risk communication and risk management. Risk assessment is the scientific evaluation of known or potential adverse health effects resulting from human exposure to foodborne hazards. This consists of four steps: hazard identification, hazard characterization, exposure assessment and risk characterization. The output of risk assessment may be a qualitative or a quantitative (numerical) expression of risk as well as attendant uncertainties. Hazard identification considers epidemiological data linking the food and biological/chemical agent to human illness and the certainty associated with such effects. At the hazard characterization step, a qualitative or quantitative description of the severity and the duration of the adverse health effect that may result from the ingestion of the micro-organism/toxin/chemical contaminants is made. During exposure assessment, an estimate of the number of bacteria or the level of a biotoxin or chemical agent consumed through the concerned food is made. The Codex defines the risk characterization step as the process of determining the qualitative and/or quantitative estimation including attendant uncertainties of the probability of occurrence and the severity of the known or potential adverse health effect in a given population based on hazard identification, exposure assessment and hazard characterization. As an example of a risk assessment, the Food and Agriculture Organization of the United Nations/World Health Organization risk assessment for choleragenic *Vibrio cholerae* in warmwater shrimp in international trade is presented. Risk management is the process of weighing policy alternatives in the light of the results of risk assessment and if required, selecting and implementing appropriate control options, including regulatory measures. Risk communication is an interactive process of exchange of information and opinion on risk among risk assessors, risk managers and other interested parties. Examples of risk management measures adopted based on risk assessment are presented.

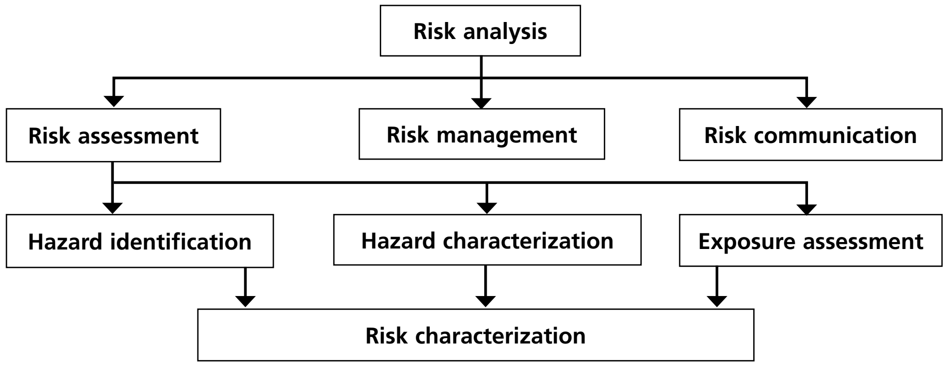
INTRODUCTION

Outbreaks of food-borne illnesses continue to be a major problem worldwide, and international trade in food products is increasing. According to World Health Organization (WHO) estimates, 1.8 million deaths related to contaminated food or water occur every year. Traditionally, food safety programmes have focused on enforcement mechanisms for final products and removal of unsafe food from the market instead of a preventive approach. In such a model, the responsibility for safe food tends to concentrate on the food-processing sector. The Food and Agriculture Organization of the United Nations (FAO) is recommending a food-chain approach that encompasses the whole food chain from primary production to final consumption. In such a system, the responsibility for a supply of food that is safe, healthy and nutritious is shared along the entire food chain by all involved in the production, processing, trade and consumption of food. Stakeholders include farmers, fishermen, processors, transport operators (raw and processed material) and consumers, as well as governments obliged to protect public health. In order to protect public health and facilitate international food trade, the member countries of the World Trade Organization (WTO) have signed the Sanitary and Phytosanitary (SPS) Agreement. Under this agreement, member countries have a right to take measures to ensure that consumers are supplied with safe food, but they also have the obligation to ensure that their food safety regulations are based on risk analysis and are not arbitrary and used as a means to protect domestic producers from competition. Considering that nearly 50 percent of the fish traded in international markets comes from aquaculture, it is important to ensure that the aquaculture sector is producing safe food. The food-chain approach to food safety is based on five important aspects:

- The three fundamental concepts of **risk analysis** – risk assessment, risk management and risk communication – should be incorporated into food safety. There should be an institutional separation of science-based risk assessment from risk management, which is the regulation and control of risk.
- **Traceability** from the primary producer (including fish feed) through post-harvest treatments, food processing and distribution to the consumer should be improved.
- **Harmonization of food safety standards** is necessary; this implies increased development and wider use of internationally agreed-upon, scientifically based standards. The Technical Barriers to Trade (TBT) Agreement of WTO tries to achieve this by ensuring that arbitrary standards do not become barriers to international trade.
- **Equivalence of food safety systems** that achieve similar levels of protection against food-borne hazards, whatever means of control are used. This is a requirement under the SPS Agreement.
- Increased emphasis on **risk avoidance or prevention at source** within the whole food chain – from farm or sea to plate – is necessary to complement conventional food safety management based on regulation and control.

Complementing the current emphasis on regulation and control of the food safety system with preventive measures to control the introduction of contamination at source requires the adoption of practices in food production, handling and processing that reduce the risk of microbiological, chemical and physical hazards entering the food

FIGURE 1
The risk analysis process



chain. There are some hazards such as chemical contaminants and biotoxins in shellfish that cannot be simply removed from foodstuffs. The adoption of sound practices along the food chain based on principles defined in Good Aquaculture Practices (GAP) and in-plant control of food processing based on hazard analysis and critical control point (HACCP) analysis is important to prevent such hazards from entering the system. By using a risk-based approach to the management of food safety, food control resources can be directed to those hazards posing the greatest threat to public health and where the potential gains from risk reduction are large relative to the resource use. Establishing risk-based priorities requires sound scientific knowledge and effective systems for reporting the incidence of food-borne diseases.

Guidelines for performing risk analysis have been brought out by the Codex Alimentarius Commission (CAC). According to Codex, risk analysis is a process consisting of risk assessment, risk management and risk communication. Risk assessment is a scientifically based process involving the following four steps: hazard identification, hazard characterization, exposure assessment and risk characterization (Figure 1).

THE RISK ANALYSIS PROCESS

Hazard identification

This involves identification of biological or chemical agents capable of causing adverse health effects that may be present in a particular food or group of foods. Products of aquaculture include freshwater and marine finfish as well as shellfish (molluscs and crustaceans). Hazard identification considers epidemiological data linking the food and biological/chemical agent to human illness (CCFH, 1998) and the certainty and uncertainty associated with such effects. Data from national surveillance programmes, microbiological and clinical investigations, and process evaluation studies are important (Fazil, 2005). At the hazard identification step, a qualitative evaluation of available information is carried out and documented. The characteristics of the organism/toxin/chemical agent, including its effects on the host and mode of action, are considered. Table 1 lists known or potential hazards associated with products of aquaculture. Based on epidemiological evidence, only a few microbial agents are known to be involved in foodborne illnesses; however, only a small number of outbreaks have been adequately investigated. Therefore, limitations of hazard identification with respect to biological agents include the expense and difficulty involved in outbreak investigations, and the difficulties involved in the isolation and characterization of certain pathogens such as viruses. However, for most chemical agents, clinical and epidemiological data are unlikely to be available. Since the statistical power of most

TABLE 1
Biological and chemical hazards associated with aquaculture products

Known or potential hazard	Product likely to be affected	Epidemiological evidence
BIOLOGICAL AGENTS		
Bacteria		
Vibrio vulnificus	Molluscan shellfish	Strong
V. parahaemolyticus	Shellfish	Strong
V. cholerae	Fish and shellfish	Very weak
Salmonella	Fish and shellfish	Very weak
Viruses		
Norovirus	Molluscan shellfish	Strong
Hepatitis A virus	Molluscan shellfish	Strong
Parasites		
Fish-borne trematodes *(Opisthorchis viverrini, Clonorchis sinensis)*	Finfish	Strong
Biotoxins		
Paralytic shellfish poisoning (PSP)	Molluscan shellfish	Strong
Diarrhetic shellfish poisoning (DSP)	Molluscan shellfish	Strong
Amnesic shellfish poisoning (ASP)	Molluscan shellfish	Strong
Neurotoxic shellfish poisoning (NSP)	Molluscan shellfish	Strong
Chemical agents		
Polychlorinated biphenyls (PCBs)	Finfish and shellfish	Epidemiological data lacking
Pesticides	Finfish and shellfish	

epidemiological investigations is inadequate to detect effects at relatively low levels in human populations, negative epidemiological evidence is difficult to interpret for risk assessment purposes. Where positive epidemiological data are available, consideration should be given to variability in human susceptibility, genetic predisposition, age-related and gender-related susceptibility, and the impact of factors such as socio-economic and nutritional status. Due to a paucity of epidemiological data, hazard characterization may have to rely on data derived from animal and *in vitro* studies.

Some examples of hazard identification are given in Box 1.

Exposure assessment

At this step, an estimate of the number of bacteria or the level of a biotoxin or a chemical agent consumed through the concerned food is made. This involves documenting the sources of contamination, frequency, concentration and estimation of the probability and the concentration that will be consumed. This requires information on the pathogen (e.g. ecology of the microbial pathogen, distribution, growth, inhibition or inactivation during handling and processing), on the food (food composition – pH, water activity, nutrient content, presence of antimicrobial agents, competing microflora; processing practices; handling at retail and consumer preparation practices), and on the consumer (population demographics, food consumption patterns).

Primarily, exposure assessment is concerned with estimating the likelihood of being exposed to the hazard through consumption of the food under consideration and the amount or dose to which an individual or population is exposed. Microbial hazards are much more dynamic as compared to chemical hazards because of the potential of micro-organisms to multiply in foods or their numbers being reduced due to handling, processing or storing (e.g. freezing) of foods and consumer preparation (e.g. cooking) steps that may inactivate them. With respect to microbial toxins, a combination of the microbes' characteristics and the chemical-like effects of the toxin are to be considered. Data on the concentration of the pathogen in the food at the time of consumption are rarely available and therefore, it is necessary to develop models or assumptions to estimate the likely exposure. For bacteria, the growth and death of the organism under the predicted handling and processing conditions of the food are considered in the model, which would take into account the effects on the pathogen due to time, temperature, food chemistry and the presence of competing microflora. However, biological agents like viruses and parasites do not multiply in foods. In these cases, handling, storage and processing conditions may affect their survival.

BOX 1
Some examples of hazard identification

Vibrio vulnificus occurs in warm estuarine environments all over the world and three biotypes have been reported (Bisharat and Raz, 1997; Bisharat *et al.,* 1999; Strom and Paranjpye, 2000). Nearly all human cases resulting from seafood consumption are due to Biotype 1. Biotype 2 is associated with infections in cultured eel and Biotype 3 is limited to wound infections associated with handling cultured fish in ponds. Annually, about 30–40 cases of primary septicaemia due to Biotype 1 are reported from the United States of America, but there is little epidemiological evidence of cases in other countries. Nearly all cases are associated with consumption of raw oysters harvested from the Gulf coast. Although foodborne *V. vulnificus* infections are rare, case fatality ratio is high, exceeding 50 percent (Hlady and Klontz, 1996; Mead *et al*., 1999). Individuals with pre-existing liver diseases are at the greatest risk of contracting primary septicaemia and subsequent mortality, but other chronic illnesses and immunodeficiency conditions are also associated with increased risk. *Vibrio vulnificus* is not a hazard that is specific to aquaculture products. Natural beds of oysters, mussels and clams may contain this organism. As the organism is not derived from faecal contamination, its presence is not higher in polluted environments.

Vibrio parahaemolyticus is a halophilic bacterium found in coastal and estuarine environments throughout the world (Joseph, Colwell and Kaper, 1982). However, most environmental strains are not human pathogens. Strains isolated from clinical cases produce a thermostable direct hemolysin (TDH) or a TDH-related hemolysin (TRH) (Joseph, Colwell and Kaper, 1982; Honda, Ni and Miwatani, 1988). Gastroenteritis, an illness of short duration and moderate severity that is characterized by diarrhea, vomiting and abdominal cramps, is the most common clinical manifestation of *V. parahaemolyticus* infection. Individuals with underlying medical conditions (diabetes, alcoholic liver disease, hepatitis, those receiving immunosuppressive therapy for cancer or AIDS) do not seem to be more susceptible to initial infection, but they may have higher risk of the infection developing into septicaemia. In the United States of America, most infections are associated with consumption of raw oysters; but in other countries, a wide variety of seafood including finfish, crayfish, crabs, shrimp and clams have been involved. In the United States of America, about 4 500 cases occur annually; a much higher number of cases is reported from Japan. While most outbreaks are sporadic, outbreaks with pandemic potential have been reported recently, and the strains involved belong mostly to O3:K6, O4:K68 and O1:KUT serotypes. Cases involving these serotypes appeared in India in 1996 and were detected in Southeast Asia, Japan and the United States of America (Okuda *et al.,* 1997; Daniels *et al.,* 2000). This organism is present in both cultured and wild fish and shellfish and is not derived from faecal contamination of the waters.

Hazards associated with foodborne viruses have been recognized recently. Transmission of norovirus and hepatitis A virus through consumption of raw molluscs has been reported from several countries. The largest outbreak of hepatitis A occurred in and around Shanghai in the People's Republic of China in 1988 in which more than 293 000 individuals became sick after eating clams (Xu *et al.,* 1992). Several cases have been reported from the United States of America, Australia and Europe (Richards, 2006). The bacteriological standards for shellfish-growing waters seem to be ineffective in preventing viral disease outbreaks. An outbreak of hepatitis A occurred in Spain in 1999 with 184 cases from clams meeting European Union standards (Sanchez *et al.,* 2002). Outbreaks of illness due to shellfish-borne norovirus have been reported from the United States of America, Australia, several countries in Europe, China and Japan (Richards, 2006). Unlike the *Vibrio* spp. mentioned above, these viruses are derived from sewage contamination of shellfish-growing areas. There is a high rate of secondary spread of viruses following a food-borne episode. Therefore, it is a challenge to obtain reliable estimates for the proportion of illness that is foodborne.

With respect to chemical hazards, exposure assessment requires information on the consumption of relevant foods and the concentration of the chemical of interest in the foods. Chemical contaminants and pesticides are generally present, if at all, at very low concentrations. Estimation of the dietary intake of chemical contaminants requires information on their distribution in foods that can only be obtained by analysing representative samples of relevant foods with sufficiently sensitive and reliable methods. Guidelines for estimation of dietary intake of contaminants are available from WHO (GEMS/Food, 1985).

Hazard characterization and dose-response analysis

At this step, a qualitative or quantitative description of the severity and the duration of the adverse health effect that may result from the ingestion of microorganism/toxin/chemical contaminants is made. The virulence characters of the pathogen, effect of food matrix on the organism at the time of consumption (factors of the food such as high fat content that may protect the organism by providing increased resistance to gastric acids), host susceptibility factors and population characteristics are considered. Wherever data are available, a dose response analysis is performed. Data for dose response analysis may come from outbreak investigations, human volunteer studies, vaccine trial studies or animal studies. In the example given later in this paper, dose response for choleragenic *V. cholerae* in seafood has been estimated based on data from vaccine trials.

Risk characterization

Codex defines the risk characterization step as the process of determining the qualitative and/or quantitative estimation including attendant uncertainties of the probability of occurrence and the severity of the known or potential adverse health effect in a given population based on hazard identification, exposure assessment and hazard characterization. The output of risk characterization is not a simple qualitative or quantitative statement of risk. Risk characterization should provide insights into the nature of the risk, including a description of the most important factors contributing to the average risk, the largest contributions to uncertainty and variability of the risk estimate and a discussion of gaps in data and knowledge. A comparison of the effectiveness of various methods of risk reduction is also presented.

The output of risk characterization is the risk estimate, which may be qualitative (low, medium, high); semi-quantitative (the risk assessors making a ranking, i.e. a number within a range, e.g. 0–100); or quantitative (the risk assessors predicting the number of people who are likely to become ill from the pathogen-commodity/product combination). Qualitative risk assessment is performed when data are inadequate to make numerical estimates, but when conditioned by prior expert knowledge and identification of attendant uncertainties, data are sufficient to permit risk ranking or separation into descriptive categories of risk. An example of qualitative risk assessment is given by Huss, Reilly and Ben Embarek (2000), who estimated the risk as high for consumption of molluscan shellfish, fish eaten raw, lightly preserved fish and mildly heat-treated fish. Low-risk products were chilled/frozen fish and crustaceans, semi-preserved fish and heat-processed (canned) fish. Dried and heavily salted fish were considered to have no risk of pathogenic bacteria.

Quantitative risk assessments are based on mathematical models incorporating quantifiable data and emphasize the likelihood of an adverse health effect (e.g. illness, hospitalization, death). These can be further subdivided into deterministic and probabilistic risk assessments. For deterministic risk assessment, single input values that best represent the factors in the system are chosen. The values could represent the most likely value or values that capture a worst-case situation. Deterministic risk assessment does not provide information on the uncertainty of the risk estimate.

However, selecting worst-case values and combining worst-case input values across multiple factors affecting food safety performance may be too stringent for most of the industry if risks are associated with extremes of performance. In the case of probabilistic risk assessments, input values are distributions that reflect variability and/or uncertainty. Uncertainty analysis is a method used to estimate the uncertainty associated with models and assumptions used in the risk assessment.

Almost always, risk assessments have a statement specifying that insufficient data were available in one or more areas and, as a result, a certain amount of caution should be attached to the estimate. Caution, as a result of lack of precise information, leads to uncertainty, and it is always important to record the data gaps that lead to uncertainty. Later, if that knowledge becomes available, the level of uncertainty will be reduced so that the risk estimate becomes more accurate. Risk assessment is an iterative process and may need re-evaluation as new data become available. Wherever possible, risk estimates should be reassessed over time by comparison with independent human illness data.

Risk management

Risk management is the process of weighing policy alternatives in the light of the results of risk assessment and if required, selecting and implementing appropriate control options including regulatory measures. According to Codex (FAO, 1997), risk management should follow a structured approach involving the elements of risk evaluation, risk management option assessment, implementation of management decision, monitoring and review.

Risk evaluation

Risk evaluation involves identification of a food safety problem, establishment of a risk profile, ranking of hazards for risk assessment and risk management priority, establishment of policy for conduct of risk assessment, commissioning of the risk assessment and consideration of the risk assessment results. Identification of the food safety issue is the entry point for preliminary risk management activities and may come to the attention of the risk manager through disease surveillance data, inquiry from a trading partner or consumer concern. A risk profile comprises a systematic collection of information needed to make a decision. This can include description of the food safety issue, information about the hazard, any unique characteristics of the pathogen/human relationship, information about the exposure to the hazard, possible control measures, feasibility and practicality, information on adverse health effect (type and severity of illness, subset of population at risk) and other information for making risk management decisions. Based on the information generated in the risk profile, the risk manager may be able to make a range of decisions. Where possible and necessary, the risk manager may commission a risk assessment. This would involve defining the scope and purpose of the risk assessment, defining risk assessment policy, interactions during the conduct of the risk assessment and consideration of the outputs of risk assessment.

Risk option assessment

This step consists of identification of available management options, selection of the preferred management option, including consideration of appropriate safety standard, and making the final management decision. Optimization of food control measures in terms of their efficiency, effectiveness, technological feasibility and practicality at different points in the food chain is an important goal. A cost-benefit analysis could be performed at this stage.

Implementation of the risk management decision
This will usually involve regulatory food safety measures such as the Hazard Analysis and Critical Control Points (HACCP). There could be flexibility in the measure applied by the industry as long as it can be objectively demonstrated that the programme is able to achieve the stated goals. On-going verification of the food safety measure is essential.

Monitoring and review
This is the gathering and analysing of data that gives an overview of food safety and consumer health. Foodborne disease surveillance identifies new food safety problems as they emerge. If the monitoring indicates that the required food safety levels are not being reached, redesign of the measures will be needed (FAO/WHO, 2002).

Further risk management considerations
Protection of human health should be the primary consideration in arriving at any risk management decision. Other considerations (e.g. economic costs, benefits, technical feasibility and societal preferences) may be important in some contexts, particularly in deciding on the measures to be taken. However, these considerations should not be arbitrary and should be made explicit. Risk management should:

- include the identification and systematic documentation of all elements of the risk management process including decision-making, so that the rationale is transparent to all interested parties (e.g. consumer organizations, food industry and trade representatives, educational and research institutions, and regulatory bodies);
- include determination of risk assessment policy as a specific component. (Risk assessment policy sets the guidelines for value judgments and policy choices that may need to be applied at specific decision points in the risk assessment process, and preferably should be determined in advance of risk assessment, in collaboration with risk assessors.);
- ensure the scientific integrity of the risk assessment process by maintaining the functional separation of risk management and risk assessment. (However, as risk analysis is an iterative process, interactions between risk managers and risk assessors are essential for practical application.);
- lead to decisions that take into account the uncertainty in the output of the risk assessment. (The risk assessment should include numerical expression of uncertainty, and this must be conveyed to risk managers in an understandable form so that the full implications of the range of uncertainty are included in risk management decisions.);
- include clear, interactive communication with consumers and other interested parties in all aspects of the process;
- be a continuing process that takes into account all newly generated data in the evaluation and review of risk management decisions.

Governments in a number of countries are undertaking quantitative risk assessments for specific microbiological hazards in foods with the intention that the output can be used to develop national food safety measures. This is also a requirement in international trade in foods because the SPS Agreement under the World Trade Organization (WTO) permits countries to take legitimate steps to protect the life and health of their consumers, while prohibiting them from using these measures in ways that unjustifiably restrict trade. The standards, guidelines and recommendations of Codex are considered by WTO to reflect international consensus regarding requirements for protecting human health and safety. A member country's food safety measures are considered justified and in accordance with the provisions of the SPS Agreement if they are based on Codex standards or guidelines. Failure to apply Codex standards could create potential for dispute if a member applies a standard that is more restrictive for trade than necessary to achieve the required level of protection. Members are required to justify levels of protection higher than those in Codex by using risk assessment techniques.

In the context of food safety, an appropriate level of protection (ALOP) is a statement of public health protection that is to be achieved by the food safety systems implemented in that country. Most commonly, ALOP is articulated as a statement of disease burden associated with a hazard/food combination and its consumption within the country. ALOP is often framed in the context for continual improvement in relation to disease reduction. For example, if a country has 100 cases of *Vibrio parahaemolyticus* due to consumption of raw oysters per 100 000 population and wants to implement a programme that reduces the incidence, there are two possible approaches in converting this goal into a risk management programme. The first is the articulation of a specific public health goal, i.e. to reduce the number of cases to 10 per 100 000 population. This is based on the assumption that there are practical means of achieving this. The alternate approach is to evaluate the performance of risk management options currently available and select an ALOP based on one or more of these options. This is often referred to as the as low as reasonably achieved (ALARA) approach.

Implementation of a food safety control programme greatly benefits by expression of ALOP in terms of the required level of control of hazard in foods. The concept of food safety objective (FSO) provides a measurable target for producers, consumers and regulatory authorities. FSO has been defined as "the maximum frequency and/or concentration of a microbiological hazard in a food at the time of consumption that provides the appropriate level of protection" (FAO/WHO, 2002). FSOs are usually used in conjunction with performance criteria and/or performance standards that establish the required level of control of hazard at other stages in the food chain. A performance criterion is the required outcome of a step or a combination of steps that contribute to assuring that the FSO is met. Performance criteria are established considering the initial level of hazard and changes during production, distribution, storage, preparation and use of the food. The control of *Listeria monocytogenes* in foods provides an example of the need to consider a structured risk management approach (Box 2).

BOX 2

The control of *Listeria monocytogenes* in foods

The FAO/WHO (2004) risk assessment for *L. monocytogenes* in ready-to-eat foods indicates that *Listeria* is frequently consumed in small amounts by the general population without apparent ill effects. Dose response data indicate that only higher levels of *Listeria* have caused severe disease problems. It is also evident that *Listeria* is a bacterium that will always be present in the environment. Therefore, the critical issue may not be how to prevent *Listeria* in foods, but how to control its survival and growth in order to minimize the potential risk. Complete absence of *Listeria* is unrealistic and unattainable for many foods, and trying to achieve this goal can limit trade without having any appreciable benefit to public health. A relevant risk management option, therefore, is to focus on foods that support growth of *Listeria* to high levels, rather than those that do not. Thus, establishment of tolerable low levels of *Listeria* in specific foods may be one food safety objective established by risk managers after a rigorous and transparent risk analysis. However, there is no internationally accepted FSO for *L. monocytogenes*, and the Codex Committee on Food Hygiene (CCFH) has come up with questions to the risk assessment team including an estimation of the difference in risk resulting from FSOs varying between "absence" (0 cells/25 g) and 1 000 cells/g.

Risk communication

Risk communication is an interactive process of exchange of information and opinion on risk among risk assessors, risk managers and other interested parties (e.g. government agencies, industry representatives, the media, scientists, professional societies, consumer organizations, other public interest groups and concerned individuals). The practical application of risk communication in relation to food safety involves all aspects of communication among risk assessors, risk managers and the public. Risk communication may originate from official sources at the international, national or local levels. It may also be from other sources such as industry, trade, consumers and other interested parties. In some cases, risk communication may be carried out in conjunction with public health and food safety education programmes. The goals of risk communication are to:

- promote awareness and understanding of the specific issues under consideration during the risk analysis process by all participants;
- promote consistency and transparency in arriving at and implementing risk management decisions;
- provide a sound basis for understanding the risk management decisions proposed or implemented;
- improve the overall effectiveness and efficiency of the risk analysis process;
- contribute to the development and delivery of effective information and educational programmes, when they are selected as risk management options;
- foster public trust and confidence in the safety of the food supply;
- strengthen the working relationships and mutual respect among all participants;
- promote the appropriate involvement of all interested parties in the risk communication process; and
- exchange information on the knowledge, attitudes, values, practices and perceptions of interested parties concerning risks associated with food and related topics.

At an international level, organizations like the Codex Alimentarius Committee (CAC), FAO, World Health Organization (WHO) and WTO are involved in risk communication. The general subject Codex Committees are involved in risk management such as development of standards, guidelines and other recommendations. Risk assessment information is often provided by the Joint FAO/WHO Expert Committee on Microbiological Risk Assessments. The FAO/WHO Codex Secretariat carries out risk communication through publication of various documents and Internet-based communications. The WTO SPS Committee manages the implementation of the SPS Agreement for WTO member countries; and, through the notification procedure required by the SPS Agreement, it communicates risk management decisions among those member countries.

National governments have the fundamental responsibility of risk communication while managing public health risks, regardless of the management method used. Governments that are members of CAC need to take an active role in the Codex process and ensure that all interested parties in their countries contribute to the national position on Codex matters to the extent practicable and reasonable. Since industry is responsible for the safety of the food it produces, it has corporate responsibility to communicate information on the risks to the consumers. Food labeling is used as a means of communicating instructions on the safe handling of food as a risk management measure. Consumer organizations can work with government and industry to ensure that risk messages to consumers are appropriately formulated and delivered.

FAO/WHO RISK ASSESSMENT FOR CHOLERAGENIC *VIBRIO CHOLERAE* IN WARMWATER SHRIMP IN INTERNATIONAL TRADE: EXAMPLE OF A RISK ASSESSMENT

Seafood exports are a major source of foreign exchange for many Asian countries. Incidentally cholera is endemic in some Asian countries; and exports are often affected whenever there are reports of cholera in seafood-producing countries. Shrimp constitute the major seafood commodity that is affected. In 2003, there were 4.3 million tonnes of shrimp in international trade, of which 70 percent was warmwater shrimp. Considering the importance of shrimp from warm waters in international trade, FAO/WHO set up an expert committee to perform a risk assessment for *Vibrio cholerae* in warmwater shrimp processed for export. This section summarizes the findings of the FAO/WHO Drafting Group; the complete risk assessment is given in FAO/WHO (2005).

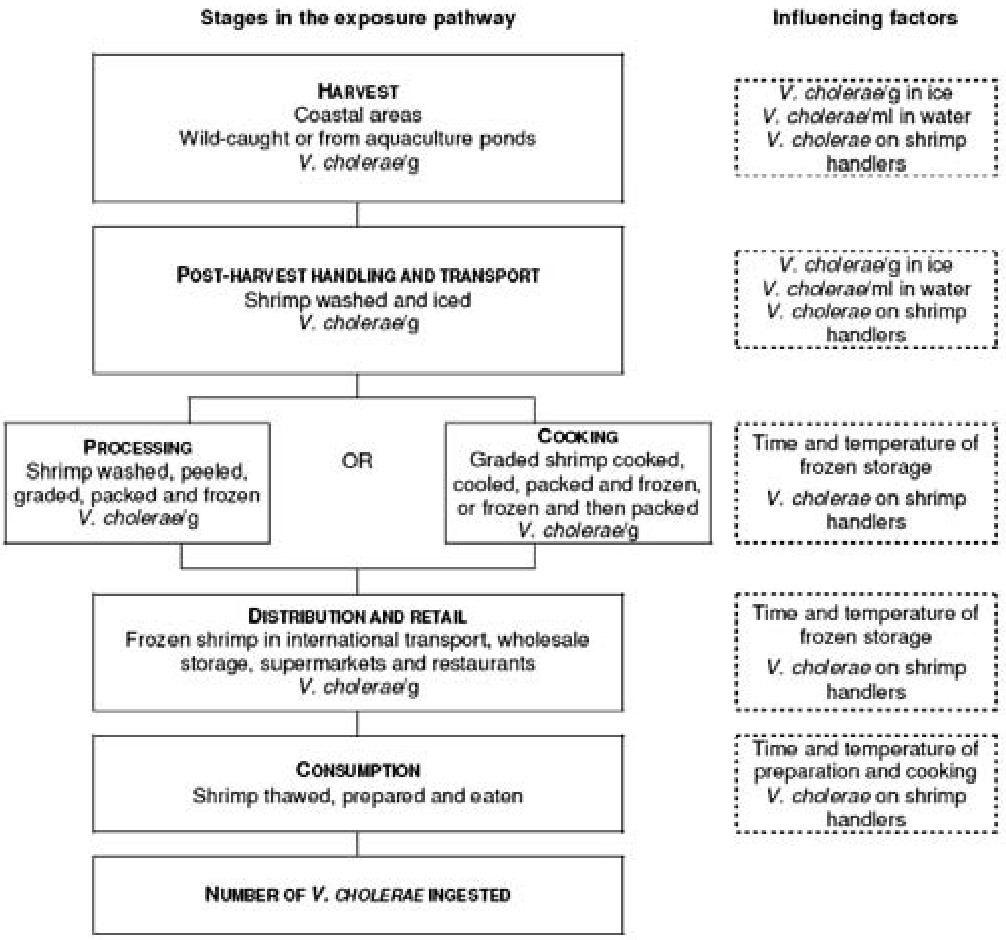
Vibrio cholerae is a heterogeneous species consisting of over 220 serotypes. The disease cholera is caused only by serotypes O1 and O139, which are also referred to as choleragenic *V. cholerae*. Strains belonging to non 01/non-0139 serotypes of *V. cholerae* are widely distributed in the aquatic environment and are mostly nonpathogenic to humans, although they are occasionally associated with sporadic cases of gastroenteritis (Kaper, Morris and Levine, 1995; Desmarchelier, 1997). Choleragenic *V. cholerae* are characterized by their ability to produce cholera toxin, which is a complex protein consisting of A and B subunits. Production of cholera toxin is encoded by *ctx*AB genes. The *ctx* gene is present in a filamentous bacteriophage that infects *V. cholerae* through a pilus called toxin co-regulated pilus (Waldor and Mekalanos, 1996; Faruque, Albert and Mekalanos, 1998). Since the *ctx*AB gene is phage encoded and there may be loss of bacteriophage in some environmental strains, it is possible to isolate non-toxigenic *V. cholerae* O1 from the environment and occasionally from seafoods like shrimp (Colwell, Kaper and Joseph, 1977; Kaper *et al.*, 1979; Dalsgaard *et al.,* 1995). Serotyping alone is inadequate to detect choleragenic *V. cholerae* due to serological cross reactions (Shimada, Sakazaki and Oue, 1987; Dalsgaard, Mazur and Dalsgaard, 2002). Thus use of molecular techniques such as polymerase chain reaction (PCR) or DNA probe hybridization has become important in determining the presence of choleragenic *V. cholerae* in seafood (Koch *et al.,* 1993, Karunasagar *et al.*, 1995).

In the aquatic environment, *V. cholerae* may be associated with copepods (Huq *et al.,* 1983). But copepods are planktonic organisms while shrimp are demersal and therefore, *V. cholerae* is generally not associated with shrimp in their natural environment. Under an FAO-sponsored shrimp microbiology project during the late 1980s, shrimp surface and gut were tested for the presence of *V. cholerae* in a number of countries such as India, Thailand, Sri Lanka, Indonesia, Malaysia and the Philippines. The data from this study indicated absence of choleragenic *V. cholerae* in association with shrimp (Karunasagar *et al.,* 1990, 1992; Fonseka, 1990; Rattagool *et al.,* 1990). Although one study in the mid 1990s detected *V. cholerae* O1 in tropical shrimp, molecular studies indicated that the isolates were non-toxigenic (Dalsgaard *et al.*, 1995).

For risk assessment, it is important to consider the prevalence and concentration of choleragenic *V. cholerae* in shrimp during all stages of the farm to fork chain. The model considered in this risk assessment is shown in Figure 2. Warmwater shrimp intended for export is handled as per HACCP guidelines, which involve the use of adequate ice to cool shrimp immediately after harvest, use of potable water to make ice, hygienic practices in handling and processing etc. Studies conducted in Peru during an epidemic of cholera in 1991 have shown that contamination of seafood with *V. cholerae* can be prevented by adopting HACCP procedures (De Paola *et al.*, 1993).

Freshly harvested shrimp have a bacterial count of about 10^3–10^4 cfu/g, and diverse bacterial groups are present (Karunasagar *et al.,* 1992). If contamination with *V. cholerae* occurs in raw shrimp, this organism has to compete with other natural flora

FIGURE 2
Production to consumption pathway for exposure assessment for choleragenic *Vibrio cholerae* in warmwater shrimp



Source: FAO/WHO, 2005.

on the surface of shrimp. Studies indicate that *V. cholerae* is unable to multiply in raw shrimp (Kolvin and Roberts, 1992). Studies conducted in our laboratory show that icing and storage in ice for 48 hr can lead to a 2 log reduction in *V. cholerae* levels, if the organism was present on shrimp before icing (Table 2). Studies conducted in Argentina show that freezing and frozen storage of shrimp can lead to a 3–6 log reduction in levels of *V. cholerae* (Reilly and Hackney, 1985; Nascumento *et al.,* 1998). As shrimp are normally consumed after cooking, and as *V. cholerae* is sensitive to heat with a D value of 2.65 min at 60 °C (ICMSF, 1996), it can thus be expected that there will be about a 6 log reduction in numbers during cooking of shrimp (Table 2).

For risk assessment, dose-response data are important. Data based on human volunteer studies conducted in the United States in connection with cholera vaccine trials (Cash *et al.,* 1974; Black *et al.,* 1987; Levine *et al.,* 1988) indicate that the infective dose would range from 10^6–10^8 for different strains of choleragenic *V. cholerae*. Data on the prevalence of choleragenic *V. cholerae* in warmwater shrimp were based on "port of entry testing for *V. cholerae*" at Japan, the United States of America and Denmark. Of 21 857 samples of warmwater shrimp tested, two were positive (0.01 percent) for choleragenic *V. cholerae.* The risk assessments assumed that 90 percent of warmwater shrimp are eaten cooked and 10 percent are eaten raw (as sashimi, etc.). Qualitative risk assessment indicated that the risk to human health is very low. Since the risk of the organism occurring in shrimp is low, the organisms would need to multiply in the product to attain infectious levels, but during the processing of warmwater shrimp

TABLE 2
Effect of processing on levels of choleragenic *Vibrio cholerae* in shrimp

Processing step	Temperature distribution (°C)	Time distribution	Effect on population of V. cholerae O1	Source of data
HARVEST				
Handling time before icing				Industry data for time, temperature, Kolvin and Roberts (1982) for multiplication
Cultured shrimp	15–35	0–1 hr	No effect	
Wild-caught shrimp	10–30	0–3 hr	0–1 log increase	
WASHING				
Washing and icing of cultured shrimp	0–7	1–4 hr	1 log reduction	Dinesh (1991)
Washing in seawater of wild-caught shrimp	0–30	1–4 hr		
ICING				
Icing during transport (including on board fishing vessel for wild-caught shrimp) to processor	0–7	2–16 hr (cultured) 2–48 hr (wild-caught)	2–3 log reduction	Karunasagar (unpublished)
WATER USE				
Water use during handling at processing plant	4–10	1–3 hr	No effect	Industry data, Kolvin and Roberts (1982)
TEMPERATURE				
Temperature during processing before freezing	4–10	2–8 hr	No effect	Industry data, Kolvin and Roberts (1982)
COOKING				
Cooking at processing plant	>90	0.5–1.0 min (This is the holding time at >90 °C)	>6 log reduction	Based on industry data on total plate count (Sterling Foods Mangalore, India, pers. comm.) In shrimp homogenate $D_{82.2}$=0.28 (Hinton and Grodner 1985)
FREEZING				
Freezing of cooked and raw products, storage, and shipment time	-12 to -20	15–60 d	2–6 log reduction	INFOFISH (pers. comm.) for shipment time, Reilly and Hackney (1985); Nascumento *et al*. (1998) for survival in frozen shrimp

Source: from FAO/WHO, 2005.

(icing, freezing, cooking), significant reductions in level are expected to occur (Table 3). Also epidemiological evidence shows no link between imported warmwater shrimp and cholera in importing countries. Semiquantitative risk assessment using Risk Ranger (Ross and Sumner, 2002) estimated 1–2 cases per decade for Japan, the United States and Spain. For other shrimp-importing countries, the estimate was 3–4 cases/century. For a quantitative risk assessment, numerical inputs for a full harvest to consumption model were not available; hence a shortened exposure pathway that began at the port of entry of the importing country was taken (Figure 3). The quantitative model estimated that the median risk of acquiring cholera from warmwater shrimp in selected importing countries ranges from 0.009 to 0.9 per year. The prediction of low risk by each of the approaches mentioned above is supported by the absence of epidemiological evidence that warmwater shrimp has ever been incriminated in any cholera outbreak in any developed nation in the world.

CONCLUSIONS

Food safety systems based on a risk analysis approach are essential to protect public health and promote international trade in food products, including products of aquaculture. Risk assessment is a science-based process and requires reliable

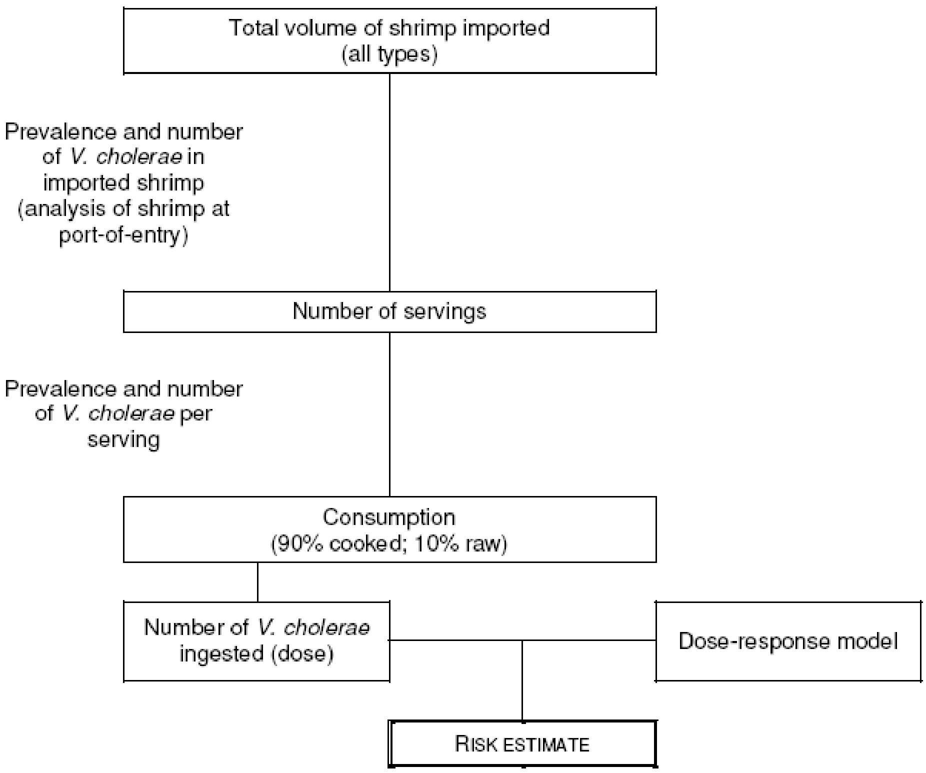
TABLE 3
Qualitative risk assessment for choleragenic *Vibrio cholerae* in warmwater shrimp

Product	Identified hazard	Severity[1]	Occurrence risk[2]	Growth in product required to cause disease	Impact of processing and handling on the hazard	Consumer terminal step[3]	Epidemiological link	Risk rating
Raw shrimp	*V. cholerae*	II	Very low	Yes	Level of hazard reduced during washing (0–1 log), icing (2–3 logs), freezing (2–6 logs)	No	No	Low
Shrimp cooked at the plant & eaten without further heat treatment	*V. cholerae*	II	Very low	Yes	Level of hazard reduced during washing (0–1 log), icing (2–3 logs), cooking (>6 logs), freezing (2–6 logs)	No	No	Low
Shrimp cooked immediately before consumption	*V. cholerae*	II	Very low	Yes	Level of hazard reduced during washing (0–1 log), icing (2–3 logs), freezing (2–6 logs), thawing and cooking (>6 logs)	Yes	No	Low

[1]Severity of the hazard classified according to International Commission of Microbiological Specifications for Foods (ICMSF 2002). Level II = serious hazard; incapacitating but not life threatening; sequale rare; moderate duration.
[2]Very low occurrence of illness – an average of less than one case per ten million population per year based on the data for over a six-year period. This reflects the situation in all countries considered except Japan, which experienced an average of less than one case per million population.
[3]Cooking, which brings about >6 log reduction in the level of V. cholerae.

Source: FAO/WHO, 2005.

FIGURE 3
Import to consumption pathway used in quantitative risk assessment



Source: FAO/WHO, 2005.

data. It involves expertise in different fields such as food production (aquaculture), microbiology, epidemiology, food-processing technology and statistics. Thus, it requires both human and financial resources, and this could be one of the major constraints for developing countries. This has been recognized in WTO agreements. The SPS Agreement encourages the provision of technical assistance to member states, particularly developing countries, through bilateral agreements and via international organizations. SPS accepts Codex standards and guidelines as representing international consensus. Thus Codex standards serve as the benchmark for comparison of national SPS measures. The FAO/WHO Trust Fund for Participation in Codex provides resources to enhance developing-country participation in Codex standard setting. The Standards and Trade Development Facility (STDF) is a joint initiative of the World Bank (WB), FAO, the World Organisation for Animal Health (OIE), WHO and WTO that aims to strengthen donor contribution in standard setting related to food safety. STDF provides small grants for pilot projects that build capacity in standard setting and development in developing countries. STDF also provides assistance to government and the private sector in meeting international standards and promotes interagency coordination and donor collaboration in the delivery of technical assistance. Developing countries can make use of these opportunities to strengthen their capacity in the area of food safety and public health protection.

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Pathogen risk analysis for aquaculture production[1]

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ABSTRACT

In the context of aquatic animal health, pathogen risk analysis (also termed "import risk analysis") is a structured process for analysing the disease risks associated with the international and domestic movements of live aquatic animals and their products. Risk analysis provides a clearly defined framework for a structured, repeatable process, thereby removing to a large extent, ad hoc and arbitrary decision-making with regard to requests to import aquatic animals and their products.

Risk analysis is only one of a large number of components in a national aquatic animal health programme and cannot function effectively unless other components of the national programme have also been developed. In addition to appropriate legislation and policy, and the means to implement them, these other required components include capacity in areas such as diagnostics, quarantine and inspection services; disease surveillance, monitoring and reporting; national pathogen lists; legislation and enforcement; contingency planning; etc.

This paper provides an overview of the pathogen risk analysis process, a list of relevant instruments (treaties and agreements), and examples of actual risk analyses and information sources, as well as a discussion of the way forward, particularly focusing on challenges that will faced by developing countries.

INTRODUCTION

The international trade of live aquatic animals is carried out for various reasons including aquaculture development and sustainment, the ornamental fish industry and

[1] This paper is based primarily on the *Manual on risk analysis for the safe movement of aquatic animals* (Arthur *et al*., 2004) and a paper entitled *Pathogen risk analysis for biosecurity and the management of live aquatic animal movements* (Arthur *et al*., 2008).

the live food fish market. Live fish are also moved across national borders to support the development of capture and sport fisheries, for use as bait, as biological control agents and for research (Arthur, 2004; Subasinghe and Bartley, 2004).

Gametes, fertilized eggs, fry, fingerlings, and spat, as well as broodstock are constantly being moved to support aquaculture development. While the international movement of fertilized eggs and gametes is infrequent in some parts of the world (particularly in Asia), this method is recommended by international codes of practice for species introductions and transfers (e.g. the European Inland Fisheries Advisory Commission [EIFAC] and the International Council for the Exploration of the Sea [ICES], as it generally involves a lower risk of pathogen transfer (Turner, 1988; ICES, 2005).

In Asia and Latin America, immature stages of many species are frequently moved across international borders in large numbers. New industries that are hindered by non-existent or temporarily insufficient national production (e.g. milkfish fry, oyster spat, prawn postlarvae) or industries involving species whose life cycles have not been completed to a commercial level (e.g. groupers, tiger prawn) are associated with these types of movements. Hossain (1997) provides a good example, in Bangladesh, of the magnitude of this trade, estimating an importation level in 1995, of about 50 million nauplii and postlarvae of giant tiger prawn to support the country's developing shrimp culture industry.

Broodstock movement, on the other hand, is less frequent and typically involves only a few animals at a time. Such movements are characteristic for species without closed life cycles at a commercial level (prawns) and for new aquaculture species, in order to avoid delays in aquaculture start up due to the time needed for maturation of juveniles to broodstock.

To support the live food market, fish, crustaceans and molluscs are moved both internationally and domestically. Examples include movement of live oysters from producing countries to consuming countries (e.g. to Europe, North America and South Africa) and the intra-regional trade in Asia involving live finfish and shellfish (e.g. groupers, seabass, shrimp, cockles, etc.) for consumption in seafood restaurants.

The ornamental fish trade is a major industry. Khan *et al.* (1999) and Davenport (2001) reported that the international trade in ornamental fish involves more than 2 000 species and hundreds of millions of fish annually. The culture and trade of aquarium fish is an important source of foreign exchange earnings for some countries. For example, Malaysia, one of the world's main exporters of aquarium fish, produced some 338 million freshwater ornamental aquatic organisms in 2001, including some 293 million freshwater fish belonging to more than 90 species (Latiff, 2004). In 2001, Malaysian production of freshwater ornamental aquatic organisms was valued at over 81 million Malaysian Ringgit (US$21.3 million), a figure which had increased by an average annual rate of 7.5 per cent since 1997.

As a sector, the aquarium fish trade is highly unregulated, involving a high volume of transshipment that often masks the country of origin of individual shipments and species. The complexity of the trade often makes guarantees of the health status difficult, if not impossible. Although ornamental fish diseases have not received the detailed attention they deserve, there is increasing evidence of the presence of a wide variety of pathogens and parasites, some of which are important disease agents of cultured and wild fish or are human pathogens (see references in Arthur *et al.*, 2008). Koi herpesvirus disease is one of the most serious of these diseases and recently caused major losses in wild and cultured common carp (*Cyprinus carpio*), an important food fish in some countries in Asia.

Because of the volume of live aquatic animals traded internationally, the diversity of species being moved, and the many known and potential pathogens that infect aquatic species, countries have often faced great difficulty in trying to find methods that will reduce the risk of spreading transboundary pathogens that could seriously impact their domestic aquaculture industries and aquatic biodiversity. Developing countries, in particular, constantly face this challenge in view of the lack of expertise, capacity, policy, legislation and financial resources necessary to adequately manage transboundary disease risks.

GENERAL PURPOSE OF A PATHOGEN RISK ANALYSIS

Pathogen risk analysis (termed "import risk analysis" when international trade is involved) is a structured process for analysing the disease risks associated with the international and domestic movements of live aquatic animals and their products. "Risk" is the potential that an unwanted, adverse consequence (a serious disease outbreak) will result from the importation or domestic movement of a living aquatic animal or its product (a "commodity") over a given period of time. Risk therefore combines the elements of both likelihood and impact.

A pathogen risk analysis (MacDairmid, 1997; Rodgers, 2004; Arthur *et al*., 2004, 2008; Murray *et al*., 2004; OIE, 2007) seeks answers to the following questions:

1) What serious pathogens could the commodity be carrying?
2) If the commodity is infected by a serious pathogen, what are the chances that it will enter the importing country and that susceptible animals will be exposed to infection?
3) If susceptible animals are exposed, what are the expected biological and socio-economic impacts?
4) If the importation is permitted, then what is the risk associated with each pathogen?
5) Is the risk determined for each pathogen in the risk assessment acceptable to the importing country?
6) If not, can the commodity be imported in such a way that the risk is reduced to an acceptable level?

Risk analysis provides a clearly defined framework for a structured, repeatable process, thereby removing to a large extent, ad hoc and arbitrary decision-making with regard to requests to import aquatic animals and their products. Its greatest strength is its flexibility. The process is based on science and is transparent (by having a structured and defined process that is understood by all and by incorporating extensive stakeholder consultation), therefore allowing subjective decisions that enter the process to be recognized. An internationally accepted method, risk analysis provides importing countries with the means to protect themselves against exotic diseases while assuring their trading-partner countries that any disease concerns are justified and are not disguised barriers to trade. It also allows for uncertainty of scientific knowledge. Through the application of the precautionary approach, importing countries are permitted the time needed to address any important information gaps where research is needed to support sound decision-making.

RELEVANT TREATIES AND AGREEMENTS

International trade liberalization resulting from the General Agreement on Tariffs and Trade (GATT) and the creation of the World Trade Organization (WTO) in 1995 consequently brought major changes in the patterns of world trade. With the adoption of the *Agreement on the Application of Sanitary and Phytosanitary Measures* (the SPS Agreement) in 1994, WTO member countries are now required to use the risk analysis process as a means to justify restrictions on international trade in live aquatic animals or their products based on risk to human, animal or plant health beyond the application of the sanitary measures outlined in the OIE *Aquatic Animal Health Code* (WTO, 1994; Rodgers, 2004; Arthur *et al*., 2004). As a result, risk analysis has become an internationally accepted standard method for deciding whether trade in a particular commodity poses a significant risk to human, animal or plant health, and, if so, what measures, if any can be applied to reduce that risk to an acceptable level.

The World Organisation for Animal Health (OIE, formerly the Office international des Épizooties) 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. The OIE's *Aquatic Animal Health Code* (OIE, 2007) outlines the necessary basic steps in the risk analysis process that should be followed; however, decisions as to the details of the process are left to individual member countries.

Risk analysis is only one of a large number of components in a national aquatic animal health programme (FAO/NACA, 2000; Arthur *et al.*, 2004). It cannot function effectively unless other components of the national programme have also been developed, such as appropriate legislation and policy, and the means to implement them; and capacity building in the areas of diagnostics, quarantine and inspection services; disease surveillance, monitoring and reporting; national pathogen lists; legislation and enforcement; contingency planning; etc.

Table 1 provides a list of examples of instruments (treaties and agreements) at different levels (international, regional and national) concerned with aquatic animal health issues.

SCOPING A PATHOGEN RISK ANALYSIS

The preparation of a detailed and accurate commodity description that contains all essential information concerning the proposed importation (e.g. health status of the stock; the number, life cycle stage and age of the animals to be imported; the handling and treatment methods applied before and during shipment; etc.) is an important initial step in the scoping process. Once a decision has been made that a risk analysis is required, the risk analysis team established by the Competent Authority will decide on the type of risk analysis (i.e. qualitative or quantitative) to be conducted. A working group with appropriate expertise that will conduct the actual risk analysis will be formed (Figure 2). The full cooperation of the exporting country in providing such information is essential. Risk assessment methodology may range from the purely

TABLE 1
Examples of instruments at different levels concerned with aquatic animal health issues

International codes/treaties/guidelines	Reference
OIE's *Aquatic Animal Health Code*	OIE (2007)
*Code of Practice on the Introductions and Transfers of Marine Organism*s of the International Council for the Exploration of the Seas (ICES)	ICES (2005)
Code of Conduct for Responsible Fisheries (CCRF) of the Food and Agriculture Organization of the United Nations (FAO)	FAO (1995)
Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) of the World Trade Organization (WTO)	WTO (1994)
FAO Technical Guidelines for Responsible Fisheries. No. 5, Suppl. 2 – *Health management for responsible movement of live aquatic animals*	FAO (2007)
Regional guidelines	
Codes of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms of the European Inland Fisheries Advisory Commission (EIFAC)	Turner (1988)
FAO/NACA Asia regional technical guidelines for the responsible movement of live aquatic animals	FAO/NACA (2000)
National strategies	
AQUAPLAN: Australia's National Strategic Plan for Aquatic Animal Health	AFFA (1999)
Canada's National Aquatic Animal Health Programme (NAAHP)	Olivier (2004)
USA's National Aquatic Animal Health Plan	Amos (2004)
Thailand's Strategic Plan for Aquatic Animal Health	Kanchanakhan and Chinabut (2004)

Source: Bondad-Reantaso and Subasinghe, 2008.

qualitative to the purely quantitative. In most cases, a qualitative approach will be simplest, quickest and most cost-effective.

OVERVIEW OF THE RISK ANALYSIS PROCESS

Figure 1 shows the four main components of the OIE risk analysis process and their interrelationships, while Figure 2 outlines the steps in the risk analysis process.

THE STEPS IN THE RISK ANALYSIS PROCESS

The principal components of the risk analysis process, as illustrated above (Figures 1 and 2) are: hazard identification, risk assessment (release, exposure and consequence assessments, which become the basis for risk estimation), risk management (composed of risk evaluation, option evaluation, implementation and monitoring and review) and risk communication (a continuous activity that takes place throughout the entire process).

Hazard identification

The hazard identification step determines what pathogens could plausibly be carried by the commodity. From this initial list of pathogens, those pathogens that pose a serious risk to the importing country will then be determined. Examples of criteria used when considering whether or not a pathogen constitutes a hazard include the following:

- the pathogen must have been reported to infect, or is suspected of being capable of infecting the commodity;
- it must cause significant disease outbreaks and associated losses in susceptible populations; and
- it could plausibly be present in the exporting country.

A list of information sources (disease databases, taxonomic databases, fish databases, abstracting services, internet Web sites) that can be used to obtain information needed to support hazard identification is provided in Table 2.

An example of the process used for hazard identification during a recent risk analysis for the introduction of blue shrimp, *Litopenaeus stylirostris*, from Brunei Darussalam to Fiji (Bondad-Reantaso *et al*., 2005) is provided in Box 1.

Risk assessment

The actual risk assessment consists of four components:

1. Release assessment is the step that determines the pathways whereby a pathogen can move with the commodity from the exporting country to the border of the importing country and the likelihood of this occurring. Information required for release assessment includes the following:

FIGURE 1
The four components of risk analysis

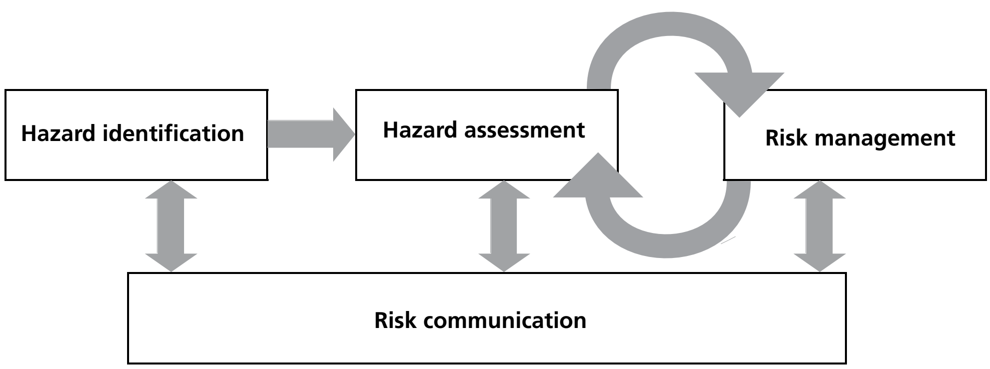
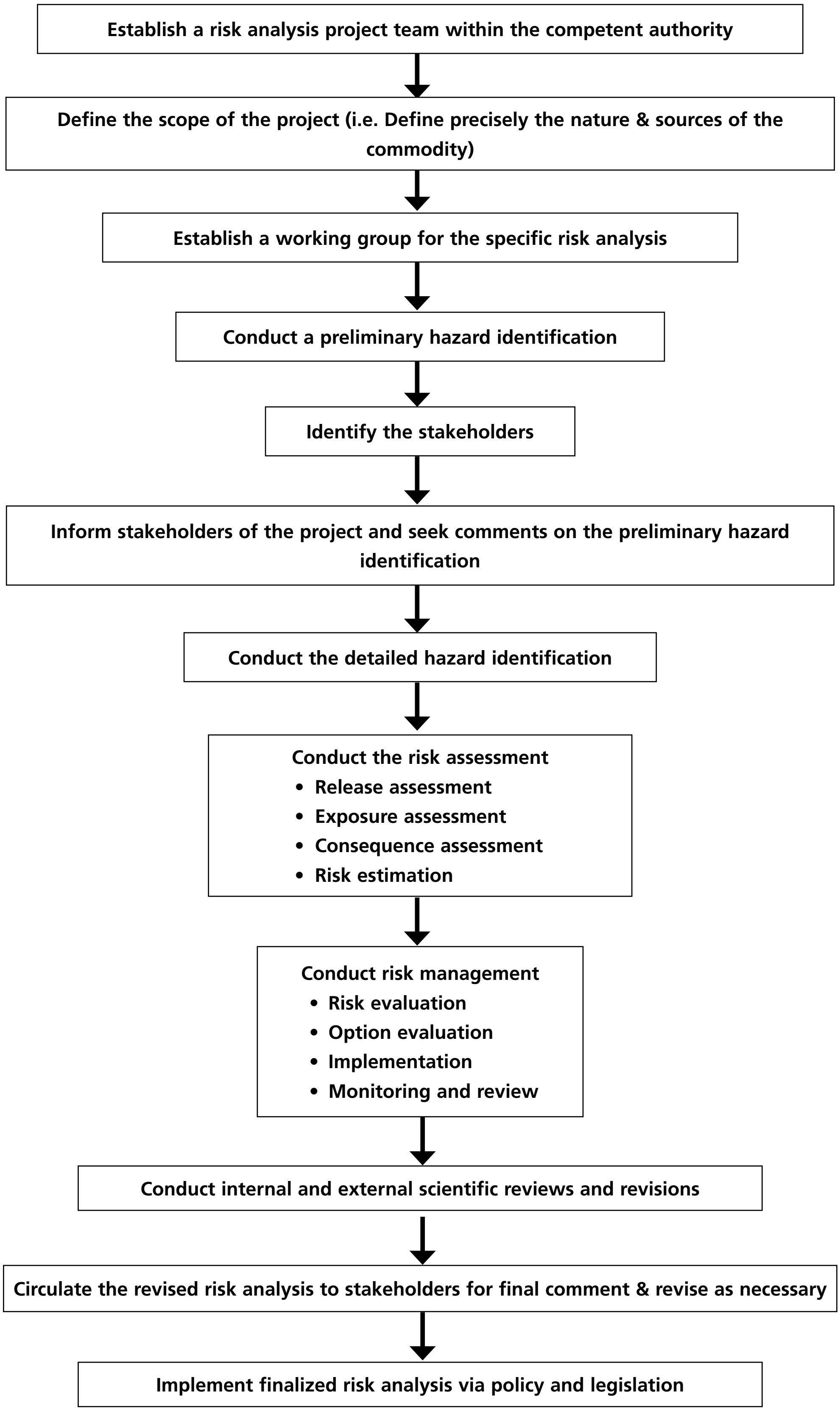


FIGURE 2
A simplified diagram showing the steps in the risk analysis process



Source: Arthur *et al.*, 2004.

TABLE 2
Examples of information resources to support hazard identification

Type of information resources	Access
Scientific and disease databases and abstracting services	
AGRICOLA (Agricultural Online Access)	http://agricola.nal.usda.gov/
Aquatic Animal Pathogen and Quarantine Information System (AAPQIS)	http://www.aapqis.org
Aquatic Science and Fisheries Abstracts (ASFA)	http://www.fao.org/fi/asfa.asfa.asp
Biological Abstracts and BioResearch Index (BIOSIS), database for biological and medical sciences	http://www.biosis.org
Cambridge Scientific Abstracts	http://www.csa.com
Commonwealth Agricultural Bureaux (CAB) Veterinary Sciences/Medicine database	http://www.cabi.org
Food Science and Technology Abstracts database (International Food Information Service)	http://www.ifis.org
INGENTA	http://www.ingenta.com
Northeastern Aquatic Animal Health Directory	http://www.old.umassd.edu/specialprograms/nrac
OIE Collaborating Centre for Information on Aquatic Animal Diseases	http://www.collabcen.net
PubMed, a service of the National Library of Medicine	http://www.ncbi.nlm.nih.gov/entrez/query.fcgi
Science Citation Index, Institute for Science Information (ISI)	http://scientific.thomsonreuters.com/products/sci/

BOX 1

An example of the results of a hazard identification exercise, part of a pathogen risk analysis for the introduction of blue shrimp, *Litopenaeus stylirostris*, from Brunei Darussalam to Fiji

The criteria set for a pathogen or disease to be considered in the preliminary hazard identification were:

- the potential hazard must be an identifiable biological agent or a disease believed to be produced by a single (as yet unidentified) biological agent (thus generalized syndromes are not considered)
- the agent must have been recorded from *L. stylirostris* (any life cycle stage) or it must be listed by the OIE as a serious disease affecting other penaeid shrimp.

The preliminary hazard identification determined that there were 19 pathogens fulfilling the above criteria (Tables 1 and 2).

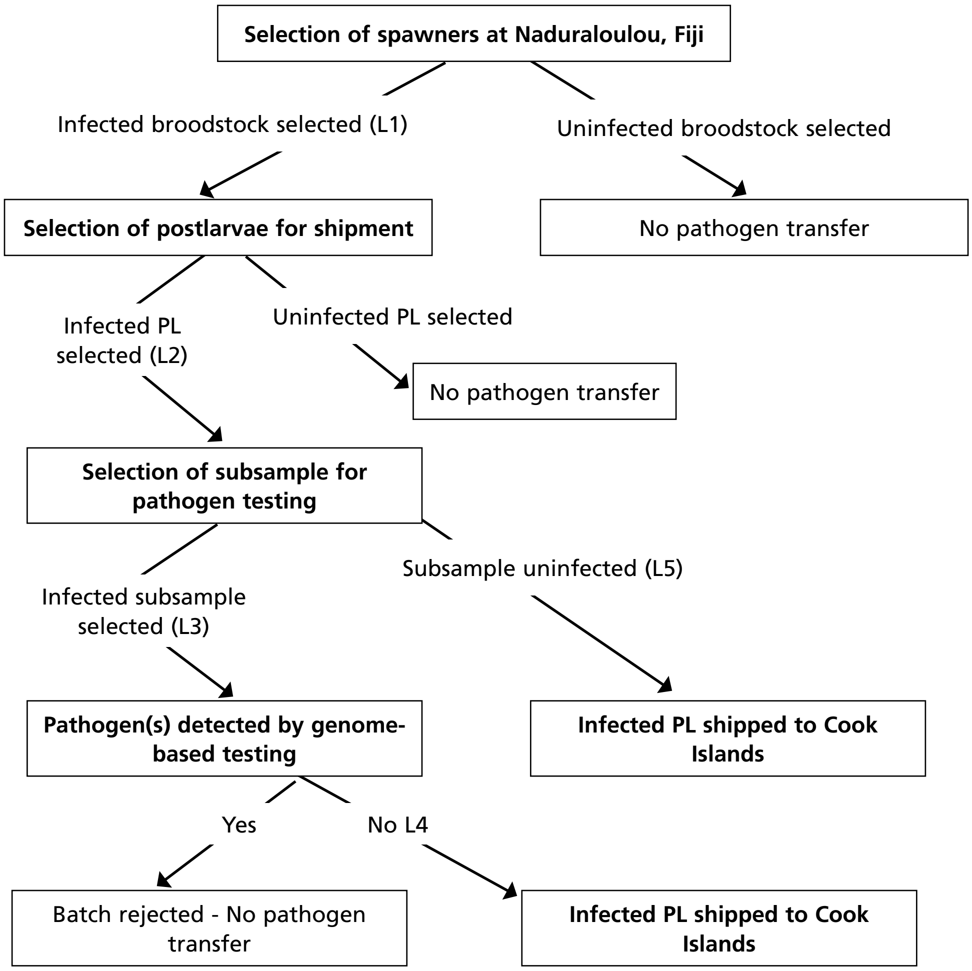
Another set of criteria was drawn up that needed to be fulfilled in order for a potential hazard be given further consideration (i.e. considered a hazard). These were:

- the pathogen must have been reported to infect, or is suspected of being capable of infecting postlarval *L. stylirostris;*
- the agent must be an obligate pathogen (i.e., it is not ubiqitous free-living organism that is capable of becoming an opportunistic pathogen of *L. stylirostris* under certain environmental or culture conditions);
- the agent must cause significant disease outbreaks and associated losses in populations of *L. stylirostris* or, if not a significant pathogen of *L. stylirostris*, it must cause serious disease outbreaks in populations of other species of penaeid shrimp; and
- it must be plausible that the agent might be present in populations of *L. stylirostris* in Brunei Darussalam.

In the final analysis, some comments and observations were presented as to why some of the pathogens were not given consideration and which of the 19 pathogens were recognized as requiring further consideration. These pathogens became the subject of detailed risk assessment. In this particular case, out of the 19 pathogens, eight were given further consideration (see Box 2).

Source: Bondad-Reantaso *et al.*, 2005.

FIGURE 3
Simplified Pathways Diagram for the release of viral pathogens in *Macrobrachium rosenbergii* postlarvae from Fiji to Cook Islands. Not considered are less probable pathways such as via shipping water or fomites, or failure of the diagnostics tests to detect true positives. In this simplified example, the likelihood that infected PL will be released (LR) can be expressed as LR = (L1 x L2 x L3 x L4) + (L1 x L2 x L3 x L5)



Source: Arthur *et al.*, 2005.

- Biological factors: susceptibility (species, life stage), means of transmission (horizontal, vertical), infectivity, virulence, routes of infection, outcomes of infection (sterile immunity, incubatory or convalescent carriers, latent infection), impact of vaccination, testing, treatment and quarantine
- Country factors: evaluation of the exporting country's official services in terms of diagnostics, surveillance, and control programmes and zoning systems; incidence and/or prevalence of the pathogen; existence of pathogen-free areas and areas of low prevalence; distribution of aquatic animal population; farming and husbandry practices; geographical and environmental characteristics
- Commodity factors: ease of contamination; relevant processes and production methods; effect of processing, storage and transport; quantity of commodity to be imported

2. *Exposure assessment* is the step that determines the pathways by which susceptible populations in the importing country can be exposed to the pathogen and the likelihood of this occurring (Figure 3). Information required for exposure assessment includes the following:

- Biological pathways: description of pathways necessary for exposure of animals and humans to the potential hazards and estimate of the likelihood of exposure
- Relevant factors:
  - Biological factors: susceptibility of animals likely to be exposed (species, life stage), means of transmission (horizontal, vertical), infectivity, virulence and stability of potential hazards, route of infection, outcome of infection
  - Country factors: presence of potential intermediate hosts or vectors, fish and human demographics, farming and husbandry practices, customs and cultural practices, geographical and environmental characteristics
  - Commodity factors: intended use of imported animal, waste disposal practices, quantity of commodity to be imported

3. Consequence assessment is the step that identifies the potential biological, environmental and economic consequences expected to result from pathogen introduction. Information required for consequence assessment include the following:

- Potential biological, environmental and economic consequences associated with the entry, establishment and spread
  - Direct consequences: outcome of infection in domestic and wild animals and their populations (morbidity and mortality, production losses, animal welfare), public health consequences
  - Indirect consequences: economic considerations (control and eradication costs, surveillance costs, potential trade losses [such as embargoes, sanctions and lost market opportunities]), environmental considerations (amenity values, social, cultural and aesthetic conditions)

4. Risk estimation is the step that calculates the overall risk posed by the hazard (the unmitigated risk) by combining the likelihood of entry and exposure with the consequences of establishment (Table 3).

In the risk assessment process, the use of pathway analysis and scenario diagrams is very important. They serve as useful tools in identifying possible routes (pathways) and the individual events or steps in each pathway that need to occur for a given pathway to be successfully completed. Not only do they provide a logical process by which the critical risk steps (events) leading to pathogen introduction and establishment in an importing country can be identified, they also allow estimation of the probability of each event occurring, thus leading to an overall estimate of the probability of a given pathway being completed. When incorporated unto the pathway analysis, the effectiveness of a risk mitigation measure can be determined, which can then allow the recalculation of the overall risk to see whether the risk can be reduced to an acceptable level. Another advantage of using the pathway/scenario diagram approach is that it allows for sensitivity analysis, whereby the most influential pathway steps that

TABLE 3
Example unmitigated risk estimation combining the results of the exposure and consequence assessments for a hypothetical hazard using three qualitative rankings (high, medium and low)

Likelihood of entry and exposure	Consequence of establishment	Unmitigated risk estimate
Low	Low	Low
Low	Medium	Medium
Low	High	Medium
Medium	Low	Medium
Medium	Medium	Medium
Medium	High	High
High	Low	Medium
High	Medium	High
High	High	High

Source: Arthur *et al.*, 2004.

determine the final risk estimate for a particular pathogen can be identified. This greatly assists in targeting risk mitigation measures and in identifying areas where information needs are most critical, particularly in areas where highly sensitive pathway steps are associated with a degree of uncertainty or subjectivity.

Risk management

Risk management is the step in the process whereby measures to reduce the level of risk are identified, selected and implemented. The three steps involved are briefly described below:

- In the *risk evaluation* step, the unmitigated risk estimate for the hazard is compared with the level of risk acceptable (the acceptable level of risk, ALOR) to the importing country. If the estimated risk is within the ALOR, the importation can be approved. However, if the risk posed by the commodity exceeds the ALOR, then risk mitigation measures should be considered.
- During *option evaluation* possible measures to reduce the risk are identified and evaluated for efficacy and feasibility, and the least restrictive measure(s) found to reduce the risk to an acceptable level are selected. The process is essentially the same as that used during risk assessment, with new scenarios and pathways being constructed that incorporate steps for possible risk mitigation measures to determine their ability to reduce the overall risk (now the mitigated risk estimate) to an acceptable level.
- During *implementation and monitoring and review,* the requirements for importation, including any mitigation measures, are presented to the proponent and the importation process is monitored and reviewed by the importing country's Competent Authority to assure that all conditions for importation are met.

During the risk management step, it is important to keep in mind several important principles of the SPS Agreement related to the risk management process. These are:

- Risk management measures must be applied in the least trade restrictive manner possible – *principle of least restrictiveness.*
- The concept of equivalence allows the exporting country the opportunity to prove that its own risk mitigation measures lower the risk to within the importing country's ALOR – *principle of equivalence of mitigation measures*.
- The importing country must apply the same ALOR (i.e. accept the same level of risk) at both external (international) and internal (national) borders, and the ALOR must be applied consistently across the range of commodities in which the country trades, without prejudice as to the country of origin – *principle of consistency in application*.

An important concept that needs to be understood in the risk management step is what is called the "acceptable level of risk" or "ALOR".[2] ALOR is the level of risk that can be tolerated by a country when importing live aquatic animals or their products. It is the standard to which the results of a hazard analysis are compared (the unmitigated risk estimate) to determine if an importation should be approved, as well as the standard to be applied in determining whether risk mitigation measures can be effective in reducing risk to an acceptable level (the mitigated risk).

Many factors need to be carefully weighed by politicians when establishing the ALOR. These include the importance of protecting national biodiversity and natural ecosystems, the availability of species for aquaculture and capture fisheries development, the need for social and economic development, and past trading practices, including those in the plant and livestock sectors.

[2] The "appropriate level of protection" or "ALOP", which can be thought of as the inverse of ALOR, is often used in stating a country's level of risk tolerance.

Examples of a conclusion of a pathogen risk analysis and the associated risk management measures identified and recommended as an outcome of the risk analysis process are given in Box 2.

Risk communication

Risk communication is the step whereby information and opinions regarding hazards and risks are gathered from potentially affected and interested parties during a risk analysis, and by which results of the risk assessment and proposed risk management measures are communicated to decision-makers and interested parties in the importing and exporting countries. Risk communication is a multidimensional and iterative process, ideally beginning at the start of the risk analysis and continuing throughout the whole process. It is the stage that provides over-all system integrity. In order to achieve such integrity, a clear communication strategy is required (i.e. what kind of message, the medium, to whom and the frequency of iteration, mechanism for seeking input/ feedback, etc.). An effective risk communication has the following key components: transparency, consensus building, stakeholder cooperation and consultation.

As the risk analysis process may involve a large number of agencies, organizations and individuals that have an interest in its outcome, key stakeholders should be identified early in the process. The primary stakeholders in a risk analysis process are the proponents, the Competent Authorities of the exporting and importing countries, and the risk analysis team. Many other stakeholders will be interested in the outcome of a risk analysis; the precise agencies, organizations and individuals will vary depending on the commodity being considered and its intended use. To give an example, a risk analysis involving the importation of a live marine mollusc for aquaculture development may include the following potential stakeholders: oyster farmers, oyster traders, restaurant owners, fish vendors, consumers, aquaculturists, seafood processors, conservationists, and concerned international, national and local governments and agencies.

Table 4 provides a list of the pathogen risk analyses for aquatic animals that have been conducted or are currently in progress;

The precautionary approach

The large amount of uncertainty that is seen during many risk analyses is due to the general lack of basic knowledge and information that is needed in the process. In fisheries management and elsewhere where governments must take decisions based on incomplete knowledge, the "precautionary approach" is widely used. FAO's *Code of Conduct for Responsible Fisheries* states that:

"States should apply the precautionary approach widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment. The absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures." (FAO, 1995).

A "precautionary approach", within the context of risk analysis for aquatic animals, would be that both importing and exporting nations act responsibly and conservatively to avoid the spread of serious pathogens (Arthur *et al*., 2004).

There are at least three points whereby the precautionary approach may come into play within the context of risk analysis for aquatic animal movement:

- throughout the risk analysis process, when "*cautious interim measures*" are considered necessary to ban or restrict trade until a sound risk analysis can be completed;
- during the pathways scenario portion of the risk assessment process, when sensitivity analysis reveals key information gaps that must be addressed by targeted research; and
- during risk management, when risk mitigation measures are identified to reduce the risk to an acceptable level.

BOX 2

Example of conclusions from a pathogen risk analysis (PRA) for the introduction of blue shrimp, *Litopenaeus stylirostris*, from Brunei Darussalam to Fiji and risk management measures identified and recommended as an outcome of this PRA

Conclusions of the pathogen risk analysis

Both Fiji and Brunei Darussalam, as members of the World Trade Organization (WTO), and Brunei. as a member of the Office international des épizooties (OIE) are bound to fulfill their obligations as WTO/OIE members, particularly in implementing new agreements such as the *Agreement on the Application of Sanitary and Phytosanitary Measures* (the "SPS Agreement"). The principal objective of the SPS Agreement is to ensure that governments do not use food safety and quarantine requirements as unjustified trade barriers to protect their domestic agricultural industries from competitive imports. The SPS agreement also ensures that governments can give health protection priority over trade.

The absence of historical and current information on the health status of the stock of origin, and the lack of responsiveness of the exporter and Government of Brunei to provide information necessitate the application of the precautionary approach. ***Because of the high risk of introducing serious pathogens, further importations from this source should not be permitted until adequate information to assess risk is provided by Brunei.*** The Government of Fiji is urged make an official request to the Government of Brunei, both directly and through the offices of the SPC and OIE, to obtain this crucial information, which should be carefully evaluated prior to making a final decision as to whether or not to permit these introductions to continue. Fiji and Brunei should cooperate fully in order to address the critical information gaps in a timely and transparent manner.

Based on the preliminary hazard identification, six viruses and two bacteria were recognized as potentially serious hazards associated with the importation of PL of *Litopenaeus stylirostris* from Brunei Darussalam:

- White spot syndrome virus (WSSV)
- Infectious hypodermal and haematopoietic necrosis virus (IHHNV)
- Taura syndrome virus (TSV)
- Yellow head virus (YHV)
- Baculovirus penaei (BP)
- Hepatopancreatic parvo-like virus (HPV)
- Necrotising hepatopancreatitis (NHP)
- *Vibrio penaeicida*

Four of the six viruses (WSSV, IHHNV, TSV and YHV) are among the most serious pathogens of both cultured and wild shrimp. These pathogens have been introduced and spread on a global scale due to the irresponsible movement of shrimp broodstock and PL for aquaculture development, and perhaps through other means, such as via aquaculture products (e.g. frozen shrimp), other animal carriers (reservoir hosts, passive carriers) and other abiotic factors.

The associated levels of risk (release, exposure and consequence) for these pathogens exceed the appropriate level of protection (ALOP) recommended for Fiji (see Table 1). From an economic, social and biological perspective, it is well worth the cost and effort to protect Fiji, as far as possible, from the potential irreversible impacts of these pathogens.

BOX 2 (continued)

TABLE 1
Summary of the results of assessment of unmitigated risk for eight potential hazards

Pathogen[1]	Likelihood of Release	Likelihood of Escape	Probable Consequence
IHHNV	moderate	moderate	moderate
TSV	moderate	moderate	low
WSSV	moderate	moderate	moderate
YHV	moderate	moderate	moderate
BP	moderate	moderate	low
HPV	moderate	moderate	moderate
NHP	low	low	low
V. penaeicida	low	low	low

1 Infectious hypodermal and haematopoietic necrosis virus (IHHNV), Taura syndrome virus (TSV), white spot syndrome virus (WSSV), yellow head virus (YHV), *Baculovirus penaei* (BP), hepatopancreatic parvo-like virus (HPV), necrotising hepatopancreatitis (NHP).

Mitigation measures are available that can be applied to reduce the risk associated with all hazards to below that specified by the ALOP. The most important of these are:

- All shipments of PL to be imported into Fiji should be of "high health" status and should originate from a facility certified as using specific pathogen free (SPF) broodstock *L. stylirostris.* The facility must demonstrate a proven track record of producing PL free of the specific diseases through a documented history of pathogen surveillance, evidence of adherence to strict biosecurity protocols and an over-all health management plan. The facility must provide sufficient guarantees as to the health status and history of its stock. An on-site inspection visit to the production facility by an internationally recognized shrimp health expert on behalf of the Government of Fiji should be made to assure that the protocols, diagnostic procedures, security, etc. are adequate to validate guarantees of health status.[1,2]
- The production facility in the exporting country should also meet the following pre-border requirements:
  - The batch of PL destined for export should be separated as early as possible from other stocks reared in the facility of origin and should be maintained in tanks separate from the rest of the stocks;
  - Detailed records should kept of the health status and mortality rates of each batch of *L. stylirostris*. Such records should be made available to the Competent Authority responsible for health certification;
  - A statistically appropriate sample taken from the batch intended for export should be tested for the eight pathogens using the recommended methods (for OIE listed diseases, these are the methods specified by OIE (2003));
  - Should a batch of PL test positive for any of the eight hazards, the batch will be rejected and future importations from the infected production facility prohibited until such a time that freedom of the facility from disease can be clearly demonstrated.

1 SPF is a concept that is generally poorly understood (see Carr 1996, Lotz 1997). Once broodstock or PL produced by an SPF facility leave that facility, they are no longer considered to have SPF status for the specific pathogens indicated, because the level of biosecurity under which they are being maintained is now decreased. When transferred to a commercial hatchery or grow-out facility having adequate, albeit lower level health security, they and any nauplii and PL derived from them may be referred to as 'high health' shrimp. Because their health status is now less certain, a new historical record for that facility must be established.

2 An alternate approach, and one that would provide a higher level of protection from exotic disease, would be a single importation of a limited number of SPF broodstock *L. stylirostris* that would be used to establish a breeding program in a biosecure facility in Fiji.

- The importing country should implement the following post-border requirements:
  - The receiving facility should meet minimum requirements with regard to its design and operation such that the risk of pathogen exposure is minimized. (see Annex I).
  - A health monitoring system should be in place at the receiving facility so that a new historical record of health and mortality status can be established.
  - No animals are to be removed from the receiving facility without prior permission from the Ministry of Fisheries and Forestry (MFF), Fiji;
  - The operators must report any occurrences of serious mortalities or disease outbreak; and
  - A farm level contingency plan should be developed requiring that in the event of a serious disease outbreak or mortality, all animals will be destroyed and disposed of in an approved sanitary method, and the facility fully disinfected before restocking (see Annex II).
- Importations from countries with a known history of occurrence of serious shrimp pathogens should be avoided unless the production facility is able to clearly demonstrate freedom from serious pathogens. Ideally, the country of origin should have capable veterinary or aquatic animal health services (an evaluation of the Competent Authority may be necessary) and an established program of disease surveillance and control in place to manage the disease.
- The stock of *Litopenaeus stylirostris* currently being cultured in Fiji is considered to represent a high risk to the national disease status. To reduce this risk, the following risk management measures are recommended:
  - No animals should to be moved from the receiving facility (Gulf Seafood Fiji Ltd.) without prior permission from the Ministry of Fisheries and Forestry (MFF);
  - The operators should be required to report any occurrences of serious mortalities or disease outbreak.
  - The production facility should meet minimum standards of construction and operation so as to minimize the possibility that pathogens will gain access to natural waters through escapes, exposure of potential carriers, transfer by birds and other vectors, and release of virus into natural waters. Suggested standards are given in Annex I.
  - A contingency plan should be developed requiring that in the event of a serious disease outbreak or mortality, all animals will be destroyed and disposed of in an approved sanitary method, and the facility fully disinfected before restocking. The components of such a contingency plan are given in Annex II.

THE WAY FORWARD

Developing countries face many challenges in undertaking pathogen risk analysis. Combining national expertise with the risk analysis expertise available in neighbouring countries through regional approaches may be the most cost-effective way for many countries to conduct risk analyses involving common and shared aquatic species. This approach will also involve sharing of databases and other sources of information. Particularly for introductions involving shared waterways, the sharing of risk analysis approaches and associated costs will be a practical action.

Regional efforts to establish hatcheries and stocks with known health history, e.g. specific pathogen free (SPF) stocks, for the most frequently traded species (e.g. tilapia, marine shrimp, giant freshwater prawn, oysters) should be strongly considered by developing countries. Accepting risks inherent in importing live aquatic animals of uncertain health status is not justified.

The risk analysis process is science-based and as such requires adequate supporting scientific information based on high quality research obtained from published

TABLE 4
Examples of pathogen risk analyses for aquatic animals

Title	Agency	Authors/ Date
Current import risk analysis: non-viable bivalve molluscs.	Australian Department of Aquaculture, Fisheries and Forestry (AQIS)	In progress[1]
Current import risk analysis: freshwater crayfish	AQIS	In progress
Current import risk analysis: prawns and prawn products	AQIS	In progress
Current import risk analysis: freshwater finfish	AQIS	In progress
Import risk analysis: frozen, skinless and boneless fillet meat of *Oreochromis* spp. from China and Brazil for human consumption.	MAF Biosecurity New Zealand	Johnson (2007)
Import risk analysis: Freshwater prawns (*Macrobrachium rosenbergii*) from Hawaii	New Zealand Ministry of Agriculture and Fisheries (MAF)	MAF (2006)
Pathogen and ecological risk analysis for the introduction of the Blue Shrimp, *Litopenaeus stylirostris*, from Brunei Darussalam to Fiji	Secretariat of the Pacific Community (SPC)	Bondad-Reantaso *et al.* (2005)
Pathogen and ecological risk analysis for the introduction of giant river prawn, *Macrobrachium rosenbergii*, from Fiji to the Cook Islands	SPC	Arthur *et al.* (2005)
Import risk assessment: juvenile yellowtail kingfish (*Seriola lalandi*) from Spencer Gulf Aquaculture, South Australia	Island Aquafarms, Ltd. and NIWA, New Zealand	Diggles (2002)
Import risk analysis on live ornamental fish	AQIS	Kahn *et al.* (1999)
Import risk analysis on non-viable salmonids and non-salmonid marine finfish	AQIS	AQIS (1999)
Supplementary import risk analysis – head-on gill-in Australian salmonids for human consumption.	Biosecurity Authority, MAF	MAF (1999)
Import health risk analysis: salmonids for human consumption	Ministry of Agriculture Regulatory Authority, New Zealand	Stone, MacDiarmid and Pharo (1997)

[1] Information on animal risk analyses in progress can be accessed at: http://www.daff.gov.au/ba/ira/current-animal

scientific literature. Nonetheless, unpublished information obtained from colleagues as well as expert opinion can also be used. Scientists having considerable research experience can make a valuable contribution to the risk analysis process. In addition to scientific information and input from experts, an individual risk analysis may also require specific targeted research to address critical information gaps identified during sensitivity testing.

Greater attention should be given to generating information and knowledge essential to risk analysis. There is thus a need to establish the appropriate research capacity and to conduct targeted studies. Examples of essential research areas include pathogen studies, information on trade and most importantly, studies on biological pathways for the introduction (release assessment), establishment (exposure assessment) and spread (consequence assessment) of a pathogen. Other important areas of research include studies on host susceptibility; modes of transmission; infectivity, virulence and stability; intermediate hosts and vectors; and effects of processing, storage and transport. For newly emerging diseases as well as some diseases in poorly studied aquatic animal species, basic studies on their pathology and methods for rapid and accurate diagnosis are essential to facilitate accurate risk assessment and biosecurity management. Increased surveillance of wild fish to detect significant disease problems at an early stage is also needed (Bondad-Reantaso *et al*., 2005).

Occasionally, despite the best risk analysis and risk mitigation measures, serious pathogens will be introduced and cause major disease problems. This is due to limitations in diagnostic techniques, the existence of cryptic pathogens and the ability of benign organisms (normally non-pathogenic parasites, bacteria, viruses, fungi, etc.) to become pathogenic when introduced to new hosts and environments. Good disease surveillance and reporting as well as well-designed contingency plans will be necessary.

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ANNEX I

TABLE 1

Results of the preliminary hazard identification (note: for all pathogens,there is no information available as to occurrence in either the exporting or the importing country) Y=Yes, N=No, P=Plausible, ?=Uncertain

Pathogen	Infects PL stage	Causes significant disease	Further consideration required	Comments
Viruses				
White spot syndrome virus (WSSV)	Y	Y	Y	Significant pathogen of penaeid shrimp; global distribution; wide host range; experimental infections lethal to *Litopenaeus stylirostris.*
Infectious hypodermal and haematopoietic necrosis virus (IHHNV)	Y	Y	Y	Significant pathogen of penaeid shrimp; infects a wide range of penaeids; occurs both in wild and cultured shrimp; a major pathogen of *L. stylirostris.*
Taura syndrome virus (TSV)	Y	Y	Y	Significant pathogen of penaeid shrimp; *L. stylirostris* recently found to be susceptible.
Yellow head virus (YHV)	Y	Y	Y	Natural infections in *Penaeus monodon*, lethal experimental infections in *L. stylirostris* and other species.
Viruses				
Baculovirus penaei (BP)	Y	Y	Y	Causes serious disease in *Farfantepenaeus duorarum, F. aztecus, L. vannamei* and *P. marginatus.*
Hepatopancreatic parvo-like virus (HPV)	Y	Y	Y	Natural infection in *P. monodon, Fenneropenaeus merguiensis, P. semisulcatus* and *L. stylirostris.*
Lymphoid organ vacuolization virus (LOVV)	Y	N	N	Identical histopathology occasionally observed in *L. stylirostris.*
Rhabdovirus of penaeid shrimp (RPS)	Y	N	N	Uncertain if a true pathogen of penaeid shrimp.
Bacteria				
Necrotising hepatopancreatitis (NHP)	Y	Y	Y	Reported only from American penaeids *(L. vannamei, F. aztecus, L. stylirostris, L. setiferus* and *F. californiensis).*
Vibrio harveyi	Y	Y	N	Vibriosis affects all penaeid species; mortality ranges from inconsequential to 100%; worldwide distribution.
V. vulnificus	Y	Y	N	
V. parahaemolyticus	Y	Y	N	
V. penaeicida	Y	Y	Y	Reported from New Caledonia; a significant pathogen of *Marsupenaeus japonicus.*
Shrimp tuberculosis (*Mycobacterium marinum, M. fortuitum* and *Mycobacterium* sp.)	?	N	N	Ubiquitous; potentially infectious to all penaeids
Rickettsia-like organisms	P	N	N	*L. stylirostris* experimentally infected by rickettsia of *P. marginatus.*
Parasites				
Haplosporidium sp.	?	N	N	In cultured and wild penaeid shrimp including *L. stylirostris.*
Fungi				
Lagenidium spp.	Y	N	N	Affects all penaeids
Sirolpidium spp.	Y	N	N	Affects all penaeids
Fusarium solani	P	N	N	Opportunistic pathogen; isolated form both cultured and wild crustaceans. All penaeids probably susceptible; *L. stylirostris* moderately susceptible.

Source: Bondad-Reantaso *et al.*, 2005[1]

[1] References column has been deleted from this table (see Bondad-Reantaso *et al.,* 2005).

ANNEX II

TABLE 2

Known or probable infectivity of important pathogens in *Litopenaeus stylirostris* and seven penaeid species reported to occur in Fiji. (Y=Yes, N=No, P=Plausible, NI=No Information)

Pathogen[1]	*Litopenaeus stylirostris*	*Penaeus monodon*	*P. canaliculatus*	*P. semisulcatus*	*P. latisulcatus*	*Fenneropenaeus merguiensis*[2]	*Metapenaeus anchistus*	*M. elegans*
Viruses								
IHHNV	Y	Y	NI	Y	NI	N	NI	NI
TSV	Y	Y	NI	NI	NI	Y	NI	NI
WSSV	Y	Y	NI	Y	NI	Y	NI	NI
YHV	Y	Y	NI	NI	NI	Y	NI	NI
BP	Y	N	NI	NI	NI	NI	NI	NI
HPV	Y	Y	NI	Y	NI	Y	NI	NI
LOVV	Y	Y	NI	NI	NI	NI	NI	NI
RPS	Y	NI	NI	NI	NI	NI	NI	NI
Bacteria								
NHP	Y	NI	NI	NI	NI	NI	NI	NI
Vibrio spp.	P	P	P	P	P	P	P	P
V. penaeicida	Y	NI	NI	NI	NI	NI	NI	NI
Mycobacterium spp.	P	P	P	P	P	P	P	P
Rickettsia-like organisms	Y	NI	NI	NI	NI	Y	NI	NI
Parasites								
Haplosporidium sp.	Y	NI	NI	NI	NI	NI	NI	NI
Fungi								
Lagenidium spp.	P	P	P	P	P	P	P	P
Sirolpidium spp.	P	P	P	P	P	P	P	P
Fusarium solani	Y	N	NI	NI	NI	N	NI	NI

[1] Infectious hypodermal and haematopoietic necrosis virus (IHHNV), Taura syndrome virus (TSV), white spot syndrome virus (WSSV), yellow head virus (YHV), Baculovirus penaei (BP), hepatopancreatic parvo-like virus (HPV), lymphoid organ vacuolization virus (LOVV), rhabdovirus of penaeid shrimp (RPS), necrotising hepatopancreatitis (NHP).

[2] Established exotic species.

Source: Bondad-Reantaso *et al.*, 2004.

Application of risk analysis to genetic issues in aquaculture

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ABSTRACT

In this review and synthesis, I explore the application of risk analysis to genetic harms posed by aquaculture, noting significant work to date and identifying areas where work is still needed. Harms posed by culture of a stock of aquatic organisms relate to chains of events occurring after an escape or release from a culture system. Direct genetic harms will flow from the cultured stock interbreeding with reproductively compatible populations in the receiving ecosystem, and could include loss of adaptation in natural populations, introgression of new genetic material into species' gene pools and, in the extreme case, loss of locally adapted populations. Risk assessment is an estimation of the likelihood of the occurrence of genetic harm becoming realized following exposure to a genetic hazard. The likelihood of harm being realized given exposure to a hazard is difficult to quantify with current knowledge, and we might often be restricted to evaluating risk qualitatively on the basis of: (1) the species at issue, (2) the effect of genetic background or improvement on the net fitness of the animal in the receiving ecosystem at issue and (3) the stability and resiliency of receiving community. Should distribution and production of a cultured stock pose unacceptable genetic harm to a population in the receiving ecosystem, the question then turns to design, selection and implementation of a programme of actions to minimize risk. Effective communication of principles and application of risk analysis is needed to organizations in both developed and developing countries.

INTRODUCTION

The development of aquaculture poses major benefits for mankind. Application of quantitative and molecular genetic principles plays an important and growing role in the development of aquaculture. Many approaches have been applied to obtain genetically superior aquaculture stocks (Tave, 1993; Dunham, 2004; Gjedrem, 2005), including use of high-performance nonindigenous stocks and species and development and use of selectively bred stocks, interspecific hybrids, triploids and transgenic lines. Genetic improvement of cultured stocks has increased production levels and production efficiency (WFC, 2003; ADB, 2005).

There is growing recognition that aquaculture can pose harms to natural aquatic systems (Pillay, 1992; Bardach, 1997; Costa-Pierce, 2003). Among them are genetic harms to natural populations in receiving ecosystems, including loss of adaptation in natural populations, introgression of new genetic material into species' gene pools and in the extreme case, loss of locally adapted populations. As I explain below, principles of risk analysis can be applied to genetic harms posed by aquaculture. The purpose of a genetic risk analysis is to identify risk pathways, estimate risk probabilities, develop procedures to manage risk and communicate the results to stakeholders, thereby minimizing harm to aquatic and human populations. Principles of risk analysis have been applied to aquaculture (Reantaso, Subasinghe and Van Anrooy, 2006), including aspects relating to use of non-indigenous species (e.g. Kohler and Courteney, 1986) and to some types of genetic manipulations, most notably to triploid oysters (Dew, Berkson and Hallerman, 2003; NRC, 2004c) and transgenic fishes (e.g. OAB, 1990; Hallerman and Kapuscinski, 1995; Kapuscinski *et al.*, 2007a), but less thoroughly or not at all to others. Here, I explore the application of risk analysis to genetic harms posed by aquaculture, noting significant work to date and identifying areas where work is still needed.

RELEVANT INTERNATIONAL POLICY

Recognition that aquaculture poses genetic harms to natural populations is relatively recent and has not received a high level of attention by governmental and intergovernmental agencies. Hence, standards, guiding principles and codes of conduct vary widely among the respective approaches used to produce cultured stocks (Table 1). Transfer and use of non-indigenous species is addressed in a number of national policies and international agreements (Welcomme, 1986; Sindermann, 1986; Thorgaard and Allen, 1992). Research and commercial use of genetically modified organisms (GMOs) is subject to the Convention on Biological Diversity (CBD, 1992), specifically the Cartegena Protocol on Biosafety under that convention (CBD, 2000) and implementation policies flowing from it, with national polices for aquatic GMOs mostly still under development. Use of non-indigenous stocks, interspecific hybrids and ploidy-manipulated aquatic species is regulated in some, but not all countries.

SCOPING A RISK ANALYSIS

Consideration of genetic harms posed by cultured fishes must be based on an understanding of key concepts underlying the science and practice of risk analysis

TABLE 1
Selected policies, codes of practice and databases relevant to genetic risk analysis for aquaculture stocks

Exotic species
Code of Conduct for Responsible Fisheries (FAO, 2007b)
Code of Practice on the Introduction and Transfer of Marine Organisms (EIFAC, 1988; ICES, 1995)
FAO Technical Paper 294 (Welcomme, 1988)
Database of Introductions of Aquatic Species (FAO, 2007a)
Non-indigenous genotypes
United States court order[1]
Genetically modified organisms
Convention on Biological Diversity (CBD, 1992)
Cartagena Protocol on Biosafety (CBD, 2000)
United States Coordinated Framework for the Regulation of Biotechnology (OSTP 1985, 1986)
United States Performance Standards for Safely Conducting Research with Genetically Modified Fish and Shellfish (ABRAC, 1995)
European Union Directive 2001/18/EC (EU, 2001)
Norwegian Gene Technology Act (Norwegian Ministry of Environment, 1993)

[1] In its ruling in *U.S. Public Interest Research Group vs. Atlantic Salmon of Maine*, the United States District Court in Maine on May 28, 2003 banned culture of European strain Atlantic salmon in United States waters (NRC, 2004a).

(NRC, 2002). In a genetic context, a *harm* is defined as gene pool perturbation resulting in negative impacts to a species. A *hazard* is defined as an *agent or process* that has the potential to produce harm. A *risk* is defined as the *likelihood* of harm resulting from exposure to the hazard. Risk, R, is estimated as the product of the probability of exposure, $P(E)$, and the conditional probability of harm given that exposure has occurred, $P(H|E)$. That is, $R = P(E) \times P(H|E)$. The steps in risk analysis, then, are to:

1) identify potential harms;
2) identify hazards that might lead to harms;
3) define what exposure means for an aquaculture stock and assess the likelihood of exposure, $P(E)$;
4) quantify the likelihood of harm given that exposure has occurred, $P(H|E)$; and
5) multiply the resulting probabilities to yield a quantitative estimate of risk.

Exact probabilities of risk are difficult or impossible to determine for all types of possible harm. Indeed, it is unlikely that all possible harms would be known *a priori*, particularly with respect to any indirect effects. Hence, it may be necessary – based on current knowledge of population genetics, population dynamics, receiving ecological communities and experience with cultured stocks – to classify levels of concern regarding likely genetic impacts posed by cultured stocks into *qualitative* categories ranging from low to high.

Risk assessment might best be considered as embedded in a three-stage, interactive framework involving the range of stakeholders (Figure 1). Involvement of the full range of stakeholders will bring all existing knowledge into the process, make the process transparent to stakeholders and enhance the understanding and acceptance of the outcome of risk analysis. Stage I involves identifying the problem at hand, engaging stakeholders, identifying possible technical solutions to the problem at hand and identifying potential harms, risk pathways and assessment methods. Stage II is the risk assessment itself, leading to estimating the likelihood that harm will become realized should a proposed action be taken. Upon estimation of that risk, a decision is faced as to whether the risk is acceptable. If it is acceptable, the decision may be made to go forward. If the level of risk is unacceptably high, risk management measures would be identified and residual risk quantified, and the decision of whether to go forward would again be considered. Should the proposed action be implemented, genetic, ecological and social outcomes should be monitored. Because all potential harms and associated pathways cannot be known and precisely predicted *a priori*, it will be necessary to update the risk analysis as knowledge accumulates using an adaptive management approach (NRC, 1996; Kapuscinski, Nega and Hallerman, 1999). Below, I focus on genetic harms and elaborate on each step in risk assessment.

HARM IDENTIFICATION

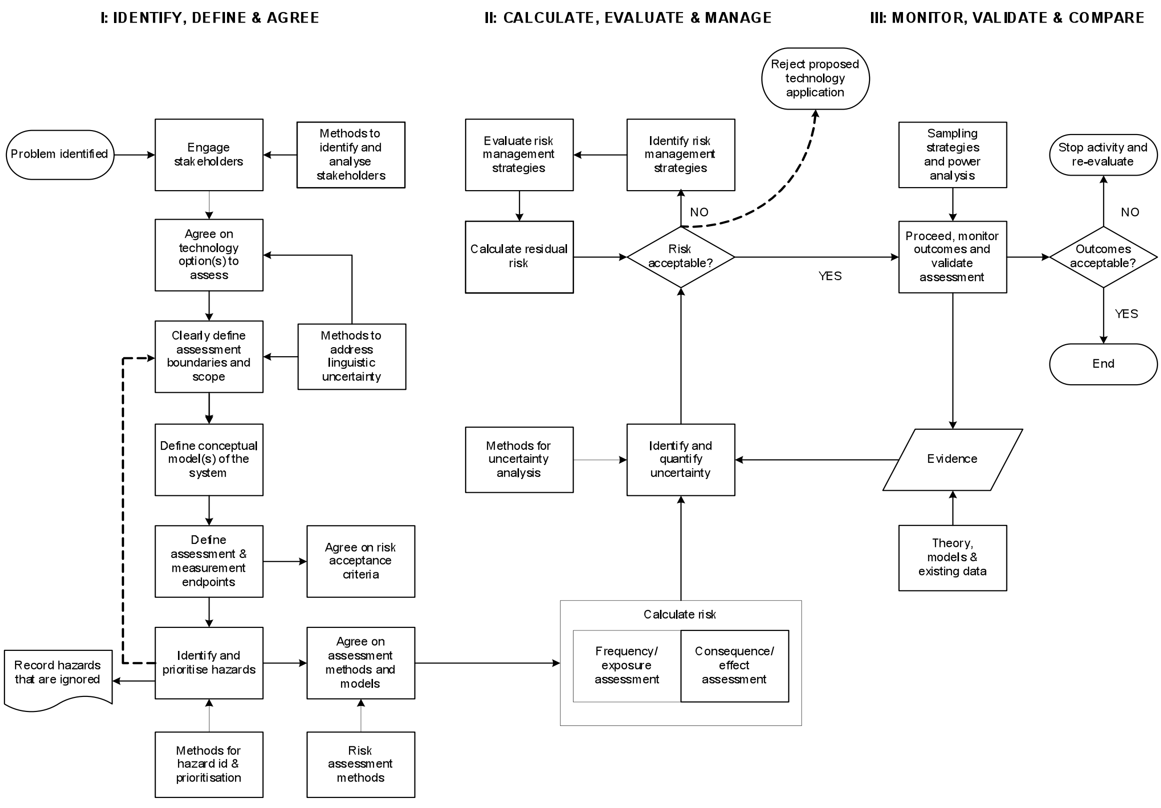
The harms posed by culture of a stock of aquatic organisms relate to chains of events occurring after an escape or release from a culture system. Potential harm must be identified on a case-by-case basis and will depend on the phenotype of the organism, and not *per se* on the genetic manipulation used to produce the stock. *Direct* genetic harms will flow from the cultured stock interbreeding with reproductively compatible populations in the receiving ecosystem. Indirect effects will flow from competition or predation by the cultured stock on other populations or species in the receiving ecosystem.

Loss of adaptation

Natural selection mediates adaptation of a population to its environment by changing allele frequencies at fitness-related genes. Allele frequencies at fitness-related genes will differ among cultured stocks and wild populations. Interbreeding with escaped cultured organisms will displace allele frequencies at fitness-related genes in wild

FIGURE 1

Overview of a highly interactive risk assessment framework (Hayes *et al.* 2007). The framework is divided into three stages. In the first stage, participants agree upon an assessment option, define the scope of the assessment, agree on a conceptual model, identify assessment and measurement endpoints and culminate with an agreed-upon list of prioritized hazard end-points. In the second stage, the risks and uncertainties associated with these hazard end-points are assessed, risks compared to predetermined acceptance criteria and, as appropriate, risk management strategies identified and evaluated. In the third stage, results of monitoring are used to test the predictions of the risk assessment, thereby generating additional data used to reexamine uncertainty in the risk assessment



populations from selective optima, posing loss of fitness. The degree of harm will be a function of the degree of differentiation among the two gene pools, the relative proportion of spawners from the respective groups and the selective pressure imposed by the receiving ecosystem. While it should be noted that not all natural populations at selective optima, the chance of improving fitness through breeding with escaped fish is remote.

For some traits, fitness depends upon expressing *combinations* of alleles across fitness-related loci. The coadapted gene complexes arise by chance and are maintained by natural selection (Hallerman, 2003). For example, anadromous salmonids must express an appropriate combination of run timing, embryonic development rate, post-hatching behaviour, migration and maturation traits in order to complete their life cycle. Interbreeding of differently coadapted populations poses outbreeding depression, or loss of fitness due to breakdown of coadapted gene complexes. The degree of harm will be a function of the degree of difference of the coadapted phenotypes and how many genes determine the traits at issue.

Although we often focus on underlying genotypes, fitness is a phenotypic trait. When selecting mates, individuals must assume that phenotype is a reliable indicator of fitness. This assumption is not always reliable. For example, size is often a fitness-related trait in fishes. However, a fish may be large because it grew in a culture system, not because it expresses genes conferring fitness in the wild. In particular, expression of an introduced growth hormone gene may confer large size upon a transgenic fish, although its offspring may exhibit decreased viability. Such unfavourable tradeoffs among fitness-related traits are termed Trojan gene effects (Muir and Howard, 2001). If the magnitude of the tradeoff is sufficiently large, under certain demographic conditions, a population may face the risk of extinction.

Cultured stocks often have lower effective population sizes (N_e) than natural populations. Escape or release of cultured stocks can decrease the effective size of a receiving population, even if the census count of individuals rises (Ryman and Laikre, 1991). Smaller effective population size implies less genetic variability and less ability to respond adaptively to changes in selection pressures. For example, resistance to pathogens and parasites is often a function of allelic or haplotypic diversity, especially at major histocompatibility complex loci affecting recognition of non-self and coordination of immune response (Hedrick, 2002). It also heightens the risk of subsequent inbreeding.

Introgressive hybridization

Escape or stocking of a non-indigenous species poses possible interbreeding with a reproductively compatible species in the receiving environment. Should the resulting interspecific hybrid prove fertile, it poses the risk of introgressive hybridization with the native species, threatening the genetic integrity of the native species (Campton, 1987; Rhymer and Simberloff, 1996). Similarly, escape or stocking of a fertile interspecific hybrid poses the harm of introgressive hybridization.

Indirect effects

Escape or release of cultured stocks may also pose *indirect* genetic harms to populations in the receiving ecosystem. Through competition or predation, by reducing the abundance of affected populations, the cultured stocks may reduce their effective population size, causing loss of genetic variability and ability to adapt in face of changing selective pressure, and also increase the likelihood of subsequent inbreeding and extinction. Should cultured fish interbreed unsuccessfully with a population in the receiving ecosystem, the loss of reproductive investment increases demographic risk. This mechanism can be realized by interbreeding of a cultured stock and a natural population resulting in a sterile hybrid. Also, triploid males of some species undergo gonadal maturation, steroidogenesis and gametogenesis, and may secure matings (Benfey *et al.,* 1989; Inada and Taniguchi, 1991; Kitamura, Ogata and Onozato, 1991). Any such matings would result in aneuploid broods (Benfey *et al.,* 1986), which would not prove viable (Inada and Taniguchi, 1991). Indirect effects also may be realized through changes in the aquatic community caused by the cultured stocks.

Case studies illustrating potential harms posed by cultured stocks are presented in Box 1.

Sources of information

Sources of information to support harm identification will vary for different classes of aquaculture stocks. There is a large literature on harms posed by non-indigenous species, including species pertinent to aquaculture, as well as policies developed to control their introduction and use. Impacts of exotic fishes in the United States are reviewed in a volume edited by Courtenay and Stauffer (1984). The American Fisheries Society featured discussion of issues posed by introduced species in a special publication of *Fisheries* (Kohler, 1986). Book-length treatments include Rosenfield and Mann (1992) and Devoe (1992). Ecological and socio-economic impacts of invasive alien species were reviewed by Ciruna, Meyerson and Gutierrez (2004). A Database of

BOX 1

Genetic harms posed by cultured organisms

Entry of cultured fish into natural populations may pose genetic harms to receiving populations (Waples, 1991; Utter, 2003; Kapuscinski and Brister, 2001). Here, I present examples of such potential harms.

Direct effects. Interbreeding of cultured stocks and natural populations poses direct genetic harms. Natural selection operates upon alleles at fitness-related loci, over time mediating adaptation of populations to their environments. Across a landscape, spatial heterogeneity of natural selection results in adaptive genetic divergence of populations. However, escape of widely cultured fish stocks and interbreeding with local populations will tend to homogenize genetic variation over time. Escapes of Atlantic salmon (*Salmo salar*) from net-pen aquaculture comprise 70 percent of the spawning stock in some Norwegian rivers, with a mean of 29 percent across rivers. Mork (1991) developed a model to assess one-generation effects of escape and interbreeding of cultured fish on genetic differentiation of natural populations. Substantial reductions in genetic differentiation – i.e. reductions of up to 80 percent in the genetic differentiation statistic, G_{ST} – were predicted. Gharrett (1994) modeled the net effects of immigration and selection on the rate of genetic change on natural populations, but concluded that without knowing the extent of genetically effective migration and the magnitude of loss of fitness, it is not possible to predict outcomes. Focusing on salmonids, Hindar, Ryman and Utter (1991) reviewed studies of the genetic effects of cultured fish on natural fish populations, finding a wide variety of effects, from no detectable effect to complete introgression to complete replacement of natural populations. They recommended measures for genetic protection of natural populations, including secure confinement, use of sterile fish and monitoring of gene flow. Case studies involving non-salmonid species are less numerous. A survey of channel catfish (*Ictalurus punctatus*) populations in Alabama, United States (Simmons *et al.,* 2006) showed no evidence of genetic impact from loss of cultured fish into natural populations, i.e. no apparent dispacement of allele frequencies of natural populations near fish farms from those of natural populations farther away.

Selective forces acting across fitness-related loci may result in combinations of alleles – termed coadapted gene complexes – that confer fitness upon their carriers. Interbreeding of a cultured stock with a locally adapted natural population may lead to outbreeding depression and loss of fitness. Cultured Atlantic salmon stocks are genetically and behaviourally differentiated from natural populations (Einum and Fleming 1997; Gross 1998, NRC 2004a). A two-generation experiment comparing fitness traits among wild, cultured, F_1, F_2 and backcross salmon showed that cultured and hybrid salmon exhibited reduced survival, but faster growth than wild fish, and that their parr displaced wild parr competitively (McGinnity *et al.,* 2003). In an independent experiment, the lifetime reproductive success of farmed salmon was 16 percent that of native salmon, and the productivity of the native population was reduced by more than 30 percent by interbreeding (Fleming *et al.,* 2000).

Fishes select mates on the basis of phenotype, which is taken as a reliable indicator of fitness. When phenotype is misleading and individuals choose mates whose offspring ultimately exhibit low fitness, this is termed the Trojan gene effect (Muir and Howard, 2001). The theory was developed in order to assess risks associated with interbreeding of escaped or released transgenic fish with a natural population. Recurrence equations predict the frequency of the transgene and population number as a function of the degree of tradeoff among, for example, heightened mating success and reduced juvenile viability. Simulations showed that fitness values determine whether the transgene persists, is purged from the gene pool by selection or a Trojan gene effect occurs, leading the population to crash. Experiments are ongoing to parameterize the model using growth hormone-transgenic medaka and Atlantic salmon. While the theory was developed for risk assessment for transgenic fish, it could be applied to any organism whose fitness is affected by genetic manipulation.

BOX 1 (continued)

Genetic harms posed by cultured organisms

Genetically effective sizes of cultured stocks typically are lower than those of natural populations. Escape or release of cultured fish into a receiving population may reduce N_e and increase the risk of inbreeding if the proportion of cultured fish is sufficiently high, an outcome termed the Ryman-Laikre (1991) effect. Wang and Ryman (1991) and Waples and Do (1994) extended the theory to multiple generations and considered the effect of population age structure. Hatchery Atlantic salmon exhibited significant changes in allele frequencies and loss of low-frequency alleles relative to the natural population from which they had been derived one generation earlier (Tessier, Bernatchez and Wright 1997). Estimates of drift and inbreeding effective population sizes showed that the risk of random genetic drift and inbreeding had doubled over the one generation of supplementation.

Introgressive hybridization. Escape or release of interspecific hybrids, if fertile, pose the harm of introgressive hybridization. For example, hybrid catfish (*Clarias macrocephalus x C. gariepinus*) escaping from farms in central Thailand interbred with native populations of *C. macrocephalus*, giving rise to introgressive hybridization with both wild and cultured stocks (Senanan *et al.,* 2004). Similarly, poor management of tilapia stocks led to unwanted hybridization of previously pure species to occur by escapes into the wild, as well as by intrusions from the wild (McAndrew and Majumdar 1983, Macaranas *et al.,* 1986). In Bangladeshi hatcheries, 8.3 percent of silver carp (*Hypophthalmichthys molotrix*) broodstock exhibited bighead carp (*Aristichthys nobilis*) alleles, while 23.3 percent of bighead carp exhibited silver carp alleles (Sattar *et al.,* 2005). While some individuals may have been F_1 hybrids, others were advanced-generation hybrids, compromising the integrity of the respective broodstocks and their performance in aquaculture.

Indirect effects. Escape or release of cultured stocks in the absence of interbreeding may pose indirect effects. To elaborate on one possible mechanism, triploidy often is used as a means of reproductively confining cultured stocks, and all-female triploid stocks may be produced to minimize demographic risks to a receiving population. However, use of triploid aquaculture stocks raises three issues (NRC 2004c). A first issue is the efficacy with which triploids are produced, which differs between the interploid cross among tetraploids and diploids (near 100 percent) and *de novo* induction (generally <100 percent) methods (Downing and Allen 1987; Guo, deBrosse and Allen 1996), but does not reach a full 100 percent. Hence, triploid verification will have to be implemented to manage risk. A second issue has to do with the stability of the triploid state. A small percentage of Pacific and Suminoe oysters have shown signs of progressive reversion to the diploid state, depending on species, individual and tissue (S.K. Allen, Jr., quoted in NRC 2004c). A third issue pertains to the functional sterility of triploid adults. Triploid males of some species may undergo gonadal maturation and steroidogenesis (Benfey *et al.* 1989). Male triploid fish have sometimes been found to produce haploid or aneuploid sperm (Lincoln and Scott 1984; Allen, Thiery and Hagstrom 1986; Benfey *et al.,* 1986; Allen 1987) Should they mate with diploid females (Inada and Taniguchi 1991; Kitamura, Ogata and Onozato 1991), the resulting broods will prove inviable, reducing the reproductive success of the receiving population. Triploid females generally show little ovary development, although there are some apparent exceptions in both fish (Benfey and Sutterlin 1984) and shellfish (Komaru and Wada, 1989, Allen and Downing, 1990). Triploid Pacific and Suminoe oysters are almost, but not completely sterile (Allen and Downing, 1990, Guo and Allen 1994). Should the non-native species escape genetic confinement in the Cheapeake Bay, it would pose competition with the already-declining native Eastern oyster (NRC 2004c, Box 2).

Introductions of Aquatic Species (DIAS) is maintained by the Food and Agriculture Organization of the United Nations (FAO) (Bartley *et al.,* 2006; FAO, 2007a). Studies identifying harms posed by non-indigenous genotypes to receiving populations notably include Hindar, Ryman and Utter (1991), Utter (2003), and Kapuscinski and Brister (2001). Campton (1987) reviews interspecific hybridization in fishes, and Schwartz (1972, 1981) provides citations to the early literature on hybridization in fishes. Harms posed by triploids have been reviewed by ABRAC (1995) and the NRC (2004b, c). Harms posed by transgenic fish and shellfish have been reviewed by ABRAC (1995), the Scientists' Working Group on Biosafety (1998), the NRC (2002, 2004a) and Kapuscinski *et al.* (2007a).

HAZARD IDENTIFICATION

In the context of genetic risk analysis, the hazardous agent is the cultured stock because it is the entity that poses genetic harm to populations in a receiving ecosystem. In the aquaculture context, the hazardous agent may be a non-indigenous species; an interspecific hybrid; or a non-indigenous, selectively bred, triploid or transgenic stock.

RISK ASSESSMENT

In the context of genetic risk analysis, risk assessment is an estimation of the likelihood of the occurrence of genetic harm becoming realized following exposure to a genetic hazard. Because realization of harm would require occurrence of a chain of events, it often is useful to consider risk assessment in terms of the components of the chain. For example, Figure 2 illustrates the sequence of events needed to assess the likelihood of direct genetic harm becoming realized from culture of a transgenic fish (Kapuscinski *et al.*, 2007b). To illustrate risk assessment for a specific case, examples of the types of data, studies and scientific expertise that would be needed to assess risks related to gene flow from transgenic fish to wild populations are presented in Table 2. Below, I elaborate upon release assessment, exposure assessment and consequence assessment, followed by risk estimation.

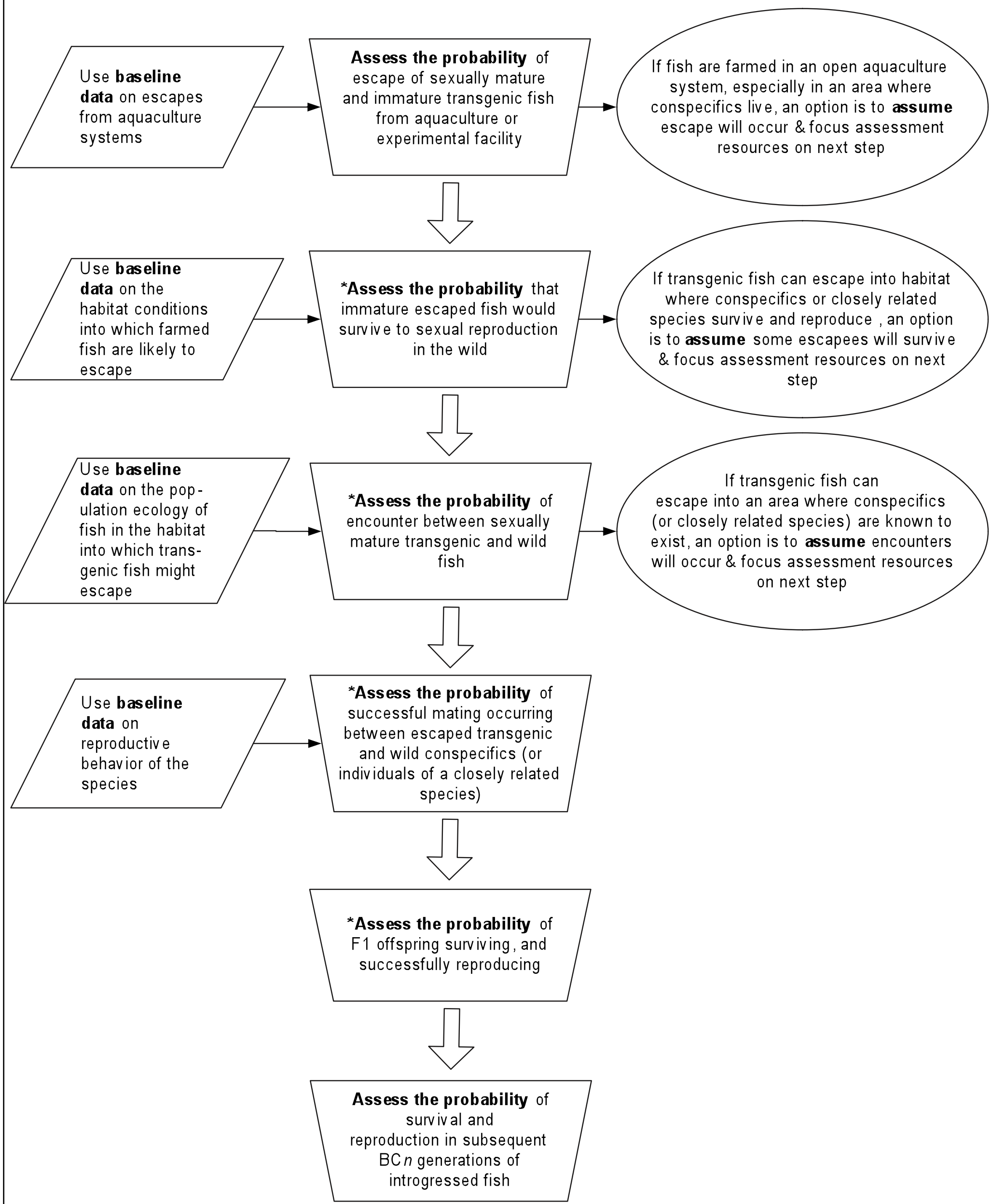
Likelihood of release

Routine aquaculture operations frequently involve the loss of small numbers of cultured fish to the natural environment, with occasional catastrophic losses of larger numbers of fish due to equipment failure, storm damage or flood (Hallerman and Kapuscinski, 1992; CEQ and OSTP, 2001). The information required for a release assessment in a particular context relates to the biological factors, commodity factors and country factors pertinent to that aquaculture system. Biological factors relate to the aquatic species at issue, as they affect the likelihood of escape. Finfishes are mobile; in particular the smallest life stages are hard to confine. Crustaceans vary, with many decapods able to escape by crawling or burrowing out of culture systems. Molluscs are easy to confine at the benthic adult stage, but harder to confine at the pelagic juvenile stages; in some cases, the earliest life stages can escape confinement in aerosols. Commodity factors relate to production methods; that is, different culture systems provide a continuum of confinement, from low to high ranging from extensive production in near-natural systems, to cages and net-pens in oceans and lakes, to intensive production in managed ponds and raceways, to indoor recirculating systems. Country factors are a consequence of policies and permit systems regulating aspects of siting, culture systems and operations management procedures, as they all affect likelihood of release. In the lack of express or enforced policies, operations of individual farms will vary widely and complicate a release assessment. Especially for developing-country contexts, such a release assessment must assume that cultured stock will escape.

Likelihood of exposure

Upon escape or release, for a cultured stock to prove a hazard, it must establish itself in the community long enough to impose harm. Hence, for risk assessment, the critical factor is the likelihood that the cultured stock will become established in the receiving

FIGURE 2
A conceptual pathway for conducting an assessment of gene flow from a ransgenicstock to a wild population (Kapuscinski *et al.*, 2007 b). Asterisks denote assessment steps that require empirical data on traits of the transgenic fish



ecosystem, which is *P(E)*. The likelihood of establishment is dependent on three factors: the species' invasiveness, fitness of the selectively bred stock and characteristics of the receiving ecosystem.

A first aspect of evaluating likelihood of genetic exposure to a cultured stock is the species' invasiveness, i.e. its ability to escape, disperse and become feral in aquatic communities. Many aquaculture species – notably including tilapias, carps and salmonids – exhibit great abilities to disperse and establish themselves in ecosystems in which they are not native.

A second aspect of ecological exposure is the fitness of the cultured stock in the receiving ecosystem. Production traits in domesticated aquaculture stocks include improved growth rate, feed conversion efficiency and disease resistance. Traits conferring fitness in culture systems may not be the same as those conferring fitness

TABLE 2

Examples of types of data, studies and scientific expertise needed to assess gene flow from transgenic fish to wild populations (Kapuscinski *et al.*, 2007 b)

Description of Data Need	Types of Studies[1] (Generally from Simplest to Most Complex):	Studies (May) Require Expertise in:
Data to estimate entry potential		
What is the rate of escape from existing aquaculture or experimental facilities ("propagule pressure")?	• Field studies to detect and quantify escapees • Mandatory self-reporting of escapes by relevant facilities (requires infrastructure for enforcement) • Mark-recapture studies • Use of molecular genetics markers • Mixed-stock analysis • Video surveillance	• Fisheries assessment methods • Molecular genetics methods, such as PCR-mediated detection of specific genes
What is the pattern of escapes from existing aquaculture facilities?	• Field studies to detect escapees • Molecular lab studies, especially when genetic markers are the only way to differentiate cultured and wild fish • Use of telemetry systems	• Fish population dynamics and field assessment methods • Life history of the species in question • Spatial (GIS) modeling
What proportion of immature transgenic escapees are likely to survive to sexual maturity in the natural environment?	• Mark-recapture field experiments • Laboratory experiments to determine survival rates relative to wild-type • Mixed-stock analysis	• Life history of the species in question • Fish population dynamics and field assessment methods • Fish ecology
Data to estimate introgression potential		
Do transgenic escapees disperse in a spatial and temporal pattern and in a phenotypic state that make them likely to find available mates?	• Field sampling for presence of escapees at critical times and places vis-à-vis the native population • Laboratory experiments and spatial modeling	• Life history of the species in question • Fisheries assessment methods • Spatial (GIS) modeling
Are transgenic escapees likely to mate with wild conspecifics (or to hybridize with closely related species) in the natural environment?	• Laboratory studies of mating behaviours of transgenic fish • Field sampling to determine what environments are suitable for reproduction	• Life history of the species in question, especially of mating behaviours and breeding in captivity • Fisheries assessment methods
Are F_1 or BC_n progeny likely to survive and reproduce successfully in the natural environment?	• Laboratory experiments in which matings between transgenic and wild fish can be controlled	• Life history of the species in question, especially of mating behaviours and breeding in captivity • Genetics and breeding programmes
What is the relative net fitness of transgenic fish, compared to a selected captive or wild population?	• Laboratory experiments in which transgenic and comparative strains of fish can be bred and measured for fitness components (fecundity, fertility, age at sexual maturity, mating advantage, juvenile viability, adult viability)	• Life history of the species in question, especially as it might guide prioritizing the most important fitness component traits to examine
What is the spatial distribution of populations of wild conspecifics, or closely related species, in the accessible ecosystem?	• Field sampling for presence of wild fish • Telemetry studies	• Fish systematics (ichthyology) for correct identification of fish species in the wild • Fish behavioural ecology • Fisheries assessment methods • Population genetics techniques and analysis
How many reproductively active wild conspecifics, or closely related species, live in the accessible ecosystem?	• Field sampling for direct estimation of abundance of wild fish • Mark-recapture studies	• Fish population dynamics and field assessment methods
Other desirable data		
How might transgenic fish's phenotype be expressed in a variable natural environment?	• Laboratory experiments in which fish can be exposed to manipulations of environmental variables contributing to survival and reproductive success in the wild (e.g. variable density, natural food or other simulations of natural habitat features)	• Fish behaviour • Fish genetics • Life history of the species in question, especially as it might guide prioritizing the most important environmental variables
What is the population genetic structure of the wild populations?	• Field sampling wild fish to collect tissue • Laboratory analysis of genetic structure of population (allozyme to DNA marker studies)	• Population genetics techniques and analysis
How will the genetic background of the transgenic and wild strains affect the probability of introgression?	• Laboratory experiments in which matings between transgenic and wild fish from different strains can be controlled	• Life history of the species in question, especially of mating behaviours and breeding in captivity • Genetics and breeding programmes

[1] Any studies using transgenic fish should be well confined to prevent the escape of transgenic fish into the wild.

in the wild. A key question, then, is how genetic improvement might indirectly affect traits determining fitness in the receiving ecosystem, perhaps affecting the likelihood that the cultured stock would become established in the receiving ecosystem. Genetic improvement that increases fitness increases the probability of establishment and results in a higher level of genetic concern. It is difficult to make predictions of the effects of genetic improvement on fitness in the wild in a general sense. For example, experience with domestic farm animals suggests that selective breeding generally does not increase the fitness of animals in natural environments, for example, because of physiologic imbalances or growth demands in excess of food availability in natural environments. However, genetic concerns posed by aquaculture stocks expressing improved production traits cannot be dismissed as non-concerns. Selective breeding has not differentiated most fish stocks dramatically from the wild type and, hence, their fitness in the wild generally is expected to remain high. It is possible for selectively bred stocks to overcome, for example, viability disadvantages if other fitness components are enhanced, such as mating success, fecundity or age at sexual maturity. The key issue is change in the *net* fitness of the selectively bred fish over the *entire* life cycle. The six net fitness components of an organism's life cycle to be considered are juvenile viability, adult viability, age at sexual maturity, female fecundity, male fertility and mating success (Muir and Howard, 2001).

The third aspect of ecological exposure is the stability and resilience of the receiving community. A community is regarded as stable if ecological structure and function indicators return to initial conditions following perturbation (Pimm, 1984). Resilience is the property of how fast the structure or function indicators return to their initial conditions following perturbation. Ecosystems that are most stable will suffer the least harm, with unstable communities suffering the greatest harm. For example, decreases in native species following introductions of tilapias occurred most frequently in aquatic ecosystems with less diversified fish faunas; decreases in native species were observed in high elevation lakes of Madagascar with few native species, but not in coastal lakes with many native species (Moreau, 1983). Characterization of community stability and resilience does not generally prove straightforward. Agreement on how to assess community resiliency likely will come only when viewpoints focusing separately on population dynamics, energetics and adaptations of individual species are reconciled (Ricklefs, 1990).

A key caveat for assessing ecological exposure is that we cannot limit the spread of an escaped aquaculture stock to a particular receiving ecosystem. Thus, we must consider whether a cultured stock can become established in all possible ecosystems to which it can gain access. If any of these communities is vulnerable, ecological concern would be high. For this reason, precaution suggests that risk should be assessed and managed for the most vulnerable ecosystem into which the escaped or released aquaculture stock is likely to gain access.

CONSEQUENCE ASSESSMENT

Because of the uniqueness of each cultured stock, culture system and receiving ecosystem, evaluating ecological risk will have to be conducted on a case-by-case basis. The likelihood of harm being realized given exposure to a hazard is difficult to quantify, especially with a lack of empirical data for the many kinds of genetic stocks at issue. This linkage is the weakest aspect of current understanding for genetic risk analysis. As a consequence, we might often be restricted to evaluating risk *qualitatively* on the basis of: (1) the species at issue, (2) the effect of genetic background or improvement on the net fitness of the animal in the receiving ecosystem at issue and (3) the stability and resiliency of receiving community. The outcome of such an analysis is likely to be a predication that likelihood of harm given exposure to a genetic hazard is "high", "medium", "low" or "near-zero".

Estimation of risk

Rating an overall level of genetic risk posed by a given action then would be based on the product of the three factors, likelihood of release, likelihood of exposure and likelihood of harm given exposure. Because the overall level of genetic risk is a product, if one is negligible, then the overall level of concern would be low. In contrast, genetic improvement that increases fitness of a highly invasive species for introduction into a vulnerable community raises a high level of concern. The estimate of risk might then be compared to a previously set acceptable level of risk (ALOR) to determine whether to go ahead, whether to reconsider the action under conditions of risk management or whether to reject the action at issue.

RISK MANAGEMENT

Should an oversight body determine that distribution and production of a cultured stock poses genetic harm to a population in the receiving ecosystem, the question then turns to how to manage the associated risk. Risk management is the design, selection and implementation of a programme of actions to minimize risk. Considering genetic harms in the context of formal risk analysis, it becomes clear that the best approach for minimizing the likelihood of harm being realized is to minimize exposure to the hazard (Mair, Nam and Solar, in press). Four non-mutually exclusive approaches include: (1) geographic location, (2) physically confining the cultured stock on aquaculture facilities, (3) reproductively confining cultured stocks and (4) operations management.

Geographic location. Context is key; the ease or difficulty of managing risk will depend greatly on the geographic location of an aquaculture facility. Sites subject to flooding, violent storms or wave action are poorly suited for confinement of production stocks.

Physical confinement. Physical confinement of cultured aquatic organisms will require a combination of measures in order to prove effective (ABRAC, 1995). Virtually all physical confinement systems will include barriers to escape of cultured organisms from the culture site, including mechanical or physical/chemical barriers. Mechanical barriers are structures that physically hold back cultured organisms from escaping the project site. Examples include stationary or moving screens (e.g. floor drains, standpipe screens), tank covers, filters (e.g. gravel traps), grinders or pumps and French drains. A French drain is a filter for screening effluent from an aquaculture facility that contains gravel and geotextiles through which even small lifestages cannot pass. Physical or chemical barriers use manipulation of physical (e.g. temperature) or chemical (e.g. pH) attributes of effluent water to induce 100 percent mortality of any escaped organisms before they can reach the accessible ecosystem. The set of barriers must prevent escape of the hardest-to-retain lifestage held at the aquaculture operation, usually the smallest lifestage. Because no barrier is 100 percent effective at all times, for effective physical confinement, each possible escape path from the aquaculture facility would have redundant barriers to escape of cultured organisms. Barriers also must prevent access of predators that can carry cultured organisms off-site (e.g. avian predators) or damage ponds (e.g. muskrats), allowing escape of cultured organisms.

Reproductive confinement. A key element of many risk management strategies is reproductive confinement, especially for cases where physical confinement alone is unlikely to prove effective. Two approaches, culture of monosex or sterile stocks, might be applied singly or in combination. All-triploid stocks can be produced most reliably by the crossing of diploid and tetraploid broodstock, although lack of tetraploid broodstock precludes the approach for many species. Alternatively, triploid stocks can be produced by *de novo* induction. *De novo* triploidy induction is not always 100 percent effective and, hence, triploid broods will have to be screened to determine whether they are indeed all-triploid (NRC, 2004b). This extra handling and screening adds to the cost of seed-stock production. Other approaches for reproductive confinement may become available in the future (Devlin and Donaldson, 1992), including the possibility of reversible sterility through transgenesis (Uzbekova *et al.,* 2000).

Operations management. Operations management is a key, though often overlooked, aspect of a confinement system. Measures are needed to: (1) ensure that normal activities of workers at the aquaculture operation are consistent with the goal of effective confinement, (2) prevent unauthorized human access to the site and (3) ensure regular inspection and maintenance of physical confinement systems. Effective supervision of project personnel is critical for operations management. Materials transfer agreements may prove important for limiting ill-considered distribution of aquaculture stocks.

Operations management must consider biosecurity after cultured organisms are removed purposefully from the culture site, that is, through the marketing process. For biosecurity purposes, it would be best if only dead fish were sent to market. This is counter to marketing practices in many countries, where live sales prevail. Live sale is a known route for introductions of non-indigenous species, and evidenced by recent introductions of snakeheads (Perciformes: Channidae) and swamp eels (Synbranchiformes: Synbranchidae) in the United States (Collins *et al*., 2002; Orrell and Weight, 2005).

Effective risk management calls for combinations of confinements. Combinations of risk management measures are advisable so that failure of any one measure will not necessarily lead to escape of confined stocks. It is infeasible to anticipate the best combination of risk management measures for every possible case. Differences in species, production traits, receiving ecosystems and culture systems will affect the case-by-case determination of appropriate risk management measures. The issue of what combination of risk management measures proves practical for a programme where the goal is to provide poor farmers with access to high-performance stocks requires further discussion.

Adaptive management. Many critical unknowns complicate risk assessment and risk management for aquaculture stocks. The adaptive management approach is based on recognition that knowledge of the environmental and social systems into which the aquaculture stocks would enter is *always* incomplete. Management should evolve as knowledge of these systems increases. Management cannot adapt if realized by a single passage through breeding, decision of whether and how to distribute the stocks and implementation of the distribution programme. Instead, adaptive management would include risk assessment for candidate areas for distribution, incorporation of risk management in the distribution programme and capacity building as appropriate to meet programme goals. Once the aquaculture stocks are distributed, culture operations and receiving ecosystems would be monitored for indicators of ecological and social conditions. Should monitoring indicate that benefits are being realized without harms occurring, then few if any adjustments to programme implementation are required. However, should monitoring indicate that production of cultured stocks is *not* contributing to nutritional and economic well-being of farmers or that the stocks are escaping and impacting receiving ecosystems, then it will prove necessary to redefine goals, revise implementation and continue monitoring. Kapuscinski, Nega and Hallerman (1999) discuss adaptive management regarding biotechnologically modified organisms; the general approach is readily adaptable to all classes of aquaculture stocks.

RISK COMMUNICATION

Genetic risk communication is the transmission of the ongoing process and ultimate results of genetic risk analysis to stakeholders and the general public. In particular, pre-agreed contingency plans, which are part of the FAO (1995) precautionary approach, as a useful form of risk communication and for achieving agreement on what to do if things go wrong, or well. Genetic risk assessment and risk management are emerging areas in aquaculture science. While genetic hazards are well known, the associated risks are not well quantified. Genetic risk management, while widely applied at the research scale, is not widely applied at commercial aquaculture operations. Hence, we do not yet have a body of case studies to exemplify effective communication of genetic risk management.

Development and implementation of communication strategies for genetic risk analysis will involve crafting the message appropriate to the case at hand and its effective delivery to target audiences. Two sorts of message are at issue – general explanation of risk analysis as applied to genetic harms and information about applications of risk analysis to specific genetic issues facing the aquaculture community. Results of risk analysis should be communicated to all stakeholders, including agency officials (in national, regional and international agencies, including the FAO, the aquaculture sector, the nongovernmental organization (NGO) sector, the academic sector and the general public. Different groups of stakeholders will be reached most effectively by different means. Written materials will include FAO publications, such as the proceedings of this workshop, and technical manuals (e.g. ABRAC, 1995; Scientists' Working Group on Biosafety, 1998; Kapuscinski *et al*., 2007a). Electronic media will include interactive websites (e.g. ABRAC, 1995). Risk communication through direct interpersonal contact will prove effective and should include discussions of aquaculture extension agents with small farmers and workshops at regional aquaculture meetings targeting the commercial sector. Instructional materials should be developed that integrate genetic risk analysis into fisheries and aquaculture curricula.

CONCLUSIONS

Aquaculture operations pose genetic harms to natural populations in the receiving environment. The risk analysis framework is useful for identifying, evaluating and addressing genetic harms posed by escape or release of aquaculture stocks. Direct genetic harms include loss of adaptation, introgressive hybridization and reduction of effective population size, community-level changes; indirect effects upon other species might be mediated by predation or competition. The likelihood of release from an aquaculture operation depends upon the species, culture system and operations management practices at issue. The likelihood of exposure due to establishment of an aquaculture stock in the receiving ecosystem depends upon its invasiveness and net fitness, and upon the stability and resilience of the receiving ecosystem. The likelihood of harm becoming realized given exposure to the hazard is difficult to quantify given present knowledge, and in the immediate term, may be best considered qualitatively. Risk is estimated by multiplying the likelihoods of release, exposure and harm given exposure to the hazard. In the aquaculture context, risk management focuses on minimizing exposure to the hazard by means of physical confinement, reproductive confinement and operations management procedures. Effective risk communication will require explanation of how risk analysis is applied to genetic issues, as well as discussion of case studies relevant to aquaculture.

FUTURE CHALLENGES

A number of technical issues face genetic risk analysis for aquaculture stocks. Regarding genetic risk assessment, more baseline data and case studies are needed. Opportunities for many informative case studies were effectively lost for the lack of baseline data or because we did not monitor a population until after a genetic harm was realized. Background information useful as case study material is scattered across the scientific and grey literature and is not as well developed for aquaculture as for fisheries management. Understanding of some key issues – e.g. likelihood of outbreeding depression and fitness of transgenic fishes – is still emerging. Other future challenges include lack of knowledge of: long-term impacts of genetic changes, levels of variation needed to maintain viable populations over the long term and relative risks of different classes of genetically modified aquaculture stocks. Hence, development of quantitative genetic risk analysis is very incomplete, especially with regard to estimating the likelihood of harm becoming realized given exposure to a hazardous agent. There are but a handful of definitive case studies of formal genetic risk analysis in the aquaculture literature – notable examples include the finding of no significant impact for the Auburn University field test of transgenic common carp (OAB, 1990) and the risk analysis for introduction of triploid Asian oysters into Chesapeake Bay (Dew, Berkson and Hallerman, 2003; NRC, 2004c; Box 2). Taken together, all these observations suggest the need for more genetic risk analysis studies, especially for nonsalmonid systems. Regarding risk management, while reliable confinement can be achieved for capital-intensive systems, more effort must be directed to developing and demonstrating cost-effective confinement systems for small aquaculture operations.

Regarding oversight of aquaculture by governments and non-governmental organizations, while the theory of risk analysis is established, we as a profession need to apply it, drawing upon definitive case studies for guidance. As experience is gained, an adaptive approach to management of aquaculture systems would be appropriate, not only for genetic risks, but also more generally for other types of risks. Effective communication of principles and application of risk analysis is needed to organizations in both developed and developing countries. There is a need for capacity-building in oversight bodies, especially in the public sector.

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Ecological risk assessment and management of exotic organisms associated with aquaculture activities

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ABSTRACT

Ecological risk assessment (ERA) can be defined as a logical and systematic process for objectively defining the probability of an adverse effect (or impact) on an organism or collection of organisms when challenged by an environmental modification such as introduction of exotic organisms. Aquaculture activities have been thought to be one of the major pathways for introducing exotic aquatic species that may become established as nuisance or pest species. This review provides comprehensive guidelines in ecological hazard identification, risk analysis methodologies, risk management and communication in relation to the introduction of exotic species, particularly those with the potential to become established pests. The best strategy for minimizing impacts from invasive species is to prevent their introduction and their subsequent release or escape into the environment. Effective ERA processes are, therefore, needed to identify most or all potentially invasive species and restrict their introduction or use in aquaculture, while encouraging the use of species that have low invasion potential and can provide net economic benefits for the aquaculture industry and society at large. Both qualitative and quantitative ERA approaches are described in this review, but more emphasis is placed on the former because of its simplicity and practicality. Given the fact that data availability has a huge influence on the quality and confidence of the risk assessment, it is essential to put more effort and funding into basic research on the life histories, population dynamics and ecology of aquaculture organisms and establish better regional and

international information systems concerning these species. Most importantly, concerted efforts should be made to educate consumers and industries about the ecological risk and economic impacts of invasive organisms, and mandate implementation of legally binding species-specific risk assessments and risk management so as to reduce the risks of biological invasion through aquaculture activities.

INTRODUCTION

Ecological risk assessment (ERA) can be defined as the process of determining the nature and likelihood of effects of anthropogenic actions on animals, plants and the environment (SETAC, 1997; USEPA, 1998). In more precise terms, ERA is a logical and systematic process for objectively defining the probability of an adverse effect (or impact) on an organism or collection of organisms when challenged with an environmental modification such as habitat destruction, chemical contamination, invasion of exotic species, infection with disease organisms or some other potential stressor (Newman, Roberts and Hale, 2001; Sergeant, 2002). In 1998, the United States Environmental Protection Agency (USEPA) published the Federal Guidelines for ERA (USEPA, 1998), which provides the basic terminology, concepts, assessment framework and step-by-step procedures of ERA, with special emphasis on assessing ecological risks of chemical contamination. In general, ERA includes four key phases:

- problem formulation (i.e. identification of hazards and sensitive receivers);
- parallel analysis of exposure and effect (i.e. pathway and risk analysis);
- risk characterization; and
- risk management and communication.

Such a framework has been recently adopted to assess ecological risks associated with aquaculture activities (e.g. Visuthismajarn *et al.*, 2005; Colnar and Landis, 2007). For instance, the Working Group 31 on Environmental Impacts of Coastal Aquaculture of the IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) has examined the issue of risk assessment of coastal aquaculture with the objectives of promoting harmonization and consistency in the analysis of risk and uncertainty, and improving risk communication (Hambrey and Southall, 2002). Although this GESAMP report covers many important topics such as ERAs for pollutants released from the farms, alternation of benthic communities beneath the farm and interaction of farmed fish with wild populations (Chapter 9; Hambrey and Southall, 2002), it does not deal with ecological risks arising from diseases originating in farmed animals or the introduction of exotic species.

HAZARD IDENTIFICATION IN AQUACULTURE

Ecological (pest) hazard identification

There are diverse operational systems in aquaculture, ranging from inland pond culture to offshore ocean culture with submerged cages (Table 1). The major farming species also vary, including various finfish, shrimp, crab, lobster, oyster, mussel, snail, abalone and sea cucumbers. Different operational systems and farming species pose different ecological risks to the surrounding natural environment (Table 1). These ecological risks can be broadly classified into seven categories:

- habitat alternation or destruction;
- organic pollution and eutrophication;
- chemical contamination with pesticides and therapeutics;
- infection with disease organisms;

TABLE 1
Ecological risks associated with various aquaculture operation systems. Anticipated relative risk levels are indicated with abbreviations

	Ecological hazard	Inland closed systems (freshwater)		Semi-open systems in wetland/ mangrove (brackishwater)		Open-water systems (lakes or coastal waters)				Offshore open-ocean systems
		Fish pond	Shrimp/crab/ snail pond	Fish tidal pond	Shrimp/crab/ sea cucumber tidal pond	Open-water cages/ net-pen or fish	Open-water cages for shrimp/crab	Bivalves on lines or in cages	Clams on natural sandy shore	Submersible cages for offshore finfish
1	Habitat alternation or destruction	M	M	V	V	H	H	H	H	H
2	Organic pollution and eutrophication	L[1]	L[1]	V	V	H–V[2]	H–V[2]	L–M[2]	L	M
3	Chemical contamination with pesticides and therapeutics	L	L	V	V	V	V	N.A.	N.A.	M–H
4	Genetic risks of escaped culture animals	M–H	M–H	V	V	V	V	V	V	V
5	Introduction of exotic "contaminant" species	V	V	V	V	V	V	V	V	V
6	Infection with disease organisms	H	H	H	H	H	H	H	H	H
7	Use of wild pelagic fish for feed	L–H[3]	L–M	H	L–M	H	L–M	N.A.	N.A.	V

[1] Assuming that effluent and sediment are treated before reuse or disposal.
[2] The risk level depends on the stocking density.
[3] The risk level would be reduced if polyculture mode is adopted (i.e. farming herbivores, omnivores and carnivorous fishes in the same pond).

Legend: V – very high risk; H – high risk; M – moderate risk; L – low risk; NA – not applicable

- genetic risks of escaped culture animals;
- depletion of wild fish stock to provide food for cultured carnivorous fish; and
- introduction of exotic species.

The overall ecological risks of inland closed-culture systems with proper confinement are anticipated to be comparatively low provided that the effluent and any contaminated sediment are treated and handled properly (Table 1). In contrast, tidal-pond, open-water cage (or net-pen) and offshore ocean culture systems pose relatively higher ecological risks because of the direct contact between the farms and adjacent aquatic environments. Wastes are directly discharged to the natural habitat, while farmed animals can more easily escape from the farm to the environment through human errors (e.g. escape during transfer between cages, so called "leakage") or episodic events (e.g. storms or tropical cyclones) (Table 1). As other articles in this proceedings deal with the ecological risks associated with pollution from farm wastes and chemicals (Phillips and Subasinghe, 2008, this volume), pathogens and diseases (Reantaso and Arthur, 2008, this volume), as well as the genetic risks from escaped organisms (Hallerman, 2008, this volume), this article primarily aims to provide comprehensive guidelines in ecological hazard identification, risk analysis methodologies, risk management and communication in relation to the introduction of exotic species, particularly those with the potential to become established pests or nuisance organisms.

Definition of hazards associated with introduction of exotic species

Accidental or intentional introductions of non-native species have become an alarming global environmental problem, because many of these introduced non-native species are able to establish, spread and eventually become nuisance and/or invasive beyond their natural ranges (Elton, 1958; Sugunan, 1995; Kolar and Lodge, 2001; Jeschke and Strayer, 2005; De Silva *et al*., 2006; Soto *et al.,* 2006). In some cases, these introduced organisms become competitors that deplete or exclude native species where their niches overlap, through competition for space or food. In other instances, they may drive native species to extinction through direct predation. For example, the introduction of the predatory Nile perch (*Lates niloticus*) in the 1950s into Lake Victoria, East Africa, has been cited as causing the extinction of more than 200 native fish species (Reinthal and King, 1997). Similarly, there is evidence that the introduction of predatory fish into the Sepik River, New Guinea, in an attempt to enhance fisheries stocks, has been associated with the decline of indigenous species (Dudgeon and Smith, 2006). Other biological impacts of invaders include interbreeding between escaped aquaculture animals and wild conspecifics (Youngson *et al.,* 2001), transmission of disease and/or parasites (Snyder and Evans, 2006) and alternation of community structure. Chen (1989) reported that the introduction of grass carp (*Ctenopharyngodon idellus*) in Donghu Lake in Wuhan, People's Republic of China, dramatically reduced submerged macrophytes, resulting in ecological changes that brought about increases in the abundance of silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) but, more importantly, the disappearance of most of the 60 native fish species in the lake.

Apart from these ecological impacts, the establishment of invasive organisms may have social and economic impacts. Introduced salmonids in southern Chile, for example, resulted in substantial changes in the abundance and distribution of native fishes, with profound consequences for fishing practices and fisheries management (Soto, Jara and Moreno, 2001). The economic impacts included the costs of losing natural resources and the environmental services they support (e.g. native species and biodiversity) and controlling the nuisance species.

Once invaders establish in the wild, it is extremely difficult to eradicate them, and such control measures are often very costly and ineffective. For example, the United States and Canada together spend about US$ 15 million annually to control the sea lamprey (*Petromyzon marinus*) in the Great Lakes (Goddard, 1997). The overall economic costs of invasive species in the United States alone have been estimated at US$ 120 billion annually (Pimentel *et al.,* 2000, 2005). Furthermore, 42 percent of the species on the threatened or endangered species lists in the United States are at risk primarily because of exotic invasive species (Pimentel, Zuniga and Morrison, 2005). It is a reflection of the ecological and economic impacts of biological invasions that a number of treaties and agreements (obligatory and voluntary) exist at the international and regional levels to provide legal instruments and institutions for prevention and control of invasive species. Those concerned with aquatic taxa are listed in Annex 1.

Aquaculture activities are considered one of the major pathways for introducing non-native aquatic species that may become invasive (Weigle *et al.*, 2005; Casal, 2006). First, exotic species that are deliberately introduced for culture may subsequently escape from the farm and establish themselves as nuisance organisms in the wild. Introduction of tilapias (Cichlidae: *Oreochromis*, *Tilapia* and *Sarotherodon*) as foodfish in fresh or brackishwater aquaculture systems, for example, has resulted in significant ecological and economic impacts in the tropics and subtropics (Canonico *et al.,* 2005). Secondly, farmed species such as oysters, clams and mussels can harbour other exotic "contaminant" species (including pests, parasites and pathogens) on their shells, in their tissues or associated with sediments in their bodies or mantle cavities (Minchin, 1996). Therefore, aquaculture-related transfers of half-grown oysters between countries can result in the unintentional introduction of exotic species and pathogens (see examples in Minchin, 1996).

Once exotic species have been introduced, there is a significant likelihood that they will become invasive species. Jeschke and Strayer (2005) have estimated that approximately one in four vertebrate introductions becomes invasive. Consequently, the best strategy for minimizing impacts from invasive species is to prevent their introduction and their subsequent release or escape into the environment (Weigle *et al.,* 2005). Effective risk assessment processes are needed to identify most or all potentially invasive species and restrict their introduction or use in aquaculture, while encouraging the use of species that have low invasion potential and can provide net economic benefits for the aquaculture industry and society at large (Keller, Lodge and Finnoff, 2007). Leung *et al.* (2002) have estimated that if the introduction of the zebra mussel (*Dreissena polymorpha*) had been prevented by spending US$0.32 million in risk assessments and prevention measures, the benefits to the United States of America would far exceed the US$0.5 million spent annually in managing this established invader. In addition to more effective risk assessments of potential invasiveness of candidate species before introduction, improved management and practices in handling and transport of aquaculture organisms (e.g. appropriate packaging in transportation, effective quarantine and sterilization of water from shipping containers), as well as education and communication with the practitioners and stakeholders are needed.

A conceptual model and essential information for hazard identification

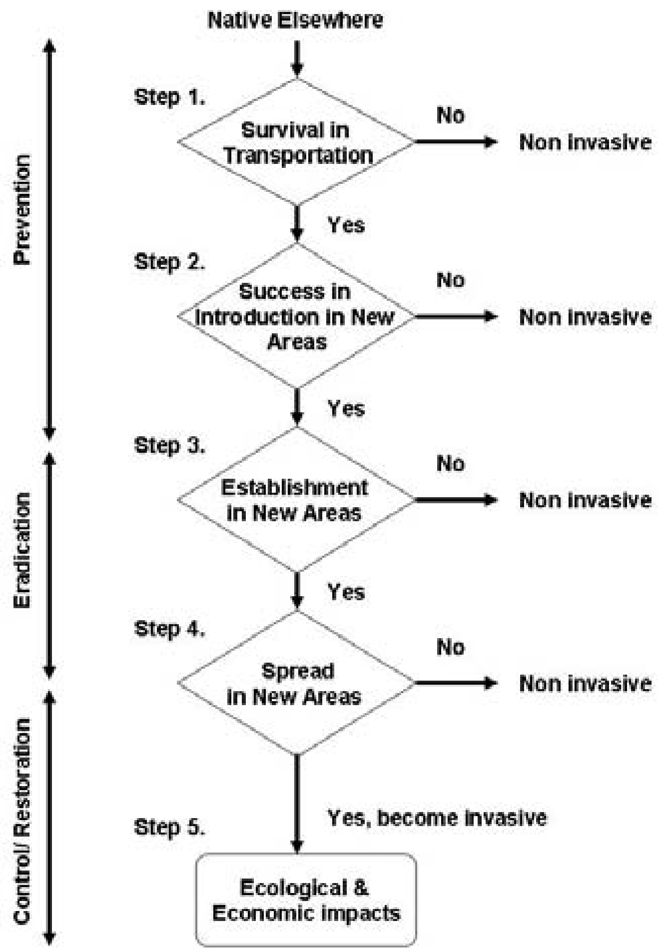
It is of utmost importance that regulatory authorities, risk assessors and risk managers understand the processes involved in the introduction, establishment and spread of exotic species in aquaculture industries before beginning risk analysis. The invasion sequence typically follows five key steps:

(1) individuals of the target species are collected and transported from their native geographical range to new locations where they do not occur naturally (they must survive handling and transportation stresses);
(2) the target species is introduced into the new location where it is an exotic species (the introduction may be intentional or unintentional);
(3) individuals become established at the point of introduction;

(4) the established population subsequently grows and spreads to other locations; and
(5) the invaders became a nuisance and cause ecological and economic impacts (Figure 1).

It is theoretically possible to predict and assess the invasion risk of the candidate species based on this model by way of multiple-level evaluations of the survival probability in Step 1, the chance of introduction via different pathways (e.g. accidental escape) in Step 2, the chance of establishment in the wild in relation to environmental conditions (e.g. temperature, salinity and food availability) in Step 3, and the likelihood of spread in Step 4. Information required for an effective risk assessment includes species-specific biological and ecological information such as invasion history of closely related species; life-history parameters and lifecycle pattern, mobility, feeding habits and habitat occupancy in the native environment, including tolerance limits of temperature, salinity and other physicochemical factors. Also essential are data related to the proposed introduction, such as the quantity of introduced organisms, frequency of introduction, handling practices and the aquaculture operation system

FIGURE 1
A typical invasion sequence of exotic species, with the corresponding management options (prevention, eradication and control/restoration) at different stages



Source: Modified from Kolar and Lodge, 2001; Sakai *et al.*, 2001.

(Risk Assessment and Management Committee, 1996; Kolar and Lodge, 2002; Kelly, Drake and Lodge, 2007).

RISK ASSESSMENT METHODS IN AQUACULTURE – OVERVIEW AND SOME EXAMPLES

Ecological risk assessment for introduction of exotic species

Current ecological risk assessment protocols can be classified into either qualitative or quantitative approaches. Both approaches are principally built upon the skeleton of the invasion sequence presented in Figure 1. The former approach is based on largely qualitative categorizations of putative diagnostic characteristics of invasive species, all available relevant information (see above) and weight-of-evidence judgement by experts. Detailed guidelines and protocols of this qualitative approach can be found in the *ICES Code of Practice on the Introductions and Transfers of Marine Organisms* (ICES, 2004), the *Generic Non-indigenous Aquatic Organisms Risk Analysis Review Process* (Risk Assessment and Management Committee, 1996) and the *Weed Risk Assessment of Australia* (Groves, Panetta and Virtue, 2001).

In contrast to the qualitative approach, quantitative methods are more sophisticated, as they require extra efforts in data mining, and technical inputs from experts on mathematical modelling and statistical computation (Kolar and Lodge, 2001). Given the benefit of more published studies on biological invasions over the last 15 years, more data allowing the development of quantitative methods for risk screening of exotic organisms have become available, making it possible to identify the major biological characteristic(s) of invasive species that predict invasion risk. These advanced computation-intensive approaches are more powerful than the qualitative approach and provide quite accurate prediction of invasive species with >80 percent accuracy (Kolar and Lodge, 2001; Keller, Drake and Lodge, 2007).

Despite the relative success of the quantitative approach, quantitative methods are complex and require highly-skilled personnel for implementation. On the other hand, qualitative methods are highly flexible and relatively easy to follow, and are thus more likely to be adopted by regulatory authorities worldwide. Since there is an urgent need to implement risk analysis in aquaculture, simple and practical methods are needed so that the process can begin and, it is hoped, prevent biological invasions from aquaculture activities as soon as possible. Once this generic, qualitative approach is established, the method could be gradually improved and advanced by incorporating quantitative elements. Accordingly, this review places more emphasis on the qualitative approach, whereas the quantitative approach is only briefly described.

Qualitative risk analysis

The method described herein originates from the *Generic Non-indigenous Aquatic Organisms Risk Analysis Review Process* (hereafter referred to as the Review Process) that was developed by the United States Federal Aquatic Nuisance Species (ANS) Task Force in 1996 (Risk Assessment and Management Committee, 1996). As the Review Process also provides detailed information on the history and development of the exotic pest risk assessment, risk analysis philosophy and additional notes regarding the risk assessment protocols, we have not repeated this material here.

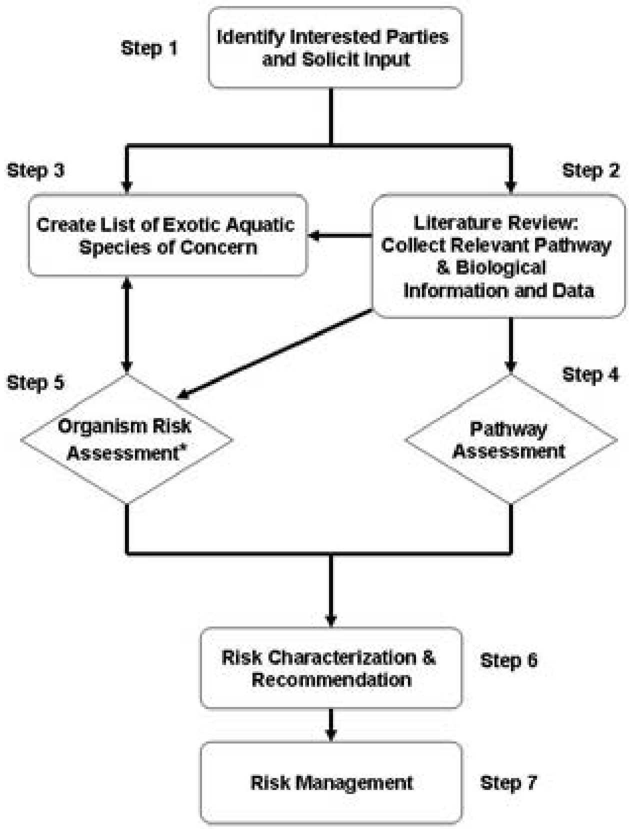
In accordance with common aquaculture practices, slight modifications of the Review Process have been made in this paper with a view to providing comprehensive, user-friendly guidelines for risk analysis of invasiveness of exotic species. The objective is to evaluate the risk of introducing exotic organisms into a new environment via a standardized process, but it may also provide recommendations for appropriate mitigation and/or risk management options. Like the conventional ecological assessment framework (USEPA, 1998), the qualitative risk analysis also comprises:

(i) problem formulation;
(ii) risk analyses (referred to as Pathway Analysis and Organism Risk Assessment in this paper); and
(iii) risk characterization.

(i) Problem formulation and assessment framework

Biological invasion risk is a sum of the risks incurred in the transportation, introduction, establishment, spread and impact stages along the sequence of biological invasion (Figure 1). The qualitative risk analysis should comprise two major components, namely Pathway Analysis and Organism Risk Assessment (Figure 2; the Review Process). To initiate the risk assessment process, the regulatory authority should identify interested parties such as governmental officials, practitioners, representatives from related non-governmental organizations (NGOs), academics, biological invasion experts and other related stakeholders who will provide valuable input and comments on the risk assessment processes (Figure 2; Step 1). Such an initiation step is vital, as this will improve communication of potential risks among all parties, reduce bias and make the processes more open and transparent to the general public. Both components require extensive and comprehensive literature reviews on the pathway-related matters (e.g. history, ecological risk and mitigation measures) and information on the biology, ecology and invasion history of the species of concern (Figure 2; Step 2). In addition, projected information such as the quantity, life stages and exact origin of the organisms is needed for both pathway and organism analyses. It will be advantageous if the

FIGURE 2
A conceptual framework for the qualitative risk assessment for introduction of exotic organisms. (*details of the organism risk assessment are presented in Figure 3)



receiving country or region has already created a list of exotic aquatic species (Step 3) and an archive of their biological and ecological data, as well as invasion history. Such a database will greatly help to speed up the analysis. Based on all available information, the corresponding risk of each invasion step (i.e. introduction pathway, establishment and spread, as well as ecological and economic impacts) is assessed through the standardized Pathway Analysis and Organism Risk Assessment (Steps 4 and 5) based on the principle of weight-of-evidence by a group of experts (Menzie *et al.*, 1996). Subsequently, the overall risk of the intended introduction of the exotic species can be characterized using a standardized rating scheme (Step 6). The results can be used to formulate appropriate mitigation measures and improve risk management (Step 7).

(ii) Pathway and organism risk analyses

Pathway analysis

Pathway analysis is largely conducted through collection of relevant information. The following is a generalized list of information required for the pathway analysis:

- Describe the introduction pathway (intentional vs. unintentional introduction).
- Determine mechanism and history of the pathway.
- Determine the exact origin(s) of organisms associated with the pathway.
- Determine the numbers of organisms and species travelling with the pathway.
- Determine the intended use of the exotic organisms (as animal feeds or culture organisms for food and/or aquarium trade).
- Review the history of past experiences and previous risk assessments (including international examples) on the pathway or similar pathways.
- Review past and present mitigation actions related to the pathway.

As mentioned previously, there are two major pathways of introducing exotic organisms through aquaculture activities: intentional introduction of exotic species as culture organisms that eventually enter the natural environment (usually via accidental escape) and unintentional introduction of exotic organisms associated with imported culture organisms or live foods for aquaculture feed. It is important to evaluate the likelihood of escape within the intentional introduction pathway, particularly, in relation to the aquaculture system and facilities. In general, closed-circulation land-based systems pose relatively lower probability of escape in contrast to open-water systems, which have very high risks. Current management practices for minimizing escape of farmed organisms should be carefully reviewed with special reference to local conditions. Unintentional introductions are more likely associated with bivalve aquaculture because of the risk from associated "hitchhiker" organisms (see above; Minchin, 1996). Different handling processes can result in very different risks of biological invasion. If the organisms have undergone a quarantine procedure (e.g. brine dip of transfers) and are transported in reduced density, the risk of bringing in exotic species will be lower (Minchin, 1996). In some cases, traditional methods for packing shellfish can be problematic. For instance, many exotic species such as the green crab (*Caricinus maenas*) and the algae *Codium fragile* are believed to have been introduced to North America because they were among seaweeds used to pack shipments of bait worms (Weigle *et al.*, 2005). In addition, shipment containers usually contain water that may include juveniles, larvae or eggs of exotic species. If such water is disposed of in the new aquatic environment, it may give exotic organisms an opportunity to establish. Proper sterilization of such water (e.g. through boiling) is needed before discharge. Better codes of practice (e.g. ICES, 2004) should be followed by the aquaculture industry to control such risks. In addition, a risk assessment that reviews and examines the current practices of handling and transportation of shellfish is needed to generate accurate risk predictions. As the unintentional pathway shows a particularly high potential for introducing exotic organisms, it should trigger an in-depth risk analysis.

TABLE 2
Classification of native and exotic species according to their characteristics. The priority of concern for each category is also given

Category	Organism characteristics	Concern
1a	A species is exotic and not present in the region or country.	Yes
1b	An exotic species, which has already been present in the region or country, is capable of further expansion.	Yes
1c	An exotic species is currently present in the region or country and has reached probable limits of its range, but is genetically different enough to warrant concern and/or able to harbour another exotic pest.	Yes
1d	An exotic species present in the region or country has reached probable limits of its range, and does not show any of the other characteristics of 1c.	No
2a	A native species but is genetically different enough to warrant concern and/or able to harbour another exotic pest, and/or capable for further expansion.	Yes
2b	Native species is not exhibiting any of the characteristics of 2a.	No

Source: Risk Assessment and Management Committee, 1996.

Creating a list of exotic aquatic organisms of concern
In Step 3 (Figure 2), a list of exotic species of concern can be developed by identifying the species associated with the pathway, and then classifying them into in one of the categories listed in Table 2. Subsequent Organism Risk Assessments should be conducted for any listed species in categories 1a, 1b, 1c or 2a. The Food and Agriculture Organization of the United Nations' (FAO) Database on Introductions of Aquatic Species (DIAS) includes records of species introduced or transferred from one country to another and contains additional taxa, such as molluscs and crustaceans and marine species (http://www.fao.org/fi/website/FISearch.do?dom=introsp). If the exotic organisms are fish species, the risk assessor may visit and check relevant information in FishBase (Froese and Pauly, 2007; http://www.fishbase.org), which has a section dealing with invasive species associated with aquaculture and the aquarium trade and providing the origin and invasion history of exotic species in different countries. Furthermore, the Global Invasive Species Database which is managed by the Invasive Species Specialist Group (ISSG) of the International Union for the Conservation of Nature (IUCN) Species Survival Commission also provides useful information for the Organism Risk Assessment, such as a searchable database on invasive aquatic species, with references and links to relevant websites (www.issg.org/database).

Organism risk analysis
This manual follows the convention of considering any species as invasive that not only becomes established, but also spreads readily in its new range (Elton, 1958). Invasive organisms must be able to pass through all the key stages (Steps 1–5 in Figure 1) along the sequence of successful biological invasion. The Organism Risk Assessment element in Figure 2 (Step 5) is the most important component of the Review Process used in evaluating and determining the risk associated with a pathway. The Risk Assessment Model (i.e. PIES-COM model) that drives the Organism Risk Assessment (Figure 3) has two major parts – the "probability of establishment" and "consequence of establishment", as described in the equations below:

$$\text{Invasion Risk} = \{\text{Probability of Establishment}\} \times \{\text{Consequence of Establishment}\} \quad (1)$$
$$\text{Invasion Risk} = \{P \times I \times E \times S\} \times \{C \times O \times M\} \quad (2)$$

Where
P = Estimated probability of the organism being on, with or in the Pathway
I = Estimated probability of the organism surviving in transit and Introduction
E = Estimated probability of the organism colonizing and Establishing a population
S = Estimated probability of the organism Spreading beyond the colonized area
C = Estimated the Consequence of all possible ecological impacts if established

O = Estimated the Overall perceived impact from social and/or political influences
M = Estimated economic impact (i.e. Money) if established

This Risk Assessment Model contains seven essential elements (i.e. PIES·COM). The probability of establishment is a product of the probabilities of the pathway associated with the particular species (*P*), successful introduction (*I*), successful establishment (*E*) and spread of the species in the new environments (*S*) (Figure 3). The consequence of establishment includes the ecological impact potential (*C*), perceived impact from social and political points of view (*O*) and the economic impact potential (*M*) (Figure 3). The various elements of the PIES·COM model are portrayed as being independent of one another for model simplification, and the order of the elements in the model does not necessarily reflect the order of calculation. Based on the available information and experts' judgement on all relevant considerations (Table 3), a risk rating is given to each element in the model from one of the three levels: Low, Medium or High. As the certainty of such risk ratings will be influenced considerably by the available information and its quality and reliability, it is important to record the source of information to support the risk rating and state the degree of uncertainty that the assessor associated with each element. The degree of uncertainty can be classified into:

- Very Certain (VC): firm conclusion;
- Reasonably Certain (RC): reasonably convinced;
- Moderately Certain (MC): more certain than not;
- Reasonably Uncertain (RU): reasonably indecisive; or
- Very Uncertain (VU): a guess.

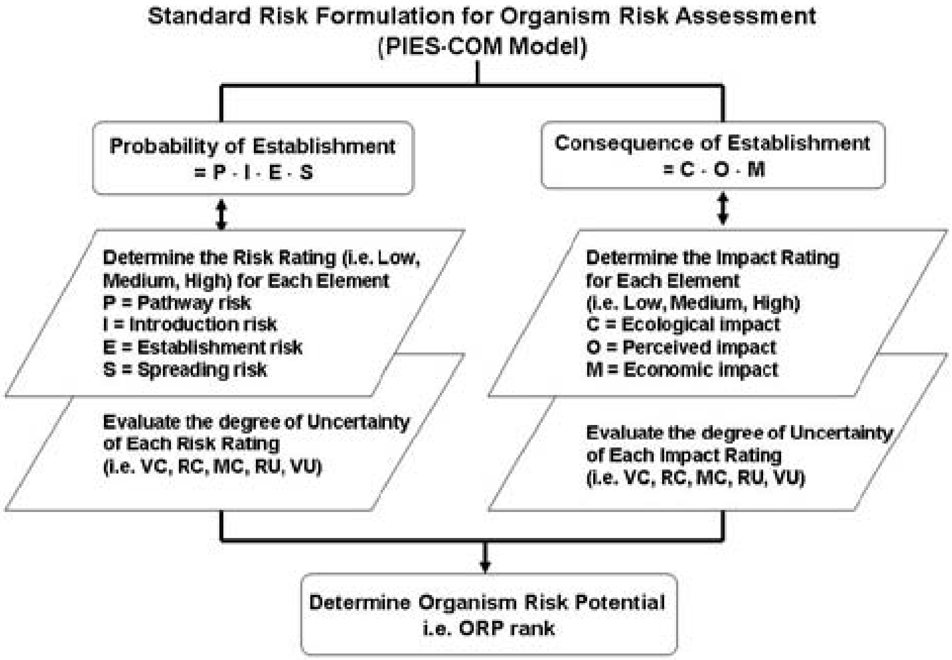
TABLE 3
Characteristics and areas for consideration in the Organism Risk Assessment on the seven key elements (PIES·COM) in the Risk Model (see Figure 3)

Symbol	Element	Characteristics and assessment areas
Probability of establishment		
P	Exotic organisms associated with the pathway	The assessor has to answer whether or not the organisms show a convincing temporal and spatial association with the pathway.
I	Exotic organisms surviving the transit	The assessor should examine the organism's hitchhiking ability in commerce, ability to survive during transit, stage of lifecycle during transit, number of individuals expected to be associated with the pathway or whether it is deliberately introduced.
E	Exotic organisms colonizing, establishing and maintaining a population	The assessor should investigate whether the organisms will come in contact with an adequate food resource, encounter appreciable abiotic and biotic environmental resistance, and have the ability to reproduce in the new environment.
S	Exotic organisms spreading beyond the colonized area	The assessor should evaluate whether the organisms have ability for natural dispersal, ability to use human activity for dispersal, ability to readily develop races or strains, and should estimate the range of probable spread.
Consequence of establishment (CE)[1]		
C	Ecological impact	The assessor should consider the impact on ecosystem destabilization, reduction in biodiversity, reduction or elimination of keystone species, reduction or elimination of endangered/threatened species, and effects of control measures.
O	Perceived impact	These may include aesthetic damage, consumer concerns and political repercussions.
M	Economic impact	Consideration aspects include economic importance of the aquaculture practitioners, damage to natural resources, effects to subsidiary industries, effects to exports, ad control costs.

[1] Notes: The elements considered under Consequences can also be used to record positive impacts that an exotic organism might have, for example, its importance as a biological control agent, aquatic pet, sport fish, scientific research organism or based on its use in aquaculture. The final risk rating will reflect a balance between the cost, the benefit and the risk of introducing the exotic organisms. When determining the CE score, the three elements are not treated as equal: C and M are given a higher weighting than O.

Source: Risk Assessment and Management Committee, 1996.

FIGURE 3
A schematic diagram illustrating the Organism Risk Assessment with the seven key elements



Legend: VC – very certain; RV – reasonably certain; MC – moderately certain; RU – reasonably uncertain; VU – very uncertain)

For elements with certainty at or below MC, it is important to obtain more data as soon as resources (time, money and efforts) permit. The accuracy of the risk analysis can be greatly improved by minimizing uncertainty. While recording the source and details of the information to support the risk analysis, a code of reference should be assigned for each cited document or information source. The reference codes may include:

- **G**: general knowledge, no specific source;
- **J**: judgement evaluation by experts only; or
- **E**: extrapolation; information specific to invasive species not available, however available information on related organisms has been applied.
- **(Author, Year)**: Literature cited.

It is important to stress that the outcome of an Organism Risk Analysis is very likely ecosystem specific (Kolar and Lodge, 2002). Therefore, the risk assessor must consider the potential introduction of the organisms with reference to local conditions such as heterogeneity of aquatic environments, hydrographic parameters, existing biological communities and climate, etc. The risk assessor may incorporate methodologies such as geographical information systems (GIS), climate and ecological models, decision-making software, expert systems and graphical displays of uncertainty in order to increase the precision of one or more elements in the Organism Risk Assessment Risk (Assessment and Management Committee, 1996).

Biological traits of exotic organisms can be potential predictors indicating whether or not they will be invasive. Although biological traits vary among different stages of invasion (Figure 1) and are likely taxonomic specific, some rules-of-thumb about criteria for successful exotic invaders can be generalized from peer-reviewed literature and are listed below. They may be used to inform the risk assessment, to prioritize management efforts and to further develop quantitative risk assessment models.

a) *Having high fecundity*: Keller, Drake and Lodge (2007) showed that fecundity of exotic molluscs is positively related to their invasiveness, and thus fecundity can be used as one of the key criteria to screen their likelihood of becoming invasive species. Females of any molluscan species with an annual per-female output exceeding 162 offspring are likely to become invasive. Based on this criterion, any broadcast spawner with high fecundity would pose a high risk of biological invasion. For example, apple snails (Ampullariidae: *Pomacea canaliculata*) have a minimum clutch size of ~100 eggs and are able to lay many clutches annually (Keller, Drake and Lodge, 2007); these highly invasive snails have spread across much of tropical East Asia since their introduction from South America (Cowie 2004).
b) *Fast-growing in the establishment stage*: Kolar and Lodge (2002) demonstrated that successful fishes in the establishment stage (Figure 1, Step 3) often grow faster than non-invasive species.
c) *Slow-growing in the spreading stage*: Fishes that spread quickly exhibit slower relative individual growth rates than those which spread slowly (Kolar and Lodge, 2002).
d) *Tolerant of wide ranges of temperature and salinity*: Successful fishes in the both establishment and spreading stages (Steps 3–4) are able to tolerate wider ranges of temperature and salinity than are fishes that fail to invade (Kolar and Lodge, 2002).
e) *Predatory invaders that eat a range of prey*: Invasive predatory species are usually non-specialists with respect to prey preferences and eat a wide range of prey types (Kolar and Lodge, 2002).
f) *Smaller and more eggs*: Invasive fishes generally have smaller eggs and more of them than non-invasive fishes (Kolar and Lodge, 2002; Keller, Drake and Lodge, 2007).
g) *With a history of invasion*: It is reasonable to assume that the probability of organism invasiveness increases if the species has a history of invasion (Kolar and Lodge, 2001, 2002).
h) *Exotic taxa distantly related to native species*: Strauss, Webb and Salamin (2006) studied all grass species in California and discovered that highly invasive grass species are, on average, significantly less related to native grasses than are introduced but non-invasive grasses. This hypothesis has yet to be tested for aquatic organisms, but it is noteworthy that the spread of tilapias in Asia is associated with a virtual lack of native cichlids (Sri Lanka, with two native cichlids, is the exception).
i) *High number of individuals released and many release events*: The probability of establishment of exotic species increases with the number of individuals released and the number of release events (Kolar and Lodge, 2001).

Examination of the attributes of an exotic aquatic molluscan species within its native home range before introduction can provide some indication whether it will breed and recruit within the new environment (Minchin, 1996). Studies on the morphology and behaviour of the intended introduction in relation to those eco-morphologically similar native species may greatly aid in identifying the likely effects of competition before an introduction takes place (Minchin, 1996). Studies of chromosome numbers can provide some indication of whether hybridization is possible between native and introduced species (Minchin, 1996).

(iii) Risk characterization

Determination of the organism risk potential

The Organism Risk Potential (ORP) is generated from the probability of establishment (PE) and the consequence of establishment (CE): i.e. the risk ratings and impact ratings of the elements in Table 3. The PE is assigned the value of the element (among P, I. E and S) with the lowest risk rating; some examples are shown in Table 4. Such a conservative estimate of the probability of establishment is justified because each of four elements must be present for the organism to become established, and the degree of biological uncertainty for success at each step is often high (Risk Assessment and Management Committee, 1996). For determining the CE score, the three elements (C, O and M) are not treated as equal and the Economic Impact and Ecological Impact are given a higher weighting than the Perceived Impact. The key for obtaining correct CE scores under different impact rating combinations of the three elements is shown in Table 5. It is important to note that the element M (economic impact) can also be positive impacts. An exotic organism might have its importance as a protein source for human consumption, a biological control agent, an aquatic pet, a sport fish and/or a scientific research organism. Tilapias (e.g. *Oreochromis mossambicus* and *O. niloticus*) are a good example to illustrate this point. Although exotic tilapias have been regarded as invasive fish species in many parts of the world (Canonico *et al.,* 2005), they can have beneficial effects on human livelihoods in tropical Asia (De Silva *et al.,* 2004) where they are an essential protein source; this has given rise to their nickname of "aquatic chicken" in Sir Lanka and Indonesia (De Silva *et al.,* 2004, 2006). Obviously, there is a disparity in attitudes toward management of exotic species in tropical Asia, where maintenance of human livelihoods is a dominant consideration, and in other parts of the world (e.g. North America, Australia), where the beneficial effects of exotic species are of lesser concern and more emphasis is placed upon the conservation of native biodiversity (for further discussion, see Dudgeon and Smith 2006). It is therefore anticipated that different countries will give different rating to Perceived (O) and Economic (M) Impacts based on their own socioeconomic viewpoints. The final risk-rating for CE will reflect a balance between the costs, benefits and risks of introducing exotic organisms.

After calculation of PE and CE, all seven risk element estimates (P, I, E, S, C, O and M) can be combined into an ORP rating that represents the overall risk of the organisms being assessed. This ORP rating can be determined using the key shown in Table 6. The determination of ORP generally favours the environmental protection (following the precautionary principle), as a higher rating is given to borderline cases

TABLE 4
Examples for derivation of the score for the probability of establishment (PE)

	Pathway	Introduction	Establishment	Spread
Scenario 1				
Risk Rating	High	Low	Medium	Medium
		PE Score = Low		
Scenario 2				
Risk Rating	Medium	High	High	Medium
		PE Score = Medium		
Scenario 3				
Risk Rating	High	High	Medium	High
		PE Score = Medium		

TABLE 5
Key for determination of the final score of the Consequence of Establishment (CE)

Scenario	Ecological	Economic	Perceived	CE Score
1	H	L,M,H	L,M,H	H
2	L,M,H	H	L,M,H	H
3	M	M	L,M,H	M
4	M	L	L,M,H	M
5	L	M	L,M,H	M
6	L	L	M,H	M
7	L	L	L	L

Legend: Impact rating described as H – high; M – medium; L - low

Source: Risk Assessment and Management Committee, 1996.

(cases 2, 4, 6 and 8 in Table 6). This approach is needed to help counteract the high degree of uncertainty usually associated with biological situations (Risk Assessment and Management Committee, 1996).

Determination of the pathway risk potential

The overall pathway risk is a sum of pathway-associated risks along the total invasion sequence. The seven risk element ratings of ORP are employed to estimate the combined risk or Pathway Risk Potential (PRP). In practice, results of the rating distribution of the seven elements (e.g. 1 High, 3 Medium and 3 Low) for deriving the ORP are used to determine the final risk rating of the PRP as shown in Table 7. Thus, the PRP generally reflects the highest ranking ORP.

An example of the data sheet format for the Organism Risk Assessment, with step-by-step procedures, is given in Annex 2.

Risk characterization based on ORP and PRP ratings

Once the final rating(s) of ORP and/or PRP have been estimated, the risk characterization is decided following the definition of ratings given in Table 8.

In these risk-characterization procedures, the selection of low, medium and high ratings throughout various levels should mainly be driven by available information

TABLE 6

Key for determination of the final rating of Organism Risk Potential (ORP)

Case	Probability of establishment	Consequence of establishment	OPR rating
1	High	High	= High
2	Medium	High	= High
3	Low	High	= Medium
4	High	Medium	= High
5	Medium	Medium	= Medium
6	Low	Medium	= Medium
7	High	Low	= Medium
8	Medium	Low	= Medium
9	Low	Low	= Low

Source: Risk Assessment and Management Committee, 1996.

TABLE 7

Key for determination of the Pathway Risk Potential (PRP) based on the rating distribution of the seven elements used for deriving the Organism Risk Potential (ORP)

Characteristics of the rating distribution of the seven elements used for deriving the ORP	PRP rating
1 or more scored with High rating(s) out of the seven	High
5[1] or more scored with Medium rating(s) out of the seven	High
1–5[1] scored with Medium rating(s) out of the seven	Medium
All scored with Low ratings	Low

[1] Note: The number 5 used in this table is arbitrary. The selection of value 4 or 5 is possible when the number of medium-risk organisms reaches a level at which the total risk of the pathway becomes high.

Source: Risk Assessment and Management Committee, 1996.

TABLE 8

Risk characterizations based on the final rating of ORP or PRP

Rating of ORP or PRP	Definition	Actions
Low	Acceptable risk: organism(s) of little concern	• Introduction may be permitted • No mitigation is required
Medium	Unacceptable: organism(s) of moderate concern	• Introduction should be banned or should be controlled via risk management • Mitigation is required
High	Unacceptable: organism(s) of high concern	• Introduction should be banned • Prevention rather than mitigation is mandated, and control measures should be considered.

such as biological statements under each element. As the low, medium and high ratings of the individual elements cannot be defined or measured, they remain judgemental in nature. Indeed, the Risk Assessment and Management Committee (1996) has stressed that "it is important to understand that the strength of the Review Process is not in the element-rating but in the detailed biological and other relevant information statements that motivates them". The final estimate of ORP or PRP only provides a summary of the entire risk assessment and some guidance for the decisions about whether or not an exotic species should be introduced, or whether control measures should be in place for introductions that are allowed or whether measures should take place to mitigate the effects of exotic species that have already become established (i.e. retrospective risk assessment). However, the final decision made by the risk assessors should be based on a holistic approach coupled with the weight-of-evidence assessment.

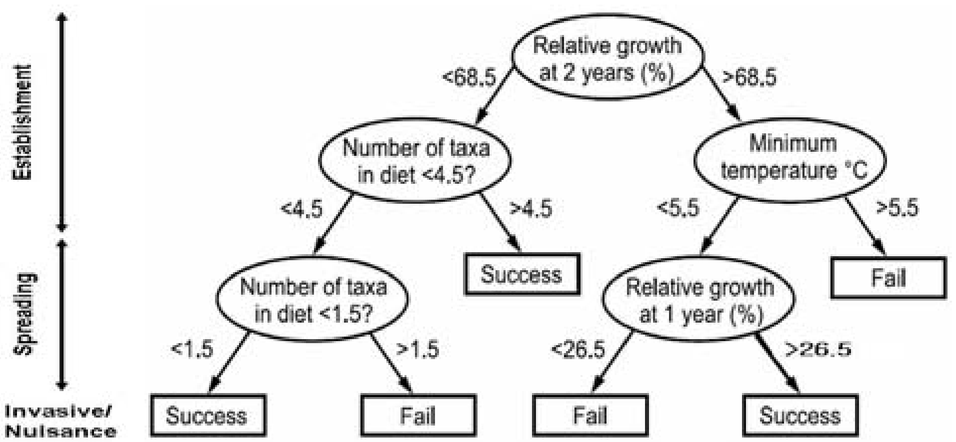
Quantitative risk analysis

Quantitative risk methods have been developed by Kolar and Lodge (2002) to quantify and predict the ecological risk of exotic freshwater fishes becoming invasive if they are introduced to North America. The methods are based on multivariate statistical methods including discriminant function analysis (DFA) and categorical and regression tree analysis (CART). Thirteen life-history characteristics, five habitat requirements and six aspects of invasion history and human use were used in the risk assessment model. DFA revealed the key features of fish species that were able to pass through the two main steps of the invasion process (establishment and spread; Figure 1): (1) successfully established fishes were fast growing, with a wide tolerance of salinity and temperature and a history of invasion; (2) quickly spreading fish species had a relatively slower growth rate and were tolerant of a wide temperature range and (3) successful invasive fishes have smaller eggs and wider tolerance for salinity and temperature. DFA allowed identification of the failed and successful fish species in each invasion stage with >80 percent accuracy (Kolar and Lodge, 2002).

CART is a model-based statistical technique involving model construction based on prior knowledge. Kolar and Lodge (2002) constructed their CART model for predicting invasive fishes with the critical values of minimum temperature threshold,

FIGURE 4

Schematic diagram showing the CART model developed by Kolar and Lodge (2002). Invasion filters represent sequential stages of the invasion process through which a species must successfully pass if it is to pose and invasion risk to the new aquatic environment. The critical value for each filter (e.g. diet breadth: >4.5 prey taxa) is also shown



dietary breadth and two measures of relative growth using information from literature and the results from their DFA analyses. The resulting CART model (Figure 4) assumed that established predatory fishes must growth faster (i.e. add >68.5 percent of initial body weight) within the first two years of introduction, have a wide dietary breadth (eat >4.5 prey taxa) and tolerate a minimum winter temperature of 5.5 °C (as prevails in the Great Lakes area) (Figure 4). For the spreading stage, the model assumes that rapidly spreading fishes have a slightly narrower diet breadth (<1.5 prey taxa) than in the establishment phase and a somewhat slower growth rate (add >26.5 percent of initial body weight). This CART model could correctly identify the species invasiveness for 43 out of 45 species inspected (Kolar and Lodge, 2002), which is very encouraging. Although this quantitative method requires more data input and advanced statistical analyses, it not only identifies potentially invasive species but also reveals essential biological traits that have significant correlations with invasiveness and may be useful criteria for screening risk. Like the qualitative analysis, uncertainties also exist in these quantitative methods (e.g. 5–20 percent error in the prediction; Kolar and Lodge, 2002), and therefore the results should be carefully evaluated with other available relevant information with respect to the key risk assessment elements described in the qualitative risk assessment (i.e. P, I, E, S, C, O and M).

Given the deterministic power of this quantitative method, many researchers have adopted or modified the approach of Kolar and Lodge (2002) in risk assessment for exotic aquatic organisms over the past few years (e.g. Rixon *et al.,* 2005; Jeschke and Strayer, 2005; Keller, Drake and Lodge, 2007; Miller *et al*., 2007). This risk assessment model can be even modified to account for the various life stages of exotic species under different climate scenarios. For example, Colnar and Landis (2007) have recently developed a risk assessment model for evaluation of invasiveness of various life stages (e.g. planktonic larval stages) of the introduced European green crab (*Carcinus maenas*) in North America in relation to habitat suitability and climate. Their model suggested that the risk of invasion impacts from *C. maenas* is substantially higher when El Nino-driven current dispersal is taking place.

Since 2002, at least ten articles using quantitative method in organism risk assessment for aquatic biological invasion have been published in peer-reviewed journals (Annex 3). Six of them are studies of fishes, two on molluscs, one on a crab species and one on marine fouling organisms. The frequency of studies of fishes probably indicates the generally greater availability of biological data. It also indirectly reflects the fact that these quantitative methods can be data limited. Increased data availability will certainly improve the predictive ability of the quantitative approach to organism risk assessments, as well as enhancing its popularity in management of biological invasion in the future. Note, however, that much of the data required for successful prediction is of the type generated by fundamental descriptive studies of growth and population dynamics, but investigations of this type are currently rather unfashionable and may be constrained by funding. Ultimately it may be the availability of such information, and not the complexity of the statistical models or the training required to use them, that will restrict the application of quantitative risk assessment approaches to predicting species invasiveness.

"All models are wrong, but some are useful" - a famous quote of George Box seems also correct with respect to the risk assessment models described above. In an important recent study, Ricciardi and Cohen (2007) have tested the relationship between the invasiveness of introduced species and their impacts on native biodiversity. They found no correlations between these variables for introduced plants, mammals, fishes, invertebrates, amphibians or reptiles. The results suggest that the mechanisms of invasion and impact are not strongly linked, and thus the probability of establishment and spread are not directly reflected by the impact of invasion. This may be good news, since it implies that highly invasive species do not necessarily have the strongest impacts. At present, quantitative methodologies seldom incorporate the impact analysis component in their models, and thereby omit some crucial elements (ecological, economic and perceived impacts) of risk prediction, making them less accurate. Fortunately, the qualitative risk assessment method (i.e. PIES·COM model mentioned above) not only examines the risk of organism invasiveness, but also explicitly considers the ecological, economic and perceived impacts resulted from biological invasion. Both quantitative and qualitative methods are, therefore, complimentary leading to a more holistic and accurate risk analysis.

RISK MANAGEMENT IN AQUACULTURE

Recommendations for ecological (pest) risk management

Management objectives inevitably depend on the stage of the biological invasion, whether at the prevention (i.e. risk assessment and education), eradication, or control and restoration stages (Figure 1). More attention should be paid to the risk prevention, to minimize the chances of an introduction or the necessity for eradication or control measures. Eradication is often impossible when the exotic organisms have already established (Kolar and Lodge, 2001), but the probability of establishment can be minimized if the recommendations made below are adopted.

1. ***Mandatory risk assessment.*** There is an urgent need to make Organism Risk Assessment a legally binding process in aquaculture industries, especially in Asia where >90 percent of the world's total annual aquaculture tonnage is produced (FAO, 2004). If this is not possible, regulatory authorities such as local governments and FAO should allocate more effort to educating consumers and aquaculture industries so that they understand the ecological and economic impacts of introducing invasive organisms, with the hope that this education will induce the industry to voluntarily follow the best code of practices (e.g. ICES, 2004).
2. ***Database of invasive aquatic organisms.*** The development of both global and regional databases of exotic species would greatly help management of introduced organisms (Michin, 1996; Casal, 2006). For instance, Bower *et al.* (1994) have reviewed the pests, parasites and pathogens of molluscs and listed a total of 45 species infecting oysters, 24 in clams and cockles, 18 in scallops, 17 in mussels and 4 in abalones. Such a list can provide an initial basis for the management of any introduction and transfer of marine molluscs. Once screening for known exotic species in consignments has been implemented, appropriate control/mitigation measures can then be applied to minimize the chance of introducing nuisance species (Minchin 1996). At present, some international organizations have databases (e.g. FAO, IUCN and World Fish Centre) that provide generic information on invasive aquatic species. However, regional data and information on exotic species and their controls are usually limited and scattered in different peer-reviewed journals and local agency/project reports (Casal, 2006). It is often not an easy task for risk assessors to collate all relevant information for a particular organism. It has been suggested that an international database should be created through the use of Internet technology, sharing of databases or having a gateway or portal to which all introduced and invasive organisms-related databases link (Casal, 2006). The FishBase information system offers a good model.
3. ***Implementation of Codes of Practice***. Management practices designed to prevent releases of exotic organisms should be adopted in aquaculture industries (Weigle *et al*., 2005). A number of guidelines are available for management of introduction and transfer of aquatic organisms. Of these, the *ICES Code of practice on the introductions and transfers of marine organisms 2004* is the most relevant to aquaculture operations. The regulatory authorities should make this an essential

code of practice with which operators must abide and make efforts to promote its use if legislation is not possible.

4. ***Documentation of the movement of live aquatic organisms.*** It is essential to implement a mandatory reporting system documenting the details of any import and transportation of exotic organisms. More stringent requirements for reporting live species imports should be implemented (Weigle *et al.*, 2005), as such reporting can indicate the magnitude of international transport of organisms and the existing and/or potential threat faced by ecosystems due to species invasiveness (Casal, 2006).
5. ***Mandatory reporting system for escape.*** A mandatory reporting system for escapes will be vital for assessing the risk of introduction stage since, if escapes are not reported, the apparent risks of introduction cannot be estimated accurately. If the escape rates are high (i.e. higher than the accepted threshold), appropriate control measures should be implemented to rectify the problem. Accidental or episodic events of escape (e.g. due to bad weather or nets breaking) must be immediately reported to the risk management authority, which can then respond to the escape as quickly as possible through a mandated contingency plan involving capture or destruction of the escapees. Currently, few regions have implemented an escape-reporting system, and the requirement for reporting varies significantly among these regions (Annex 4; Naylor *et al.*, 2005). Significantly, there are no such requirements in Asia where most of the world's aquaculture takes place. Iceland, for example, has the strongest penalties (including the loss of aquaculture licenses) for failure to comply with escape-related regulations. In contrast, merely symbolic fines for major escape-events are levied in British Columbia, Canada, if the events are not reported promptly (Naylor *et al.*, 2005). Where possible, aquaculturists should keep a good record of any escape events (whether chronic "leakage" or episodic), with information such as the number, species, weather and date, and should inform the authorities as soon as possible after a major event.
6. ***Effective quarantine and wastewater sterilization.*** In general, companies that handle live shellfish require more scrutiny than those handling fresh finfish (Weigle *et al.*, 2005; Minchin, 1996), as many exotic organisms harboured by the shellfish may enter the new environment unintentionally. To reduce such risks, the organisms should be put through a quarantine procedure, while wastewater from shipping containers should be sterilized prior to discharge (Minchin, 1996; ICES, 2004).
7. ***Improvement of technology to reduce escape risk.*** Containment in farms should be improved so as to minimize the numbers of escapees (e.g. use of stronger net materials, tauter nets to deter seals; Naylor *et al.*, 2005). Emergency recovery procedures are also essential (see 5) as a back-up measure in the case of containment failure (Youngson *et al.*, 2001).
8. ***Development of artisanal fisheries on escaped exotic species.*** The chance of escaped populations of exotic organisms impacting native species may be reduced by allowing local artisanal fishing, as this can offer a way to control the population size of exotics if the fishing methods can be appropriated targeted (Soto, Jara and Moreno, 2001).

Recently, leading scientists in the field of biological invasion have put forward some important recommendations for improving the policy and management of biological invasions in the United States (Box 1; Lodge *et al.*, 2006). Many of these recommendations can also be applied in risk management for global aquaculture industries.

After completion of a risk assessment for an exotic species, risk managers are responsible for determining appropriate management actions. These should include both policy and operational measures. The Risk Assessment and Management Committee (1996) has suggested the key elements for risk management and operational requirements during and after the risk assessment (see Box 2). To evaluate the effectiveness of the implementation of risk management measures, the ecological risk assessments should be repeated on a regular basis to ensure that the risk of biological invasion remains low. Such repetition constitutes a form of sensitivity analysis to the initial risk assessment.

ECOLOGICAL (PEST) RISK COMMUNICATION

It is essential that the draft and final risk assessment reports, and especially those generated from the qualitative approach, be reviewed by external experts who are not associated with the outcome of the assessment or with the risk assessors. The reviewers should be able to assess the quality of research and identify any problems, bias or misjudgement that may have arisen.

This risk communication process is extremely important for risk issues of high visibility in society. All documentations of the risk assessment should be made available

BOX 1

Biological invasions: recommendations for United States policy and management

Facts:
Invasions by harmful non-native increasing in number and area affected. The damages to ecosystems, economic activity and human welfare are accumulating. Without improved strategies based on recent scientific advances and increased investments to counter invasions, harm from invasive species is likely to accelerate.

Way forwards:
The Government is required to increase the effectiveness of prevention of invasions, detect and respond quickly to new potentially harmful invasions, control and slow the spread of existing invasions, and provide a national centre to ensure that these efforts are coordinated and cost effective.

Recommended actions:

(1) Use new information and practices to better manage commercial and other pathways to reduce the transport and release of potentially harmful species;

(2) Adopt more quantitative procedures for risk analysis and apply them to every species proposed for importation into the country;

(3) Use new cost-effective diagnostic technologies to increase active surveillance and sharing of information about invasive species so that responses to new invasions can be more rapid and effective;

(4) Create new legal authority and provide emergency funding to support rapid responses to emerging invasions;

(5) Provide funding and incentives for cost-effective programmes to slow the spread of existing invasive species in order to protect still uninvaded ecosystems, social and industrial infrastructure and human welfare; and

(6) Establish a National Centre for Invasive Species Management to coordinate and lead improvements in federal, state and international policies on invasive species.

Source: Lodge *et al.*, 2006.

BOX 2

Elements of risk management and operational requirements

A. Elements to consider in risk management policy:

- Risk assessments (including uncertainty and quality of data)
- Available mitigation safeguards (i.e. permits, industry standards, prohibition, inspection)
- Resource limitations (i.e. money, time, locating qualified experts, information needed)
- Public perceptions and perceived damage
- Social and political consequences
- Benefits and costs should be addressed in the analysis

B. Risk management operational steps:

a. ***Maintain communication and input from interested parties***: Participation of interested parties should be actively solicited as early as possible. All interested parties should be carefully identified because adding additional interested parties late in the assessment or management process can result in revisiting issues already examined and thought to have been brought to closure. They should be periodically brought up-to-date on relevant issues.

b. ***Maintain open communication between risk managers and risk assessors:*** Continuous open communication between the risk managers and the risk assessors is important throughout the writing of the risk assessment report. This is necessary to ensure that the assessment will be policy relevant when completed. Risk managers should be able to provide detailed questions about the issues that they will need to address to the risk assessors before the risk assessment is started. This will allow the assessors to focus the scientific information relevant to the questions or issues that the risk managers will need to address.

c. ***Match the available mitigation options with the identified risks:*** Matching the available mitigation options with the identified risks can sometimes be done by creating a mitigation plan for the organisms, or group of organisms. Where a specific organism or group of organism requires a specific mitigation process (e.g. brine dip of transfers for oysters), the efficacy for control should be recorded. Using this process it will become apparent which mitigation(s) would be needed to reduce the risk to an acceptable level.

d. ***Develop an achievable operational approach:*** Each new operational decision must consider a number of management, agency and biological factors that are unique to any specific organism or pathway. At an operational risk management level, each essential component in the operational sequence (risk assessment, current standard and policy, effective mitigation, feasibility and monitoring) should be examined before approval of the importation or release or action against an exotic organism or pathway is taken. These include the risk assessment, the development of conditions for entry to meet current industry or regulatory standards, effective mitigation of any identified potential exotic aquatic organisms, feasibility of achieving the mitigation requirements and finally, a system of monitoring to ensure that all mitigation requirements are maintained.

Source: Risk Assessment and Management Committee, 1996.

BOX 3

Risk communication consideration for risk managers

- Plan carefully and evaluate the success of your communication efforts.
- Coordinate and collaborate with other credible sources.
- Accept and involve the public as a legitimate partner.
- Listen to the public's specific concerns.
- Be honest, frank and open.
- Speak clearly and with compassion.
- Meet the needs of the media.

Source: USEPA, 1995

to the stakeholders (or interested parties), especially the aquaculture practitioners. The risk manager should allow feedback from the stakeholders and independent reviewers and respond to any comments. Original sources of supporting information in the risk assessment should be adequately documented for reviewers and stakeholders, and this may help to further identify information gaps (Risk Assessment and Management Committee, 1996). If there is disagreement on the results of a risk assessment (e.g. ratings in one or more of seven risk assessment elements) by the reviewers (or stakeholders), the reviewer or opponent party can point to the data used in determining that specific element-rating and show what information is missing, misleading or in need of further explanation. The Risk Assessment and Management Committee (1996) has stressed that focusing on information can help resolve disagreements and minimize the chances of preconceived outcome diluting the quality of the element-rating by the reviewers or interested parties.

To achieve effective and positive risk communication, the risk managers should clearly describe the sources and causes of the risks and potential impacts related to the proposed introduction. The degree of certainty in the risk assessment decision and the options for reducing the risks are also important and should be explained to interested parties (USEPA, 1995). Other important considerations for risk communication are shown in Box 3. In some cases, additional follow-up actions will be needed to address the comments made by the reviewers and/or stakeholders. Depending on the importance of the assessment, uncertainty in the risk assessment results and available resources (e.g. money and time), it may be worthwhile to conduct an additional iteration of the risk assessment with a view to refining the results and supporting a final management decision (USEPA, 1998).

CONCLUSIONS

Given the ever-increasing global demand for and production of aquaculture products and the globalization of aquaculture industries, it is anticipated that imports of live aquatic organisms and thus the potential for introduction of exotic organisms will increase in the near future. Aquaculture-associated activities are important pathways for exotic introductions, some of which become invasive and nuisance species with significant ecological impacts and economic losses. Although some recent reviews indicated that the majority of introduced exotic species has done little ecological harm to native aquatic biodiversity (Escapa *et al*., 2004; De Silva *et al*., 2006; Soto *et al.,* 2007; FAO Database on Introductions of Aquatic Species), ecological risks from biological invasions as have occurred in Lake Victoria and Donghu Lake should not be ignored (Chen, 1989; Reinthal and King, 1997). Anthropogenically driven deterioration of environmental conditions in inland waters, drainage basins and coastal marine environments can make the conditions less congenial to native species and consequently favour exotic, robust species (De Silva *et al.*, 2006). Thus risk assessors should take both ongoing and projected environmental changes and the ecological risk of introducing exotic species into account.

The implementation of proper risk assessment schemes for screening the potential invasiveness of aquatic organisms before introduction will certainly reduce the risk of importing invasive species and thereby minimize ecological and economic impacts. The qualitative assessment methods described in this paper, which are easy to use and do not require large amounts of resources or expertise, can be readily adopted in Asia, which is the global centre of aquaculture production. The assessment method can be further developed and enhanced with advanced quantitative methods, if more relevant biological information on the taxonomic group of concern is available. As data and information availability has a huge influence on the quality and confidence of the risk assessment, it is essential to put more effort and funding into in basic research on the life histories, population dynamics and ecology of aquaculture organisms, and establish better regional and international biological invasion information systems for these species. Finally but most importantly, concerted efforts should be made to educate consumers and industries about the ecological risk and economic impacts of introducing invasive organisms, and to establish mandatory application of legally binding species-specific risk assessments and risk management that will reduce the risks of biological invasion through aquaculture activities.

FUTURE CHALLENGES

With the growth of aquaculture industries, many farmers are attempting to culture new and profitable species. Among these new developments, many invertebrate species are now being introduced into aquaculture systems. The new culture organisms include various species of sea cucumbers, sea urchins and sea squirts. These new species may also be transported internationally with consequent risks of biological invasion. This certainly presents a real challenge to the current risk assessment and management practices that mainly deal with fishes, crustaceans and molluscs. More basic biological and ecological studies on these new farming species in relation to the predicted invasive sequence are needed.

Making risk assessment of biological invasion a legally binding procedure in aquaculture industries, especially in Asian countries, will remain the biggest and most difficult challenge. If this cannot be achieved, it is unlikely that voluntary risk assessment and management would be effective in preventing or controlling biological invasions. More efforts should be put into the development of economic instruments to give incentives to the aquaculture industry to follow the relevant codes of practice and risk assessment protocols.

Although better international network and surveillance systems for prevention and control of invasive aquatic organisms through aquaculture are needed, such tasks will require resources, adequate funding and coordination among countries in collating and updating relevant information and databases. These tasks are perhaps the greatest challenges.

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ANNEX 1

A list of examples of current international and regional treaties and agreements (obligatory and voluntary) for protection against invasive aquatic species[1]

Instrument/institution	Relevant provisions/decisions/resolutions
Convention on Biological Diversity (Nairobi, 1992) http://www.biodiv.org	Article 8(h). Parties to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".
United Nations Convention on the Law of the Sea (Montego Bay, 1982) http://www.un.org/Depts/los/index.htm	Article 196. States to take all measures necessary to prevent, reduce and control the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes.
The Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar, 1971) http://www.ramsar.org	COP7-Resolution VII.14 on Invasive Species and Wetlands
Convention on Migratory Species of Wild Animals (Bonn, 1979) http://www.cms.int/	Range State Parties of Endangered Migratory Species (Annex 1) to prevent, reduce or control factors that are endangering or likely to further endanger the species, including exotic species. (Article III (4)(c)). Agreements for Annex II Migratory Species to provide for strict control of the introduction of, or control of already introduced exotic species detrimental to the migratory species (Article V (5)(e)).
Convention on the Law of Non-navigational Uses of International Watercourses (New York, 1997) http://www.un.org/	Watercourse States shall take all necessary measures to prevent the introduction of species, alien or new, into an international watercourse. (Article 22).
International Plant Protection Convention (Rome, 1951, as amended in 1997) https://www.ippc.int/IPP/En/default.jsp	Creates an international regime to prevent spread and introduction of plants and plant products through the use of sanitary and phytosanitary measures by Contracting Parties. Parties establish national plant protection organizations and agree to cooperate on information exchange and on the development of International Standards for Phytosanitary Measures. Regional agreements for Europe and the Mediterranean, the Asia-Pacific, Near East, Pacific, Caribbean, North America, South America and Africa.
Plant Protection Agreement for the Asia and Pacific Region (Rome, 1956) https://www.ippc.int/IPP/En/default.jsp	Contracting governments to prevent the introduction into and spread within the South East Asia and Pacific Region of plant diseases and pests. A supplementary agreement under Article III of the IPPC.
IUCN-Guidelines for the Prevention of Biodiversity Loss Caused by Invasive Alien Species (2000) http://www.iucn.org/	Guidelines designed to increase awareness and understanding of the impact of alien species. Provides guidance for the prevention of introduction, re-introduction, and control and eradication of invasive alien species.
Guidelines for the Control and Management of ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens. (Resolution A.868 (29)1997, International Maritime Organisation) http://www.imo.org	Provides guidance and strategies to minimize the risk of unwanted organisms and pathogens from ballast water and sediment discharge. Revokes the "Guidelines for Preventing the Introduction of Unwanted Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges" (IMO Resolution A. 774 (18) 1991).
Agenda 21-United Nations Conference on Environment and Development (Rio, 1992) http://www.un.org/esa/sustdev/documents/agenda21/index.htm	Calls for increasing protection of forests from disease and uncontrolled introduction of exotic plant and animal species (11.14); acknowledgement that inappropriate introduction of foreign plants and animals has contributed to biodiversity loss (15.3); appropriate rules on ballast water discharge to prevent spread of non-indigenous organisms. 17.30(vi); controlling noxious aquatic species that may destroy other aquatic species (chap. 18-40(e)(iv)).
Code of Practice on the Introductions and Transfers of Marine Organisms (ICES/EIFAC 2004) http://www.ices.dk/reports/general/2004/ICESCOP2004.pdf	Recommends practices and procedures to diminish risks of detrimental effects from marine organism introduction and transfer, including those genetically modified. Requires ICES members to submit a prospectus to regulators, including a detailed analysis of potential environmental impacts to the aquatic ecosystem.
Code of Conduct for Responsible Fisheries (FAO 1995) http://www.fao.org/fi/agreem/codecond/ficonde.asp	Encourages legal and administrative frameworks to facilitate responsible aquaculture. Including pre-introduction discussion with neighbouring states when non-indigenous stocks are to be introduced into transboundary aquatic ecosystems. Harmful effects of non-indigenous and genetically altered stocks to be minimized especially where significant potential exists for spread into other states or country of origin. Adverse genetic and disease effects to wild stock from genetic improvement and non-indigenous species to be minimized.

ANNEX 1 (continued)

Instrument/institution	Relevant provisions/decisions/resolutions
Code of Conduct for the Import and Release of Exotic Biological Control Agents (FAO 1995) http://www.fao.org	Aims to facilitate the safe import, export and release of such agents by introducing procedures of an internationally acceptable level for all public and private entities involved, particularly where national legislation to regulate their use does not exist or is inadequate. Outlines specific responsibilities for authorities of an exporting country, who should ensure that relevant regulations of the importing country are followed in exports of biological control agents.
Preventing the Introduction of Invasive Alien Species. Resolution A-32-9, International Civil Aviation Organisation (ICAO) (1998) http://www.icao.int/	Urges all Contracting States to use their civil aviation authorities to assist in reducing the risk of introducing, through civil air transportation, potentially invasive species to areas outside their natural range. Requests the ICAO Council to work with other United Nations organizations to identify approaches that the ICAO might take in assisting to reduce the risk of introducing potential invasive species.
Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (UNEP 1995) http://www.gpa.unep.org/	Introduction of alien species acknowledged as having serious effects upon ecosystem integrity.

[1] *Source*: http://www.chinabiodiversity.com/etf/appendix3-en.htm

ANNEX 2
Organism risk assessment form

(Modified from the generic non-indigenous aquatic organisms risk analysis review process, report to the aquatic nuisance species tasks force 1996)

File No.: ________________________________

Date: ________________________________

Organism (Scientific and common names): ________________________________

Analyst(s): ________________________________

Pathway: ________________________________

Origin of the Organism: ________________________________

1. Literature review and background information (summary of life history such as growth rate, egg size, diet breadth, reproduction strategy etc., distribution, tolerable rages of temperature and salinity, and invasion history if any; include references):

2. Pathway Information (include references):

3. Rating elements for the PIES·COM model: Rate statements as L: Low, M: Medium, or H: High. Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Cite the literature (i.e. author, year) or use the reference codes of the biological statement (G: General knowledge, J: Judgment evaluation and E: Extrapolation) where appropriate and the uncertainty codes (VC: Very certain, RC: Reasonably certain, MC: Moderately certain, RU: Reasonably uncertain and VC: Very uncertain) after each element rating.

3.1. Probability of Establishment

Risk Element	Element Rating (L, M, H)	Uncertainty Code (VC, RC, MC, RU, VU)	Reference Codes
Pathway risk			
Introduction risk			
Establishment risk			
Spreading risk			

3.2. Consequence of Establishment

Impact Element	Element Rating (L, M, H)	Uncertainty Code (VC, RC, MC, RU, VU)	Reference Codes
Ecological impact			
Perceived impact			
Economic impact			

4. Risk Characterization

4.1. Determination of a combined rating for the probability of establishment (PE) by taking the lowest rating among the four elements.

	Pathway	Introduction	Establishment	Spreading
Risk Rating (L, M, H)				
PE Score (L, M, H) =				

4.2. Determination of a combined rating for the probability of the consequence of establishment (CE Score) by matching one of the listed scenarios with the current study.

Scenario	Ecological	Economic	Perceived	CE Score
Impact Rating for this study (L, M, H)				
1	H	L,M,H	L,M,H	H
2	L,M,H	H	L,M,H	H
3	M	M	L,M,H	M
4	M	L	L,M,H	M
5	L	M	L,M,H	M
6	L	L	M,H	M
7	L	L	L	L

4.3. Determination of the final rating of organisms risk potential (ORP) by putting the values of PE and CE determined from 4.1 and 4.2, and matching with one of the listed cases with this study. ORP Rating (L, M, H) = ____________________________

Case	Probability of Establishment	Consequence of Establishment	OPR Rating
Rating for this study (L, M, H)			
1	High	High	= High
2	Medium	High	= High
3	Low	High	= Medium
4	High	Medium	= High
5	Medium	Medium	= Medium
6	Low	Medium	= Medium
7	High	Low	= Medium
8	Medium	Low	= Medium
9	Low	Low	= Low

4.4. Determination of the pathway risk potential (PRP) based on the rating distribution of the seven elements used for deriving the organism risk potential (ORP), by matching one of the following listed scenarios. PRP Rating (L, M, H) = ____________________

Characteristics of the Rating Distribution of the Seven Elements for Deriving ORP	PRP Rating
1 or more scored with High rating(s) out of the seven	High
5* or more scored with Medium rating(s) out of the seven	High
1–5* scored with Medium rating(s) out of the seven	Medium
All scored with Low ratings	Low

*Note: The number, 5 used in this table is arbitrary. The selection of value 4 or 5 is possible when the number of Medium risk organisms reaches a level at which the total risk of the pathway becomes high.

4.5. Recommendations on the proposed introduction and mitigation measures based on the definition given below.

Rating of ORP or PRP	**Definition**	**Actions**
Low	Acceptable risk: organism(s) of little concern	• Introduction may be permitted • No mitigation is required
Medium	Unacceptable: organism(s) of moderate concern	• Introduction should be banned or should be controlled via risk management • Mitigation is justified
High	Unacceptable: organism(s) of high concern	• Introduction should be banned • Mitigation is justified

Recommendations: ____
____
____

5. Specific Management Questions: ______________________________
____
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6. Remarks: ______________________________
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7. Cited References: ______________________________
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– End of the Organism Risk Assessment –

ANNEX 3

Recent studies applying quantitative risk assessment models for predicting and assessing the invasiveness of aquatic organisms

Species or taxonomic group of concern	Region of study	Reference
Molluscs	San Francisco Bay, USA	**Miller, A.W., Ruiz, G.M., Minton, M.S. & Ambrose, R.F.** 2007. Differentiating successful and failed molluscan invaders in estuarine ecosystems. *Mar. Ecol. Progr. Ser.,* 332: 41–51.
Green crab (*Carcinus maenas)*	Washington, USA	**Colnar, A.M. & Landis W.G.** 2007. Conceptual model development for invasive species and a regional risk assessment case study: the European green crab, *Carcinus maenas*, at Cherry Point, Washington, USA. *Hum. Ecol. Risk Assess.,* 13: 120–155.
Molluscs	Laurentian Great Lakes	**Keller, R.P., Drake, J.M. & Lodge, D.M.** 2007. Fecundity as a basis for risk assessment of nonindigenous freshwater molluscs. *Cons. Biol.,* 21: 191–200.
Fishes (Cyprinidae)	USA	**Chen, P.F., Wiley, E.O. & Mcnyset, K.M.** 2007. Ecological niche modeling as a predictive tool: silver and bighead carps in North America. *Biol. Invas.,* 9: 43–51.
Fishes	Europe and North America	**Jeschke, J.M. & Strayer, D.L.** 2006. Determinants of vertebrate invasion success in Europe and North America. *Global Change Biol.,* 12: 1608–1619.
Fishes	California, USA	**Moyle, P.B. & Marchetti, M.P.** 2006. Predicting invasion success: freshwater fishes in California as a model. *Bioscience*, 56: 515–524.
Fishes	Colorado River, USA	**Olden, J.D., Poff, N.L. & Bestgen, K.R.** 2006. Life-history strategies predict fish invasions and extirpations in the Colorado River Basin. *Ecol. Monogr.,* 76: 25–40.
Fouling organisms	New Zealand	**Floerl, O., Inglis, G.J. & Hayden B.J**. 2005. A risk-based predictive tool to prevent accidental introductions of nonindigenous marine species. *Env. Manag.,* 35: 765–778.
Fishes	Laurentian Great Lakes, Canada	**Rixon, C.A.M., Duggan, I.C., Bergeron, N.M.N., Ricciardi, A. & Macisaac, H.J.** 2005. Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. *Biodiversity Cons*., 14: 1365–1381.
Fishes	California, USA	**Marchetti, M.P., Moyle, P.B. & Levine, R.** 2004. Alien fishes in California watersheds: characteristics of successful and failed invaders. *Ecol. Appl.,* 14: 587–596.

ANNEX 4

Regulations of aquaculture escapes in 2003[1]

Country	Facility design	Prevention and response plans	Monitoring and enforcement
United States (Maine)	Each aquaculture facility must employ a containment management system to prevent the escape of fish. Starting in May 2004, all Atlantic salmon placed in net pens must be of North American origin. The use of transgenic fish is prohibited. Timeline established for marking all new fish placed in net pens to identify the facility owner and confirm that the fish are from Maine.	Each facility must report known or suspected escapes of more than 50 fish with an average weight of at least 2kg each within 24 hours.	Certain agencies are authorized to inspect aquaculture facilities for compliance with general permit. Each containment management system will be audited at least once per year and within 30 days of a reportable escape.
United States (Washington)	All marine finfish hatched after 31 December 2003 must be marked so that they are individually identifiable to the aquatic farmer. The use of transgenic fish is prohibited.	Aquaculture facilities must have an escape prevention plan and an escape reporting and recapture plan.	Aquaculture facilities must have procedures for monitoring the implementation of the escape prevention plan. Employees of the Washington Department of Fish and Wildlife are authorized to conduct inspections at the aquaculture facilities.
Canada (British Columbia)	Regulations exist for construction, installation, inspection, and maintenance including comprehensive regulations for net cages and related structures.	Aquaculture facilities must have written escape response plans. Facilities must verbally report any escapes within 24 hours of the discovery of an escape or evidence suggestion an escape.	Inspectors are authorized to investigate facilities' compliance with aquaculture regulations. No requirement for monitoring by license holder. Monitoring only via Atlantic Salmon Watch reporting system.
Canada (New Brunswick)	No escape regulations exist.	No escape regulations exist.	No escape regulations exist.
Chile	No escape regulations exist.	No escape regulations exist.	No escape regulations exist.
Faroe Island	No escape regulations exist.	No escape regulations exist.	No escape regulations exist.
Iceland	No specific requirements, but escape prevention is a general condition of aquaculture operating licenses.	Aquaculture operating licenses must specify plans to catch escaped fish. Escaped fish must be reported immediately.	Compliance with regulations is monitored twice annually. Failure to comply with regulations can result in loss of operator license. No system of public reporting on compliance.
Ireland	No specific requirements, but escape prevention is a general condition of aquaculture operating licenses.	Facility owners must immediately report fish escapes and have contingency plans for fish escapes.	No systematic collection of data on contingency plans for fish escapes or plans for escape prevention. On-site audits of wear or fatigue on key elements of aquaculture system.
Norway	No specific requirements for escape prevention, although regulations are under development. Farms are required to have nets in the sea around each site in winter for monitoring escaped farm fish.	Aquaculture facilities must keep contingency plans for limiting the size of escapes and recovering escaped fish. Escapes must be reported immediately.	Government operates "national program of action against escapes" and examines contingency plans and recorded keeping on operational procedures.
Scotland	For existing sites, a voluntary code of practice for stock containment addresses the design and construction of aquaculture equipment and procedures that could affect escapes. New sites must have escape prevention plans.	For existing sites, a voluntary code of practice requires contingency plans for recapturing escaped fish. New sites must have contingency plans.	No evidence of government monitoring of escape prevention procedures or of contingency plans for escapes.
Tasmania	No escape regulations exist.	The holder of a marine farming license must take reasonable precautions to prevent the release, deposit or escape into state waters of any introduced fish.	No escape regulations exist.

[1] From Naylor *et al.*, 2005.

Application of risk analysis to environmental issues in aquaculture

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ABSTRACT

Global production from aquaculture is growing, and future growth will be essential to support human food demands. The development of aquaculture as a newly emerging food production sector poses some risks to the natural environment and human health, as detailed in various publications and studies over the past 20 years. The use of risk analysis to identify hazards and to assess and manage environmental risks associated with aquaculture development is, however, relatively new. This review identifies potential environmental hazards related to aquaculture and outlines methods for assessing, managing and communicating risk. As the risk analysis approach is rather new to the aquaculture sector, recommendations for further action are also provided. Reference is also made to the recent work on risk analysis by the GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) Working Groups on Environmental Impacts of Coastal Aquaculture (Anon., 2007) that has helped to explore and define approaches and options for environmental risk assessment and communication in coastal aquaculture.

INTRODUCTION

Global production from aquaculture has grown substantially, contributing significant quantities to the world's supply of fish for human consumption. This increasing trend is projected to continue in forthcoming decades. The sector is envisioned to contribute more effectively to food security, poverty reduction and economic development by producing –with minimum impact on the environment and maximum benefit to society – 83 million tonnes of aquatic food by 2030, an increase of 37.5 million tonnes over the 2004 level (FAO, 2006).

The recognition by government of the need for sound aquaculture policies, population growth, increasing purchasing power of people, opening of new markets facilitated by trade liberalization, and technological advances bring greater opportunities for further development of the sector. The stagnating level of capture fisheries; strengthening of institutional capacity; increasing consumer demand for diversified, safe and quality aquatic products; increasing environmental concerns; the scarcity of land and water resources; and supporting small-scale farmers all pose major challenges to the sector.

The development of aquaculture as a newly emerging food production sector poses some risks to the natural environment and human health, as detailed in various publications and studies over the past 20 years. The use of risk analysis to identify hazards and to assess and manage environmental risks associated with aquaculture development is, however, relatively new. The purpose of this review is to identify potential environmental hazards related to aquaculture and outline methods for assessing, managing and communicating risk. As the risk analysis approach is rather new to the aquaculture sector, recommendations for further action are also provided. Reference is also made to the recent work on risk analysis by the GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) Working Groups on Environmental Impacts of Coastal Aquaculture (Anon., 2007) that has helped to explore and define approaches and options for environmental risk assessment and communication in coastal aquaculture.

In most countries, environmental impact assessment (EIA) is the main existing and legally required assessment tool, and many of the elements of risk analysis are already included in the EIA process, although associated with somewhat different terminology. Risk analysis should therefore be part of EIA and strategic environmental assessment, rather than considered as a separate or even parallel process. It is also emphasized that the risk analysis process (as for EIA) needs to be related to management. The analysis is of limited practical use if there is no management framework suitable for addressing the most significant environmental risks associated with aquaculture development.

RISK ANALYSIS

Risk analysis is a tool for understanding where to focus management efforts to most effectively reduce the potential environmental effects of human activities. Risk assessment is considered part of the process of risk analysis, and is being widely used for human health and ecological assessments, varying widely in scope and application. Some assessments look at single hazards in a range of exposure scenarios such as many health risk analyses (e.g. Codex food safety-related risk analysis consideration of a chemical); others are more site-specific and look at the range of risks posed by an installation, while others are very broad and may consider multiple hazards posing multiple risks to ecosystems and human health.

There are some differences in terminology used in risk analysis and risk assessment, across a varied range of uses. In broad terms, risk assessments being carried out to examine the effects of hazards on humans (health risk assessment) (Fairman, 1999) and ecosystems (ecological risk assessment). Ecological risk assessment is the process of estimating likelihoods and consequences of the effects of human actions or natural events on plants, animals and ecosystems of ecological value, that is, the study of risks to the natural environment. Environmental risk assessment has been defined as the examination of risks resulting from technology that threaten ecosystems, animals and people, i.e. it is broader than health and ecological risk assessments. It includes human health risk assessments, ecological or ecotoxicological risk assessments, and also specific industrial applications of risk assessment that examine end-points in people, biota or ecosystems. The uses of risk assessments are likewise wide and varied. The risks examined in the assessment can be physical, such as radiation, biological, such as a genetically modified organism (GMO) or pathogen, or chemical, such as an immuno-toxic substance.

The target/receptor to be examined in the risk assessment also varies. Human beings are the species most extensively considered in human health risk assessments – but other single species risk assessments are common in ecological risk assessments. Many ecological risk assessments have solely considered a single or a few species, since only ecologically representative organisms are selected as assessment end-point. Increasingly, ecological risk assessments are being applied to ecosystems or habitats, greatly increasing complexity. Environmental risk assessments as applied to aquaculture may therefore include the wide range of targets/receptors from humans to ecosystems.

Risk assessments also refer to "end-points". End-points are the environmental value that is to be protected, operationally defined by an ecological entity and its attributes. Ecological end-points should be ecologically, socially and politically relevant; sensitive to the potential stressors; amenable to measurement and relevant to the management goals (Suter, 1993). End-points can be mortality or morbidity in human health assessments or other single species assessments. For some ecological risk assessments, end-points may be those that indicate biodiversity or disturbance to ecological systems. These varied approaches are all relevant to aquaculture and are associated with a wide range of potential environmental hazards and a wide range of end-points. The term end-point is closely related those of impact, management objective and indicators used in EIA terminology.

Risk analysis and assessment approaches may seem overly complex and with varied terminology being applied, but the method also has considerable potential to simplify and focus the analysis and subsequent management recommendations on key environmental issues of concern. In practice, except for a few more advanced countries, it has been rarely used as a formal tool for addressing potential environmental hazards in aquaculture, within government or private business, and its potential as a tool for supporting better regulation and management of the aquaculture sector remains largely untested.

There are a number of unifying principles underlying all risk assessments. These underlying principles are developed from those laid down by Covello and Merkhofer (1993) as follows:

- Problem formulation – to formulate the problem being addressed, and the scope of the risk analysis;
- Hazard identification – to determine the nature of potential hazards (threat or stressor);
- Release assessment – to determine the likelihood of a "release" associated with the hazard[1];
- Exposure assessment – to determine the magnitude and extent the physical effects of an undesirable event (identified in the hazard identification and release assessment stages);
- Consequence assessment – attempts to quantify the possible damage caused by the exposure to the hazard; and
- Risk estimation – consists of integrating the estimation of the probability of release and exposure events with the results of the consequence assessment to produce an estimate of the overall risk or probability of the event occurring.

[1] The term "release", which is appropriate for single pathogen or contaminant risk analyses, is potentially confusing for some ecosystem-level risk analyses. Several ecological risk analysis protocols skip this phase and move from hazard identification to the exposure and consequence analysis.

International risk analysis protocols

Internationally recognized risk analysis protocols do exist, and the process is well established as a tool for health and ecological management and decision-making in various sectors. It is therefore important to look at the applicability of those protocols and pathways in applying risk analysis to aquaculture before considering creation of new protocols and pathways. It is also emphasised that in most countries, EIA is the main existing and legally required assessment tool, and many of the elements of risk analysis are already established within this framework.

Examples of existing risk analysis protocols in related disciplines are the World Organisation for Animal Health's (OIE) import risk analysis protocol, which focuses on aquatic animal diseases and health (Murray *et al.,* 2004,), and the international principles and guidelines for the conduct of microbiological and other food safety associated risk assessments, as developed by the Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO) Codex Alimentarius Commission. Ecological risk analysis protocols are also being used for analysing impacts associated with introduction of exotic species, genetically modified organisms, residue contamination and increasingly, ecosystems. These approaches are clearly applicable in aquaculture, depending on the hazards and risks being analyzed.

Application of risk analysis in aquaculture

Risk assessment and management approaches to addressing environmental issues are increasingly being used at all levels of policy and regulation, with a wide range of applications (Fairman *et al.*, 1998), including:

- designing of regulation, for instance in determining societally "acceptable" risk levels that may form the basis of environmental standards;
- providing a basis for site-specific decisions, for instance in land-use planning or identifying a suitable site of an hazardous installation;
- prioritizing environmental risks, for instance in the determination of which chemicals to regulate first; and
- comparing risks, for instance to enable comparisons to be made between the resources being allocated to the control of different types of risk or to allow risk substitution decisions to be made.

Risk analysis has traditionally been a function of policy and regulatory agencies and most development has taken place in these fields. Environmental risk analysis is now becoming more common in industry in many industrialized countries, partly as a result of the use of risk analysis in regulation. The scope of risk analysis in industry for example includes:

- compliance with legislation,
- product safety,
- financial planning,
- site-specific decision-making, and
- prioritization and evaluation of risk reduction measures.

Although risk assessment and management have and will continue to become increasingly important environmental management tools, it is important to look at what the techniques can actually achieve and equally as importantly, what they cannot. Some of the good points, as identified by DEFRA (2002) include:

- a technique that can weigh-up information that is basically in different "languages";
- a mechanism to aid decision-making;
- a basis for effective risk communication; and
- a method for highlighting and prioritizing research needs.

There are a number of disadvantages and pitfalls:

- The techniques have been criticized for a number of reasons, some of which are

not real criticisms of the techniques but are related to the philosophical basis of carrying out such assessments in the first place (e.g. some stakeholders in ecological risk assessments conducted in Australia objected to the use of a risk assessment approach to single "end-points", arguing that the environment was too complex to simplify).
- Criticisms focusing on the use of the techniques include possible over-reliance and over confidence in results; a narrow focus on parts of a problem rather than the whole and awkward relationship between risk assessment and the precautionary principle.

Risk analysis has been less used to date in aquaculture, except for human food safety hazards (Codex) and hazards associated with movement of live aquatic animals (OIE and some ecological risk analyses concerning introduction of exotic species or genetically modified organisms). In Australia, risk analysis is becoming extensively used for policy development in aquaculture (DPIF, 2004, 2005) for:
- identifying appropriate monitoring methods for offshore aquaculture (risk analysis used to prioritize environmental issues, and the monitoring methods were part of the controls);
- developing translocation protocols used in risk assessments to determine relative risk of various translocations (level of risk associated with geography – local, interstate, international) and species (endemic, introduced, exotic);
- developing Codes of Practice to minimize risk of disease transfer (e.g. abalone viral ganglioneuritis);
- developing best practice environmental guidelines (e.g. for salmonids and recirculating aquaculture systems); and
- developing protocols for monitoring trout farms based on the size of the farm relative to a variety of environmental criteria.

GESAMP (Anon., 2007) has explored the application of risk analysis and identified various "objectives" for both the application of the risk assessment and risk communication protocols in coastal aquaculture as follows: [2]
- **Integration into sustainable use paradigms**: Risk assessment as a science-based assessment that must be integrated into a broader socio-economic decision-making process to determine resource allocation for sustainable use. Risk analysis provides the basis for doing this through use of explicit levels of acceptable protection that are dictated by social processes and a consistent and explicit mechanism for transparent application of the precautionary principle.
- **Separation of scientific analysis from valuation:** Risk assessment is a science-based analysis. In itself, it does not determine if a predicted outcome is good or bad, acceptable or unacceptable. Determination of these values can only occur when the predicted outcome is combined with social and economic information. In other words, "risk communication" and involvement of "stakeholders" are essential for effective application of risk analysis.
- **Non-discrimination**: Comparable situations should not be treated differently and different situations should not be treated in the same way, unless there are objective grounds for doing so.
- **Transparency**: To optimize the accuracy, effectiveness and social licence for aquaculture activities, risk communication must start early in the risk analysis process and communicate the information stakeholders and decision-makers require in a manner they can utilize.
- **Consistency**: Measures should be comparable in nature and scope with measures already taken in equivalent areas in which scientific data are available.

[2] Although GESAMP refers to these "objectives", they are more like statements and do not effectively convey the objectives of using risk analysis in the context of aquaculture and aquaculture management.

- **Proportionality**: Risk management measures must not be disproportionate to the marginal change in risk and to the desired level of protection. It also must not aim for zero risk. Where no hazard can be identified, the risk assessment risk assessment should be concluded and the risk evaluated as non-significant.
- **Monitoring of predicted effects**: Where ongoing monitoring is identified as a necessary component of risk management, the initial assessment must be considered as of a provisional nature. Availability of more reliable scientific data may lead to changes in understanding of the mechanisms leading to environmental change and the level of risk (increased or decreased) associated with aquaculture . A requirement to monitor must be tied to a requirement of regulators to regularly report on the outcome and implications of monitoring.

Risk analyses have been applied to a limited extent in aquaculture and mostly for assessing hazards and risks associated with a single species or pathogen and most commonly in the context of human health, pathogens and species introductions (Table 1). Less common is the use of risk analysis to address other environmental issues associated with aquaculture development. There are also considerable gaps in knowledge and experience, particularly in the context of aquaculture and environmental interactions in developing countries. The need for new tools for environmental management of aquaculture is emphasized by various authors (e.g. Focardi, Corsi and Franchi, 2005).

Capacity for risk analysis

It must be recognized that many forms of risk analysis are a significant undertaking, requiring considerable capacity, both in terms of human skills and access to suitable information and tools, which may limit their application in some developing countries. For example, Hart *et al.* (2001) recommend that ecological risk assessments in wetlands involve a multidisciplinary team comprising a social scientist and experts with skills that may include ecology, biology, hydrology, water quality, environmental chemistry, ecotoxicolgy, statistics and modeling.

TABLE 1

Brief summary of some uses of risk analysis in addressing environmental issues in aquaculture

Hazard categories	Risk analysis approach	Examples in aquaculture	Key references
Human health: • Food safety hazards associated contaminants (residues, pathogens, chemicals) • Health and safety	FAO/WHO Codex and other health risk analysis protocols	Risks of *Vibrio* in seafood	Codex Alimentarius Commission (www.codexalimentarius.net)
Aquatic animal health: Release of pathogens	As outlined in the OIE Aquatic Animal Health Code	Many examples – e.g. import risk analysis associated with white spot syndrome virus in shrimp (Australia, Pacific islands)	OIE (www.oie.int) OIE (2007)
Ecological: • Release of genetically modified organisms (GMOs), exotic species, escapes	Ecological risk analysis used with single issue/ species	Impacts of salmon escapes Introduction of exotic *Penaeus* species to Pacific islands	Naylor *et al.* (2005) Arthur *et al.* (2004a)
• Release of wastes and other contaminants	Widely applied in industry, but limited application to aquaculture	Application to monitoring protocols for aquaculture wastes in salmonid culture (Australia) Organic contaminants in farmed salmon Use of antibiotics in aquaculture	DPIF (2004) Hites *et al.* (2004) Christensen, Ingerslev & Baun (2006)
• Disturbance/loss of ecosystem/biodiversity	Ecological risk analysis, but complex because of multiple hazards and multiple stresses that may effect many components of ecosystems	Very limited application to aquaculture to date. Some work on salinity impacts of shrimp farming Collection of wild pearls for aquaculture	Visuthismajarn *et al.* (2005) Wells and Jernakoff (2006)

On the other hand, risk analysis might offer some scope to contribute to capacity building and more efficient use of resources. One of the benefits of undertaking a risk analysis is to map out relationships and critical areas of uncertainty and ignorance. If this uncertainty is associated with potential severe impacts, then either the precautionary approach is invoked (according to local priorities!) or more research is required. However, the initial analysis is valid at all states of knowledge/capacity for research – indeed it contributes to building that capacity (J. Hambrey, pers. comm.).

ENVIRONMENTAL CONCERNS IN AQUACULTURE

On a global scale, the major areas of environmental concerns for aquaculture are now well identified, and include the following:

- wetland and habitat utilization and damage to ecosystem functions;
- abstraction of water;
- sediment deposition and benthic impacts;
- effluent discharge, hypernutrification and eutrophication;
- environmental contamination and human health risks associated with veterinary drugs;
- human health concerns related to chemical, biological and physical food safety hazards;
- ground water contamination;
- exotic species introduction;
- genetic impacts on wild populations;
- introduction of aquatic animal pathogens and pests;
- other wildlife and biodiversity impacts; and
- social issues related to resource utilization and access.

These issues have been discussed and reviewed in numerous papers and books (GESAMP, 1991, 2001; Barg, 1992; Naylor *et al.*, 1998; Phillips, 1998; Asche, Bremnes and Wessells, 1999; Black, 2001; Hindar, 2001; Crawford, 2003). Although the concerns are highly diverse and are farming species/system and site specific, there are some common characteristics to be taken into account if improved environmental management is to be achieved:

- Many of the impacts are subtle and cumulative – often insignificant in relation to a single farm but potentially highly significant for a large number of farms producing over a long period of time, particularly if crowded in relation to limited resources.
- Some of the impacts may be highly dispersed through space and time, depending on such factors such as seasonality, farm management, stocking practices and others.
- There is a high level of uncertainty and ignorance associated with many potential impacts of aquaculture. This argues for more extensive use of the precautionary approach to aquaculture but makes gathering and analysis of risk analysis data problematic.

Relevant treaties, agreements and guidelines

There are a number of international, regional and national standards; guiding principles; codes of practice or protocols available that relate to environmental issues and management in aquaculture, some of which can be useful for guidance in problem formulation and hazard identification, and in scoping the environmental risk analysis and risk management measures. Key international documents that encourage improved environmental management of aquaculture and provide relevant guidance or standards include:

- the Code of Conduct for Responsible Fisheries (CCRF), which provides principles and criteria for responsible fisheries, including (Article 9) on aquaculture (FAO, 1995);

- International Principles for Responsible Shrimp Farming (FAO/NACA/UNEP/WB/WWF, 2006);
- Convention on Biological Diversity (CBD, 2003),
- Codex Alimentarius food safety standards, Codes of Practice and guidelines; and
- World Organisation for Animal Health (OIE) Aquatic Animal Health Code (OIE, 2007)

However, international agreements by no means cover all aspects related to environmental risks associated with aquaculture production. For example, the Convention on Biological Diversity (CBD) recognizes that there are gaps and inconsistencies in the requirements for risk analysis associated with alien aquatic species and specifically mentions that movement of alien species associated with aquaculture is still not covered by any binding international instrument, despite the acknowledged vulnerability of aquatic biodiversity to biological invasion (CBD, 2003).

Environmental hazards

DEFRA (2002) defines "hazard" as a property or situation that in particular circumstances could lead to harm. "Hazard" is defined by the European Union (EU) more broadly as an agent, medium, process, procedure or site with the potential to cause an adverse effect (EU Commission, 2000).

Applied to aquaculture, such definitions could encompass, for example, the release of solid waste or nutrients, habitat disturbance or damage due to building of ponds in a wetland, abstraction of water leading to low river flows or the introduction of an exotic species. Where risk analysis is to be applied at the policy level, the hazard could be as broad as the adverse impacts of aquaculture on the environment.

Environmental interactions of aquaculture are extremely varied, and therefore a wide range of hazards can be identified, encompassing those affecting ecology as well as human health. While much attention is given to environmental hazards arising from aquaculture, there are also hazards arising from other sectors that may lead to harm for aquaculture. Environmental hazards can therefore arise from both within and outside the aquaculture sector and may cause harm to aquaculture or to the environment. It is important to understand that the nature of the hazards and the process of hazard identification should characterize those aspects that might facilitate the expression of undesirable effects. As a priority step before hazard identification, problem formulation, or what the risk analysis is trying to achieve and why, is also important in focusing efforts and resources. Recognizing such issues and to prevent expending unproductive effort, analysis should be terminated if hazard identification fails to identify evidence of an increased probability of the occurrence of an undesirable effect.

Environmental hazards and risk associated with aquaculture relate primarily to the siting, design and operations of aquaculture enterprises and their varied interactions with the surrounding environment, principally water, land, biodiversity and other natural resources required by aquaculture, as well as in some cases human food safety and health aspects. Many of the natural resources used by aquaculture are commonly shared with other aquaculturists or other user groups in coastal and inland areas (e.g. water), and therefore environmental hazards associated with aquaculture are of common concern to society in many countries.

There is no easy classification of the diversity of environmental hazards in aquaculture, but in general these may be classified broadly, with some overlap, as given below.

1) Disturbance or damage to ecosystems and biodiversity, including:
   - Hazards associated with the siting and operation of aquaculture facilities and damage to natural or man-made ecosystems and biodiversity, such as land clearing or ecosystem disturbance in mangroves, coral reefs and other sensitive habitats.

- Hazards associated with the release through escape or deliberate stocking of aquatic animals, including genetic impacts on native stocks, GMOs and disease. The escape of inbred or genetically modified aquaculture stocks also represents a concern for genetic diversity of wild stocks related to inappropriate breeding measures. Deliberate stocking of fish in culture-based fisheries may raise similar concerns over impacts on wild populations.
- Demand for fishmeal and fish oil is of concern in relation to damage to fish stocks and marine ecosystems associated with the use of fishmeal and fish oil in aquaculture diets.
- Collection of wild fry, fingerlings and broodstock from natural marine and freshwater ecosystems.

2) Water quality and supply
- Discharge of various solid and dissolved material from aquaculture farms leading to water quality changes in receiving waters. The discharge of solid and dissolved pollutants in intensive aquaculture effluent is a major environmental hazard leading to risks of water and sediment pollution, but more subtle changes, such as that caused by the filtering of organic material and plankton by mollusks, should also be considered. The seepage and discharge of saline pond water is a further hazard that may cause salinity changes in of groundwater and surrounding agricultural land.
- Consumptive use of water by aquaculture operations is a hazard that may lead to reduced flows and hydrological changes in natural habitats, mainly concerned with aquaculture farms utilizing water from freshwater ecosystems.
- Release of environmental contaminants arising from improper use of veterinary drugs, chemicals and other materials and their discharge to the environment.

3) Animal health and welfare
- Release of pathogens to the natural environment leading to aquatic animal and plant diseases and potential for impacts on both wild and cultured aquatic organisms.

4) Human health
- Food safety hazards associated with aquaculture, including chemical, biological and physical hazards associated with the farming, harvest and post-harvest treatment of farmed aquatic animals and plants.
- Occupational health hazards associated with the aquaculture working environment.

Examples of environmental hazards that may impact on aquaculture include the release of contaminants from other sectors, red tides, water abstraction and physical damage caused by natural hazards such as extreme weather, climate change or even catastrophic events such as the 2004 Indian Ocean tsunami.

Identification of hazards in aquaculture

The wide range of environmental hazards in aquaculture and sometimes, the costs of risk analysis, make it necessary at the outset to carefully determine the scope of the risk assessment. Decisions need to be made and clearly articulated on the specific objectives and scope of the risk assessment (e.g. qualitative or quantitative analysis of a single or multiple threats to a single or multiple environmental assets; determination of spatial and temporal scale). These decisions will guide the type of data and information that need to be gathered and help to identify knowledge gaps.

At this "problem formulation and hazard identification" stage, existing information typically needs to be compiled for the following:

- the environment of interest, particularly its most important assets (and their values), or at least those that need to be protected or are potentially at risk;
- the hazard(s) to which the environmental assets are, or may be, exposed; and
- the types of effects that the hazard(s) may have on the environmental assets.

The synthesis of such information should be done in consultation with stakeholders through an agreed-upon process. For example, the assigning of the "values" of ecological aspects in particular requires consultation to determine their significance for society and local communities.

End-points

End-points are the environmental values that are to be protected, operationally defined by an ecological entity and its attributes. For example, salmon are valued ecological entities; reproduction and age class structure are some of their important attributes. Together "salmon reproduction and age class structure" could form an assessment end-point. In other cases, ecological characteristics such as the abundance of some sensitive species could be considered. Ecological end-points should be ecologically, socially and politically relevant, sensitive to the potential stressors, amenable to measurement and relevant to the management goals (Suter, 1993).

The specific undesirable end-points that need to be managed may be identified in a variety of ways. Some of the end-points are the result of legislative mandates or international agreements. Others may be derived from special socio-economic concerns and may be identified through community consultations. Legislation and policies of the national or regional authority may identify some end-points that need to be managed. The IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) notes five broad categories of environmental effects or end-points commonly raised as concerns by society in relation to temperate coastal marine aquaculture:

- changes in primary producers:
  –abundance (i.e. of macroalgae and marine angiosperms)
  –composition (i.e. harmful microalgae);
- changes in survival of wild populations due to genetic change, disease or competition from escaped aquatic animals and plants from aquaculture facilities;
- changes in composition and distribution of macrobenthic populations;
- changes in trophic resources; and
- changes in habitat (physical and chemical).

However, the actual end-points associated with the wide range of potential hazards in aquaculture will vary and will be site specific. Prior to initiating a risk analysis, it is important to identify the "end-point(s)".

Risk assessment[3]

Risk assessment is a process for evaluating the likelihood of adverse environmental effects arising from the hazard. This phase incorporates the release assessment, exposure (likelihood) assessment and consequences (effects) assessment. These are described separately below. The most pertinent information sources and techniques should be used, although these will vary depending on the assessment. Some types and sources of information include (Standards Australia 2004a, 2004b):

- past records, including relevant published literature;
- experiments and investigations;
- modeling;
- practice and relevant experience;
- results of public consultation; and
- specialist and expert judgements.

[3] Some ecological risk assessment guidelines refer to this step as "analysis".

Release assessment

Release assessment consists of describing the probability of release, as well as the quantity, timing and distribution of a hazard in an environment. If the release assessment demonstrates no significant probability of release, the risk assessment need not continue.

For example, a release assessment associated with a hazard such as discharge of nutrients from an intensive aquaculture farm would examine the probability of nutrient release, amounts of the nutrients of interest, timing and distribution into the receiving environment. The term release assessment is less relevant to some hazards associated with aquaculture, such as the siting of farms and habitat conversion. Some ecological assessments therefore do not consider this part of the risk assessment.

Exposure assessment

Exposure assessment determines the likelihood of the effects of an undesirable event (identified in the hazard identification and release assessment stages). Data on the effects of a hazard provide little useful information without knowledge on the actual level of exposure of the end-point to the hazard.

Thus exposure assessment aims to determine the likelihood that the environmental asset(s) of concern will be exposed to the hazard and therefore, that an effect will be realized. For a biological hazard, such as an invasive species, exposure assessment might involve integrating information on the source of the species, the potential route of entry into the ecosystem of interest, rate of spread, habitat preferences and associated distribution. Existing information (e.g. remotely sensed imagery) or habitat suitability modelling can be used for such purposes. If the exposure assessment demonstrates no significant likelihood of significant exposure, the risk assessment may conclude at this step.

The outputs of the exposure assessment should involve and be crosschecked with stakeholders to ensure that data and information were used and interpreted appropriately. The assessment should also be iterative. Information that is obtained throughout the process should allow for reassessment of an earlier step. In particular, discoveries during the analysis stage may encourage a shift in emphasis. Rather than being considered a failure of initial planning, this constant reassessment enables environmental risk assessment to be a dynamic process well suited to ecological study.

Consequence assessment

Consequence assessment aims to determine and characterize the impacts or consequences of the release on the measurement end-points selected during problem formulation. For example, reduced water quality (for whatever reason) might impact aquatic ecosystems as measured by reduced species diversity and abundance of macroinvertebrate and/or fish communities. It is desirable to quantify the magnitude of impact to the extent possible. The process of risk assessment associated with the theoretical release of solid organic material from a marine fish farm is summarized in Table 2.

Risk estimation[4]

This step integrates the outcomes of the effects (consequences) and exposure (likelihood) assessments in order to determine the level of risk (i.e. consequences × likelihood) to environmental values (end-points).

In general, there are three levels at which this analysis of risks can be undertaken: qualitative, semiquantitative and quantitative. Often, risk assessments are undertaken in a tiered manner, with initial screening-level qualitative or semiquantitative analyses

[4] Referred to as risk characterization in some ecological risk analysis documents.

TABLE 2
Risk assessment approach applied to solid organic material from an intensive marine fish farm

Risk analysis step	Description	Methods
Potential hazard	Discharge of organic fish farm waste	Consultation Analysis
End-point	Benthic macrofauna diversity and species retained	Scientific, legal review and public consultation
Release assessment	Assess amounts, patterns and types of organic wastes released from fish farm (uneaten food, faeces, displaced fouling organisms)	Review of scientific data, management information.
Exposure assessment	Assess organic material settling on the benthos (i.e. being exposed to solid organic waste)	Benthic models (relating current, depth and settling velocity of sold waste), site assessments
Consequence assessment	Assess how benthic macrofauna diversity and species are impacted by organic material accumulation rates	Review of scientific literature, site assessments
Risk estimation	Estimate consequences; the probability and extent that benthic macrofauna diversity and species will be impacted	Risk evaluation matrix method

being done prior to more detailed quantitative analyses. This approach can be used to first rank the threats and associated hazards so that more effort can be allocated to quantitative risk analyses for the most important (i.e. highest priority) hazards. Quantitative risk assessment methods are becoming more widely used. They include decision or logic trees, probabilistic methods, predictive models, dynamic simulation models and Bayesian networks (McDaniels, Keen and Dawlatabadi, 2006; GESAMP, 2007). An example of a qualitative risk estimation using a simple matrix approach is shown in Table 3.

GESAMP has attempted to develop a "logic model" to explore and illustrate the complex causal chain between hazard and ecological end-points. The "release-exposure" model is rather limited and difficult to apply to many aquaculture-associated hazards

TABLE 3
Risk evaluation matrix for determining level of risk

Probability of exposure[2]	N	L	M	H	C
H	Yes	No	No	No	No
M	Yes	No	No	No	No
L	Yes	Yes	No	No	No
VL	Yes	Yes	Yes	No	No
EL	Yes	Yes	Yes	Yes	No
N	Yes	Yes	Yes	Yes	Yes
	Significance of consequences[3]				

[1] Yes = the risk is acceptable and the activity can be permitted; No = the risk is unacceptable and the activity cannot be permitted without further risk management.
[2] Level of probability: H=high, M=moderate, L=low, VL=very low, EL=extremely low, N=negligible.
[3] Level of significance: C=catastrophic, H=high, M=moderate, L=low, N=negligible.

Source: Standards Australia, 2004a.

(it was developed originally in relation to simple toxic chemical release and exposure of organisms). GESAMP has therefore built up causal models with information on the probability of a causal effect, the uncertainty (lack of knowledge or unpredictability) associated with the relationship and the severity of the effect (intensity, extent, duration).

This approach may serve as a useful tool to: a) analyze the nature and overall significance of the risk, b) communicate and exchange knowledge and perspective on the various relationships and associated risks/uncertainties and c) focus further work on key areas where probability, severity and uncertainty are all high, and where research can significantly reduce uncertainty.

There are also many variations on this in the form of networks, trees, matrices and associated scoring systems that can be used to explore alternative outcomes and/or the likely benefit to be derived from specific management interventions.

The wide range of environmental issues in aquaculture therefore requires a wide range of tools and approaches. The complexities of environmental risk assessment in aquaculture will also be influenced by a complex interaction of different factors related to the sector, such as:

- the variability associated with technology, farming and management systems, and the capacity of farmers to manage technology;
- the variability associated with location (i.e. climatic, water, sediment and biological features), the suitability of the environment for the cultured animals and the environmental conditions under which animals and plants are cultured;
- the financial and economic feasibility and investment, such as the amount invested in proper farm infrastructure, short versus long-term economic viability of farming operations, investment and market incentives or disincentives, and the marketability of products;
- the socio-cultural aspects, such as the intensity of resource use, population pressures and social and cultural values and aptitudes in relation to aquaculture; social conflicts and increasingly, consumer perceptions, all play an important role; and
- institutional and political factors such as government policy and the legal framework, political interventions, plus the scale and quality of technical extension support and other institutional and non-institutional factors that are also influential in determining the risks, possibilities for management and the success with which the risk analysis approach can be applied.

The risk analysis approach however can also be used, as it has been in Australia, to explore the risks associated with different technologies and indeed, to use such information to develop industry codes of practice (DPIF, 2005).

The role of social aspects

The social aspects of environmental risk analysis for aquaculture deserve special attention. Economic, political, legal and social concerns play important roles throughout the assessment, evaluation and decision-making stages of risk management. Ensuring dialogue between interested parties at all stages requires an understanding of the social aspects of risk along with an appreciation of the mechanisms by which stakeholders can be actively engaged in the process.

The evaluation of risk entails a judgment about how significant the risk is to the receiving environment and to those concerned with, or affected by, the decision. In conjunction with formal scientific input, this requires the examination of public and political judgments about risks alongside the measurable costs and benefits of the activity in question. The precise knowledge required for an objective evaluation is often lacking for environmental risk assessment and an element of judgment is therefore usually needed. Furthermore, environmental quality involves both scientific elements and social elements. There is, therefore, a need to consider carefully the social dimensions of a risk as a part of the decision-making process. Indeed, the process of risk analysis has, perhaps unfairly, been criticized as being "too scientific" and ignoring social values.

Society is increasingly conscious of the harm that its activities can cause to the environment and the harm to people or the loss of quality of life that can result from environmental degradation. Decisions about environmental risks should, according to DEFRA (2002), take account of social issues because:

- General awareness of environmental risks has increased, and this is often associated with heightened levels of concern;
- Recent experience has shown how essential it is to have in place a framework that ensures transparency in decision-making and that forms a justifiable basis for policies on environmental protection;
- Calls have been made for a greater degree of public involvement in decision-making processes for environmental protection; and
- There is increasing pressure on those who create and regulate risk to inform the public about the risks to which they and their environment are exposed.

In conjunction with the assessment of a risk, it is important therefore to ensure the decision-maker asks whether the risk is likely to be acceptable to those concerned with, or affected by, the risk or consequent management decision. Evaluating the social significance of a risk can guide decision-making and help towards communicating about the risk to interested parties. It is, therefore, essential that the decision-maker considers social dimensions as part of the processes to identify, assess, evaluate and manage risks to the environment. A further detailed discussion of the social aspects of risk is provided in DEFRA (2002).

Risk management

Risk management is the design, selection and implementation of a programme of actions to minimize risk to an acceptable level. Risk management measures may also include monitoring, the outcomes of which should be used to re-assess risk as well as to determine or modify the success of risk management measures.

Risk management measures to address environmental issues in aquaculture are now being used in several countries following risk assessment. An example is in the State of South Australia, where the type and level of environmental management and reporting requirements for effluents from inland aquaculture farms are varied depending on the risk classification from the assessment phase. Higher risk farms require additional parameters and increased frequency of sampling (Government of South Australia, undated).

Risk communication

The purpose of risk communication is to supply planners, managers, industry experts, environmental agencies and laypeople with the information that they need to make informed, independent judgments about risks to their health, about the safety of the operation under consideration and about the potential environmental effects, as well as concerning the economic and social risks associated with the development (DEFRA, 2002).

Risk communication is widely recognized as a critical component of the risk analysis process. GESAMP has identified the following important aspects for risk communication as applied to coastal aquaculture:

- **Social buy-in is critical:** Offer stakeholders a sense of ownership of the process and built trust in those conducting the exercise.
- **Stakeholders needs are important:** Identify issues of concern and stakeholder priorities that need to be incorporated in hazard identification and risk assessment.

- **Show what science can and cannot say:** Provide a sound mechanism by which stakeholders are informed about the nature and strength of causal relationships and the probabilities and uncertainties associated with the predicted environmental risks of the aquaculture development.
- **Build trust:** Guarantee that transparency of the entire risk analysis process leading to decision-making is facilitated by effective exchange of information and deals with perceptions, facts and uncertainty
- **Value non-science sources of information:** Ensure that all pertinent and significant data required for the risk analysis are captured, not only from solid natural science disciplines that allow assessment environmental influence or change, but also incorporating stakeholder information on objectives, priorities and perceived risks.

Communication about environmental risks serves many important purposes. It can be used either as a tool to provide information, explain and warn, or to encourage collective partnership approaches to decision-making through greater public participation in the risk management process.

Risk communication, although difficult to achieve successfully, can be implemented in different ways. It should also aim to engage diverse stakeholder audiences. These audiences may hold different values and have different levels of understanding, and the interpretation of a message can be dependent on a variety of social factors. Provided these complexities are borne in mind and the objectives are clearly defined, communication can achieve its desired outcome.

Efforts simply aimed at the provision of quantitative risk estimates are likely to be of limited value because of the complex nature of risk judgements. Communication should be sensitive to a broad concept of risk, encompassing not only quantitative information, but also other dimensions such as individual attitudes and issues of trust and credibility. GESAMP has further highlighted various objectives for risk communication as essential to:

- offer stakeholders a sense of ownership of the process and build trust in those conducting the exercise;
- identify issues of concern and stakeholder priorities that need to be incorporated in risk identification and risk analysis;
- ensure that user knowledge is effectively incorporated into the decision process;
- provide sound mechanisms by which stakeholders are informed about the nature and strength of causal relationships and the probabilities and uncertainties associated with the development;
- guarantee that transparency of the entire risk analysis process leading to decision-making is facilitated by effective exchange of information and deals with perceptions, facts and uncertainty;
- ensure that all pertinent and significant data required for the risk analysis are captured, not only from solid natural science disciplines that allow assessment of environmental influence or change, but also incorporating stakeholder information on objectives, priorities and perceived risks;
- provide the means so that any information generated as a result of the implementation of recommendations (e.g. for mitigation or additional research) arising from the risk analysis is also captured; and
- guarantee that the results of the risk analysis are communicated in a format that is clear and useful to individuals and organizations who use the information in their decision-making processes.

Of these eight objectives, the last is by far the most complex and challenging undertaking, because the groups receiving the information can have very different levels of understanding of the subject area and its perceived and real risks. Therefore, a high degree of flexibility is required to facilitate communication between scientists, planners, managers, regulators, developers and the public at both the governmental and local levels. It is almost impossible, without empirical testing, to predict the effects that effective communication will have on people's responses. Experts and laypersons alike often face difficulties associated with communication on subjects related to choice, risk or change. The process of risk communication, therefore, also involves educational steps in order to assess and respond to risks and benefits appropriately (Fischhoff and Downs, 1997).

CONCLUSIONS

Traditional risk analysis deals primarily with the human health concerns of various anthropogenic activities, but this approach has now been broadened to encompass a wide range of environmental concerns. Numerous protocols exist for estimating the human health risks associated with various hazards, and there are an increasing number for the analysis of environmental risks arising as a result of human activity.

There are a number of environmental hazards associated with aquaculture operations. The risk analysis framework is useful for identifying, evaluating and addressing environmental hazards associated with aquaculture, however, there are clearly a number of constraints and issues to consider:

- The potential hazards from aquaculture and their impacts depend upon the species, culture system and operations management practices, and other non-technical factors such as human capacity and institutional capacity.
- The likelihood of hazards becoming undesirable consequences is difficult to quantify given present knowledge and the lack of tools. The wide range of environmental hazards related to aquaculture requires a wide range of tools for risk assessment and skills among the people concerned.
- The effective use of risk analysis in aquaculture will also require effective communication and explanation of how risk analysis can be effectively applied to aquaculture issues, for government and industry stakeholders involved with aquaculture.

RECOMMENDATIONS

A number of recommendations arise from this overview of the use of risk analysis to address environmental issues in aquaculture:

- There are presently limited experiences and case studies associated with the more complex ecological risk analyses as applied to aquaculture. Promotion of case studies and sharing of experiences are needed.
- The information on risk analysis that could be applied to aquaculture is scattered across the literature, from peer review to grey literature. A practical manual would be useful to assist risk analysis practitioners in the sector and to raise awareness on useful applications.
- The understanding of some key issues (e.g. risks associated with aquaculture and ecosystem functions, use of trash fish) is still limited. As far as possible, simple tools should be developed for the different hazards concerned with aquaculture.
- The need for developing and demonstrating cost-effective risk management systems for small aquaculture operations is apparent.
- Capacity-building in all aspects of environmental risk analysis for aquaculture is needed.
- Risk analysis has a potentially important role in policy setting but to be successful needs the institutional roles and responsibilities should be carefully considered.
- A major challenge is to apply practical risk analysis methods to the small-scale aquaculture sector.

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Introduced marine species risk assessment – aquaculture

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ABSTRACT

Risk assessment is a tool that has many applications in marine biosecurity. Its application to aquaculture has only recently moved from the protective standpoint of animal health (i.e. the World Organisation for Animal Health, OIE) to examining introduced species risks. Risks from aquaculture include use of non-native species as target stocks in aquaculture; the potential for introductions of hitchhiker (associate) species when importing new stocks; the use of non-native live, fresh or frozen feed stocks and the movement of aquaculture equipment. In contrast, the risks to aquaculture from marine bioinvasions from other sources (including other aquaculture operators) include pathogens, parasites, biofouling and harmful algal blooms. Herein, we present two types of risk assessment (non-probabilistic decision-trees and a qualitative/semi-quantitative organism impact assessment) that are currently used in the marine biosecurity system in New Zealand and Chile, but are readily applicable to other introduced species risk scenarios. These methods do not rely on quantitative risk assessment methods because sufficient quantitative data are often lacking for introduced marine species work. However, quantitative data can be used within the assessments to identify likelihoods or consequence.

INTRODUCTION

Introduced marine species pose a significant threat to the native biodiversity, economy, sense of connectedness to the marine ecosystem and spirituality of individual countries. As such, the management of such threats has high priority at international, regional and national scales. The management of introduced species risk is often undertaken under the policy/management umbrella of biosecurity (biological security against the impacts of introduced species). Biosecurity is managed before or at the border in the form of quarantine, and post-border where both intentional and unintentional incursions are evaluated to undertake response, surveillance and monitoring.

Marine biosecurity has recently been identified by a number of international, regional and national bodies as a matter of significant urgency. Marine invasions are increasing in a number of regions throughout the world through a variety of different vectors such as shipping, recreational and fishing vessel movements, aquaculture, live food and aquarium trade. Shipping has been considered to be the most significant vector of invasions; however, aquaculture associated introductions have contributed the second largest number of invaders across several regions of the world. The contribution of aquaculture to new marine invasions is likely to increase with the global diversification and acceleration of aquaculture production, particularly in regions of the world where little production is occurring.

The need to pragmatically identify the relevant risks for management consideration is paramount given the significance and increasing perception of threat that marine invasions present to marine environmental, economic, social and cultural values, coupled with the reduction of available funds for managing the marine environment. Risk analysis is used to determine how often an event may occur and what the consequences would be of such an event. Within Australia and New Zealand, standards exist that provide best practice for risk management (Australian and New Zealand Standard Risk Management AS/NZ4360:2004).

Marine biosecurity risks associated with aquaculture activities can be differentiated as risks from aquaculture associated invasions and risks to aquaculture from marine biological invasions from other sources. Risks from aquaculture include the use of non-native species as target stocks in aquaculture; the potential for introductions of hitchhiker (associate) species when importing new stocks; the use of non-native live, fresh or frozen feed stocks and the movement of aquaculture equipment. In contrast, the risks to aquaculture from marine bioinvasions from other sources (including other aquaculture operators) includes pathogens, parasites, biofouling and harmful algal blooms.

In this context, a number of relevant risk assessment methods exist; however, these follow the classic risk analysis framework. The risk management standard (AS/NZ4360:2004) can be summarized in four steps: (i) establishing the context; (ii) identifying the risk (what are the hazards); (iii) assessing the risks (risk analysis and risk evaluation); and (iv) treating the risks, and assumes that a decision external to the risk analysis concerning identification of the end-point of the risk assessment and the Acceptable Level of Risk (ALOR) occurs.

AQUACULTURE IN A MARINE BIOSECURITY CONTEXT

As the world's population increases, food security (e.g. secure access to sufficient, safe and nutritious food for all people, at all times (Maxwell and Frankenberger, 1992; FAO, 2002) has become an important goal for many nations, and consequently it has emerged on the agenda of many non governmental organizations (NGOs) and intergovernmental agencies (e.g. FAO, 2002, 2003; Southgate, Graham and Tweeten, 2007). Increased population growth puts pressure on our environment via (over) consumption of resources (Barrett, 1992; Krautkraemer, 1995), which in turn places additional demand on our agriculture and fisheries to increase production rates. A bleak outcome has been suggested that food demand will outstrip availability by 2020 (Pinstrup-Andersen and Pandya-Lorch, 1998).

World fisheries are an important global food source (Kent, 1997; Pinstrup-Andersen and Pandya-Lorch, 1998; Tidwell and Allan, 2001), providing almost 95 billion tonnes of food in 2000 (FAO, 2002). Yet total foodfish production is unable to keep up with the rate of global demand and production is decreasing at a global per capita rate (FAO, 2002). It is estimated that up to 70 percent of the world's marine fisheries are already overexploited (Pinstrup-Andersen and Pandya-Lorch, 1998; Enger and Smith, 2006), with depletion of stocks outpacing the ability of regulatory agencies to respond (Berkes *et al.,* 2006). In response to this growing demand, global aquaculture has grown swiftly over the past 50 years (Ahmed and Lorica, 2002; FAO, 2002). Thus aquaculture is now seen as a mechanism to increase food security while helping to alleviate pressure on wild capture fisheries and supporting local communities (Pinstrup-Andersen and Pandya-Lorch, 1998; Tidwell and Allan, 2001; Ahmed and Lorica, 2002; Tlusty, 2002).

Intensification within this industry has lead to a number of impacts such as increased eutrophication (Gowen, 1994), antibiotics entering waterbodies (Lalumera *et al.,* 2004), the intentional and accidental introduction of non-native species (Economidis *et al.,* 2000; Tlusty, 2002; Chapman, Miller and Coan, 2003), impacts on predators (Crowl, Townsend and Macintosh, 1992), the increased use of fishmeal that is derived from wild fish stocks (Kautsky *et al.,* 1997; Naylor *et al*., 2000; Tidwell and Allan, 2001; Tlusty, 2002) and the conversion of mangrove forests (highly productive natural systems) into aquaculture ponds (Tidwell and Allan, 2001; Seto and Fragkias, 2007).

Typically, aquaculture uses either native species (a species that has lived in an area where it has been present in geologic time or to which it arrived through nonhuman-mediated means) or introduced species (a species that has been recognizably transported by the agency of humans to a new biological region where it previously did not exist (*sensu* Carlton, 1996) as the target crop. For example, both the red and green abalone (*Haliotis rufescens* and *H. discus hannai*, respectively) were introduced to Chile in 1977 and 1982 for aquaculture purposes that target poverty alleviation (abalone is not consumed by the local community but instead is sold on the world market; A. Brown personal communication). The Chilean cultured abalone industry has been very successful and is now ranked 5th as a global producer (Flores-Aguilar *et al.,* 2007). Abalone in this region is potentially a serious space competitor to the native and locally eaten predatory gastropod *Concholepas concholepas*, and the environmental, economic and social threats are recognized by the Chilean Government (Hewitt, Campbell and Gollasch, 2006). However, the societal benefits of abalone aquaculture, through poverty alleviation and economic diversification, are seen to outweigh the costs of using an introduced species in this instance.

In some instances introduced species are also used as a source of live feed for aquaculture (Lavens and Sorgeloos, 1996; Campbell, 2007). For example, microalgal species such as *Isochrysis* sp., *Pavlova lutheri, Chaetoceros muelleri, C. calcitrans, Nannochloropsis oculata, Skeletonema costatum* and *Tetraselmis suecica* are used in aquaculture, and a variety of strains from various regions of the world are readily available for purchase online.[1] At present the use of live aquaculture feeds poses a great risk to the natural environment because it represents a typically unregulated mechanism for the introduction of non-native species (Campbell, 2007). As such, live aquaculture feeds represent a "silent-sleeper" that may pose significant risks to the environment and ultimately, to the economy.

In contained aquaculture situations, the use of introduced species for target stocks poses a low risk to the environment, as the probability of release into the surrounding environment can be managed in such a fashion as to make it minimal. Yet many aquaculture situations are not contained (e.g. shrimp pond aquaculture in Thailand (Dierberg and Kiattisimkul, 1996), abalone culture in Chile (Flores-Aguilar *et al.,* 2007) or managed and regulated in such a fashion as to provide sufficient assurances that the use of introduced species will not contaminate the local environment, creating a greater risk. In general, introduced species pose a significant threat to the native biodiversity and economic and social well being of all countries (Lubchenco *et al*., 1991, Pimentel *et al.,* 2000; Hewitt and Campbell, 2007). As such, the management of such threats has high priority at international, national and regional scales.

The use of introduced species in aquaculture complicates the social benefits received from aquaculture (food security and poverty alleviation) and must be weighed against

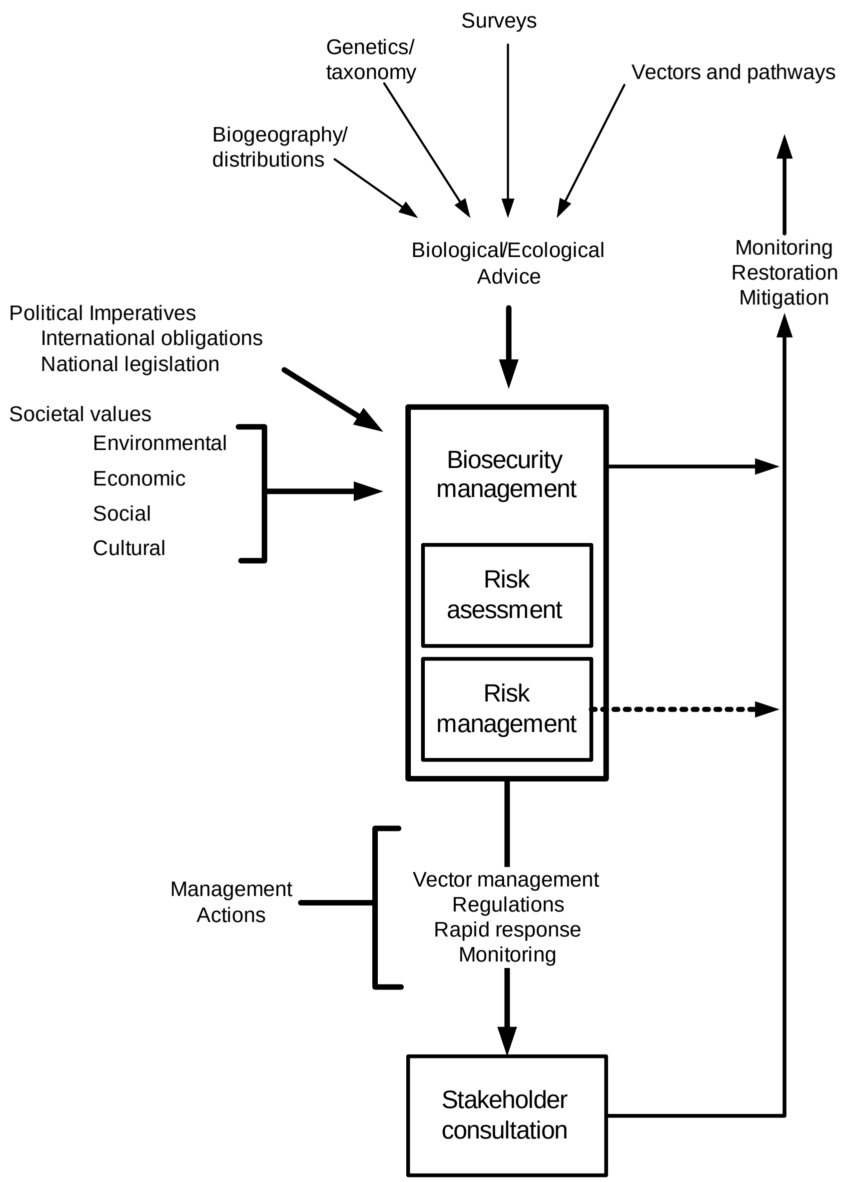
[1] For example, at http://www.cawthron.org.nz/seafood-safety-biotechnology/micro-algae-culture-collection.html; http://www.marine.csiro.au/microalgae/aquacul.html.

the impacts (costs) that introduced species may have if released into the natural environment (Hewitt, Campbell and Gollasch, 2006). A tool that is commonly used to assess the risk an introduced species poses to an area is risk analysis.

Risk analysis has become a popular tool for management because pragmatic decisions can be made that provide a balance between competing environmental and socio-economic interests, despite the limited availability of information. For example in New Zealand, risk analysis an integral component of the marine biosecurity system (Figure 1).

In this paper we describe the use of risk assessment in marine biosecurity (management of introduced marine species). We present pre-border (quarantine and import health standards) and post-border (surveillance and incursion response) examples of where risk analysis has been applied in a marine biosecurity context. Within an aquaculture context, introduced species can cause impacts to aquaculture facilities (including target species), or aquaculture can cause impacts to the natural environment via the use of

FIGURE 1
The New Zealand marine biosecurity risk model



introduced target marine species, introduced non-target marine species (referred to as "hitchhikers"), introduced live feed species and the inadvertent spread of introduced species via equipment transfer. This paper concentrates on the potential impacts that aquaculture may have on the natural environment through the use of introduced species and as such applies a precautionary approach from a Convention on Biological Diversity (CBD) ethos (i.e. it is preferable to make the mistake of denying entry to a non-pest than to allow entry of a pest, because a decision to admit a species is usually irreversible) instead of a World Trade Organization (WTO) ethos (i.e. it is preferable to allow trade unless there is a demonstrable and scientifically valid reason for not doing so).

RISK ASSESSMENT IN A MARINE BIOSECURITY CONTEXT

Risk analysis as applied in marine biosecurity consists of four processes: risk assessment (the process of characterizing risk), risk management (the process of deciding what to do about risk), risk communication (the process of explaining risk) and risk policy (a meta-topic that spans across all processes and involves the development of regulatory guidelines). In a marine biosecurity context, risk assessment consists of five steps:

- identifying end-points,
- identifying hazards,
- determining likelihood,
- determining consequences and
- calculating risk.

This process is similar to the risk management standard (AS/NZ4360:2004) used in Australia and New Zealand (Standards Australia, 2000, 2004). This risk assessment process is explained below from a marine biosecurity perspective and is based upon a semiquantitative risk assessment procedure used by the authors to capture stakeholder and expert perceptions in a number of risk assessments across several developed and developing countries.

Identifying end-points

The end-point of the risk analysis is a critical stage in scoping the context of the assessment and determines the detail of consequence analysis to be used. Typically risk analyses of unintentional introductions associated with target species, feed stocks and movement of equipment would consider quarantine end-points – that is, any unpermitted breach of the border. In contrast, the intentional importation of non-native species as target species for aquaculture or for food stocks will require an assessment of potential impacts through release. At this step an acceptable level of risk (ALOR) must be determined externally via socio-political imperatives, to set a benchmark by which all risk assessment outcomes are measured. By determining ALOR externally, transparency and consistency in the decision-making process is maintained.

Identifying hazards

Hazards in marine biosecurity are non-native species that are requested for importation for aquaculture purposes and will cause a risk. These species are typically identified pre-border through examination of their presence in the source region from which the intended transfer will occur, coupled with a history of invasions in other regions, a demonstration of impacts and an evaluation of physiological compatibility between the species and the receiving region. For transfers of equipment, standardized import risk assessments will aid in identifying the association of species in the source region with the transport pathway on the basis of duration and timing (seasonality) of exposure, and conditions and duration of transfer that might restrict or limit survival of species present on or in the equipment.[2]

[2] See, for example, http://www.biosecurity.govt.nz/imports/animals/standards/anieqpic.all.htm.

TABLE 2a
Consequence matrix: environment, as defined by the subcomponents and Including biodiversity, species, habitats, natural character, aesthetics, etc.

Descriptor	Environmental impacts from introduced species
Insignificant	• Environment reduction is minimal (<10%) compared to loss from other human-mediated activities • Reductions in environment subcomponents are not readily detectable (<10% variation) • If the introduced species was removed, recovery is expected in days; no discernible change in the environment
Minor	• Environment reduction is <20% compared to loss from other human-mediated activities • Reductions in environment subcomponents are <20% • Environment reductions and area of introduced species impact is small compared to known areas of distribution (<20%) • If the introduced species was removed, recovery is expected in days to months; no loss of keystone species populations, no discernible change in geological form and function; no local extinctions
Moderate	• Environment reduction is <30% compared to loss from other human-mediated activities • Reductions in environment subcomponents are <30% • Environment reduction and area of introduced species impact is moderate compared to known area of distribution (<30%) • If the introduced species was removed, recovery is expected in less than a year; loss of at least one keystone species or population, loss of geological form and function, no loss of primary producers; local extinction events
Major	• Environment reduction is <70% compared to loss from other human-mediated activities • Reductions in environment subcomponents are <70% • Environment reduction and area of introduced species impact is small compared to known area of distribution (<70%); likely to cause local extinction • If the introduced species was removed, recovery is expected in less than a decade; loss of several keystone species or populations, changes in trophic levels, loss of primary producer populations, loss of geological form and function; multiple local extinction events; one regional extinction
Significant	• Environment reduction is >70% compared to loss from other human-mediated activities • Reductions in environment subcomponents are >70% • Environment reduction and area of introduced species impact is small compared to known area of distribution (>70%); likely to cause local extinction • If the introduced species was removed, recovery is not expected; loss of multiple species or populations causing significant local extinctions and loss of trophic levels, potential trophic cascades resulting in significant changes to ecosystem structure, alteration to biodiversity patterns and changes to ecosystem function, loss of geological form and function; global extinction of at least one species

Source: Modified from Campbell, 2005.

Determining likelihood

The likelihood (or probability) of an event (intentional or unintentional release of a non-native species) occurring is determined using a standardized likelihood matrix (Table 1). The event is defined as an incursion (intentional or unintentional release of a species) when using a quarantine end-point or as an impact when using an impact end-point. Likelihood measures are typically represented as qualitative descriptions (ranging from rare to almost certain), or they can be represented as a probability.

To determine the likelihood for introduced target, non-target and feed species used in aquaculture the propagule strength, the likelihood of inoculation and establishment, and the likelihood of impacts are assessed. To assess the threat from equipment movement, the exposure of the equipment to the introduced species is assessed by determining the volumes or amount of exposure (frequency of exposure) and the timing of exposure (seasonality).

Determining consequences

Consequence is determined via a number of different mechanisms. Typically in marine biosecurity a semiquantitative approach is used to capture stakeholder and expert perceptions and is combined with available quantitative data. Quantitative risk

TABLE 2b

Consequence matrix: economy as defined by the subcomponents and including primary and secondary industry, tourism, education, intrinsic value, etc.

Descriptor	Economic impacts from introduced species
Insignificant	• Reduction in national income from introduced species impact shows no discernible change • No discernable change in strength of economic activities • If the introduced species was removed, recovery is expected in days
Minor	• Reduction in national income from introduced species impact is <1% • Reduction of strength in individual economic activities is <1% • Economic activity is reduced to 99% of its original area (spatial context) within New Zealand • If the introduced species was removed, recovery is expected in days to months; no loss of any economic industry
Moderate	• Reduction in national income from introduced species impact is 1–5% • Reduction of strength in individual economic activities is 1–5% • Economic activity is reduced to less than 95% of its original area (spatial context) within New Zealand • If the introduced species was removed, recovery is expected in less than a year with the loss of at least one economic activity
Major	• Reduction in national income from introduced species impact is 5–10% • Reduction of strength in individual economic activities is 5–10% • Economic activity is reduced to less than 90% of its original area (spatial context) within New Zealand • If the introduced species was removed, recovery is expected in less than a decade with the loss of at least one economic activity
Significant	• Reduction in national income from introduced species impact is >10% • Reduction of strength in individual economic activities is >10% • Economic activity is reduced to less than 90% of its original area (spatial context) within the New Zealand • If the introduced species was removed, recovery is not expected with the loss of multiple economic activities

Source: Modified from Campbell, 2005.

TABLE 2c

Consequence matrix: social as defined by the subcomponents and including aesthetics, family, individual and cultural activities, learning, etc.

Descriptor	Social Impacts from Introduced Species
Insignificant	• Social activity reduction is minimal (<1%) • No discernable change in strength of social activities • If the introduced species was removed, recovery is expected in days
Minor	• Social activity reduction is <10% • Reduction of strength in separate social activities is <10% • Social activity is reduced to less than 90% of its original area (spatial context) within the region • If the introduced species was removed, recovery is expected in days to months; no loss of any social activities
Moderate	• Social activity reduction is <20% • Reduction of strength in separate social activities is <20% • Social activity is reduced to less than 80% of its original area (spatial context) within the region • Social activity reduction is restricted to the region of incursion/impact • If the introduced species was removed, recovery is expected in less than a year and loss of at least one tourism activity
Major	• Social activity reduction is <40% • Reduction of strength in separate social activities is <40% • Social activity is reduced to less than 70% of its original area (spatial context) within the region • Social activity is reduced in neighbouring regions • If the introduced species was removed, recovery is expected in less than a decade and loss of at least one tourism activity
Significant	• Social activity reduction is >40% • Reduction of strength in separate social activities is >40% • Social activity is reduced to less than 60% of its original area (spatial context) within the region • Social activity is reduced in neighbouring countries • If the introduced species was removed, recovery is not expected and loss of multiple tourism activities

Source: Modified from Campbell, 2005.

TABLE 2d
Consequence matrix: cultural as defined by the subcomponents and e.g. using New Zealand Maori values such as whakapapa (creation), wai tapu (sacred waters), waiora (spiritual waters), wai kino (tainted or bad waters), mahinga kai (food gathering areas)

Descriptor	Cultural impacts from introduced species
Insignificant	• Cultural activity reduction is minimal (<1%) • No discernable change in strength of cultural activities • If the introduced species was removed, recovery is expected in days
Minor	• Cultural activity reduction is <10% • Reduction of strength in separate cultural activities is <10% • Cultural activity is reduced to less than 90% of its original area (spatial context) within the region • If the introduced species was removed, recovery is expected in days to months, no loss of any social activities
Moderate	• Cultural activity reduction is <20% • Reduction of strength in separate cultural activities is <20% • Cultural activity is reduced to less than 80% of its original area (spatial context) within the region • Cultural activity reduction is restricted to the region of incursion/impact • If the introduced species was removed, recovery is expected in less than a year and loss of at least one tourism activity
Major	• Cultural activity reduction is <40% • Reduction of strength in separate cultural activities is <40% • Cultural activity is reduced to less than 70% of its original area (spatial context) within the region • Cultural activity is reduced in neighbouring regions • If the introduced species was removed, recovery is expected in less than a decade and loss of at least one tourism activity
Significant	• Cultural activity reduction is >40% • Reduction of strength in separate cultural activities is >40% • Cultural activity is reduced to less than 60% of its original area (spatial context) within the region • Cultural activity is reduced in neighbouring countries • If the introduced species was removed, recovery is not expected and loss of multiple tourism activities

Source: Modified from Campbell, 2005

assessment is not common in a management context (although see Hayes and Hewitt, 1998; Hewitt and Hayes, 2001) because the data requirements are onerous, especially considering that little information is available for many introduced marine species impacts.

Introduced species impacts can affect a range of values (includes both use and non-use values). Hence, consequence matrices have been developed across four core values (environmental, economic, social and cultural) that explicitly delineate rankings of impact (consequence) from insignificant to significant (or catastrophic) to aid stakeholder and expert discussion (Tables 2a-d). These matrices provide multiple descriptions of impact at the various ranks to provide guidance in determining level of impact.

Thus, to assess the impacts of using introduced target, non-target and feed species in aquaculture, the impacts to core values are first identified (through expert opinion and data) and then evaluated. The probable impact to a region is then calculated for each introduced species. Finally, risk maps can be developed that evaluate the introduced species potential distribution if released, the species likely impacts and the core values. The resulting product of likelihood and consequence provides the risk ranking that is then compared against the ALOR identified through the external process.

Calculating risk

Estimated risk is assessed for each core value against a standard risk matrix (Table 3). Risk is described in qualitative terms, ranging from negligible to extreme. Uncertainty is represented by presenting a range of estimated risk for a core value. The outcomes of the risk assessment feed into a risk management process, which is simplistically summarized in Table 4.

EXAMPLES

Examples of relevant applications of marine biosecurity risk assessments are provided where the semi-quantitative procedure has been employed.

Pre-border examples

Typically, pre-border impacts from aquaculture are focussed on aquatic animal health standards developed by the World Organisation for Animal Health.[3] These standards are focussed on animal disease only and ignore other threats that an imported introduced species may have on the receiving environment. Thus, the impact from the release of an introduced species is rarely evaluated. In Chile, the government has developed an iterative import system that defines acceptable and unacceptable levels of risk and assesses both the risk associated with a release of an introduced species and the cost:benefits associated with farming the species (A. Brown, pers. comm.; Campbell, in press). The Chilean assessment covers all core values and hence the environment is evaluated against the socio-economic aspects.

Live feed species for aquaculture can also be assessed through the import health standards. In some circumstances these species are omitted from the process due to regulation loopholes that allow species to be given import permission (permitted) before undergoing a rigorous risk assessment. Examples of instances where import health standards have failed to protect the native environment because the marine species standards were naive (due to a poor understanding of marine species biology) or lacked a marine biosecurity expertise input include the importation of fish bait that led to the herpes virus outbreak along southern Australia, resulting in large fish kills (Griffin *et al.*, 1997).

In New Zealand prior to 1996, 85 percent of importations of microalgae (used for multiple purposes including aquaculture live feed source) did not use containment or transition facilities, of which 39 percent of these importations were released directly into the marine environment (Campbell, 2007). Also, a large proportion of records (46 percent of cases) were insufficient in recording whether containment or release of the

TABLE 3
Risk matrix

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Significant
Rare	N	L	L	M	M
Unlikely	N	L	M	H	H
Possible	N	L	H	H	E
Likely	N	M	H	E	E
Almost Certain	N	M	E	E	E

Legend: N-negligible; L – low; M – moderate; H – high; E - extreme

TABLE 4
Simplified risk management process

Risk	Likely scientific and management action(s)	Reporting
Negligible	Nil	Nil
Low	None specific	Required
Moderate	Specified scientific and management activities required	Required
High	Possible increases to scientific and management activities required	Required
Extreme	Additional scientific and management activities required	Required

[3] Formerly the Office international des épizooties (OIE); http://www.oie.int/eng/normes/en_acode.htm?e1d10

TABLE 5
The risk *Didymosphenia geminata* poses to the New Zealand core values. Likelihood is derived from Table 3 and consequence is derived from Table 4

	Stakeholder group region								
	Southland			Top of the South			Hawkes Bay		
	L	C	R	L	C	R	L	C	R
Environment	Likely	Significant	E	Possible	Major	H	Possible	Major	H
Economic	Likely	Significant	E	Possible	Significant	E	Possible	Significant	E
Social	Likely	Major	E	Possible	Moderate	H	Possible	Significant	E
Cultural	Likely	Major	E	Possible	Significant	E	Possible	Major	H

Legend: L – likelihood; C – consequence; R – risk; E – extreme risk; H – high risk

Source: Campbell, 2005

imported species occurred (Campbell, 2007). Prior to 1996, risk assessments did not occur for importations of microalgae, with a permitting process that collected data but did not strenuously assess risk being used. In 1996, the Hazardous Substances and New Organism (HSNO) Act was passed. An outcome of this new legislation was that all new organisms imported to New Zealand should have been assessed via a risk assessment process undertaken by another government ministry. Yet risk assessments still only occurred on an *ad hoc* basis (personal observation) and were not fully implemented unless a member of the Marine Biosecurity team (different government ministry) was requested to undertake such an analysis.

To improve this process, a microalgae non-probabilistic decision-tree (Figure 2) was developed to assess whether importations of microalgae should occur and to determine the risk each importation posed to New Zealand's aquatic environment. This system was implemented in 2005 and works efficiently if the government ministries communicate effectively to ensure that an expert in marine biosecurity is involved in the risk assessment process.

Such failures of the pre-border biosecurity system represent an extreme management risk but also highlight how unknown vectors (live feed) can pose a threat in an aquaculture system, although the system is regulated and meets current biosecurity standards.

Post-border example

In a post-border situation, an introduced species has been released from the aquaculture facility either unintentionally or intentionally and the end-point being assessed is impact. Risk assessments in this context determine the level of geographic spread and the level of impact to core values from the released introduced species. An example of a successful method used to assess risk in such circumstances is an Organism Impact Assessment (OIA). OIAs have been used in New Zealand to assess the risk of spread of the introduced diatom *Didymosphenia geminata* (Campbell, 2005), which was most likely introduced to New Zealand via recreational fishing equipment. OIAs have also been used to assess the risk posed by the invasive ascidian *Styela clava* (Kluza *et al.*, 2006) and to assess the threat of introduced species to high-value areas such as Marine Protected Areas (Campbell, 2006).

OIAs work by determining the likely geographic spread (likelihood) and impact (consequence) of a released species. To determine a species' potential spread, biological (e.g. environmental tolerances) and ecological (distribution and abundance) information about the released species is collated for both its realized and fundamental niche. The results of this analysis are placed into a geographic information system (GIS) to illustrate the spatial extent of the threat. For example, the likely spread of *D. geminata* in New Zealand, based on its fundamental niche, was 90 percent (26/29) of the river systems across both the North and South Islands (Campbell, 2005). Likelihood was then assessed against a standardized likelihood matrix (Table 1). Based on the species likely spread, core values (environmental, economic, social and cultural) are identified in likely affected regions. Evaluation of impacts can then occur for values that overlap with likely introduced species spread. Evaluation of impacts can be regionalized or cover an entire country.

In the *D. geminata* example, evaluations were regionalized over three zones, two in the South Island and one in the North Island of New Zealand and were examined for the 26 rivers that would likely be affected. At the time, very little literature was published on the impacts that this species had on the environment, with conflicting biological data also existing. Hence, a Delphic approach (exploring stakeholder and expert opinions and beliefs) was used to engage stakeholder groups (consisting of a cross section of society) from the three regions. Stakeholder groups determined the perceived value of each river and then the perceived change in value if *D. geminata* was introduced to the river (Atkinson and Rapley, 2005).

Uncertainty in the results was reflected by using ranges of peoples' value change. In some instances changes in perceived value could be illustrated using dollars (e.g. against economic core values), but in other instances changes in value were illustrated using a scale of low to medium (cultural values). The outcome of the perceived change in value for each core value was then assessed against the consequence matrices (Tables 2 a-d). The end result was that for the three regions a level of risk was determined based on heuristic methods (Table 5; Campbell, 2005), and from this outcome decision-makers could determine if an eradication attempt should be made.

CONCLUSIONS

In conclusion, marine biosecurity risk assessments follow standardized risk procedures and can include qualitative, semi-quantitative and fully quantitative methods depending on the complexity required for decision making. Due to significant data limitations in the marine environment, particularly with regards to baseline biological data from trading partners, semi-quantitative and qualitative assessments remain more tractable.

The precautionary approach is employed for risk assessments of non-native species whereby the species is assumed to be guilty until proven innocent. In practical terms, this translates into an assumption of harm where information may not exist, particularly when importing a new species for release. Target species Organism Impact Assessments have proven extremely useful in identifying management options, even following an incursion event, however it should be noted that the ability to predict which species will invade or the potential impact of a species once it is introduced remains poor.

Lastly, the use of non-native food stocks as live, fresh or fresh-frozen material is likely to represent the "silent sleeper" of aquaculture-associated invasions. The unmanaged use of non-native microalgae, protists and invertebrates in flow-through hatcheries and open-environment farms is likely to have caused a large number of unrecognized invasions throughout the globe. These food stocks may also represent a poorly managed pathway of pathogen importation that can affect both cultured and wild stocks, as has been the case in the Australian and New Zealand pilchard kill in the mid 1990s.

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Guidelines for ecological risk assessment of marine fish aquaculture[1,2]

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ABSTRACT

The purpose of this paper is to exemplify a basic set of guidelines for risk managers and other decision makers to use all information available to assess the different ecological risks of marine fish aquaculture in a variety of marine ecosystems. Ten areas of substantive risk in the interaction between marine fish aquaculture are perceived by the public and public administrators to be of most concern. In this review three of the 10 areas of risk are exemplified for their degree of potential adversity, together with their mitigation, in an identical step-by-step process. These examples outline the approach for conducting a risk assessment for all 10 perceived issues in the paper itself. With the help of a flowchart, the template identifies biological end points or entities and their attributes, both locally and far field, which might be affected for that respective area of risk; and appropriate

[1] This paper is based on a NOAA document edited by the above authors, an outcome of an international workshop held in April 2005 and participated by Kenneth M. Brooks (USA), Stefano Cataudella (Italy), Brett R. Dumbauld (USA), William T. Fairgrieve (USA), John R. M. Forster (USA), Robert N. Iwamoto (USA), David F. Jackson (Ireland), Sadasivam J. Kaushik (France), Michael B. Rust (USA), Philip A.D. Secretan (England), Karl D. Shearer (USA), Ole J. Torrissen (Norway) and Masashi Yokota (Japan).

[2] Outcome of the NOAA Fisheries Service Manchester Research Station International Workshop, 11–14 April 2005 and published in full as NOAA Technical Memorandum NMFS-NWFSC-71.

methodologies that can be used for measuring or monitoring the effects of exposure to each specific risk. The paper also contains a biological overview of some respective risk, and briefly discusses factors that may enhance or mitigate the risk's occurrence. For the benefit of risk managers and risk assessors in all parts of the world, the risks are framed in a matrix to suggest different orders of relevance for their application in different climatic zones.

INTRODUCTION

Few, if any, human interventions in the environment fail to have impact. In some cases interventions are potentially so damaging that they must be eliminated. On the other hand, the majority of human interventions are purposeful and designed to be of benefit to humans, so it is necessary that they proceed responsibly, sharing equitably in the use of nature's vital resources. It is thus important that these interventions are carefully managed with good stewardship to ensure that benefits can be achieved over time frames of many decades.

Aquaculture, together with fisheries and agriculture, has long been a provider of food for human consumption. For over three millennia it has been a necessary and often the only source of animal protein for pastoral communities living at subsistence levels. But within the last century, its history has dramatically changed, and science and technology have propelled modern aquaculture into semi-intensive and intensive farming systems. These systems have greatly increased its degree of exposure to the environment. Consequently, although aquaculture remains a crucial cornerstone of rural life in many countries, its modern practices and array of commercial end products are, to the rest of the world, dependent more on human life-style decisions governed by social choice.

Fortunately, an important factor in social choice as aquaculture emerges in the twenty-first century is not only to minimize the impact of all human interventions on the environment but also to sustain the existing integrity of its many ecosystems in perpetuity. This has become a challenge to all resource-based industries, not only marine aquaculture. There are innumerable aquatic ecosystems in which aquaculture intervention is feasible. Each and every ecosystem has its own very specific and desired values, and therefore for the stewards of these resources to set specific goals around these values, it is necessary for them to know in advance 1) what integrity means for each ecosystem and what specifically needs to be protected; and 2) which ecological resources and processes have to be sustained and for what reason. Compared with that of terrestrial ecosystems, comprehensive knowledge of aquatic ecosystems is severely constrained. Partly this is because much of the ecosystem lies below water and is thus not readily observable, but also the need for extensive environmental research of marine ecosystems is only now becoming recognized in many countries.

Many aquatic and terrestrial ecosystems can be said to be equally fragile, but the ecosystem components may differ as do the mechanisms available for remediation. Most human interventions in aquatic ecosystems, such as mineral extraction, fishing and now aquaculture, may induce more lasting far-field effects unless properly managed. Nonetheless, these and any other industries that integrate with open waters, such as tourism and recreational boating, all have a right to exist equitably as stakeholders. The effects on the aquatic ecosystem by one should not eliminate the existence of another, unless selection has been an informed public choice.

In enabling aquaculture to share aquatic resources responsibly, the stewards of these resources are faced with many options. Invariably these options cannot be quantified adequately, and thus managers must estimate their potential ecological risks through individual risk assessments. Nonetheless, although ecological risks are a paramount concern, the final decision is frequently decided by other factors brought to bear

BOX 1
Definition of participants in the risk assessment process

Risk manager – Any individual and organization having the responsibility or the authority to take action or require action to mitigate an identified risk. Typically the term describes a decision-maker in a government organization who has legal authority to protect or manage a resource. However, a risk manager may be any interested party who has the ability to take action to reduce or mitigate a risk; for example, the owner or manager of an aquaculture facility.
Risk assessor – A professional who brings a needed expertise to a risk assessment team from any number of relevant fields, including, for example, risk assessment, marine ecosystems, coastal zone management, marine engineering, marine biology, oceanography, aquaculture, fish nutrition, fish disease etc.
Stakeholders – Any individual, company or organization that has a direct or indirect interest in, or could be affected by, an aquaculture operation.

by social choice, such as economic benefits to a local community or issues of public health.

PURPOSE OF THE GUIDELINES DOCUMENT

The purpose of this document is to provide guidelines for risk managers, risk assessors and anyone involved in the risk assessment process (Box 1) to address risks to the environment. All possible fields are listed in Box 1. The specific focus is on the possible effects or impacts of finfish aquaculture, but with several caveats:

- The guidelines are limited only to the assessment of ecological risks. Although, as noted, final decisions are invariably made by risk managers using a broader range of factors, such assessments of economic risks and human health risks by any intervention of aquaculture are not part of this work.
- The guidelines are applicable only to the risk assessment of marine fish aquaculture. The diversity of aquaculture, with its many systems and practices producing more than 200 species of aquatic animals and plants in a variety of fresh and saline waters, is too much to consider in a single document. However, it is anticipated that these guidelines will greatly simplify risk assessments in most other fields of aquaculture.
- The guidelines are confined to the risk assessment of marine fish aquaculture based on its effects on and not from other elements of the environment. Although marine aquaculture is vulnerable to the degradation of water quality as a consequence of poorly managed development in the coastal zone, most countries have regulatory structures and guidelines in place to protect aquaculture, and in time these standards will be improved by combining the risks to the environment from all sources.

USING THE GUIDELINES DOCUMENT

Before any decisions can be made with regard to the siting or operation of a marine aquaculture facility, the first responsibility of risk managers, and that includes both managers of resources as well as managers of aquaculture operations, is to draw their conclusions from all information provided by the risk assessors that a perceived risk to a particular ecosystem has validity or not, and if so to estimate its degree of adverse effect. This may or may not be a straightforward task. In some cases the information reported to them by the risk assessors may be an excellent combination of field and laboratory data to compare with recognized benchmarks of stress, while in others it may be no more than the long-time experience of practitioners.

BOX 2

Possible contents of a risk assessment report.

- Description of preliminary objectives and plans
- Description of environmental setting for the planned development
- Description of proposed aquaculture practice and species to be cultured
- Review of the conceptual model and assessment end points
- Discussion of major data sources and analytical procedures used
- Review of stressor response and exposure profiles
- Description of risk to assessment end points, including risk estimates and adversity evaluations
- Review and summary of major areas of uncertainty, their direction, and approaches used to address them, such as:
  - Discussion of the degree of scientific consensus in key areas of uncertainty.
  - Identification of major gaps and, where appropriate, indication of whether gathering additional data would add significantly to the overall confidence in assessment results
  - Estimation of the risk probability by combining numerical data
  - Discussion of science policy judgments or default assumptions used to bridge information gaps and the basis for the assumptions
  - Discussion of how elements of quantitative uncertainty analysis are embedded in the estimate of risk

Irrespective of the final detail, it is important that the information is considered, collected, analyzed, characterized and reported in a structured fashion. This ensures that the risk assessment report is not only complete as far as it can be (Box 2), but also that it can be compared directly with similar risk assessments made by other individuals elsewhere.

These guidelines for the risk assessment of marine fish aquaculture attempt to facilitate the work of risk assessors and risk managers to achieve these objectives. In brief, the guidelines:

- identify the ten areas of substantive risk in the interaction between marine fish aquaculture operations and the environment;
- identify the biological end points or entities and their attributes, both locally and far field, that might be affected in those areas of risk;
- identify methodologies for measuring or monitoring the effects of exposure to each area of risk;
- provide a common framework or step-by-step process to estimate the degree of potential adversity of each area of risk, together with its mitigation; and
- provide a concept of the physical and environmental demands of marine fish aquaculture sites, and a matrix to suggest different orders of relevance for the application of each area of risk in different global ecosystems.

In planning a risk assessment, it is recommended that the risk managers and risk assessors, together with others with experience in marine fish aquaculture, first review the areas of risk identified as priorities in the guidelines, and establish their relevance in their own geographic region and to the particular local ecosystem where marine aquaculture facilities are to be sited. It is very probable that not all areas of risk will be applicable to every development site, and therefore a matrix has been developed as part of the guidelines to suggest some of the more common differences (see "Near-field and Far-field Effects" subsection on page 10). For those that are important, the respective templates described in Appendices A–J of NOAA Technical Memorandum NMFS-NWFSC-71 (see Appendices list) can be used.

ECOLOGICAL RISK ASSESSMENT OF MARINE FISH AQUACULTURE

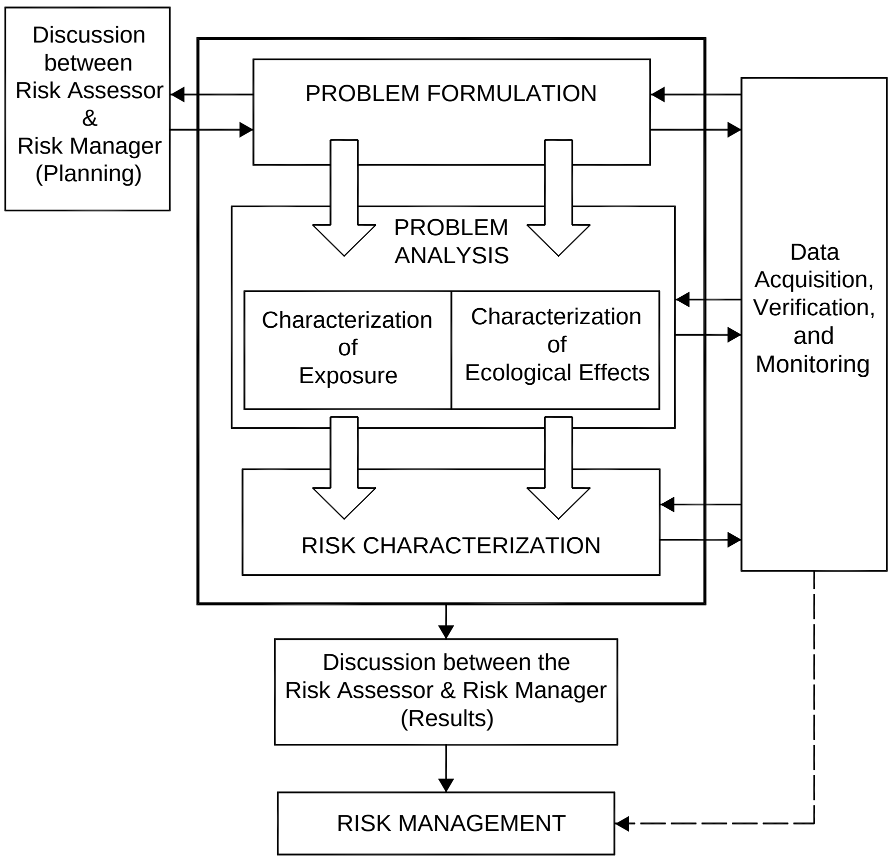
Framework

For more than 20 years, countries have been developing national guidelines for environmental risk assessment. At first their focus was predominantly on environmental risks to a single species (humans) and one end point (human health), but later nonhuman-oriented environmental risk assessments were included. These not only considered the risk to entire communities and addressed any number of selected end points, but they also included the possible effects of non-chemical stressors.

In order to accommodate the sudden burst of different views and approaches to environmental risk assessment by its member countries, the United Nations (UN) World Health Organization (WHO) developed a common analytical framework. The WHO Framework is adopted here for developing *Guidelines for Ecological Risk Assessment of Marine Fish Aquaculture* (NOAA Technical Memorandum NMFS-NWFSC-71) because it provides a generic analytical framework that has been widely reviewed and accepted by international experts in UN-sponsored workshops.

The WHO Framework (Figure 1) represents the scope of the guidelines for undertaking ecological risk assessments. It represents a three-dimensional figure, with planes surrounding the actual risk assessment to depict the total process. These planes represent the continuum for all those who are involved in the decision-making process and include not only the interactions between risk managers and risk assessors (the scientific and technical experts), but also their interaction with stakeholders who may be affected by any decision. For marine aquaculture, participating stakeholders are typically the fish farmers and their trade associations, waterfront property owners,

FIGURE 1
The WHO framework for ecological risk assessment



recreational users of waters, other fishing and aquaculture bodies, and environmental advocacy groups. The extent of stakeholder interaction, and at what point it is considered in the decision-making process, is the prerogative of the decision-maker, and varies from one country to another in accordance to the regulatory, legal and decision-making climate. Furthermore, stakeholders might perform their own risk assessments with or without the help of technical consultants, with differences arguable in court.

The risk assessment process is itself divided into three segments. These segments represent three distinct phases of work, but once again there is a continuum of interplay between the persons involved.

The following sections describe in broad terms a generic risk assessment process but without direct application to any specific category of risk. Detailed processes can be found for all the principal categories of risk from marine fish aquaculture in Appendices A–J of NOAA Technical Memorandum NMFS-NWFSC-71.

Problem formulation for marine fish aquaculture (Phase 1)

The first phase is problem formulation, or the identification of key factors to be considered in the risk assessment. Here all the necessary plans are made by the risk managers and risk assessors to determine how the analysis will be performed. These include, for example:

- the scope, focus and sources to be considered (such as the type of marine aquaculture and species);
- the biological or ecological end points and their attributes that are the concern for protection (such as sea grass preservation, maintenance of water quality, avoidance of low dissolved oxygen, avoidance of eutrophication etc.);
- a conceptual model or diagram of how the culture system being assessed is thought to be organized; and finally,
- the plan for analysing the information and conducting the rest of the assessment.

Problem formulation can be a long and difficult process. It depends on the degree of familiarity with the particular field of aquaculture, how contentious are any issues and finally, who is involved. Unfamiliar problems, such as the location of marine fish cages in the migratory routes or breeding grounds of cetaceans, unquestionably take longer to formulate compared with, say, the location of a land-based marine fish hatchery adjacent to an existing recreational marina or fish processing plant.

Modern marine fish aquaculture has been evolving for almost 50 years. Consequently, considerable experience has been building with regard to any impact on marine ecosystems all over the world. Most of the practical knowledge and experience by fish farmers themselves has never been recorded, although some has been documented in gray literature, but a considerable volume of scientific and technical research can now be found in peer-reviewed journals. With this growing background information to draw on, it is possible for risk managers and risk assessors to undertake a very comprehensive problem formulation.

For the purpose of these guidelines, the possible observed or perceived effects of marine aquaculture have been summarized in ten categories (Table 1). Within these broad designations it is not possible to include all the possible effects that might be identifiable globally, and consequently the guidelines concentrate on the sources of effects and the end points or entities of concern together with their attributes, of known importance to the majority of marine ecosystems. A risk assessment can include any number of other effects, but practical experience suggests that the ten categories and their contents illustrated here provide a strong starting point. The biological end points of these possible effects are generalized in the following paragraph.

Biological end points of marine fish aquaculture and their attributes can be described in collective terms (such as the species abundance of the infauna), or very

TABLE 1
Categorization of observed or perceived effects associated with marine fish aquaculture and the identifiable sources of the stressor

Effects	Sources
1. Increased organic loading	Particulate organic loading
	Fish fecal material
	Uneaten fish feed
	Debris from biofouling organisms
	Decomposed fish mortalities on the farm
	Soluble organic loading
	Dissolved components of uneaten feed
	Harvest wastes (blood)
2. Increased inorganic loading	Nitrogen and phosphorus from fish excretory products
	Trace elements and micronutrients (e.g. vitamins) in fish fecal matter and uneaten feed
3. Residual metals	Zinc compounds in fish fecal material
	Zinc compounds in uneaten feed
	Copper compounds in antifouling treatments
4. The transmission of disease organisms	Indigenous parasites and pathogens
	Exotic parasites and pathogens
5. Residual therapeutants	Treatment by inoculation
	Treatment in feed
	Treatment in baths
6. Biological interaction of escapes with wild populations	Unplanned release of farmed fish
	Unplanned release of gametes and fertile eggs
	Cross infection of parasites and pathogens
	Planned release of cultured fish for enhancement or ranching
7. Physical interaction with marine wildlife	Entanglement with lost nets and other jetsam
	Entanglement with nets in place, structures, moorings etc.
	Attraction of wildlife species (fish, birds, marine mammals, reptiles)
	Predator control
8. Physical impact on marine habitat	Buoyant fish containment structures and mooring lines
	Anchors and moorings
9. Using wild juveniles for grow-out	Harvest of target and nontarget species as larvae, juveniles and subadults
10. Harvesting industrial fisheries for fish feed	Increased fishing pressure on the shoaling small pelagic fish populations

specifically by location (such as the discovery of giant tubeworms at hydrothermal vents). They may also be assessed generally (such as by the presence of certain species in the epifauna) or by specific measurements (such as by n, µg/g or µg/liter).

The end points identified in these guidelines for protection from marine fish aquaculture activities may include:

- the species richness and abundance of the seston, nekton or infauna;
- the abundance of a specific species in the seston, nekton or infauna;
- the species richness and abundance of the epifauna;
- the abundance of a specific species in the epifauna;
- the abundance of a specific species of marine mammal, reptile or bird;
- the immune resistance of demersal and pelagic fishes;
- the number and fitness of individuals in the natural (conspecific) population;
- the fitness of individuals in another fish population; and
- the abundance of the industrial fisheries.

The choice of species may be guided by whether one is looking for a surrogate for system stressors, system response or protection of some desirable biological attribute. Thus, one might measure a toxic phytoplankton species because of the desire to avoid blooms of harmful or nuisance species, or one might choose a species that is indicative of degraded environmental condition (e.g. capitellid worms or the presence of *Beggiatoa* spp. in sediments) or one might measure sea grass distribution because of its high protection status.

Problem analysis for marine fish aquaculture (Phase 2)

Problem analysis is the second phase of risk assessment when all available scientific information relevant to the issue is collected and applied. For the most part it is carried out by technical experts. Problem analysis is divided into two parts. The first is the analysis of exposure, which predicts or measures the spatial and temporal distribution of a stressor and a point of concern; the second is the analysis of effects (sometimes called the exposure response), which identifies and quantifies any adverse effects caused by a stressor.

Characterizing the background of an aquaculture site

It is important to know the characterization of the marine site(s) where the stressor originates and where it may have its adverse effects. Therefore, the first step is a baseline survey or stock-taking of information about the near field and in some cases, the far field. The survey is in two parts, namely, collecting information through a literature search followed by assembling current information and data by field work.

Historical information

A valuable part of the baseline survey is a search of existing literature of water and sediment quality parameters. These include, for example, data on water temperatures, salinity, dissolved oxygen, stratification, bottom currents, water depth, background nutrient concentrations, phytoplankton species and chlorophyll, sediment grain size and organic matter content. In those cases where information is not available, then a programme of data collection should be initiated to fill the gaps. It is hard to be prescriptive about spatial and temporal scales of measurement, but measurement of some water quality parameters may need to be taken on a weekly basis during seasons of high phytoplankton productivity.

Some additional information might be available on the background levels of contaminants in both the water and the sediments. These include, for example, metals, and organics such as hydrocarbons, pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) etc. This information is particularly important (and more likely to be available) in near-shore coastal areas where there are significant anthropogenic inputs from agricultural and urban areas. In open waters, there is little potential for the accumulation or discharge of these types of contaminants, and the need is reduced.

Finally, any documentation providing a broad description of the natural history of the area, together with any reports or local knowledge of the potential for noxious phytoplankton blooms or the prevalence and intensity of known parasites is potentially useful. Information on the incidence of blooms and parasites is more likely if there are commercial shellfish resources in the area.

Current information

A typical baseline survey of current information for the lease area will include most of the items from the following checklist:

- Identification of sensitive habitats. These may include, for example, beds of macroalgae and eelgrass, coral reefs, commercially valuable shellfish beds, spawning grounds and breeding areas, migratory pathways of aquatic species, rocky reef communities and all other structures valuable as nurseries. Such habitats within 500 m of a proposed intensive farm site should be mapped, with the intention of avoiding them whenever possible.
- The background physico-chemistry of the sediments. This may include, for example, total volatile solids (TVS) or organic matter content, redox potential (Eh), sediment grain size (SGS), free sulfide (S=) and the two inorganic metals copper and zinc.

- An inventory of the species and abundance of the macrobenthic communities. This may be carried out by stratification or by the type of habitat.
- The hydrographic variables, such as currents, tides and residence times, including acoustic doppler current profiler (ADCP) data collected over at least one lunar cycle and bathymetry within 500 m of the proposed site.
- A profile of water quality, including temperature, salinity and the potential for stratification as a function of season (pycnoclines and haloclines).
- A profile of primary productivity, including major species (including any toxic species), chlorophyll (Chla), phaeophytin and dissolved oxygen (DO).
- If possible, underwater surveys recorded on a video or a series of photographs to provide an overall, semiquantitative assessment of the benthic environment of the site, especially in deep water.
- Finally, identification of activities by other resource users, such as marine sanctuaries, marine protected areas, fishing grounds, recreational areas, navigational channels, oil and mineral extraction, military training areas, approved dumping grounds etc.

The grid on which this information for the baseline survey is to be collected depends on the homogeneity of the system. A regression approach is recommended with single samples collected at intervals on four orthogonal transects beginning at the center of the proposed farm location. Samples should extend at least 500 m from the center. If video surveys are conducted first, the grab collections can be focused in areas where samples are possible, namely soft to mixed substrates. About 24 samples are adequate.

The profile of the macrobenthic community can be reduced in cost by using the smaller petite ponar grab (with a 0.0225 m^2 footprint) rather than the more standard van Veen grab (0.1 m^2).

Near-field and far-field effects

Effects of aquaculture interventions on the ecosystem are spatial and temporal. They can be localized and immediate, or distant and sometime in the future. However, both near-field and far-field effects have to be considered in the risk assessment process.

(a) Near-field effects

The near field can be defined as that area encompassing the limit of directly measurable effects. In the marine environment, the majority of human interventions, such as sand mining, dredging, drilling, waste disposal, fish processing, recreational boating etc., all have instant near-field effects, particularly on the sediments and their benthic communities in the immediate vicinity of the source. Consequently, because of the long history of these activities in marine waters, the extent and diversity of their effects are well known. They can be measured with accuracy and the particulate data and benthic biological data linked in a number of empirical or mechanistic models to assess potential risk.

With regard to the relatively recent intervention of aquaculture in the marine environment and its most localized and instant impact of wastes and contaminants accumulating on the bottom sediment beneath fish enclosures or in solution, there is a wealth of comparative information about the measurement of near-field effects on which to draw. For example: 1) in terms of sedimented organic waste, the near field describes that area in which statistically significant differences (t-tests, ANOVA etc.) or significant clines (statistically significant coefficients on dependent variables in linear or nonlinear regression analysis) in either physico-chemical or biological end points associated with aquaculture-related effects can be demonstrated at the peak of farm production; and 2) in terms of reduced concentrations of dissolved contaminants or effects of metabolic waste, the near field describes that area in which statistically significant increases or decreases in the end point of interest can be measured in comparison with local reference conditions.

Because of the extent of good data, near-field effects are generally assessed using local computer models to predict the deposition of organic material released by the producer. The DEPOMOD computer modeling tool, for example, models benthic enrichment effects by combining particle tracking with empirical relationships between the spatial distribution of solids and changes in the structure of the benthic community.

Near-field effects are usually limited or managed by regulatory authorities setting performance standards that are appropriate for the location or the region as a whole. Typically, under the terms of a permit or license, the producer is responsible for conducting the necessary monitoring and complying with the management practices adopted to enable the performance standards to be met.

(b) Far-field effects

Far-field effects are those effects that occur outside that area where statistically significant clines in relationship with the source cannot be measured. These are cumulative effects that normally can only be detected by long-term monitoring programmes at locations not directly influenced by local effects. Assessment of far-field effects associated with aquaculture becomes increasingly important as the industry expands.

The maximum spatial extent of far-field effects is a hydrologic unit that includes all inputs potentially affecting the unit. It may include, for example, a single bay, several bays or an entire estuary or delta. Far-field effects become increasingly difficult to measure in open bodies of water, such as those offshore where aquaculture may occur. However, even in large open bodies of water the same definitions could be applied.

Because of the vast scope of far-field effects, their potential is normally best assessed through computer models. These are monitored by consortiums of contributors to the cumulative effects in coordination with some level of government. Management of far-field effects is normally a public function in cooperation with all the contributors. With regard to organic loading, for example, from a number of marine fish farms into a bay 10 km distant, the regulatory authority may set Total Maximum Daily Loads (TDML) for the far field of interest (the bay), and apportion the TMDL to individual producers or farm complexes. The authority then manages the far-field effects by manipulating the respective TMDLs to meet one stated objective.

There is some concern about the far-field effects posed by pathogens that may appear on one farm on the stock held in another. Indeed, the probability of pathogens from one farm site spreading to another within x tidal cycles provides much of the basis for licensing and management in some countries.

Risk characterization for marine fish aquaculture (Phase 3)

Risk characterization is the final phase when the two analyses of exposure and effects are brought together. It is best performed using models developed to estimate effects from hypothetical risks.

In a number of fields, such as the pharmaceutical industry or chemical engineering, risk characterization can be straightforward. The point estimate of exposure is compared with the point estimate of the threshold of effects, and if the ratio is greater than one then an effect is assumed. It can be taken further with an exposure-response model, when the distribution of the exposure and effects can be shown to accumulate over a period of time. However, in the marine aquaculture industry the process of risk characterization is complicated by the fact that most of the effects are interactive. Such complexity could be dealt with by modeling, but quantifiable information for many aspects of marine aquaculture is extremely scarce. Consequently, for risk characterization the only recourse at present is either to make use of a mechanistic model for a particular site, providing the assumptions are reasonable and that the model can be adequately calibrated and validated, or to rely on all existing information and especially the classical "dose and response" laboratory information.

In assessing a risk, it is important both to qualify and quantify, where possible, the associated uncertainty. For example, the uncertainty could be described by probabilistic factors, by semi-quantitative factors or by entirely qualitative factors, such as high, medium or low. Whatever factors are chosen, it is important to include the uncertainty with any risk assessment. In addition, it is important to explain any assumptions that were used in the analysis, the scientific uncertainties, and their strengths and weaknesses.

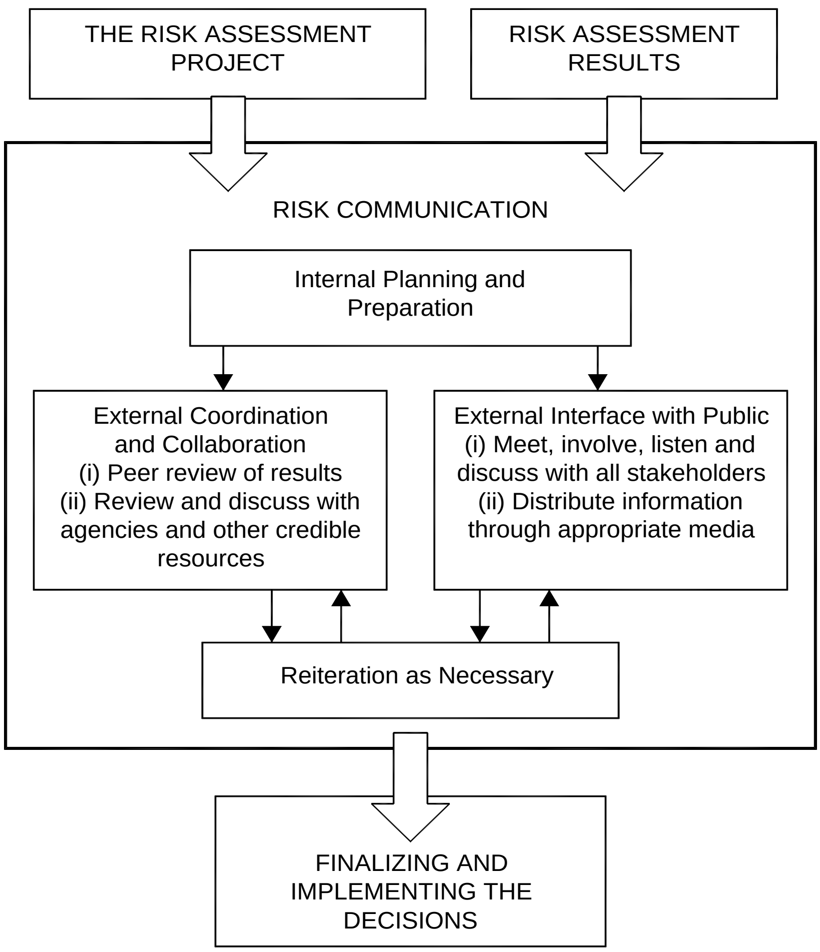
Risk characterization is carried out by scientific and technical experts, but it is not limited to them. Risk assessors and risk managers are again actively involved in the process, as during problem formulation. This is because issues might have arisen that necessitate a reiteration of problem formulation and a repeat of the problem analysis.

Risk communication

A final responsibility for everyone involved in managing risk is risk communication. This is an ongoing process at the local level and usually involves a government agency, represented by risk managers, industry and other stakeholders, and the public at large.

The objective of risk communication is to maximize the transparency of every activity related to the risk through interaction with the broadest range of interested parties (Figure 2). This objective includes risk identification, analysis, assessment, implementation of the decision and subsequent monitoring. It is important that the

FIGURE 2
The process of risk communication for the project and the results



communication process is begun as soon as possible, preferably with an announcement of the project itself.

Risk communication is carried out in a variety of ways. Productive communication is invariably conducted at public hearings when, in theory, everyone listens carefully to each other without any prejudgment of the issue. But this is not always the case, and it is important for the risk managers representing government agencies at such hearings to maintain public trust by their independence and impartiality. Good communication is also achieved by regularly circulating published materials.

Some aspects of risk assessment are scientific and very technical, and therefore, it is important that the data and all methods of collection, any models and assumptions that have been applied and any conclusions drawn are reviewed by peers.

Monitoring for subsequent risk

Decisions can be made by the risk manager based on the historical and current information gathered by the team of risk assessors and stakeholders. If the potential risk is assessed as being unlikely or small, then the risk manager can authorize the project to go ahead. However, it is important that the baseline does not change in such a way that the risk can in fact occur at a later time, and therefore the risk manager usually qualifies any decision with the requirement for the continual monitoring of certain site parameters. The task of carrying out the monitoring programme may be the responsibility of the regulatory agency, the owners or managers of the project in question, or both.

It is important that any monitoring programme is designed around the measurement of:

- standards identified by national legislation and regulation; and
- those parameters relevant to the indication of any increasing risk to the biological end points that have been identified.

Fundamental also to every monitoring programme is an exact specification of the methodology. This, for the most part, should have been established during the baseline survey. In other words, reference stations and site stations will be located and fixed along transects on the seabed or at set surface or mid-water distances from identifiable points (such as the perimeter of a facility), and all based on the predominant direction of the current. In addition, the frequency and methods of sampling will be specified and the methods of analysis will be identified together, where necessary, with laboratory instrumentation.

GLOBAL APPLICATION OF THE FRAMEWORK

Physical demands of marine fish aquaculture

For the foreseeable future, intensive marine fish aquaculture will be limited to waters of the continental shelf, which is often defined as lying above the 200-m contour. However, for the practical reasons of engineering cost, operational management and profitability, marine fish aquaculture takes place reasonably close to shore, provided that water quality conditions are suitable.

Selection of a location depends on the proposed fish farming system and practice. Again, because of the investment cost, only intensive fish production is economically feasible, and the options are floating net-pen complexes and buoyant individual cages designed to remain at the surface or to be submerged as required. Net-pen complexes are therefore usually located in coastal estuaries, sounds and lagoons that have rapid marine water exchange, have some shelter and provide anchorages that are less than 40 m deep. Individual buoyant cages can be located in less-sheltered waters, and submersible cages can be deployed in deeper water to avoid storms. However, submersible cages have limitations. Although wave energy attenuates with depth, the scale of each unit is limited by potential fatigue of the materials, the capacity of the automated feeders and the need for regular surveillance and service operations by scuba divers. Scuba divers can operate safely down to a depth of 30 m, but operate most economically around 10–15 m and working in pairs. Currently, submersible cages are being operated at depths of less than 100 m, but this may still be up to 30 km offshore.

Net-pen complexes are anchored by many separate cables, depending on their formation and size. Additional lines may anchor predator nets. Individual buoyant cages are anchored by four discrete lines that maintain tension all around continuously. Single-point anchor systems have also been used, but at some time the line will become slack, which puts a burden on the cage/line interface. The preferred substrate for the anchors themselves is sand or mud. Anchors can be bolted into rocky substrates, but the practice is costly.

Buoyant cages are designed to operate in currents up to 90 cm/sec, or about 1.74 knots. This is above what is desirable for the fish, which, when confined in strong currents, expend too much energy maintaining their position in the cage instead of growth.

Environmental demands of marine fish aquaculture

Successful marine fish aquaculture depends on a synergism between the aquaculture site and the farmer. The environmental qualities or parameters of the site must be conducive to the life history and physiology of the species of fish in culture, and the operator must provide an appropriate living space for the fish, meet all their nutritional requirements and maintain their health.

Site selection for an aquaculture facility is therefore a critical task. It is made difficult because the range of marine ecosystems in which it may be located is diverse, and the suitability of their physical and chemical properties depend significantly on the species and culture practice to be implemented. For example, there are different site demands for submersible cages containing cobia 3–5 km from the coast of Puerto Rico, pens for growing-out tuna in coastal waters within 2 km of the shoreline of Australia and enclosures for rearing seabream in shallow marine embayments in the Mediterranean.

The hydrodynamics, nutrient levels, types of pollution and other environmental parameters found in these locations are all very different. Consequently, there will be differences in the biological end points and their attributes resulting from aquaculture operations that characterize the potential risks to the environment. For example, the risk of eutrophication and change in species diversity in the benthic environment in the poorly flushed lagoons of the Mediterranean is higher than in the offshore waters of either Puerto Rico or Australia where there are greater depths and high water exchange rates.

Because of all these differences, each ecological risk assessment has to be tailored to an individual location, and an individual species and aquaculture practice. However, the categories of potential ecological risks and their fundamental methods of assessment are common, and it is only their relative importance that will vary.

A MATRIX APPROACH TO GUIDE THE APPLICATION OF RISK ASSESSMENTS

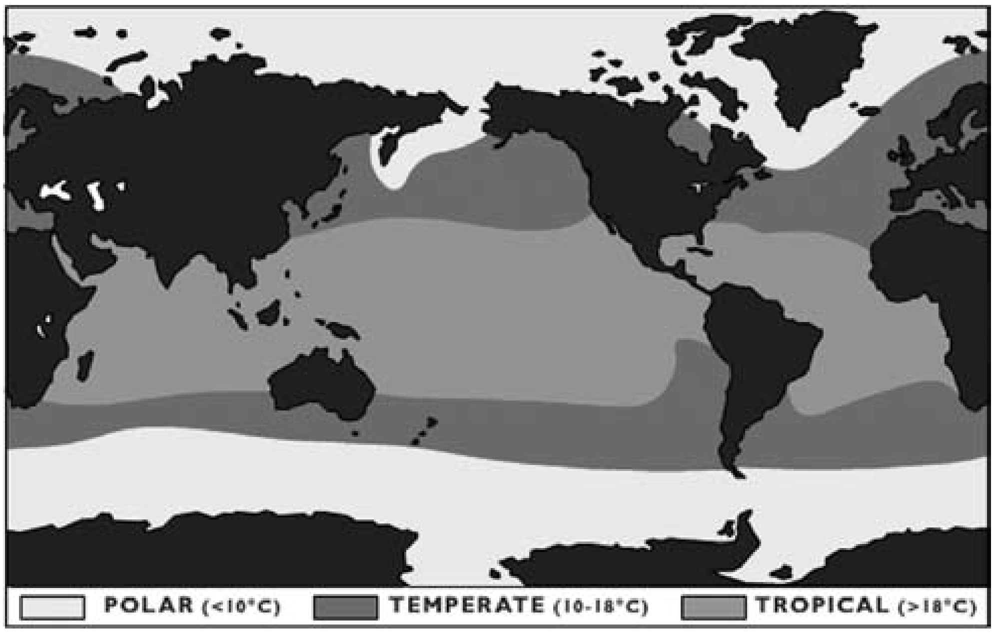
In selecting a suitable site for marine fish culture, the ideal requirement is a pollution-free environment in the epipelagic zone with good water quality parameters. Primarily, this means year-round high ambient levels of oxygen combined with salinities and temperatures that are between the middle and upper end of the ranges tolerated by the respective farm species, and maintained by a modest current and average tidal rise and fall. Unfortunately, the ideal cannot always be found, and the parameters are so diverse that most sites are selected for reasons somewhere between ideal water quality parameters and operational cost and convenience.

As marine fish aquaculture is still in its infancy in most countries and the locations where it is practiced at the present time are few, for the purpose of these guidelines it is proposed to classify the typical marine aquaculture environment into categories of biogeographical regions or zones and categories of marine epipelagic ecosystem. The definitions of the zones and categories are as follows:

- The two biogeographical zones suitable for marine aquaculture (as illustrated in Figure 3) are:
  - Temperate waters (10–18 °C). Typically cold waters with intrusions of some warmer waters from the subtropics. Temperate waters can be rich in nutrients and highly productive (waters off Australia being an exception), and consequently characterized by low light intensity levels. Temperate waters often support substantial fisheries, together with their dependent populations of birds and marine mammals.
  - Tropical waters (>18 °C). Typically warm waters with intrusions of some colder waters from the subtropics. Tropical waters are biologically very rich but nutrient poor and characterized by high light levels. Tropical waters often support migratory populations.
- The three epipelagic ecosystems are:
  - Offshore waters. Typically 3 km or more from the coast, or up to 100 m in depth, and suitable for submersible cages.
  - Coastal waters. Typically less than 3 km from the coast or up to 30 m in depth, suitable for submersible cages and floating cages, with strong tidal interchange.
  - Inshore water bodies. Typically semi-enclosed but large coastal sounds, lagoons and estuaries, relatively shallow in depth, suitable for floating cages and fixed enclosures, with good tidal flushing.

The ten categories of risk can then be evaluated in broad terms against each of the six generalized marine ecosystems in the form of a matrix (Table 2). The objective is to indicate probable differences in priority relative to each type of ecosystem and to assist risk managers and risk assessors with their problem formulation. However, the information presented in the matrix does not rule out the uniqueness of some ecosystems, and this must always be considered.

FIGURE 3
Broad biogeographical zones for marine aquaculture



Courtesy of the Gulf of Maine Research Institute

TABLE 2
Matrix to guide the application of risk assessments in the waters of different biogeographic zones[1]

	Epipelagic ecosystem in temperate waters (10–18 °C)			Epipelagic ecosystem in tropical waters (>18 °C)		
Category of possible risk	Inshore	Coastal	Offshore	Inshore	Coastal	Offshore
1. Increased organic loading	*****	**	*	*****	***	*
2. Increased inorganic loading	*****	**	*	*****	***	*
3. Residual metals	*	*	*	**	*	*
4. Transmission of disease organisms	***	**	**	***	**	**
5. Residual therapeutants	**	*	*	**	*	*
6. Biological interactions of escapes with wild populations	**	**	*	**	**	*
7. Physical interactions with marine wildlife	**	**	*	**	**	*
8. Physical impact on marine habitat	**	*	*	**	*	*
9. Using wild juveniles for grow-out	**	**	*	***	***	**
10. Harvesting industrial fisheries for fish feed	**	**	***	***	***	***

[1] Key: Potential for ecological change without management action: *****Significantly high, ****High, ***Medium, **Low , *Little or none.

GLOSSARY OF RISK ASSESSMENT AND MARINE TERMS

(a) Risk assessment terms[3]

Adverse ecological effects. Changes that are considered undesirable because they alter valued structural or functional characteristics of ecosystems or their components. An evaluation of adversity may consider the type, intensity and scale of the effect as well as the potential for recovery.

Assessment end-point. An explicit expression of the environmental value that is to be protected, operationally defined by an ecological entity and its attributes. For example, marine turtles are valued ecological entities, and the survival of individual migrating turtles is an important attribute.

Attribute. A quality or characteristic of an ecological entity. An attribute is one component of an assessment end point.

Characterization of ecological effects. A portion of the analysis phase of ecological risk assessment that evaluates the ability of stressor(s) to cause adverse effects under a particular set of circumstances.

Characterization of exposure. A portion of the analysis phase of ecological risk assessment that evaluates the interaction of the stressor with one or more ecological entities. Exposure can be expressed as co-occurrence or contact, depending on the stressor and ecological component involved.

Community. An assemblage of populations of different species within a specified location in space and time.

Conceptual model. In problem formulation, a visual representation and written description of predicted relationships between ecological entities and the stressors to which they may be exposed.

Ecological entity. A general term that may refer to a species, a group of species, an ecosystem function or characteristic, or a specific habitat. An ecological entity is one component of an assessment end point.

Ecological risk assessment. The process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

Ecosystem. The biotic community and abiotic environment within a specified location in space and time.

[3] Source of risk assessment terms: US EPA, 1992, *Guidelines for ecological risk assessment.*

Exposure. The contact or co-occurrence of a stressor with a receptor.
LC50. A statistically or graphically estimated concentration that is expected to be lethal to 50 percent of a group of organisms under specified conditions.
Measure of effect. A change in an attribute of an assessment end point or its surrogate in response to a stressor to which it is exposed.
Measure of exposure. A measure of stressor existence and movement in the environment and its contact or co-existence with the assessment end point.
Population. An aggregate of individuals of a species within a specified location in space and time.
Receptor. The ecological entity exposed to the stressor.
Recovery. The rate and extent of return of a population or community to some aspect(s) of its previous condition.
Risk characterization. A phase of ecological risk assessment that integrates the exposure and stressor-response profiles to evaluate the likelihood of adverse ecological effects associated with exposure to a stressor.
Source. An entity or action that releases to the environment or imposes on the environment a chemical, physical or biological stressor or stressors.
Stressor. Any physical, chemical, or biological entity that can induce an adverse response.

(b) Marine terms

Benthos. Collectively all those animals and plants living on or in sediments at the bottom of the sea. Benthic animals are usually described by their position in the sediment relative to the surface and their size, i.e.:

> **Infauna**. Fauna living within (burrowing in) the sediments, and
> **Epifauna**. Fauna living at or on the sediment surface. They can be sessile or slow moving, and may spend some time in the water column.

Bioremediation. Biological recovery.
Demersal. Living on or near the bottom of the sea.
Epipelagic. Pertaining to the community of suspended organisms inhabiting an aquatic environment between the surface and a depth of 200 m.
Halocline. Well-defined vertical salinity gradient in the water column.
Nekton. Collectively the macroscopic animals suspended in the sea, moving about independently of currents (includes fishes and whales).
Pelagic. Of or pertaining to the open waters of the sea (beyond 20 m depth).
Porewater. The water retained in the pores between the grains of the sediment.
Pycnocline. Well-defined vertical density gradient in the water column.
Seston. Collectively all living and dead suspended microscopic animals and particulate matter in the sea.

APPENDIXES

Appendices A through J of NOAA Technical Memorandum NMFS-NWFSC-71 are templates that outline the approach for conducting a risk assessment for each of the ten areas of marine fish aquaculture perceived by the public and public administrators to be of most concern. The titles of the appendices are listed below:

- Appendix A: Increased Organic Loading
- Appendix B: Increased Inorganic Loading
- Appendix C: Residual Heavy Metals
- Appendix D: Transmission of Disease Organisms
- Appendix E: Residual Therapeutants
- Appendix F: Biological Interaction of Escapes with Wild Populations
- Appendix G: Physical Interaction with Marine Wildlife
- Appendix H: Physical Impact on Marine Habitat
- Appendix I: Using Wild Juveniles for Grow-out
- Appendix J: Harvesting Industrial Fisheries for Aqua-feeds
- Appendix K: Workshop Participants
- Appendix L: Sources of Further Information

Financial risk analysis in aquaculture

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ABSTRACT

Financial risk analysis methods were compared with the standard components of a risk analysis (hazard identification, risk assessment, risk management and risk communication). Financial and related performance measures are critical in assessing financial risk. A variety of quantitative methods of financial risk assessment (release assessment, exposure assessment, consequence assessment and risk characterization) are presented. In financial risk assessment, financial analysis methods (capital budgeting, enterprise budgets, cash flow analysis, financial performance ratios, partial budget analysis etc.) are necessary. Numerous examples from aquaculture research illustrate methods for probabilistic risk estimation (probability trees, Bayesian networks and stochastic simulation) and non-probabilistic risk estimation (what-if/scenario-based analysis, sensitivity analysis and break-even analysis). Evaluation methods based on decision analysis principles are well-established in financial risk analysis. The paper illustrates the use of decision trees and Bayesian decision networks, risk programming (e.g. E-V efficiency and MOTAD), stochastic efficiency and multiple criteria/trade-off analysis (e.g. MCDM and AHP/ANP) for assessing financial risk in aquaculture. Since decision analysis methods are mature, a number of software packages that implement many of the methods are also represented. Financial risk analysis methods should be integrated in the early phases of hazard identification and risk assessment in order to truly manage financial risk in aquaculture. While many studies and techniques are available to analyze financial risk in aquaculture, the methods are not necessarily linked to the traditional components of a risk assessment. This paper links financial analysis with traditional risk analysis methods and demonstrates the utility of decision analysis principles in analysing risk in aquaculture.

INTRODUCTION

In aquaculture, financial risk refers to the potential loss associated with an aquaculture investment. Aquaculture investments may be public or private and made on behalf of stakeholders, including individual farmers, shareholders, farm enterprises, financial institutions and/or government institutions.

HAZARD IDENTIFICATION

Risk is defined as uncertain consequences, usually unfavourable outcomes, due to imperfect knowledge (Kaplan and Garrick, 1981; Hardaker *et al.*, 2004). Risk can be lowered by reducing or removing hazards, i.e. sources of risk. Hazards are tangible threats that can contribute to risk but do not necessarily produce risk. Agriculture and aquaculture are inherently risky financial endeavours (Goodwin and Mishra, 2000). In aquaculture, the hazards can be broadly classified as production threats or market (or economic) threats.[1] According to the United States Department of Agriculture (USDA) (Harwood *et al.*, 1999), United States producers of major field crops are concerned most with production yield and market price variability.

Financial risk represents the likelihood of a hazardous event occurring and the potential financial loss that could result. Figure 1 illustrates how financial risk links hazards to financial loss. The presence of hazards affecting production and market conditions (e.g. price, demand) can bring about financial loss.

Production threats

Production threats have a negative impact on saleable yield, resulting in a financial loss. Threats to production include disfavourable environmental conditions, equipment or other asset failure, poor-quality seedstock and broodstock, disease and pest infestation. The success of an aquaculture enterprise often depends on the tacit knowledge of a few experienced farmers and managers. Consequently, as with the performance of other assets, employee loss or disability creates financial risk because production may be disrupted (Barry, 1984; Harwood *et al.*, 1999).

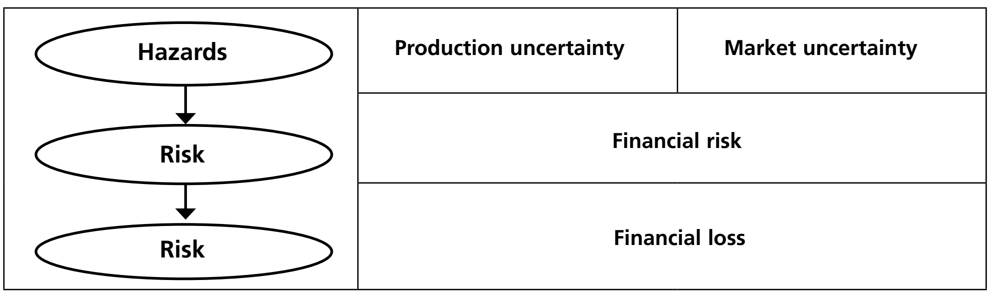
Market threats

Market threats exist in the form of product prices and regulations. Industry competition or reduced demand can lead to decreasing sale prices of aquaculture products. In either case, decreasing market prices will reduce revenue associated with sale of aquaculture products. Escalating prices of production inputs also pose a market threat because they decrease producer profit. Likewise, producers are exposed to risk due to limited supply of inputs. A recent off-shore aquaculture economic study for Pacific threadfin in Hawaii illustrates this case. The large-scale production level that was needed for the off-shore enterprise to be profitable could not be supported by the existing supply of fingerlings (Kam, Leung and Ostrowski, 2003). Recent plans for a Hawaiian off-shore cage enterprise to vertically integrate by developing an in-house hatchery suggest the realization of the financial risks from market threats posed by the study.

Government policies and other institutional threats affect the aquaculture business climate by influencing interest rates and imposing tax incentives, trade restrictions

FIGURE 1

Market and production uncertainty are commonly viewed as sources of risks that lead to financial losses



[1] See Barry (1984) and Harwood *et al.* (1999) for other classifications of risk in agriculture.

and environmental policies. For example, environmental impact assessment (EIA) and regular water sampling and analysis are costs of doing business for off-shore aquaculture production in the United States (Kam, Leung and Ostrowski, 2003). Government regulations contribute to risk because they can become increasingly demanding, costly to satisfy over time and may be subject to change.

Methods for identifying hazards with financial consequences

Preliminary information gathering helps to scope and structure a risk problem and lays the foundation for communicating risk. At the stage of hazard identification, the magnitude of the consequences and estimating the likelihood of occurrence are not critically important.

A variety of resources should be consulted to identify the hazards that contribute to financial risk. Stakeholders whose investments are at risk may provide significant insight when identifying hazards. These stakeholders can include the lenders who provide the financial support to farmers, farm owners, government agencies, consumers and members of related/affected industries.

When the hazards contributing to financial risk are not well defined, anecdotal reports are helpful in identifying hazards. Industry experts and the farmers themselves are typical secondary sources used to identify the pertinent production and market threats. Information can also be gathered from trade reports, news articles and published research (e.g. agriculture extension publications, journal articles, case studies). In gathering primary data, it's common to survey farmers and consumers, review state-of-the-art practices and gather information from members of related industries such as restaurant managers (Neira, Engle and Quagrainie, 2003, Engle *et al.*, 2005). Farmers can also be surveyed to identify hazards. In a direct marketing study for ornamental fish, for example, a producer survey identified sale prices and shipping costs as major issues prohibiting them from direct-marketing their products (Kam, Leung and Tamaru, 2005). Subsequent interviews with the ornamental wholesalers and aquaculture development programme members helped to complete the picture regarding issues affecting the ornamental industry.

In an import risk analysis (IRA) conducted by Biosecurity Australia (2006), potential hazards affecting prawn products were based on the list of diseases notifiable to the World Organisation for Animal Health (OIE, formerly the Office International des Épizooties), then refined to include diseases important to the importation of prawn and prawn products. A scientific team of specialists assisted in an IRA that identified nine diseases as hazards associated with the importation of uncooked prawns and prawn products intended for food consumption. For Hawaii, an IRA identified white spot syndrome virus (WSSV) from imported frozen commodity shrimp products as a hazard affecting local shrimp production (see Annex I). WSSV was the focus of the sample IRA based on anecdotal reports from farmers, industry experts and news sources.

Table 1 provides common examples of hazards in aquaculture as well as their sources of information.

FINANCIAL RISK ASSESSMENT

Risk assessments can be qualitative or quantitative in nature. A qualitative risk assessment is a reasoned and logical discussion of relevant factors expressed in non-numerical terms, such as high, medium, low or negligible. An excellent example of a qualitative IRA can be found in Murray (2002). Quantitative methods are useful for investigating financial risk in aquaculture because financial risk generally implies monetary loss. While qualitative methods are a viable and popular approach to analysing risk, this paper on financial risk highlights quantitative methods as a departure from qualitative methods commonly used in risk analysis. Some aspects of non-probabilistic risk estimation can be used in conjunction with qualitative risk assessments.

TABLE 1
Examples of hazards in aquaculture

Hazards		Sources of Information
Market threats • Decreasing sale prices (prices of outputs) • Increasing production costs (prices of inputs) • Availability (scarcity) of inputs • Escalating interest rates • Decreasing market demand • Limited market access • Creditor instability	**Production threats** • Seedstock low quality or limited availability • Broodstock low quality or limited availability • Equipment/asset failure • Decreasing growth rates • Disease spread • Lack/loss of skilled labour • Detrimental environment/weather conditions • Limited availability of food (especially in extensive systems)	**Primary data** • Farmer experience/hunches • On-site/field visits • Interviews with industry experts • Individual farm data • Surveys **Secondary Data** • News sources • Agricultural extension reports • Industry reports • Case studies • Anecdotal reports

TABLE 2
Elements of a financial risk assessment

Elements of a risk assessment	Defined with respect to financial risk
Release assessment	Identifying the extent to which a production or market threat could affect the aquaculture industry.
Exposure assessment	Identifying the likelihood that the hazard(s), if present, will affect the aquaculture enterprise (or stakeholder).
Consequence assessment	Identifying the financial consequences associated with the exposure to the hazard(s).
Risk characterization	Estimating the potential financial consequences associated with the hazard(s) identified.

A risk assessment refers to the process of identifying, estimating and evaluating the consequences of exposure to a hazard or a source of risk.[2] Risk assessment terminology is commonly associated with biological and environmental hazard applications (e.g. Calow, 1998; OIE, 2006). The traditional risk assessment definitions can be adapted for financial risk assessment in aquaculture (Table 2).

Release assessment

After production and market threats have been identified, a release assessment is needed to determine the extent to which potential hazards exist. The practice of risk assessment presumes that it is possible to estimate the uncertainty of the hazard existing. Quantitatively, uncertainty can be estimated in the form of probabilities (or probability distributions). When probabilities are difficult to estimate, a range of values can reflect uncertainty in the form of scenarios (e.g. best case, most likely and worst case).

For biological production threats, a release assessment will generally rely on a pathway analysis to trace the method by which a pathogen reaches the production site. As illustrated in Figure 2, pathways of exposure can be used to trace production loss attributed to contamination and the quality of broodstock and seedstock from a pond or hatchery or from the wild. For example, Hawaiian aquaculture industry members argue that white spot syndrome virus (WSSV) import risk in Hawaii may be traced to the country of origin and subsequent retail distribution channels of frozen commodity shrimp products (FCS) as illustrated in Figure 3. Trade data and incidence reports are useful for estimating the probability of a hazardous pathogen release in an importing country. Based on WSSV-outbreak incident reports, FCS import rates by region and consumption estimates, the probability of WSSV-infected retail FCS products was estimated at 32 percent for Hawaii (Kam, 2006).

In contrast to biological threats that pose financial risk, many other production threats are not due to pathogen transmission. Consequently, a pathway analysis is not necessary for a risk assessment. Production threats that originate on the farm-site are a distinct departure from biological threats traditionally traced by risk assessment

[2] Some risk frameworks consider hazard identification to be the first step of a risk assessment.

FIGURE 2
Release pathway for exotic shrimp introductions indicating points of inspection (adapted from Johnson 1990, based on Kam 2006)

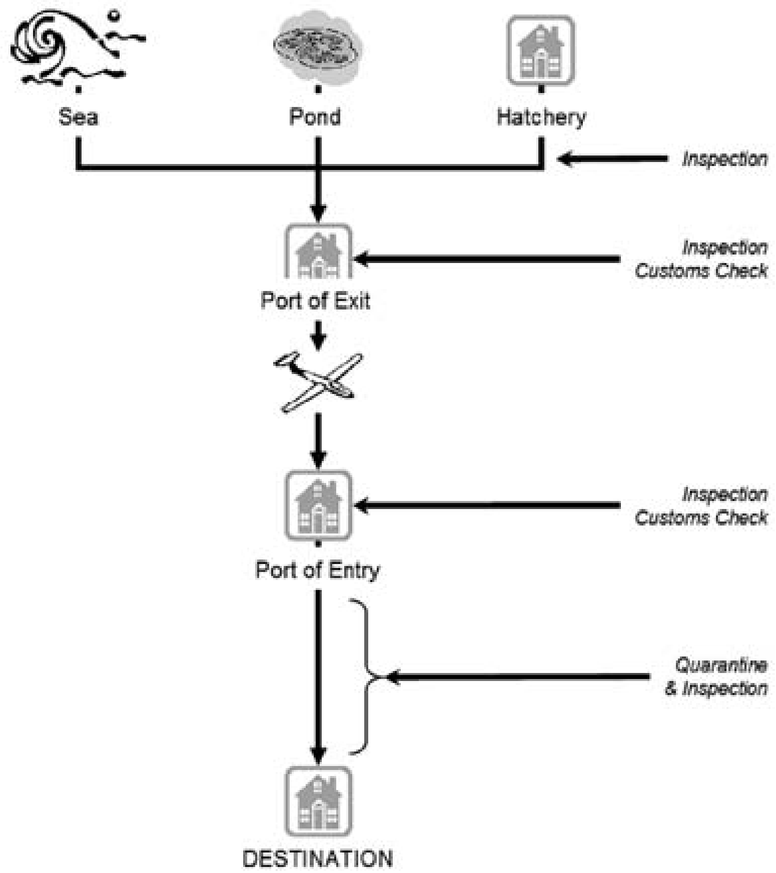
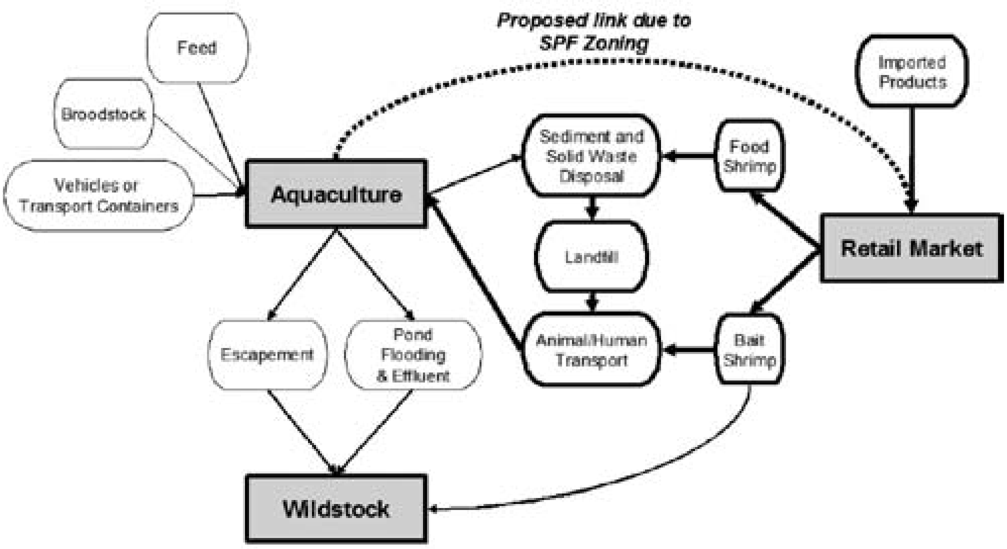


FIGURE 3
Pathways of white spot syndrome virus (WSSV) exposure between Hawaiian shrimp aquaculture, retail markets and wildstock



methods. Potential hazards that are farm-specific such as growth variation can be estimated using expert input or based on farm historical data. Other on-site risks include equipment failure, which can be quantified using expert estimates or farm data on downtime for repairs and services.

For market threats, a hazard can include the potential decrease in sale prices or demand. Hazards also come in the form of increases in the price of production inputs (e.g. cost of seedstock, broodstock, feed, water) or demand of products. Industry data are a good resource for identifying fluctuations in the volumes and prices of products sold, as well as input prices.

Exposure assessment

In contrast to release assessments that describe the extent to which the hazard exists in the environment, exposure assessments are specific to the investor(s) (or stakeholders). In biological and chemical risk analysis, exposure assessment often involves an estimate of the likelihood of intake by human or environment. Likewise, in financial risk analysis, exposure assessment involves an estimate of the probability that a hazard will affect a farm, entire industry or other unit of analysis. In studying an aquaculture industry, a hazard may affect each farm differently. Just as some populations are more resilient to biological hazards, some farms are more resilient to hazards. Their resilience or susceptibility to the threat will depend on production technologies, business strategies, site characteristics and other risk-mitigating practices. Differences between farm characteristics and practices and their association with financial risk allude to potential financial risk management strategies.

Determining the financial risk factors for a farm is often based on tacit knowledge. An exposure assessment helps to illuminate the factors contributing to financial risk and fosters risk communication. General perceptions of a farm's level of exposure in comparison to other farms can underscore the characteristics and strategies that lower a farm's financial risk. In a WSSV import risk study (described in Annex I), 13 shrimp farms were considered in the risk analysis. Different levels of exposure, based primarily on location, characterized each farm. As illustrated in the WSSV example in Figure 3, farm location influenced the extent of the WSSV threat from bait shrimp used at nearby fishing sites, shrimp truck food sales, food waste, FCS retail shrimp and disease transmission from neighbouring farms. Each farm's level of biosecurity practices (e.g. sanitary practices or physical security) was subjectively evaluated, implying further reductions in a farm's exposure to WSSV and thus financial risk. Table 3 summarizes the major farm characteristics and practices that affect financial risk.

Financial risk factors that expose farms to hazards can also be determined from farm performance measures. For example, Hambrey and Southall (2002) have identified "risk exposure" indicators such as total investment required before achieving return, time delay ("lead time") before return occurs, crop (harvesting) cycle and working capital required for a cycle. Most farms, however, do not document sufficiently detailed information needed to calculate these types of risk exposure measures. Furthermore, such risk exposure measures are often difficult to obtain for small farms. For example, while return on labour is important for smaller-scale enterprises, the data required to produce the estimates are not always available.

TABLE 3
Farm characteristics and practices that influence financial risk

Farm characteristics & practices	Examples
Crop/product selection	Diversification, specialization
Technology & practices	Operation protocols, equipment
Location	Coastal, inland, isolated
Financial leverage	Interest rates, amount borrowed
Infrastructure	Fencing, circulation system

Consequence assessment

Consequences refer to outcomes, usually a loss such as monetary loss, production loss or socioeconomic loss. The consequences can represent a single aquaculture enterprise, entire industry representing multiple enterprises or a regional economy.

Financial consequences

Since many of the principles underlying a financial risk assessment are based on financial analysis, a basic understanding of financial analysis methods is highly recommended. A training manual by Engle and Neira (2005) developed for tilapia farm business management and economics provides explanations of farm-level financial analysis methods with detailed examples for a Kenyan tilapia farm. Other useful measures and indicators of financial performance relevant to aquaculture and fishery activities can also be found in the technical paper by Hambrey (2002). Some examples of financial efficiency measures for risk assessment are presented in Table 4.

Financial risk analyses focus primarily on profitability indicators. Financial profitability can be measured in a variety of ways, including profit (net revenue or net income), return on production inputs (e.g. capital, water, land and labour), profit margin, return on investment (ROI) and internal rate of return (IRR). In order to measure profitability, a careful accounting of the costs is needed. When estimating the financial cost of a hazard, it is necessary to identify the fixed costs and variable costs. Costs that vary with production are called "variable costs" (also called operating costs). In contrast, fixed costs are costs that are incurred regardless of production activity (sometimes referred to as overhead or ownership costs). Some examples of fixed and variable costs are available in Table 5.

The distinction between fixed and variable costs is useful when conducting partial budget analyses, which investigate the impact of small changes on profit. An example of a partial budget analysis is presented in Box 1. For hazards and managerial decisions with long-term impacts, fixed costs and variable costs are needed to generate financial statements for the budget period. In addition to profitability, measures of solvency, liquidity and cash flow can be derived from financial statements including enterprise budgets, income statements, cash flow statements and balance sheets over a budget period.

Variable costs include production costs, costs of goods sold and even expenses not directly tied to the production of products

TABLE 4
Measures of financial efficiency (from Engle and Neira (2005) [1]

Solvency	Liquidity	Profitability (or viability)	Cash flow
• Debt/asset ratio • Equity/asset ratio • Debt/equity ratio • Net worth	• Current ratio • Working capital	• Profit/ha/crop (or profit/ha/yr) • Return on investment • Net farm income • Return to labour and management • Return to management • Rate of return on farm assets • Rate of return on farm equity • Operating profit margin ratio • Gross margin • Net change in profit (from partial budget analysis) • Break-even price • Benefit to cost ratio	• Cash flow coverage ratio • Debt-servicing ratio • Cash flow risk and sensitivity ratio

[1] Definitions available in Hambrey (2002) and Engle and Neira (2005).

TABLE 5
Examples of fixed and variable costs

Fixed costs	Variable costs
• Rent[1]	• Feed
• Management salaries	• Labour
• Office expenses	• Water
• Equipment depreciation	• Maintenance
• Other asset depreciation	• Sales tax

[1] In some cases, rent is treated as a variable cost; see discussion on "classifying costs" below.

BOX 1

Developing a partial budget analysis: a partial budget analysis for feed-type decision for a tilapia farm

Engle and Neira (2005) created a training manual on *Tilapia Farm Business Management and Economics* that includes a guide to creating a partial budget. The following excerpt is taken from the manual:

Partial budgets are used when considering a relatively small change on the farm. Changes may involve building additional ponds, changing type of feed, changing stocking rates with polyculture etc. Table 6 presents an analysis of a proposed change on a tilapia farm: whether or not to switch the type of feed from a pelleted diet to rice bran. The advantage of the rice bran is that it costs less than pellets. However, the disadvantage is that FRCs are higher and growth rates lower with rice bran. Bran was assumed to exhibit lower cost (3.5 Keynan shillings (KSh)/kg), but a higher FCR than pelted diet feed.

A switch to rice bran would result in reduced tilapia revenue of KSh 624 000. This reduced revenue results from lower yields of fish when fed rice bran as compared to pellets. No additional cost would apply to a switch from pellets to rice bran, nor would there be any additional revenue Table 6 also provides details of the reduced costs that would be incurred by switching to rice bran. The net change in profit would be negative (KSh -180 561), suggesting that switching feed is not profitable.

TABLE 6

Partial budget analysis used to evaluate the economic effect of changing from a pelleted diet feed to rice bran (all figures in Kenyan shillings, KSh)

	Feed		
Value of parameters that change	**Pelleted diet**	**Rice bran**	**Change in cost**
Tilapia sales	1 046 400	422 400	624 000
Feed total cost	419 904	72 074	347 832
Fingerlings total cost	108 000	59 904	48 096
Interest on operating capital	80 341	32 830	47 511
Additional costs			
None			
Reduced revenue			
Tilapia sales	624 000		
A. Total additional costs and reduced revenue	624 000		
Additional revenue			
None			
Reduced costs			
Tilapia fingerlings	48 096		
Feed	347 832		
Interest on operating capital	47 551		
B. Total additional revenue and reduced cost	443 439		
Net change in profit (B-A)	(180 561)		

or services but that vary with production volume. The variable costs associated with a hazard can include a decrease in sales resulting from unsaleable products. For market hazards, variable costs could include increases in the cost of seedstock, broodstock, feed or water. Production threats could include low food conversion ratios (FCR) that result in increased feed requirements or lower production output. Additional labour could also be required in response to production threats.

Fixed costs associated with a hazard can include the one-time expenses associated with the realized financial threat. These costs can include additional clean-up costs, preventive control measures (disease control), fines, equipment repair or enhancements. Many fixed costs require additional supporting information to identify depreciation costs and interest levels that may change on an annual basis (Engle and Neira, 2005).

BOX 2

Classifying costs to calculate profitability: a financial analysis of a Pacific threadfin hatchery

A spreadsheet model was developed to determine the viable scale for a commercial Pacific threadfin (*Polydactylus sexfilis*) hatchery in Hawaii (Kam *et al.*, 2002). The production scheme was modeled after state-of-the-art practices performed at the oceanic Institute in Waimanalo, Hawaii. For a hatchery enterprise producing 1.2 million fry per year, the cost associated with raising one 40-day old 1.00 g fry is estimated at US$0.2201 (Table 7). The largest variable costs are in labour and supplies, which comprise 49 and 9 percent of the total production cost, respectively. The combined annualized fixed cost for development and equipment is approximately 12 percent of total production cost. Based on a 20-year statement of cash flows for fry sold at US$0.25, the 20-year internal rate of return (IRR) was 30.63 percent. In comparison to the US$0.2201 unit cost for 1.2 million fry production, analyses of smaller enterprises producing 900 000 and 600 000 fry per year reflected significant size diseconomies, with unit costs of US$0.2741 and $0.3882, respectively (Figure 4).

Demand to support a large-scale Pacific threadfin commercial hatchery was uncertain. Since smaller-scale commercial hatcheries may not be economically feasible, facilities may seek to outsource live feed production modules or pursue multiproduct and multiphase approaches to production. An analysis of the production period length, for example, indicated that the cost for producing a day-25 0.05 g fry is US¢ 17.25 before tax and suggested the financial implications of transferring the responsibility of the nursery stage to grow-out farmers (Figure 5). Evaluation of the benefits gained from changes in nursery length, however, must also consider changes in facility requirements, mortality and shipping costs associated with transit, and the growout performance of and market demand for different size fry.

Additional analyses can be found in the original study, which estimated the potential cost savings associated with the elimination of rotifer, microalgae and enriched artemia production. Managerial decisions, however, would also consider the quality and associated production efficiencies of substitutes.

Classifying costs as either fixed or variable will depend on the nature of a farm's business. For example, in a Pacific threadfin hatchery economics study (Kam *et al.*, 2002), rent was treated as a variable cost because the amount of rent charged was based on a percentage of gross revenue. While salaried personnel are considered fixed costs, hourly labour and commission-based compensation are variable costs. Consequently, cost items like personnel expenditure may require further detail to specify the portion that is fixed vs variable (e.g. salary vs wages). However, for practical purposes, labour expenses are generally fixed and not typically adjusted in response to actual yields (Samples and Leung 1986). An example of a financial analysis based on an enterprise budget for a Pacific threadfin hatchery is given in Box 2.

FIGURE 4

Size economies for scaled Pacific threadfin hatchery production levels in US¢

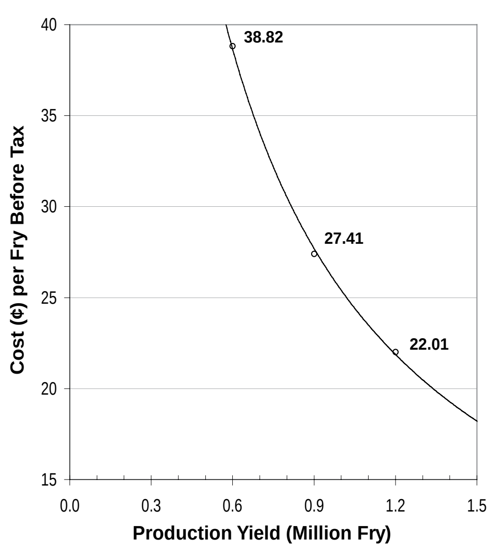


FIGURE 5
Farm production cost (US¢/fry) from spawning to early nursery

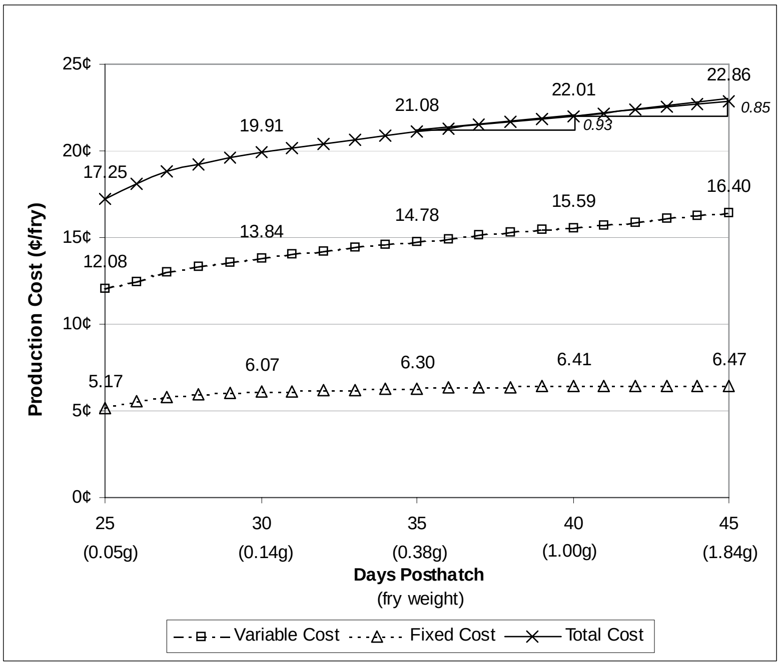


TABLE 7
Annual income in US$ for a hypothetical Pacific threadfin hatchery producing 1.2 million fry

Annual Income Year	1	2	3	4	5[1]
Gross Receipts from Production	210 000	300 000	300 000	300 000	300 000
Variable Operational Costs					
- Feed	5 442	5 442	5 442	5 442	5 442
- Supplies	24 985	24 985	24 985	24 985	24 985
- Energy	10 228	10 228	10 228	10 228	10 228
- Facilities Rent	4 200	6 000	6 000	6 000	6 000
- Labour	129 993	129 993	129 993	129 993	129 993
- Maintenance	1 557	1 557	1 557	1 557	1 557
- General Excise Tax	1 050	1 500	1 500	1 500	1 500
Total Variable Costs	177 454	179 704	179 704	179 704	179 704
Fixed Costs					
- Equipment Depreciation	10 331	10 331	10 331	10 331	10 331
- Development Depreciation	20 817	20 817	20 817	20 817	20 817
Total Fixed Costs	31 148	31 148	31 148	31 148	31 148
Contingency	8 873	8 985	8 985	8 985	8 985
Total Operational Expenses	217 475	219 837	219 837	219 837	219 837
Interest Expense	46 099	45 819	45 511	45 172	44 799
Total Expenses	263 574	265 656	265 348	265 009	264 636
Net Income Before Tax	(53 574)	34 344	34 652	34 991	35 364
Income Tax	0	6 756	6 819	6 888	6 964
Net Income After Tax	(53 574)	27 588	27 833	28 103	28 400
Cost per Fry Before Tax	0.3125	0.2201	0.2198	0.2195	0.2192
Cost per Fry After Tax	0.3138	0.2270	0.2268	0.2266	0.2263

[1] The first five years of the Income Statement are exhibited in Table 6. Fixed costs remain constant after the second year based on straight-line depreciation and production cycles that are less than a year. Variations in net income after year two are due to declining loan interest expenses and increasing income tax accrued.

Economic consequences

Financial risk can be viewed as a contributing factor to economic risk. The economic impact on an industry reflects the cumulative financial consequences experienced by industry members. When examining economic consequences, or "economic risk," we are also concerned with the impact on other industries within a region or between regions of interest, generally with less concern for the individual farm financial details. An input-output model, for example, considers relationships between different industry sectors. An input-output model defines how output from one industry becomes input of another industry among different sectors for a cross-section of the economy. Based on the structure of the economy as it relates to product consumption, the impact of policies could be projected for a regional economy or national economy. A more detailed analysis could also include welfare assessments (i.e. consumer and producer surpluses) using econometric and welfare analyses.

Other consequences

Socio-economic consequences may also be considered when evaluating financial risk. Environmental damages, social impacts (e.g. employment and income distribution issues), and the effects on international and domestic trade are also valid measures to consider. Industry performance measures (e.g. proportion of farmers experiencing a loss or farmers receiving return on labour that is lower than the wage rate) may be useful measures when considering regional socio-economic agendas (Hambrey and Southall, 2002). Principles of utility and methods for defining evaluation criteria can help to consolidate social, economic and financial considerations. These methods will be discussed later in terms of risk management objectives.

The results of a release assessment, exposure assessment and consequence assessment are combined to form a risk characterization for a hazard (or multiple hazards). Financial consequences signify the difference between financial risk characterization from other forms of risk characterization. A financial risk analysis can be conducted for any hazard that contributes to a financial loss. Methods for estimating the financial loss, or risk estimation are discussed next.

Risk characterization

The process of risk characterization produces a risk estimate that reflects the consequences and likelihood of a hazard affecting a farm. Consequently, a risk estimate integrates the results of the release assessment, exposure assessment and consequence assessment. Financial risk characterizations quantify the relative impact of hazards in comparison to a baseline – ideal situation – where no hazard exists. When no baseline is available, the consequences associated with different hazards are often compared when making risk management decisions.

Financial risk cannot be measured by budgets or performance ratios because they are based on average values and do not account for uncertainty. Consequently, principles of financial analysis are a necessary first step in financial risk assessment. Since risk is a relative measure, a financial analysis is usually conducted first as the reference point for subsequent risk analysis. For risk analysis, methods for integrating aspects of uncertainty are needed. When characterizing financial risk, decision analysis methods allow us to consider uncertainty that affects the financial measures of interest.

Decision analysis refers to the body of methods used to rationalize and assist choices under uncertainty (Hardaker *et al.,* 2004). In addition to providing managerial decision support, decision analysis techniques encourage transparency of the problem, which is essential for risk communication. This section on financial risk characterization presents modelling uncertainty using decision analytic methods. The identification and evaluation of choices will be discussed further in the section on Financial Risk Management.

From a decision analysis perspective, there are two approaches to estimating uncertainty: probabilistic and non-probabilistic estimation. In probabilistic estimation, likelihood estimates and probability distributions are used to quantify uncertainty. In non-probabilistic estimation, uncertain events – for which the likelihood of occurring

TABLE 8
Common decision analysis methods for characterizing risk

Probabilistic estimation	Non-probabilistic estimation
• Probability trees • Bayesian networks • Stochastic simulation	• What-if (scenario-based) analysis • Sensitivity analysis • Break-even analysis

is not specified – are portrayed as scenarios. Common methods for probabilistic and non-probabilistic estimation are listed in Table 8 and described next.

Probabilistic risk estimation

The probability of release, exposure and the magnitude of the consequences must be determined in order to characterize risk. When using probabilistic methods to estimate financial risk, we assume that it is possible to assess the relative likelihood of uncertain events that have a financial impact (Hardaker *et al.,* 2004; Chavas, 2005).

Uncertainty is usually expressed in terms of probabilities that are based on either frequencies or degree of belief. These approaches are respectively referred to as frequentist and subjectivist views of probability. Savage (2003) provides an excellent tutorial on using probability to represent uncertainty. In the frequentist school of thought, probability is defined as a relative frequency ratio. From the subjectivist school, probability estimates define the degree of belief that the event will occur. The discussion on random variables given in Savage (2003) introduces statistical principles that are at the heart of risk analysis.

It is rare for a risk analysis to rely purely on historical data. Data alone may not reflect uncertainty about specific current and future situations. Consequently, risk analysts will utilize probabilities based on existing frequency data as well as subjective estimates to suit their analysis. As illustrated by Hardaker *et al.* (2004), market hazards such as the variation in grain price can be based on historical data. However, probability based solely on historical data could fail to take into account anticipated changes in grain price due to current international trade talks or similar pertinent issues.

BOX 3

Characterizing financial risk using probability trees: measuring the impact of infected imported shrimp products on farm profit

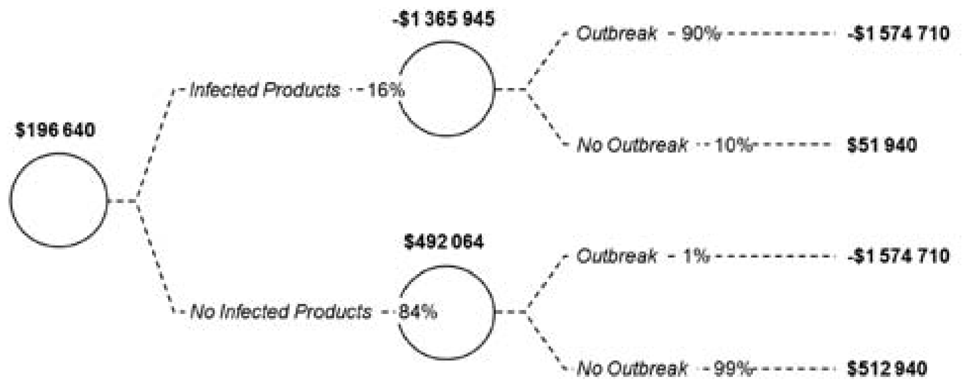
A hypothetical farm will receive an annual profit of US$ 512 940. When a WSSV outbreak occurs, the farm experiences a negative profit of -$1 574 710. The negative profit resulting from an outbreak reflects the production cost, broodstock loss and lost revenue from down-time and expenditures such as clean-up costs and start-up costs. These outcome values are represented in the terminal nodes located at the far-right of the tree.

The secondary nodes in Figure 6 suggest that the probability of an outbreak depends on whether WSSV-infected frozen commodity shrimp products are present (i.e. pathogens release in the environment). If infected products are present, the likelihood of a farm outbreak is 90 percent, and only 1 percent when infected products are not present. Based on this information, the expected value when infected products are present is 90 percent x -$1 574 710 + 10 percent x $512 710 = $1 365 945. At the left-most parent node, the expected value is based on WSSV hazard from infected frozen shrimp estimated at 16 percent. Using the same method for calculating expected values as before, the expected overall farm profit due to the WSSV hazard was not very optimistic at $196 640.

The potential loss due to the WSSV hazard is also useful in measuring risk. Using the $512 940 as the baseline profit for the farm, the cost of the WSSV hazard is $1 061 770 (= $1 574 710 - $512 940). This expected farm profit of $196 640 and potential loss of $1 061 770 reflects the farm financial risk due to probability of contamination by WSSV-infected products.

[1] McInerney, Howe and Schepers (1992) and McInerney (1996) define disease cost, or more generally, the cost associated with a hazard as the output loss + disease expenditure.

FIGURE 6
Probability tree for a simplified white spot syndrome virus (WSSV) import risk problem. Created with XLsim (AnalyCorp, 2002)



Created with XLsim (AnalyCorp 2002)

Financial risk can be characterized using expected values and uncertainty described by variability in the outcome. Probability trees, Bayesian networks and stochastic simulation are three approaches to calculating expected values and outcome variability for financial measures.

(a) Probability trees

A probability tree (or scenario tree) is a useful way of illustrating how expected values and their variability can characterize risk. Probability trees begin with an initial event and outline the various pathways and outcomes. Each fork signals that a mutually exclusive event will occur. In traditional probability trees, circles represent the chance nodes and the consequences (outcome values) are located in the far right. The outcome value at the end of each pathway represents the terminal wealth, in this case, the financial measure of interest (revenue, gross sales, net income etc.). The expected value at each fork is the sum of the probability of each event occurring multiplied by the corresponding consequences. In evaluating financial risk, a probability tree can be used to calculate the expected value, the average financial outcome and the range of financial outcomes. A demonstration of how a probability tree can be used for WSSV import risk characterization is given in Box 3 (based on Kam, 2006).

Even with the aid of software such as XLsim (AnalyCorp, 2002), it may be difficult for a risk analyst to identify every possible pathway and the associated financial consequences. Bayesian networks provide some relief from the burden of determining and manually accounting for the consequences of all pathways considered in a probability tree.

(b) Bayesian networks

A Bayesian network is a compact representation of a probability tree. Like probability trees, Bayesian networks consist of chance nodes represented as circles and consequence (or utility) nodes represented as polygons.[3] The relationships between nodes are specified by joint probability tables. A Bayesian network equivalent of the probability tree for the simplified WSSV import risk problem is exhibited in Figure 7.

Bayesian networks can be used to calculate the same expected value estimates as probability trees. The probabilities of complex pathways that are difficult to calculate in probability trees can be computed easily with Bayesian networks. Consequently, as problems become more complex, Bayesian networks may be a more eloquent way

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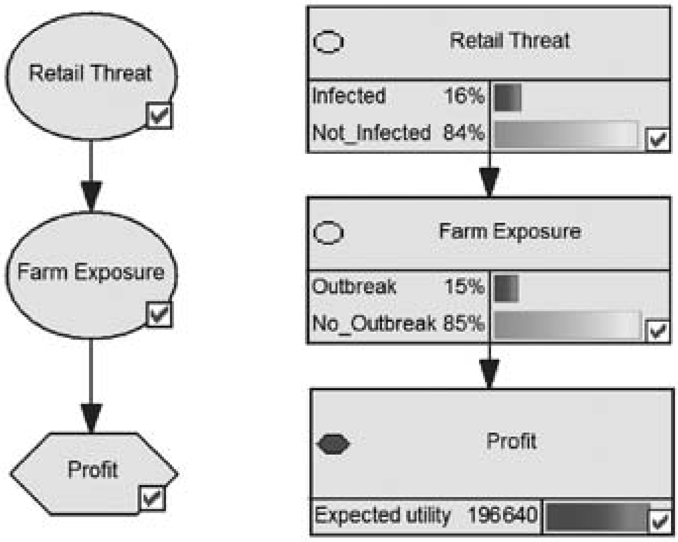
[3] In Bayesian networks, utility nodes are commonly represented as diamonds. The GeNIe software (2006) used for the exhibits adopted the convention of trapezoids to represent utility nodes.

FIGURE 7
Bayesian network example for a simplified white spot syndrome (WSSV) import risk problem. Created with GeNIe (DSL, 2006)



Release Assessment	**Probability**
Infected retail products	16%
Non-infected retail products	84%

Exposure Assessment	**Infected**	**Not Infected**
Outbreak	90%	1%
No outbreak	10%	99%

Consequence Assessment	**Farm Profit (US$)**
Outbreak	-$1 574 710
No outbreak	$ 512 940

of characterizing risk. Bayesian networks are also extremely efficient at calculating the joint and marginal probabilities that are useful for evaluating risky decisions.[4] For example, based on the Bayesian network results for the WSSV import risk problem in Figure 7, the 15 percent overall probability (marginal probability) of a farm exposure is evident. Bayesian networks also provide a visually succinct way of communicating the financial risk problem. Consequently, Bayesian networks have computational as well as conceptual benefits for complex models.

(c) Stochastic simulation

Stochastic simulation methods are useful when the financial risk is associated with complex relationships. When stochastic methods are used, the probabilities associated with each event are based on repetitive sampling (usually Monte Carlo sampling or Latin hypercube sampling) for a specific number of iterations based on specified input distributions. A detailed explanation of stochastic simulation methods can be found in Hardaker *et al.* (2004).

The input probabilities may be described by a variety of continuous distributions (e.g. triangular, normal, beta, log-normal, uniform) or discrete distributions (e.g. Poisson, exponential, user-specified). Since the input variables are defined as distributions, outcome variables are also characterized by distributions. Therefore, stochastic simulation permits us to characterize risk in terms of the expected value and the probability distribution of the financial outcome values of interest. A short example of a financial risk characterization for a tilapia farm is given in Box 4.

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[4] Discussed later in the section on Financial Risk Management.

BOX 4

Financial risk due to market and production variation – a bioeconomic stochastic simulation model for tilapia farm profitability

Engle and Neira (2005) demonstrated a stochastic simulation approach to modelling financial risk associated with market price and production variation for tilapia farms using Crystal Ball. Normal probability distributions were used for tilapia sale price and feed price (market variation). Production variation was modeled based on a triangle distribution for FCR. Triangular distributions are commonly used when there is insufficient information to define a normal distribution but the boundaries of the distribution (maximum and minimum) can be estimated.

The model demonstrates how stochastic simulation can be used to characterize risk based on the average net return/ha, potential range of net returns/ha range and the likelihood of profitability for a tilapia farms (i.e. positive net returns/ha). A 97 percent likelihood of positive profit is indicated by the portion of the distribution to the right of the dashed line in Figure 8.

BOX 5

Comparing financial risk due to production variation: using stochastic simulation to compare earthen pond and recirculating aquaculture systems (RAS) for shrimp production

Stochastic simulation was applied to a bioeconomic model for earthen pond and RAS shrimp production (Moss and Leung, 2006). Parameters for survival, mean harvest weight, mean growth weight and FCR were the sources of production uncertainty considered. Probability distributions were specified for each of these parameters based Based on the simulation results, the risk associated with each farming method was compared. As exhibited in Table 9, the average cost was higher for the earthen pond system than the RAS (US$ 7.04/kg vs $4.48/kg), and with a greater range of uncertainty (US$ 4.66–13.36 vs $3.51–5.97; Figures 9 and 10). Other statistical measures such as the coefficient of variation (CV = standard deviation/mean) can help to compare the risk associated with each system. For example, the earthen pond CV was higher than that of the RAS (0.189 vs 0.088), suggesting that the RAS is less risky financially. A comparison of the cumulative probability distributions suggests that the RAS systems are more efficient than the earthen pond systems (discussed later in Box 21).

Stochastic simulation methods are commonly used in conjunction with bioeconomic production models. A comparative cost analysis for shrimp, for example, was conducted by Moss and Leung (2006) for earthen pond systems and recirculating aquaculture systems (RAS). Production, variable and fixed cost assumptions were used to compute the cost of shrimp production to formulate a financial risk analysis for each system (see Box 5). Dalton, Waning and Kling (2004) studied market variations in electricity consumption, electricity price, wage rates and inflation parameters, as well as biological variations in survival rate and FCR. The cost per fish was compared for different combinations of production levels and feeding technologies. Valderrama and Engle (2001) studied the impact of variation in production, yield, shrimp price, seed cost, feed volume, feed price and fertilizer on shrimp farm profitability in Honduras. Their study used a variety of financial performance measures to assess financial risk, including gross receipts, total costs, net returns, net returns/ha, breakeven price and breakeven yield.

Eliciting probabilities is a challenge when complex interactions exist in a stochastic simulation model. Even when the interactions may be known intuitively, the joint

FIGURE 8
Probability distribution of net returns/ha (in Kenyan shillings, KSh) for a tilapia farm using pellet feed in Kenya

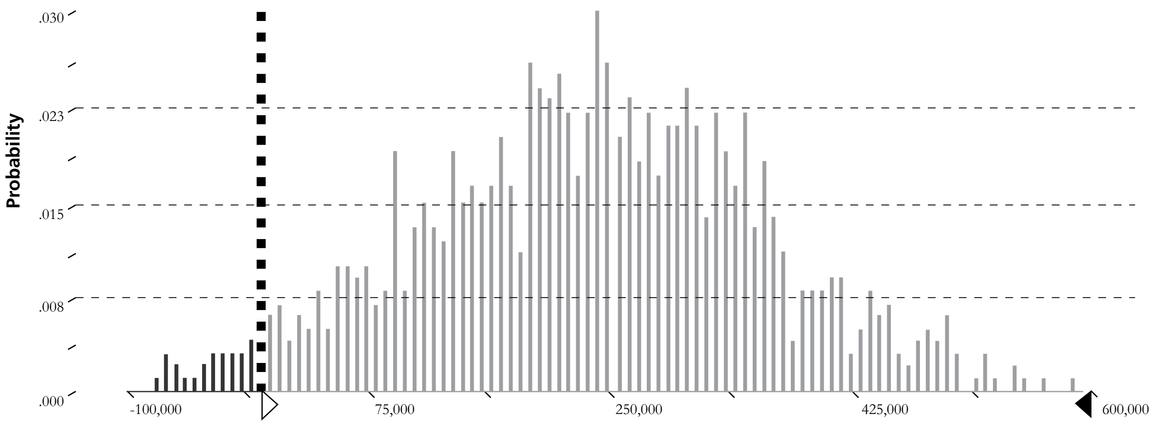
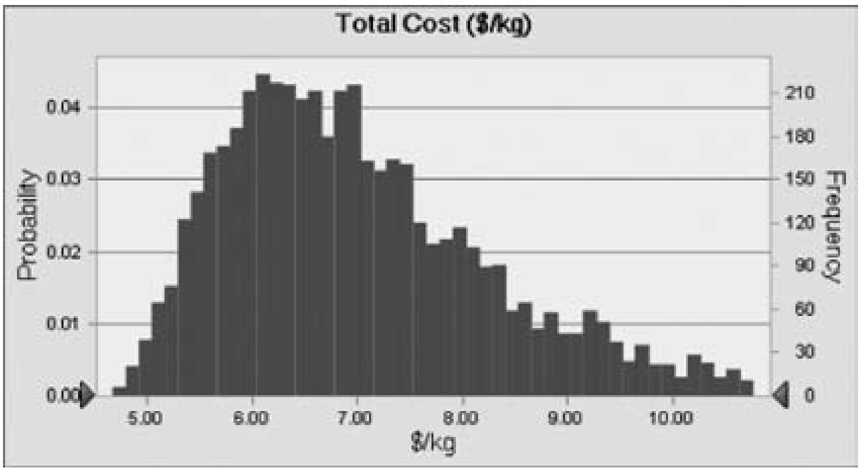


TABLE 9
Summary statistics for the sensitivity analysis of total, fixed, and variable costs (US$/kg)

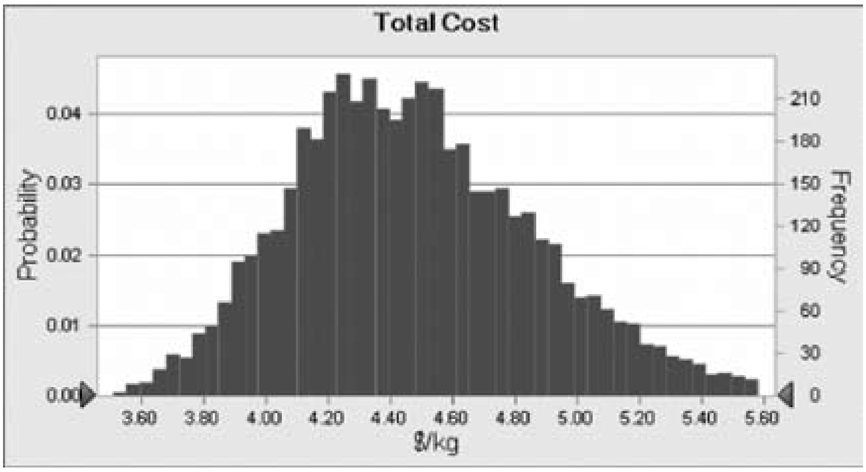
Summary Statistic	Earthen ponds			Recirculating aquaculture system		
	Total	Fixed	Variable	Total	Fixed	Variable
Mean	7.04	2.56	4.48	4.48	1.29	3.19
Median (50 percentile)	6.80	2.45	4.34	4.45	1.27	3.18
Standard deviation	1.33	0.58	0.79	0.39	0.17	0.26
Coefficient of variation	0.19	0.23	0.18	0.09	0.13	0.08
Minimum	4.66	1.56	3.04	3.51	0.92	2.54
Maximum	13.36	5.00	8.51	5.97	1.90	4.09

FIGURE 9
Distribution of total shrimp production cost for earthen ponds (US$/kg)



probability distributions can be difficult to define. If data are available, most stochastic simulation software packages will offer features to help fit a probability distribution to the existing data. Examples of financial risk assessments using stochastic simulation methods that rely on probability distributions fitted to industry data are shown in Boxes 6 and 7.

FIGURE 10
Distribution of total shrimp production cost for the recirculating aquaculture system (RAS) (US$/kg)



BOX 6

Using existing data to fit a probability distribution: a probabilistic risk analysis for the effect of prawn production yield on farm profitability

Probability analysis was used to study the impact of production yield variation on financial risk (Samples and Leung, 1986). Since a variety of factors (production costs, feed, water etc.) affect prawn production in a complex way, historical on-farm freshwater prawn data were used to fit probability distributions for three classes of pond size. Based on the data, a lognormal probability distribution was found to best model production variation for each class of farms. Financial risk was measured in terms of the average farm profit per surface hectare. Based on the results, the smaller ponds were more profitable (i.e. more efficient with their land) on average, but experienced greater risk reflected in the variation of profit (Table 10). Our perception of farm risk may be worsened by the fact that the right-skewness of the profit per hectare data (outcome variable) indicates that more farms experienced lower profits than the average of their class.

BOX 7

Using existing data to fit a probability distribution: a stochastic simulation for the effect of uncertainty on catfish farm profitability

Stochastic variables were used in a budget model to estimate financial risk for catfish farms in the Mississippi Delta (Kazmierczak and Soto, 2001). The stochastic variables used in the model were farmgate price, catfish yields and feed cost. BestFit (Palisade Corporation 1997) was used to approximate the distributions of prices and yields from historical data. Net returns were estimated for different size farms and culture methods (single-batch or multiple-batch). For both culture methods, the distribution for net returns (financial outcome variable) was negatively skewed beta distributions for each farm size. The results suggested that higher than average returns are likely for the farms modelled in the study. Further analysis suggested that economies of scale exist whereby larger farms have a lower cost of production.

TABLE 10
Selected statistical tests concerning the normality of freshwater prawn yields

Pond size	Profit $US/ha (Number of farms)	Standard deviation($US)	Coefficient of variation	Skewness
< 0.4 ha	2 308 (66)	878	0.38	1.105*
0.4–0.8 ha	2 038 (78)	585	0.29	1.432*
> 0.8 ha	1 813 (47)	523	0.28	1.967*

*p < .001

Non-probabilistic risk estimation
Risk can be characterized using probability estimates (probability trees and Bayesian networks) and probability distributions (stochastic methods) to model production and market uncertainty. Probability estimates are useful when expert knowledge or historical data are available. In contrast, non-probability estimates, described next, are useful when unprecedented situations and exploration is needed to characterize financial risk.

(a) What-if analysis
"What-if" analyses are useful for exploring different scenarios – sometimes called scenario-based analysis. A what-if analysis can be likened to exploring different paths of the probability tree, but without the probabilities or information about the likelihood of the scenario occurring. Scenarios can be used to describe multiple parameters that may change simultaneously. What-if analyses are particularly useful when the probability of each scenario occurring is unknown, i.e. not suited for probabilistic risk estimation.

An analysis of the effect of a farm's size is an example of a scenario-based analysis. When studying different size farms or production levels, the enterprise operations can change in terms of equipment, overhead (fixed costs) and operating costs (variable costs). Usually larger-scale production systems benefit from size economies as a result of production efficiencies (Kam *et al.,* 2002; Kam, Leung and Tamaru, 2006). However, this is not always the case, as found for prawn farms by Samples and Leung (1986) and for catfish farms by Kazmierczak and Soto (2001) (see Boxes 6 and 7).

What-if analyses are also useful for studying the feasibility of different production systems (e.g. pond, tank fishpond, earthen pond, recirculation system) (Kam *et al.,* 2003, Moss and Leung, 2006), feeding strategies (Kazmierczak and Soto, 2001) and scope of operations (Kam *et al.,* 2002). The what-if approach can be used to characterize the risk associated with different hazards as well as different degrees of hazard release (worst case, best case and most probable) as described in Box 8.

(b) Sensitivity analysis
Sensitivity analyses are useful for well-established production systems with clearly defined inputs and outputs (Hambrey and Southall 2002). Instead of using average (or typical values) to calculate profitability, a range of values is used for a parameter of interest. A sensitivity analysis usually consists of a table of values reflecting the range of possible values. Sensitivity is often communicated in the form of percentage changes, e.g. percent increase in profit with respect to the percentage change in cost. A sensitivity analysis helps to examine how changes in the variables representing the hazards of concern affect financial outcomes (e.g. profitability) and identify the most influential variables in a financial model. In some cases, results of a sensitivity analysis may be more useful than the financial measure determined by the model.

Sensitivity analyses are frequently used to study the impact that changes in market prices or biological parameters have on profitability. Posadas and Hanson (2006), for example, analyzed IRR sensitivity to nursery survival rates and weekly growth for shrimp. An example of a cost sensitivity analysis due to length of the nursery period

BOX 8

Using existing data to fit a probability distribution: a stochastic simulation for the effect of uncertainty on catfish farm profitability

Three scenarios were considered in evaluating the effect of disease risk on seabass and Atlantic salmon producer profitability (Thorarinsson and Powell, 2006). The impact of vaccination on operating income and net savings was examined for the worst case, best case and most probable level of unmitigated mortality due to disease. Based on the results of the analysis, vaccination was concluded to have a positive effect on operating income and net savings for the salmon producer. Seabass producers generally benefited from vaccination, except in the best case scenario (i.e. low disease mortality rate of 5 percent), where the cost of the vaccination could exceed the marginal benefit of decreasing the low level of mortality.

A sensitivity analysis was also conducted that compared market price with the changes in income. The results were used to determine the market price required by the seabass farmer to compensate for the additional cost of vaccination under each mortality scenario. A break-even analysis was used to estimate the minimum efficacy of the vaccination in order for the vaccination investment to be worthwhile. As expected from the what-if analysis results reported above, a seabass producer would require a higher potency (relative percent survival (RPS) of 25 percent) than the Atlantic salmon producer (RPS of 8 percent).

BOX 9

Using sensitivity analysis to identify significant threats to profitability: studying the effect of market and production uncertainty on offshore Pacific threadfin cage culture

A feasibility study for an offshore Pacific threadfin (*Polydactylus sexfilis*) cage production system was conducted for Hawaii (Kam, Leung and Ostrowski, 2003). The hypothetical six-cage system was based on the biotechnological requirements of and productivity demonstrated by the Hawaii Offshore Aquaculture Research Project (HOARP).
The total cost of production was estimated at US$ 3.97/lb for the production system projected to yield 914 271 lb of Pacific threadfin annually. The largest costs contributing to annual operating expenses of $3 626 556 were feed (30 percent), labour (17 percent), stocking (12 percent) and shipping (11 percent). Sensitivity analyses were conducted for several production hazards (average growth rate, stocking density, FCR and survival) and market hazards (feed price, sale price, seedstock price, leverage and loan interest rate) listed in Table 11. When comparing the sensitivity of multiple parameters, the changes in the parameter and outcome values are converted to percentages with respect to a baseline value. When percentages are used for the sensitivity analyses, the most sensitive parameters can be determined based on the largest of the unitless measures. Based on the results in Table 12, production costs are most sensitive to increased stocking densities, survival rates and average growth rates. Using the sensitivity information, management can determine which parameter values can be feasibly changed in order to reduce production costs by a desired amount.

In Figure 11, the changes in the average daily growth rate (horizontal axis) are compared to production cost and IRR. The graph is useful for determining the growth rate needed to achieve a desired rate of return. For example, in order to achieve a 20 percent rate of return, fish growth must reach an average of 3.5 g/day, resulting in estimated production cost of $3.31/lb.

BOX 10

Comparing the sensitivity of multiple parameters: a sensitivity analysis comparing milkfish production systems on profitability

Kam *et al.* (2003) conducted economic evaluations of three different commercial milkfish (*Chanos chanos*) growout systems in Hawaii. Cost structures and spreadsheet models were developed for a tank, pond and Hawaiian fishpond system (Table 13). Based on the observed practices of milkfish culture as a secondary or tertiary crop, capital costs and several operating costs were prorated to accurately depict current farm practices. The results of this study were consistent with the Hawaiian farmers' perspective toward milkfish as a species that is secondary to core production based upon current market conditions and input requirements.

A profit sensitivity analysis of the pond and tank systems with respect to sale price, production yield, labour, feed and stocking indicated that sale price, as expected, had the largest impact on profitability, followed by feed (Figures 12 and 13). The pond system was also more appealing based on the incremental returns to variable costs for percent change in the sale price in comparison to the tank system (Table 14). Cost and profit sensitivity to the level of milkfish production were also evaluated, but are not presented here.

was illustrated in Box 2 as part of the Pacific threadfin hatchery case study. In Box 9, profit sensitivity to changes in market and production uncertainty is illustrated for Pacific threadfin cage culture.

A sensitivity graph can visually demonstrate the relationship between two variables. A spiderplot displays multiple sensitivity plots for different input parameters (e.g. average growth rate, stocking density, FCR, price) as percentages against an output performance variable such as net income. Consequently, spiderplots are used to identify which of the parameters have the largest influence on performances. Examples of spiderplots for tank and pond milkfish production systems can be found in Box 10.

(c) Break-even Analysis

Sensitivity analyses are also useful for determining breakpoints and threshold values, as seen in the earlier fish vaccination example in Boxes 8 and 9. This form of analysis is called a break-even analysis, where only the value of a single parameter is determined. Annual revenue and expenses, rate of return, market (or salvage value) equipment life and capacity utilization are common factors studied in break-even analyses (Sullivan, Wicks and Luxhog, 2007). Break-even analyses are sometimes considered a special case of sensitivity analysis. These critical values, or switching values, indicate where values of certain parameters may trigger unacceptable outcomes (Hambrey and Southall, 2002). Boxes 11 and 12 include break-even analysis examples that reflect the critical values needed to be profitable.

Commentary on quantitative perspectives

Deterministic methods presume that the consequences associated with a hazard are precisely known. Deterministic estimates do not account for uncertainty. Consequently, the deterministic case is usually considered as the baseline situation for comparative purposes. The label "non-probabilistic" risk estimation was used in our discussion to indicate that uncertainty is present, but is difficult to approximate using probability estimates.

Other quantitative methods exist aside from the probabilistic, non-probabilistic and deterministic approaches previously described. In fuzzy set theory, events are not

TABLE 11
Parameter ranges for sensitivity analyses

Parameter	Minimum	Baseline	Maximum
Average growth rate	1.50 g/day	2.29 g/day	3.50 g/day
Stocking density	80.77 g/m^3	109.04 g/m^3	484.62 g/m^3
FCR	1.00	2.39	2.50
Feed price	US$ 0.25/lb	US$ 0.50/lb	US$ 0.75/lb
Sale price	US$ 2.00/lb	US$ 4.00/lb	US$ 5.00/lb
Seedstock price	US$ 0.20 ea	US$ 0.29 ea	US$ 0.35 ea
Survival	50%	61.8%	100%
Leverage (% borrowed)	0%	0%	100%
Loan rate (30 years)	6%	–	12%

TABLE 12
Production cost sensitivity to parameter changes

Parameter	Average % Change in production cost for a % increase in parameter	Baseline (= 100%)	Minimum (change from baseline, %)	Maximum (change from baseline, %)
Average growth rate	- 0.36	2.29 g/day	- 34.6	+ 52.6
Stocking density	- 0.10	109.04 g/m^3	- 25.9	+ 344.4
Food conversion ratio (FCR)	+ 0.32	2.39	- 58.2	+ 4.6
Feed price	+ 0.32	US$ 0.50/lb	- 50.0	+ 50.0
Sale price	+ 0.03	US$ 4.00/lb	- 50.0	+ 250.0
Seedstock price	+ 0.14	US$ 0.29 ea	- 31.0	+ 20.7
Survival	- 2.74	61.81%	- 19.1	+ 61.7

treated as mutually exclusive, but as having membership (association) with a other events (Bezdek 1996). Consequently, fuzzy sets convey information about similarities as opposed to relative frequencies. These quantitative perspectives are contrasted in Table 17.

Like a bioeconomic model, financial risk characterization links production and financial (economic) parameters. When the relationships between a hazard and its financial consequences are formalized in a risk characterization, it is possible to systematically compare alternative strategies. These linkages are generally specified during the financial risk assessment (release assessment, exposure assessment and consequence assessment).

BOX 11

Using sensitivity analyses and break-even analysis to assess critical values: tilapia farm net return sensitivity to feed price, survival rate and farm size

Engle and Neira (2005) provide examples of sensitivity and break-even analyses conducted for tilapia budgets by varying feed prices, survival rate and farm size. Useful information can be drawn from the analyses exhibited in Table 15(a-c). For example, it is possible to conclude from Table 15a that as feed prices increased from Kenyan shilling (KSh) 8/kg to KSh 16/g, net returns/ha decreased from KSh 397 812 to KSh 84 284. Breakeven sale prices increased from KSh 62/kg to KSh 92/kg. In Table 15b, as the survival rate increased from 75 percent to 95 percent, net returns/ha increased from KSh 149 533 to KSh 274 920 and break-even prices above total costs decreased from KSh 83/kg to KSh 75/kg. In Table 15c, as farm size increased from 0.5 to 8 ha, net returns/ha increased from KSh 228 445 to KSh 251 803, and break-even prices above total costs decreased from KSh 156/kg to KSh 9/kg.

FIGURE 11

Production cost (US$) and internal rate of return (IRR) sensitivity to changes in stocking density

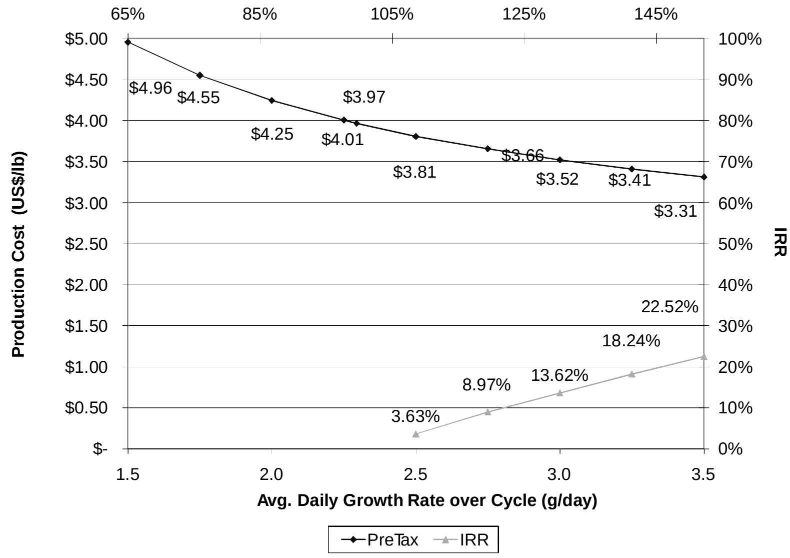


FIGURE 12

Profit sensitivity for a pond production system.

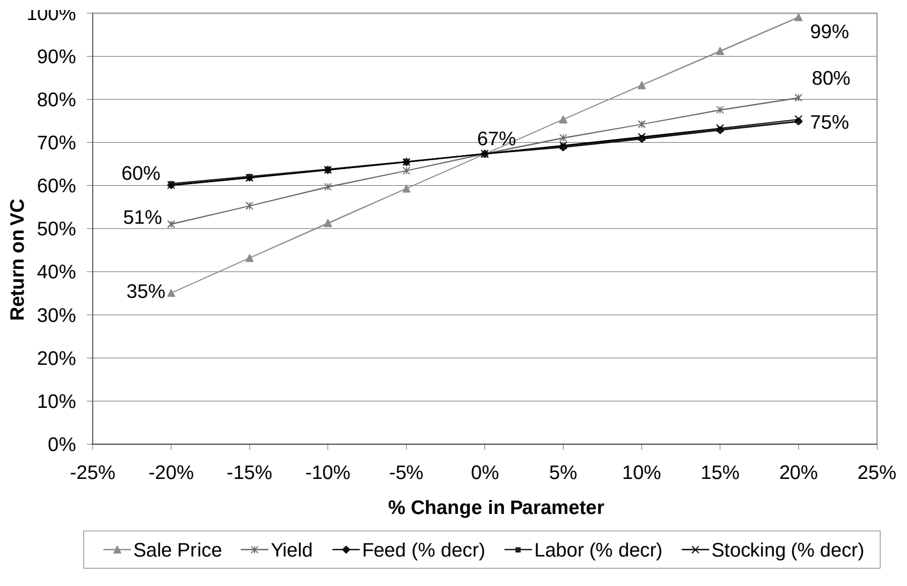


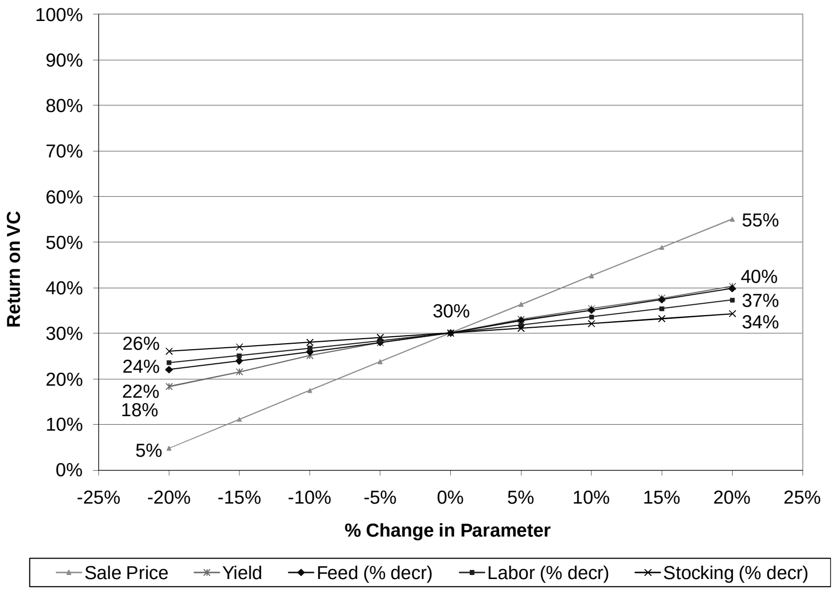
TABLE 13

Profitability of the three systems evaluated

Profitability Measures	Pond	Tank	Fishpond
IRR	[1]	[1]	192.35 %
NPV (US$)	$ -362 456	$ -124 189	$ 407 132
Marginal return (Rev-VC, US$/lb)	$ 1.20	$ -0.04	$ 1.46
Return on VC	67%	30%	59%
Return on TC	-9%	-21%	49%

[1] IRR value not available because NPV < 0

FIGURE 13
Profit sensitivity for a tank production system



% decr = percent decrease

BOX 12
Using break-even analysis to assess critical values: determining off-shore aquaculture production requirements needed in order to be profitable

A break-even analysis was conducted using an enterprise budget model developed for the Pacific threadfin off-shore aquaculture enterprise described in Box 9. The minimum value required to achieve a desired 20 percent 20-year IRR was determined using the Goal Seek feature in Microsoft Excel.

Based on the results of the break-even analysis in Table 16, the parameter that would require the smallest percentage change was the sale price, followed by improving survival rates. Since sale price may be out of the control of the manager, he may consider improving production methods, striving to achieve a 90.25 percent survival rate or a growth rate of 3.35 g/day. Other production measures require greater change in terms of percentages. Managerial insight would be needed to determine which parameters can be realistically improved in order to earn a 20 percent IRR.

TABLE 14
Profit sensitivity (return to variable costs) for pond and tank production systems

	Pond production		Tank production	
Parameter	**Baseline**	**Return on VC/ % Change in parameter**	**Baseline**	**Return on VC/ % Change in parameter**
Sale price	US$ 3.00/lb	+ 1.60%	US$ 3.00/lb	+ 1.25%
Yield (density)	10.00 fish/m^3	+ 0.74%	100.00 fish/m^3	+ 0.61%
Labour	797.17 hr/yr	- 0.36%	594.43 hr/yr	- 0.34%
Stocking (fry price)	US$ 0.25 ea	- 0.38%	US$ 0.25 ea	- 0.20%
Feed (FCR)	0.75	- 0.37%	1.50	- 0.42%

TABLE 15
Sensitivity analyses and break-even analysis

(a) Effect on net returns and break-even price above total cost of varying feed prices

Feed price (KSh/kg)	Net returns (KSh/kg)	Break-even price (KSh/kg)
8	397 812	62
10	319 430	69
12	241 048	77
14	162 666	92

(b) Effect on net returns/ha and break-even price above total cost of varying survival rates

Survival rate (%)	Net returns (KSh/kg)	Break-even price (KSh/kg)
75	149 533	83
80	181 005	81
85	241 048	77
95	274 920	75

(c) Effect on net returns/ha and break-even price above total cost of varying farm size

Farm size (ha)	Net returns/ha (KSh/kg)	Break-even price (KSh/kg)
0.5	228 445	156
1.0	241 048	77
3.0	249 256	25
5.0	250 898	15
8.0	251 803	9

TABLE 16
Parameter values required for profitability

Parameter	Minimum	Baseline (= 100%)	Maximum	Value required for profitability (> 20% IRR)	Change from baseline (%)
Average growth rate	1.50 g/day	2.29 g/day	3.50 g/day	3.35 g/m^3	+ 46.3%
Stocking density	80.77 g/m^3	109.04 g/m^3	484.62 g/m^3	177.36 g/m^3	+ 62.7%
FCR	1.00	2.39	2.50	0.89[1]	- 62.8%[1]
Feed price	US$ 0.25/lb	US$ 0.50/lb	$ 0.75/lb	US$ 0.18/lb	+ 64.0%[1]
Sale price	$ 2.00/lb	$ 4.00/lb	$ 5.00/lb	$ 4.88/lb	+ 21.8%
Seedstock price	$ 0.20/lb	$ 0.29 ea	$ 0.35 ea	–[1,2]	–[2]
Survival	50.00%	61.81%	100.00%	90.25%	+ 46.00%

[1] Parameter value required for 20% 20-year IRR outside of sensitivity range.
[2] Seedstock price required <US$ 0.00 ea, % change not feasible. (A fry sale price of US$ 0.00 ea yields a 14.44% IRR).

TABLE 17
Contrasting the perspectives of different quantitative approaches

Quantitative methods	Perspective
Deterministic	Certainty exists (no uncertainty, no risk)
Probabilistic	Uncertainty exists and is approximated
Non-probabilistic	Uncertainty exists and is explored
Fuzzy sets	Uncertainty viewed as membership with one or more states

FINANCIAL RISK MANAGEMENT

Risk assessments inform risk management, the process of evaluating and reducing risks. Risk reduction will depend on the risk management evaluation criteria or financial objectives. Financial risk management implies that something can be done to reduce risk with respect to the financial risk objective. The basic process of financial risk management includes:

- defining the risk management objective(s),
- specifying the decisions that may reduce or remove the hazards, and
- selecting an evaluation and monitoring method.

Risk management objectives

Risk management evaluation criteria are usually based on the outcome measures identified in the consequence assessment. As suggested earlier, financial risk assessment objectives are usually based on measures of profitability. In the shrimp production example in Box 5, the earthen pond system was compared with the recirculation system based on production cost. In this example, cost minimization could be a risk management objective, and the decision would entail choosing between the earthen pond system or recirculation system. A short list of possible risk objectives is presented in Table 18.

Expected utility maximization

The emphasis of the consequences or the evaluation criteria considered thus far has been monetary in nature. In decision analysis, the criteria can be a single attribute such as profit or represent multiple attributes. One common method for combining or converting values into a general measure of utility is through the use of an additive weighting scheme. According to the principle of rational choice, we prefer alternatives that maximize our expected utility. The expected utility maximization principle is conventionally used in decision analysis.

Risk aversion

When a decision-maker is assumed to have a risk-neutral attitude, a simple additive weighting scheme is used. Risk-aversion and risk-seeking attitudes require that risk be embedded into the weighting scheme. Utility is a flexible measure that can incorporate monetary and subjective criteria. Risk attitudes, for example, can be used to adjust traditional profit-maximizing analyses to reflect risk-averse behaviour (Jin, Kite-Powell and Hoagland, 2005). For example, when faced with greater risk, risk aversion may increase and our investment level will decrease. The evaluation methods previously discussed include methods for balancing the trade-off between profit-maximizing objectives with uncertainty. A demonstration of subjective expected utilities methods can be found in Hardaker *et al.* (2004).

Precautionary principle

The precautionary principle reflects a preventive approach to risk management. The precautionary principle can be contrasted with "monitor-response" regulatory

TABLE 18
Examples of risk management objectives and decisions

Risk management objective	Examples of decisions to mitigate risk	
	Action decisions	Test decisions
• Maximize profit • Minimize production cost • Minimize revenue (production) loss • Minimize environmental impact • Maximize employment • Poverty reduction	**Production Threats** • Crop diversification • Harvesting schedule • Production contracts • Crop insurance • Vaccination • Biosecurity practice • Yield (revenue) insurance **Market Threats** • Direct marketing • Leasing inputs • Enterprise diversification • Marketing contracts • Hedging in futures • Futures options contracts • Government subsidy • Rural development programmes • Vertical integration	• Biosurveillance • Agricultural inspections • Monitoring • Equipment maintenance • Water quality monitoring

frameworks, which can be viewed as a weak approach since the damage will have already been done. According to Hambrey and Southall (2002), the reactive approach is a "permissive principle" that is dangerous when considering hazards whose impacts are persistent and irreversible. The precautionary principle can be found as Principle 15 of the Rio Declaration of the United Nations Conference on Environment and Development (UNCED). The principle explicitly states that "*where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*"

At the surface, the precautionary principle could appear to reduce our confidence in methods highly regarded as having scientific rigor. Yet, by taking into account the precautionary principle, it is still necessary to identify cost-effective measures to prevent irreversible damage. Therefore, from the precautionary principle perspective, risk management methods will not seek to determine if any preventive measures should be taken, but rather which preventive measures should be carried out.

The Safety-First Rule

The "safety-first approach" is a form of lexicographic utility that is commonly used in risk analysis. As an alternative to expected utility maximization rules, the approach specifies that decisions must preserve the safety of a firm's activities, followed by a profit-oriented objective. Robison *et al.* (1984) outline the three safety-first criteria for use in risk management (see Box 13).

Management Decisions

Risk management explores alternative strategies that potentially reduce consequences, examines the feasibility of implementing measures and involves periodic review of the effectiveness of policies implemented. The alternative strategies can be classified as action decisions and information decisions. Action decisions remove or reduce hazards to reduce risk – the potential for negative consequences. Test decisions gather evidence to inform action decisions (Jensen 2001). This perspective of risk management, referred to as the "test-action" risk framework is illustrated in Figure 14.

Most risk assessment frameworks do not permit a systematic comparison between different kinds of intervention and existing farmer/fisher activities (Hambrey and Southall, 2002). However, the test-action risk framework has been demonstrated to be general enough to compare the effectiveness of different risk management strategies and compare the relative risk between hazards (Kam, 2006).

BOX 13

Safety-first rules

1. Choose an alternative that maximizes expected returns ($\bar{E}$), where the probability of a return less than a specified value (E_{min}) does not exceed a stipulated probability (P).
   $Max\ \bar{E},\ s.t\ P(E \leq E_{min}) \leq P$
2. Choose an alternative that maximizes income at the lower confidence limit (L), where probability of the a lower income does not exceed a stipulated probability (P).
   $Max\ L,\ s.t.\ P(E < L) \leq P$
3. Choose the plan with the smallest probability of yielding a return below specified level (E_{min}).
   $Min\ P(E < E_{min})$

Actions to remove or reduce hazards

The financial risk characterization examples given in the preceding section on Risk Characterization illustrated a number of comparative analyses. Such comparisons are useful for financial risk management and can be viewed as action decisions to remove or reduce hazards. In the shrimp production cost analysis in Box 5, for example, an enterprise may use the risk analysis to decide between earthen pond or recirculation system methods. Feed types (Box 1), production length (Box 2), species (Box 8) and production level (Box 11) are also examples of risk management decisions that could improve profitability.

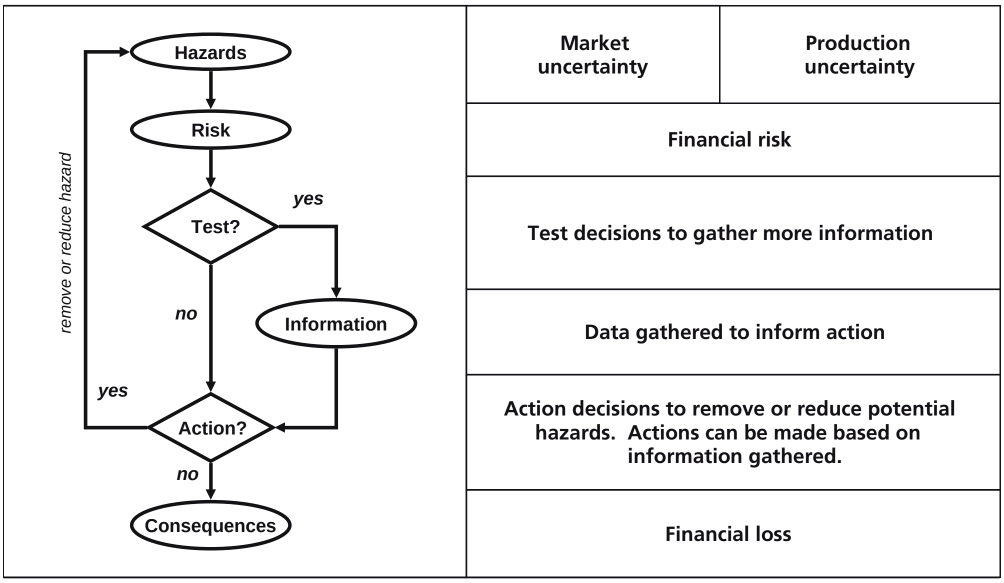
Farm enterprises can reduce financial risk in a number of ways. Farmers can reduce production threats by diversifying their product mix, changing their scale of production and re-allocating resources. The financial structure of the farm can be adjusted to combat market threats (e.g. a change in financial leverage will cause a change in the debt to equity ratio). Yield insurance is a preventive means of mitigating financial risk. In exchange for a fixed insurance premium, producers will receive protection from uncertain but potentially large losses. Like market interest rates, insurance premium rates may be based on the insured's return to productive capital, adjustment reflecting a positive rate of time preference, premium for expected inflation and a risk premium (Goodwin and Mishra 2000).

Examples of managerial decisions concerning direct marketing and biosecurity policies can be found in Annex I. Harwood *et al.* (1999) detail a number of management actions to reduce risk; other examples of action decisions to reduce risk are given in Table 18.

Tests to gather information

Tests are performed to gather information that is used to inform decisions. In risk assessment, an informative test results can reduce uncertainty and be used to revise release and exposure estimates and the expected utilities of subsequent decisions. Based on the revised expected utilities, a decision-maker might proceed with a management plan that reduces potential financial loss.

FIGURE 14
Risk management viewed as a test and action decisions to reduce consequences



Test information is not usually free. Monitoring, biosurveillance, forecasts and laboratory analyses are examples of test decisions. Test decisions might incur expenses associated with labour, materials or revenue foregone. Ideally, the cost of a test will not exceed the potential financial benefit. An example of a biosecurity risk problem considering biosurveillance as a strategy can be found in Annex I. Another example of a test decision will be presented in the section on Decision Trees and Baysian Decision Networks.

Evaluation methods

In the previous section on Risk Characterization, a number of decision analysis methods were employed for risk characterization. The following sections briefly introduce some methods for evaluating financial risk management decisions using decision analytic methods.

Decision trees and Bayesian decision networks

A common method to represent decision scenarios (a series of test and action decisions) is to use decision trees. Decision trees are an extension of probability trees (previously introduced in the section on Probabilistic Risk Estimation). Decision forks are indicated by squares and can occur at any point along the sequence of events. At each decision fork, managers can make a decision that maximizes the expected value (or utility).

Many decisions are difficult to model with traditional decision trees because decisions and outcomes are rarely linear or independent of one another. Test and action decisions can occur at different stages and in a variety of combinations. For complex models using decision trees (DTs), analysts must compare the probabilities of all branches of the tree. In contrast, Bayesian decision networks (BDNs) provide a succinct representation that clearly indicates the independencies of the model and efficiently estimates complex probabilities that are difficult for decision trees.

Both DTs and BDNs are used to analyze the impact of a sequence of test and action decisions to manage risk. In managing financial risk, we seek to determine parameter values that maximize profitability or to identify parameters that could have a strong influence on profitability. An example of the simple WSSV import risk model is presented as a decision tree and a Bayesian decision network in Box 14.

The value of test information can be calculated using DTs and BDNs. As demonstrated in Box 14, it is possible to observe the "break-even" point that would cause a decision-maker to not to ban imported products. A calculation of the value of information (VOI) for test-decisions such as biosurveillance or monitoring can provide valuable information about the amount that an individual would be willing to pay for the expected change in outcome. The expected value of information can serve as a measure of the importance of the uncertain parameter.

In VOI analysis, the results of test-decisions are fed back into a model (DT or BDN) to inform subsequent decisions using Bayesian inference. The feedback is accomplished by inverting a DT (or message passing in BDNs) and exploiting Bayes theorem to calculate the *a posteriori* probabilities. Research by Forsberg and Guttormsen (2006), presented in Box 15, studied how the value of price information could be used to influence production planning. An example of the measurement of the value of biosurveillance is discussed in Annex I.

Risk programming

Risk programming is frequently used in agriculture for whole-farm planning and also has a long history of use in aquacultural farm management. Risk management studies concerning stocking densities, scheduling decisions, level of intensity, scale of production, level of investment and disease management have employed risk programming methods (Hatch *et al.,* 1987; Hatch and Atwood, 1988; Kusumastanto,

BOX 14

Risk management using decision trees (DTs) and Bayesian decision networks (BDNs): movement restriction decisions affecting farm profit

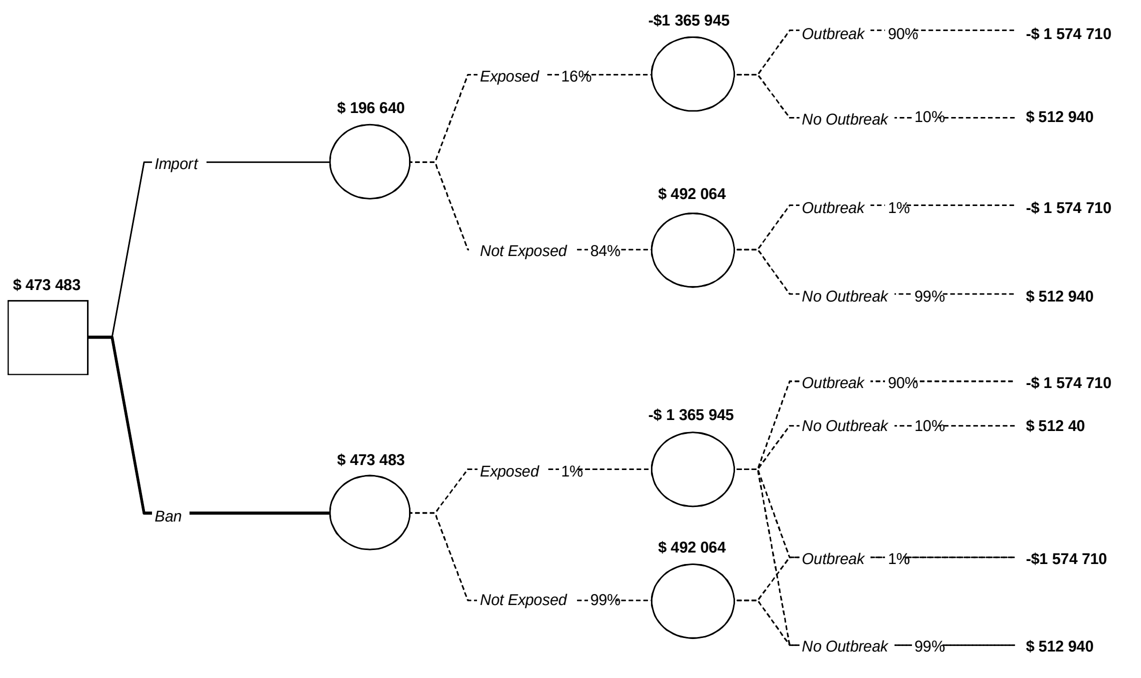
In the simple DT for the policy of a movement restriction (Figure 15), the expected utility associated with a ban is US$473 483 for the farm. Therefore, from the farmer's perspective, an import ban is preferred rather than no movement restriction at all (farm income of $196 640). These findings can also be represented in the form of a BDN in Figure 16.

In this simple movement restriction example, the cost of the ban was not explicitly stated. However, based on the decision tree, the value of the import ban is $473 483 - $196 640 = $276 843. This reflects the maximum value that a decision-maker would be willing to pay before the alternatives have an equivalent expected value.

This can be easily seen if we associate a cost with the movement restriction equal to $273 843. This equality can be seen in the expected values estimated for the movement restriction decision in Figure 17. (The expected values of the movement restriction are not exactly the same due to rounding error.) Adding a cost for the movement restriction requires a few more steps in a decision tree than in a Bayesian decision network. For the decision tree, the cost would have to be incorporated into the right-most terminal nodes along the movement restriction "ban" path.

FIGURE 15

Decision tree for a movement restriction for frozen commodity shrimp



Jolly and Bailey, 1998; Valderrama and Engle, 2004). The objectives usually seek to maximize profit subject to farm resource constraints and other restrictions.

Risk programming utilizes a sophisticated set of algorithms to find an optimal solution to a set of constraints expressed as equalities and inequalities. Risk programming is an extension of traditional mathematical programming methods (see Annex II and Box 16 for examples). In comparison to linear programming, which seeks to optimize

FIGURE 16
Bayesian decision network for a movement restriction for frozen commodity shrimp

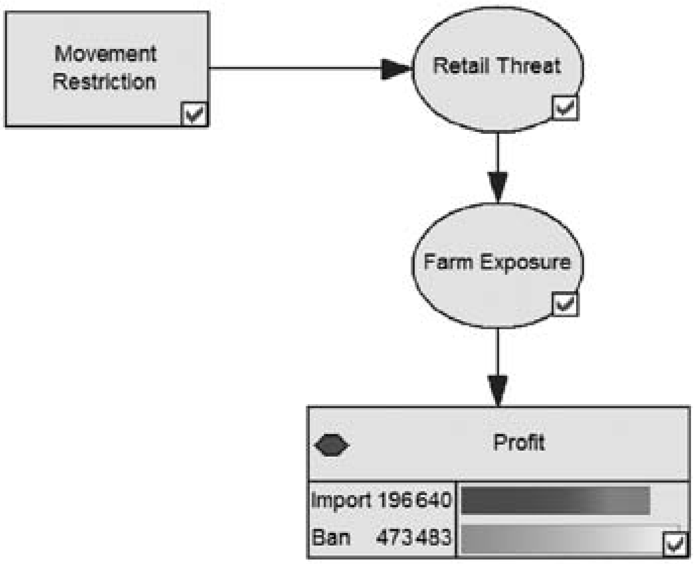
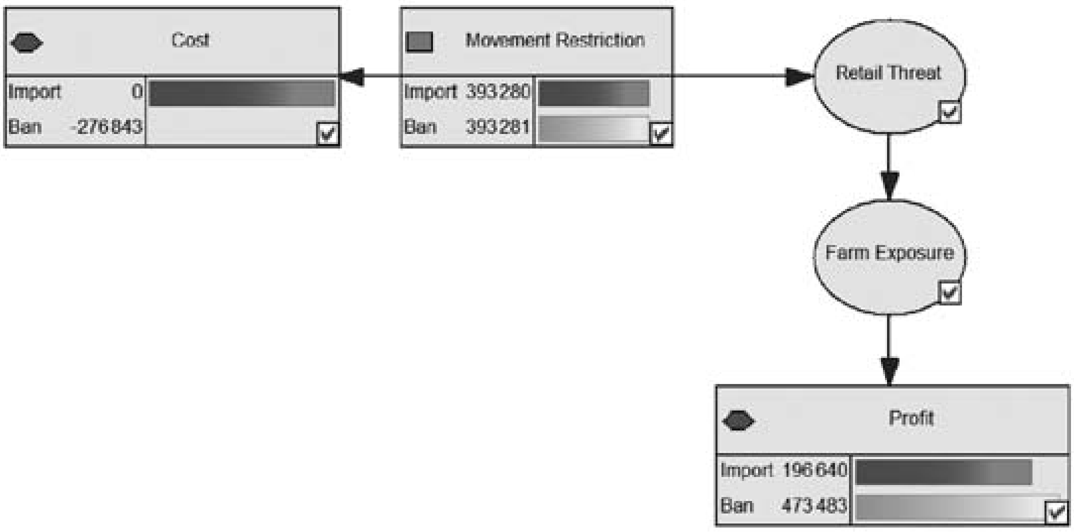


FIGURE 17
Using a Bayesian decision network to determine the decision cost (US$) in which the alternatives are equivalent



(e.g. profit-maximize), risk programming oftentimes seeks to minimize uncertainty in the outcome performance metric. Additional information about risk programming and mathematical programming models can be found in Hardaker *et al*. (2004).

(a) E-V efficiency

Expected value-variation efficiency (E-V or mean-variation efficiency) frontiers are often used to inspect an efficient set of solutions. Efficiency analyses are useful when the preferences are unknown. In E-V efficiency, an alternative *A* is preferred to *B* if the

BOX 15

Value of information analysis. Estimating the value of price information on salmon farm profit

A salmon farm harvesting model was developed by Forsberg and Guttormsen (2006). The impact of price uncertainty on harvesting decisions and farm profit was examined. The premise of their study was based on the notion that price information could be used to determine if it is more profitable to harvest (and sell) now or postpone harvesting. If a salmon farmer knew that the salmon price would go down or remain constant, a farmer would opt to harvest and sell his products. Alternatively, if he found that the price would increase in the future, he would postpone harvesting until that time. Consequently, DTs can be used to estimate the value of the market price forecast – even in cases where the forecast may not be perfect.

The management objective was to maximize NPV. The decision variables was a batch harvesting decision. The optimal harvest plan was determined for four scenarios:

Scenario 1: Constant price per kg regardless off fish size (baseline scenario = no information)

Scenario 2: Seasonal adjusted prices, same price regardless of fish size (imperfect information A)

Scenario 3: Seasonal adjusted prices, dynamic weight dependent (imperfect information B)

Scenario 4: Actual prices (perfect information).

For each scenario, the value of information (forecast model) is equal to the difference between the optimal harvest of the scenario, e.g. $\bar{E}2$, and the optimal harvest of the baseline scenario, $\bar{E}_1$. VOI = $\bar{E}_2 - \bar{E}_1$. The VOI estimates for each of the information scenarios are presented in Table 19, where perfect price information is the most expensive. Based on the results of the analysis in Table 20, a farmer would be willing to pay at most 165 Norwegian kroner (NKr) for the forecasted price information in scenario 2, and 313 NKr for the forecasted price information in scenario 3.

BOX 16

Linear programming for a network scheduling model: using linear programming measuring managerial decisions on profit and effluent discharge

A linear programming model was used by Engle and Valderrama (2004) to compare Best Management Practices (BMPs) on farm profitability (net returns/ha) and net nutrient discharge for semi-intensive shrimp farms in Honduras. The decision variables included stocking density, duration of grow-out cycle and water exchange strategy. In comparison to most studies that examine profit under production constraints, the BMP study also considered compliance with effluent discharge limits as a constraint. The study revealed the burden of additional fixed costs associated with implementing the BMPs, particularly for smaller farms.

expected utility (*E*) of *A* is greater or equal than *B*, and the variance (*V*) of *A* is equal or less than *B*, i.e. $E_A \geq E_B$ and $V_A \leq V_B$. The E-V efficient set includes only non-dominated alternatives. The E-V approach is commonly used in optimal investment portfolio problems, and likewise for analogous resource allocation problems. In conducting an E-V analysis, each alternative is plotted in two-dimensional E-V space, where the expected utility is on the vertical axis and the variance is measured along the horizontal axis. An alternative is said to be E-V efficient if there is no other alternative that lies in its “north-western” quadrant. An illustration from Hardaker *et al.* (2004) is given in Box 17.

TABLE 19
Harvesting plan, profit and value of information (VOI) for different price scenarios and fish groups

	May	September	October	Profit (in NOK) [2]	VOI [3]
Scenario 1					
Group 1			103 (5.3 kg)		
Group 2			122 (6.3 kg)	279 000	baseline
Group 3		68 (6.5 kg)	64 (7.2 kg)		
Scenario 2					
Group 1	54 (2.6 kg)[1]				
Group 2	66 (3.2 kg)			444 000	165
Group 3	78 (3.8 kg)				
Scenario 3					
Group 1		62 (4.7 kg)	34 (5.3 kg)		
Group 2			122 (6.3 kg)	592 000	313
Group 3			139 (7.2 kg)		
Scenario 4					
Group 1		92 (4.7 kg)			
Group 2		109 (5.6 kg)		1 279 000	1 000
Group 3		125 (6.4 kg)			

[1] Average weight of the harvested fish in parentheses.
[2] Profits from operation in the planning period, i.e. (Sales income – Variable cost) – Value of the fish by January 1.
[3] VOI is extra profit compared to scenario 1.

BOX 17
E-V efficiency analysis: comparing alternative crop rotation methods

In an example from Hardaker *et al.* (2004), the impact of crop rotations (alternatives K, J, I, F, G, H) on profit was demonstrated. Based on the E-V plot in Figure 18, the alternatives I, J and K are non-dominated and comprise the E-V efficient set that a manager may choose from. The manager's choice will depend on his attitude toward risk. The lines corresponding to utility levels (where, $U_1 < U_2 < U_3$) are iso-utility (indifference) curves. The angle of the curves represents typical risk aversion attitudes.

E-V efficient frontiers are also suitable for non-linear programming models. Non-linear programming, including quadratic programming methods, is used when the utility functions are non-linear, outcome performance values are not normally distributed or risk aversion exists for larger consequences. A similar method considers standard deviation as a measure of uncertainty, called E-S efficiency. (Standard deviations are equal to the square root of the variance and measure the actual units of the performance measure.) In E-S efficiency, any alternative is dominated if another alternative is above and to the left in E-S space. The linear equivalent of E-V efficiency considers the mean absolute deviation, described next.

(b) MOTAD

In contrast to the use of variance or standard deviation in E-V and E-S efficiency, MOTAD (Minimization of Total Absolute Deviations) represents uncertainty as the mean absolute deviation, M. The use of the mean absolute deviation is often desired because a simpler linear program is required for the solution. In MOTAD the total deviations are averaged using the probabilities of the states. The mean absolute deviation is used as a constraint for the problem, and the linear program is solved for various values of M. The initial value for the constraint is set arbitrarily high and solved for progressively smaller values of M. An E-M efficient frontier, however, only provides approximation of the E-V frontier. A variation called Target MOTAD programming follows the same process, however, a target income is set, and the mean deviation from the target *d* is the uncertainty constraint. An example of target MOTAD risk programming is exhibited in Box 18. A variation on MOTAD programming for measuring financial risk in aquaculture that been conducted for multiperiod planning (Kusumastanto, Jolly and Bailey 1998) is given in Box 19.

(c) Scheduling

Risk programming is frequently used to mitigate price risk and yield risk. Stochastic dynamic programming, for example, has been used to optimize production scheduling for catfish (Hatch, Atwood and Segar 1989) and shrimp (Hochman *et al.*, 1990; see Box 20) .

Stochastic efficiency

For stochastic simulation methods, the comparison between alternatives requires more than a comparison of expected values. Since outcome values may be non-normally distributed, expected utility maximization will not take into account uncertainty inherent in the decision. When average values do not adequately reflect the inherent risk, cumulative distributions functions (CDFs), for example, may represent risk more effectively.

BOX 18

Target MOTAD risk programming example: a risk-efficiency approach to making shrimp production plan decisions

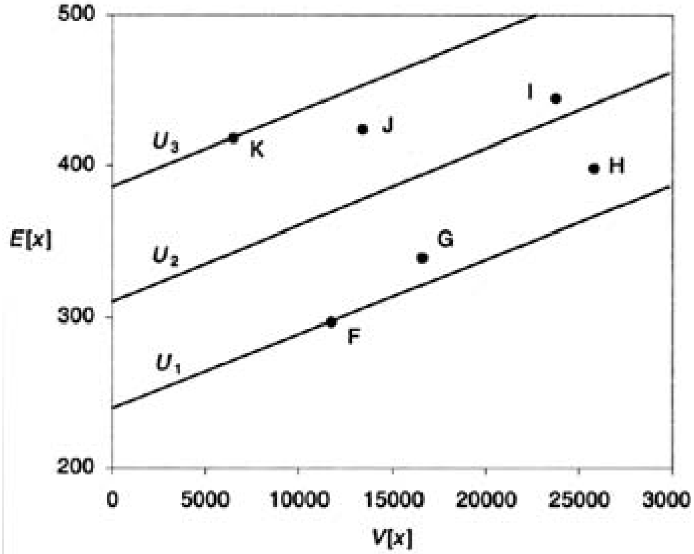
A risk programming method by Valderrama and Engle (2002) for shrimp farming in Honduras evaluated the impact of alternative production plans on expected income. A linear program (LP) was developed that modelled physical constraints (land, harvest and transfer) and financial constraints (cash flow requirements, debt balancing and annual borrowing limits) for three farm-size scenarios. The LP and Target MOTAD were solved using GAMS (GAMS Development Corporation 2007). An efficient set of production plans that maximized farm income were determined for each of the farm scenarios. Each plan described four possible management decisions that met a safety (i.e. target) level of income: stocking month, stocking density, length of the grow-out cycle and water exchange regime. An example of the Target MOTAD solution for E-M efficiency is shown in Table 20.

BOX 19

MOTAD multiperiod programming example: a risk-efficiency approach to making shrimp production plan decisions

A MOTAD multiperiod programming aquaculture production model was created by Kusumastanto, Jolly and Bailey (1998). Three types of aquaculture systems (extensive, semi-intensive and intensive) and three scales of production (2-ha small-scale, 5-ha medium-scale and 10-ha large-scale farms) were considered. The financial performance objective was to maximize net present value (NPV). Other financial measures were observed, including total investment, annual operating cost, net benefit-cost ratio (NBCR) and internal rates of return (IRR). International price variability with respect to yield variability was the main consideration of the study. The risk-efficient strategies were determined for farms in different provinces based on the MOTAD multiperiod programming.

FIGURE 18
Six crop rotations in E-V space and three indifference curves representing risk aversion [1]



[1] Expected value, E[x], and Variation, V[x]. Refer to text for explanation of E-V (Expected Value-Variation) efficiency.

TABLE 20
Summary of production activities selected in the resolution of the LP models as outlined by the GAMS output. Annual farm yields and objective function values (US$) are indicated for three different farm-size scenarios

	Farm-size scenario		
Farm size (average size)	**< 150 ha (73 ha)**	**150–400 ha (293 ha)**	**> 400 ha (966 ha)**
Annual farm yield (kg/ha)	1 256	1 384	1 401
Objective function value (US$)	$790 878	$3 439 390	$12 057 904
Production activities (ha)			
10 05 11 LW[1]	8		
10 12 19 LW	25	200	700
11 12 19 LW	40	93	266
01 12 19 LW	8		
03 20 11 LW	25	200	700
04 15 21 LW	6		
05 15 21 LW	33	93	266
06 15 21 LW	33	200	700

[1] Activity codes: Stocking month (10 = October); stocking density (5 PL/m^2); length of grow-out cycle (11 weeks); water exchange (LW = low water exchange rates).

Stochastic efficiency analysis refers to comparing risky prospects based on the full distribution of outcomes. In stochastic dominance methods, pairwise comparisons of the outcome distributions are made between alternatives. We assume that the decision-maker prefers more to less, or a positive marginal utility for the performance measures, in first-degree stochastic dominance. Graphically, this means that the CDF of one alternative must always lie below and to the right for profitability performance measures (or to the left for cost performance measures). Stochastic dominance methods are frequently used in assessing aquaculture decisions for performance measures including net returns/ha and production cost (Kazmierczak and Soto, 2001; Dalton, Waning and Kling, 2004; Moss and Leung, 2006). If the paths of the CDFs cross, neither alternative dominates based on first-degree assumptions. Other criteria for stochastic dominance

BOX 20

Risk programming for a scheduling problem: a stochastic dynamic programming model for maricultured shrimp

The difficult task of scheduling shrimp production was investigated using a stochastic dynamic decision model (Leung *et al.,* 1989, Hochman *et al.*, 1990). The model determined the optimal stocking and harvesting schedules for a 24-pond shrimp farm modelled after Oceanic Institute practices in Hawaii. The model took into account seasonality and market price variation based on historical data and growth variation based on experimental trials.

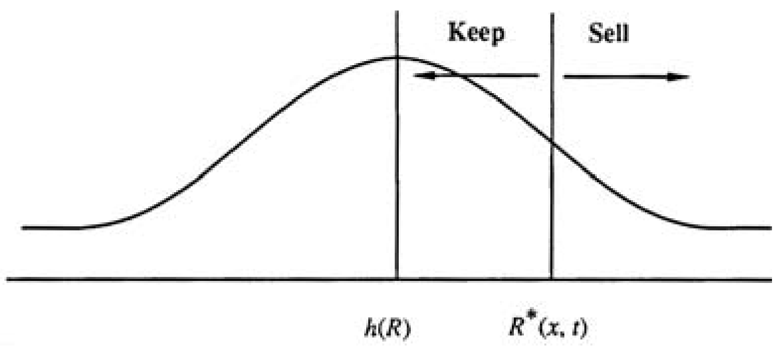
Decision rules were expressed as either cutoff revenues based on random market price and shrimp weight, or as cutoff prices and cutoff weights when only prices or weights were random. When the current realized value is less than the cutoff value R^* (P^* or W^*), the decision is to keep the crop and delay the decision to sell for another period. The cutoff revenue decision is illustrated in Figure 19.

The results of the analysis produced the probability distribution for a crop to be sold for in any given week. Based on the distributions, the corresponding cutoff values for revenue, price and weight were determined for each week. An example of the results for week 13 (November/December) is presented in Table 21.

The scheduling problem was turned into a financial investment problem, where a farmer would decide if investing in a technology to control the environment (i.e. reduce undesirable seasonality effects) would be worthwhile. This simulation experiment was conducted by applying the ideal summer conditions for the entire year. By comparing the net returns of the controlled environment (Table 22a) with the natural environmental conditions (Table 22b), the upper limit of the annualized investment cost was determined. Based on the actual market price data assumed and optimal scheduling policies, a farmer would be willing to spend about US$ 100 000 for the controlled environment system.

FIGURE 19

Schematic of the keep sell decision and cutoff revenue



BOX 21

Stochastic efficiency methods to choose between risky prospects: comparing alternative production systems on total cost of production

The stochastic simulation study by Moss and Leung (2006) in Box 5 compared production cost for earthen ponds with recirculation aquaculture systems (RAS). Based on the comparison of the cumulative probability distributions illustrated in Figure 20, the recirculation system stochastically dominates the earthen pond system.

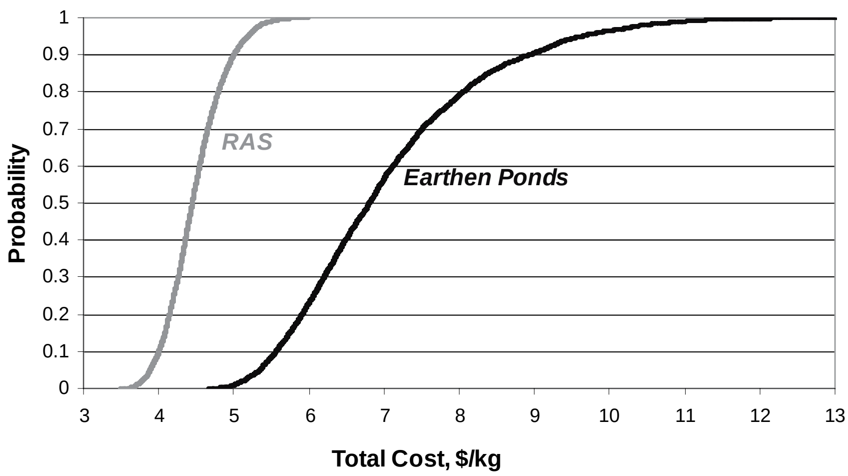
BOX 22

Stochastic efficiency methods to choose between risky prospects comparing cost uncertainty between feed technology

Dalton, Waning and Kling (2004) investigated the risk efficiency of juvenile haddock production systems according to feeding technologies (a combination and scheduling of rotifers, artemia and inert diet). Based on an examination of the CDFs for different feeding technologies (Figure 21, Table 24), the late introduction of the inert diet (microparticulates at 42–180 days; "42 MP") dominated the alternative feeding technologies, followed by 35MP and 30MP.

FIGURE 20

Cumulative distribution with respect to total cost (US$/kg) for earthen ponds compared with recirculating aquaculture systems (RAS)



have increasingly higher restrictions and are increasingly conceptually complex. A list of stochastic efficiency methods is given in Table 23. The details regarding stochastic efficiency methods can be found in Hardaker *et al.* (2004). Two examples of stochastic dominance based on cost are given in Boxes 21 and 22.

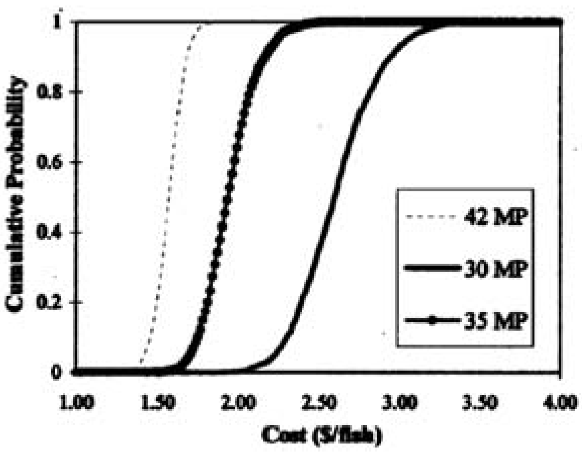
Multiple criteria (trade-offs) analysis

As previously discussed, risk management objectives can be based on financial, economic, socio-economic or other measures of utility. Risk management may be further complicated by the need to satisfy the interests of multiple stakeholders, each with their own agenda. For example, individual farms will have a profit-maximizing objective, while consumer welfare may be valued from an economy-wide perspective. Sustainability is also a multifaceted objective comprised of criterion measures. Even with a farm enterprise, a manager will have several goals that may be in conflict or require trade-offs. Two methods for handling multiple criteria, or trade-offs, are Multicriteria Decision Making (MCDM) and the Analytic Network Process (ANP).

(a) MCDM

MCDM problems involve alternatives that must be evaluated based on conflicting criteria. Conflicting criteria can exist when there are competing interests (by stakeholders) or when tradeoffs must be made. Depending on the nature of the problem, multiple objective programming (MOP) or compromise programming (CP) may be applied. MOP methods are useful when at most two objectives must

FIGURE 21
Cumulative distribution of total annual per-fish costs for three feeding technologies. (MP = microparticulates)



be simultaneously optimized. As more objectives are considered, MOP methods are difficult for risk management because the number of efficient solutions grows exponentially. CP methods, in contrast, are best suited for a large number of objectives because the method searches for a best compromise solution without putting the burden of evaluating a large number of solutions manually.

Goal programming is another popular MCDM method that is frequently used for aquaculture planning. Goal programming has been used in aquaculture development and planning for Thailand (Parton and Nissapa 1997) and Egypt (El-Gayar and Leung, 2000). An MCDM example for sustainable shrimp farming in Mexico is given in Box 23.

BOX 23
MCDM model for considering tradeoffs: analysing tradeoffs in shrimp sustainability with competing objectives

An MCDM model was developed by Martinez-Cordero and Leung (2004) to evaluate sustainable shrimp farming in the northern states of Mexico (Sonora, Sinaloa and Nayarit). The planning objectives considered were employment (E), foreign exchange earnings (XG), economic rent (ER) maximization and total pollution (TOTALPOLL) minimization. Land availability and local market demand constraints were considered. Management decisions would have to determine the shrimp farming production system for the five-year period. Three levels of intensity were considered (extensive, semi-intensive and intensive shrimp farming).

The Feasible Goals software (Dorodnicyn Computing Centre of the Russian Academy of Sciences 2006) was used to determine the efficient tradeoffs among the four objectives. As expected with most multi-objective optimization models, the analyses of the values determined for a single-objective optimizations were higher than the values of the optimal multi-objective case. This finding is expected since tradeoffs were built into the optimization problem.

In Feasible Goals, the results and tradeoffs of the MCDM model are presented as Pareto optimal tradeoff curves (Figure 22). The graphical results of the tradeoff curves characterized how the three economic objectives (ER, XG and E) were affected by the environmental objective (TOTPOLL). The results of the model could inform policy-makers about the location, production intensity and species that would promote sustainability by taking into account the competing objectives.

TABLE 21
Cutoff revenue, price, and weight for week 13

Age (x)	Case A: Random revenue			Case B: Random price			Case C: Random weight		
	Ordinal scale	Probability to Sell	Cutoff revenue ($1 per 1 000 animals)	Ordinal scale	Probability to Sell	Cutoff price ($/kg)	Ordinal scale	Probability to sell	Cutoff weight (g/animal)
1-6	20	0.00	keep	20	0.00	keep	20	0.00	keep
7	19	0.05	101	20	0.00	keep	20	0.00	keep
8	19	0.05	124	19	0.05	6.70	20	0.00	keep
9	17	0.15	137	17	0.15	6.90	20	0.00	keep
10	15	0.25	156	14	0.30	7.09	19	0.05	22.73
11	13	0.35	176	12	0.40	7.45	14	0.30	23.55
12	10	0.50	195	9	0.55	7.71	5	0.75	24.04
13	7	0.65	214	6	0.70	7.95	1	0.95	24.51
14	3	0.85	223	3	0.85	8.08	0	1.00	sell
15	0	1.00	sell	0	1.00	sell	0	1.00	sell

TABLE 22
Results for scheduling policies based on actual market price data (in US$)

(a) Natural environmental conditions

Start Stocking In	Average harvest age from stocking (wks)	Average harvest weight (g)	Cycle per year	Market price ($/kg)	Net returns (US$)
Random Price					
Spring	14.00	27.89	3.31	8.84	357 453
Summer	12.50	25.42	3.79	8.43	279 429
Fall	13.25	27.02	3.57	8.78	322 719
Winter	13.50	26.91	3.46	8.60	303 806
Fixed Scheduling					
Spring	13.00	25.89	3.54	7.81	100 008
Any Season	11.00	21.79	4.00	6.84	-82 464

(b) Controlled environmental conditions

Start stocking in	Average harvest age from stocking (wks)	Average harvest weight (g)	Cycle per year	Market price ($/kg)	Net returns (US$)
spring	14.00	29.18	3.36	9.17	450 879
Summer	13.50	28.15	3.50	9.28	491 672
Fall	13.50	28.15	3.50	8.93	390 147
Winter	13.75	28.67	3.43	9.26	425 630

TABLE 23
Stochastic efficiency assumptions

Stochastic efficiency method	Risk assumptions
First-order stochastic dominance (FSD)	Positive marginal utility
Second-order stochastic dominance (SSD)	Risk aversion
Third-order stochastic dominance (TSD)	Coefficient of absolute risk aversion decreases with income or wealth
Convex stochastic dominance (CSD)	Alternatives are superior than a combination of the other alternative

TABLE 24
Per-fish total cost for three feeding technologies (US$/fish)

Feed Technology	Mean	Median	Standard deviation	Skewness	Minimum	Maximum
30 MP[1]	2.61	2.60	0.25	0.37	1.89	3.78
35 MP	1.94	1.94	0.16	0.46	1.36	2.69
42 MP	1.57	1.57	0.09	-0.06	1.24	1.91

[1] MP = microparticulates

(b) AHP/ANP

The Analytic Hierarchy Process (AHP) is a theory of relative measurement used to prioritize alternatives based on composite ratio scales that represent relative measures of preference and feelings (Saaty 1999, 2001). In AHP, judgments are broken down into complex structures that include benefits, opportunities, costs and risks. Each alternative is scored on each criterion measure. The criterion scores are combined by a ratio weighting scheme that reflects the decision-maker's relative importance for each criterion. AHP is widely used in multicriteria decision making for resource planning and allocation and in conflict resolution.

The Analytic Network Process (ANP) extends AHP to problems with dependence and feedback. ANP is useful for a thorough and systematic analysis of factors influencing risk and where feedback and dependence are inherent. The AHP/ANP weighting scheme relies on systematic comparisons, which can be a demanding process when numerous criteria are considered. AHP/ANP methods are implemented in the Super Decisions software by Creative Decisions (2005). More information on AHP/ANP can be found in Saaty (2001).

Decision analysis software to assess financial risk in aquaculture

Decision analysis software packages are frequently used in financial risk analysis in aquaculture. The software packages mentioned throughout this paper and others are listed in Table 25.

FINANCIAL RISK COMMUNICATION

Risk communication occurs throughout risk analysis, such that information and the opinions of stakeholders are incorporated throughout the risk analysis. Results of the risk assessment and proposed risk management measures are communicated to decision-makers and stakeholders, and relevant feedback is used to revise the risk assessment.

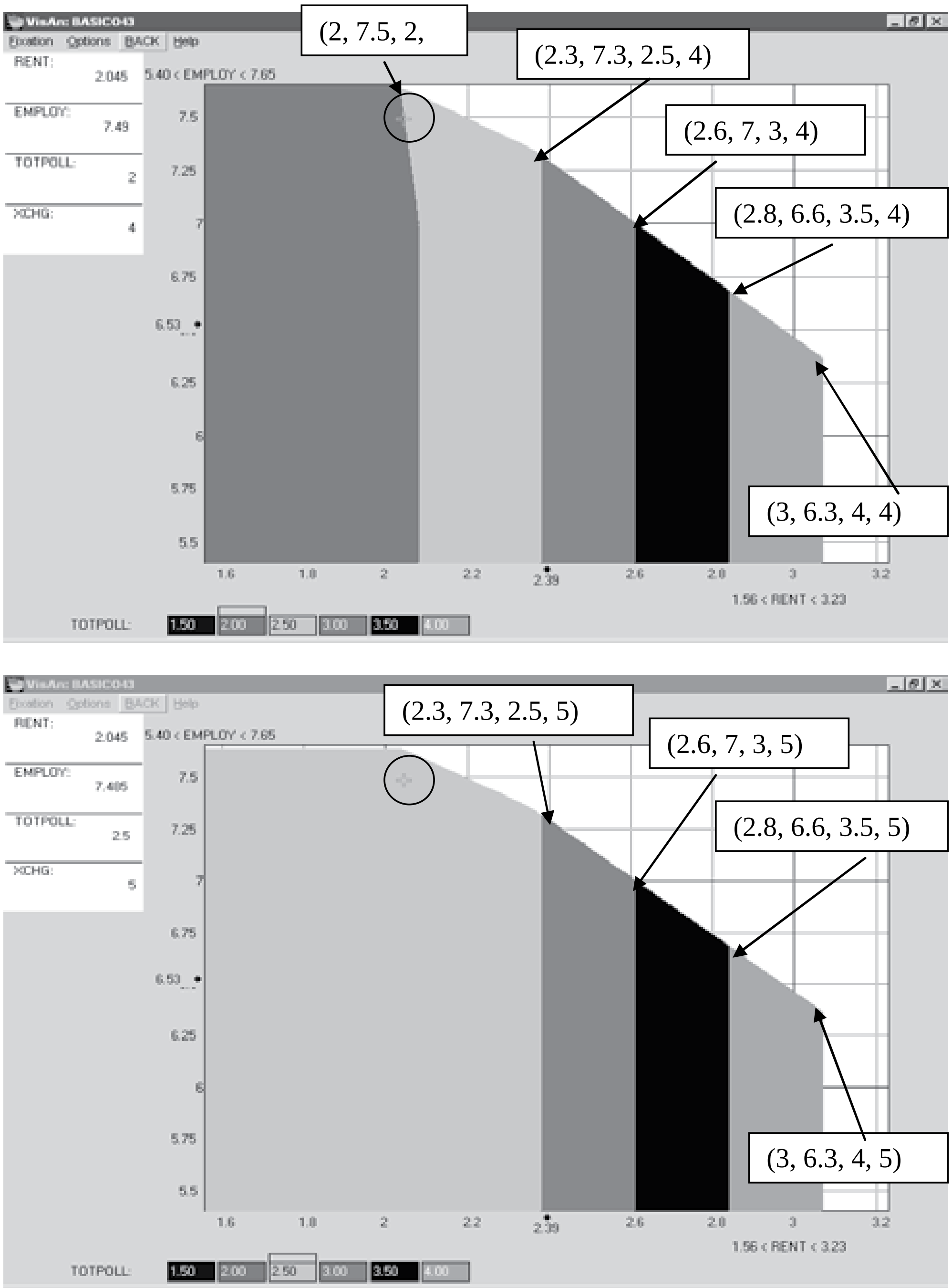
Estimating the probabilities can be a challenge. Production threats are particularly difficult to estimate because they are farm-specific and the data are not usually available. Common methods employ the use of probability wheels and reference lotteries. Barry (1984) and Hardaker *et al.* (2004) offer insights and methods for eliciting subjective probabilities.

Financial ratios can be a useful communication tool. However, some financial ratios are complex and difficult for wide audiences to interpret. Since the results of a risk

TABLE 25
Selected decision analysis software

Software Package	Vendor	Features
@Risk	Palisade	Stochastic simulation
Crystal Ball	Decisioneering	Stochastic simulation
Feasible Goals	Dorodnicyn Computing Centre of the Russian Academy of Sciences	Efficiency frontiers, decision maps, MCDM
GAMS	GAMS Development Corporation	Linear optimization, risk programming
GeNIe	Decision Systems Laboratory	Prediction, diagnosis, Bayesian networks, Bayesian decision networks
Goal Seek (feature in MS Excel)	Microsoft Excel	Single-parameter optimization
Simetar (MS Excel add-in)	Simetar, Inc.	Regression, stochastic simulation, statistical analysis, econometric modelling, forecasting
Solver	Frontline Systems	Linear optimization, risk programming
Super Decisions	Creative Decisions Foundation	ANP, AHP, (multi-criteria)
What's Best (MS Excel add-in)	Lindo Systems	Linear optimization, risk programming
XLSim (MS Excel add-in)	AnalyCorp	Decision tree, probability tree

FIGURE 22
Multicriteria Decision Making (MCDM) optimization: trade-offs between economic rent and employment. Upper plot: fixed foreign exchange earnings (XG) at $400 million; lower plot: fixed XG at $500 million



analysis are meant to inform decision-makers, interpretable results and a transparent process are necessary. Risk analysts should strive to use the simplest financial measures that can communicate the major issues.

As witnessed in the examples given throughout this paper, spreadsheet models are useful in risk analysis. Spreadsheets continue to grow in popularity and can be used by non-programmers. A number of sophisticated add-ins have been developed for Excel that can be used to analyze risk. The spreadsheet interface and add-in features assist in visualizing model uncertainty. Many of the risk analysis results in this paper were presented as probability distributions, cumulative probability distribution graphs and decision trees, which are helpful in communicating risk and comparing scenarios to wide audiences.

The decision analysis methods require that a problem be decomposed. The process of decomposition creates transparency and fosters communication. Many decision analysis software packages used in risk analysis are equipped with visual aids. Probability trees, decision trees, Bayesian networks and Bayesian decision networks, for example, illustrate causal relationships that can help to communicate the risk problem and results of the analysis. Consequently, in addition to the analytical benefits of software packages, the software packages also enable communication and promote risk understanding.

FUTURE CHALLENGES

Aquaculture ventures are inherently risky. The need to conduct financial risk analyses to reduce the potential for financial loss is clear. In spite of the variety of rigorous methods described in this document, it is not clear whether these financial risk analysis methods are widely put in practice at the present.

Financial risk analysis requires a background in financial analysis methods and generally requires the assistance of risk analysis tools. Although commercial software packages are becoming easier to use, farmers and policy-makers may require the assistance of risk analysts/modellers to decompose their financial risk concerns. Without the available resources or assistance, practitioners may not view these evaluation methods as practical or may find existing models unusable. Education, software accessibility, training and assistance will be needed in order for financial risk analysis to be widely adopted in aquaculture.

Even if the financial risk problem is decomposed, sufficient data may not be available to estimate uncertainty and characterize the financial risk. Farm-level cost and production data and industry statistics are often difficult to obtain. In particular, aquaculture production data are not regularly collected in surveys conducted by agricultural ministries or are limited to highly aggregated values. Consequently, risk analysts are obliged to seek secondary or anecdotal information to approximate the release, exposure and consequences associated with a hazard.

Methodologically, the linkage between financial risk and traditional risk analysis is weak. While many studies and techniques are available to analyze financial risk in aquaculture, the methods are not necessarily linked to the traditional components of a risk assessment (i.e. release assessment, exposure assessment, consequence assessment and risk characterization). Financial aspects in traditional risk analyses are frequently appended to risk assessments formulated for biological, ecological or environmental risk. Consequently, the financial losses only reflect aggregate values and may disregard production and price uncertainty. Since financial losses are often an afterthought, the financial analyst of the risk analysis team may be too far removed from the details and overlook factors that contribute to financial risk. Thus, it is vital that financial risk analysis methods be integrated in the early phases of hazard identification and risk assessment in order to truly manage financial risk in aquaculture.

CONCLUSIONS

In our discussion of financial risk analysis, we claim that the methods can be applied to most sources of risk, including biological, ecological and environmental hazards. The financial aspects usually measure enterprise profitability, but can also be used to measure the performance of an entire industry or economy and consider socio-economic factors. Financial and related performance measures are critical at the time of consequence assessment. The methods for release and exposure assessment in financial risk assessment are less mature than in other areas of risk assessment.

Financial risk assessment relies on static financial analysis tools, such as enterprise budgets, partial budgeting, cash flow analysis and feasibility studies. Financial risk assessment methods supplement these traditional tools by considering uncertainty from market threats and production threats. Uncertainty is characterized using probability estimates, probability distributions and scenarios.

The decision analysis approach was proposed as the method for financial risk management. In applying decision analysis methods for risk, we define risk management objectives (financial or other criteria), consider alternative strategies and select an evaluation method. A number of evaluation methods were presented that are implemented in commercial software packages. The graphical software tools and decomposition of the financial risk problem support risk communication.

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ANNEX I

FINANCIAL RISK ANALYSIS EXAMPLE

SPF WSSV-import risk for Hawaii shrimp aquaculture

Specific-pathogen free (SPF) shrimp provide added value to Hawaii's shrimp export industry. The Hawaiian SPF shrimp farming industry has been growing steadily over the last ten years due to a strong international market for SPF broodstock sold for farm production. From 2002 to 2003, Hawaiian exports of certified disease-free shrimp broodstock rose from US$ 1.7 million to $2.4 million in sales, growing from 20 percent to nearly 25 percent of the value of Hawaiian shrimp and prawn production. The SPF label enables Hawaii to market to Asian countries that desire SPF products or those that are limited to importing SPF products that are free of specific diseases (Sing 2003). The viability of Hawaii's SPF industry depends on a number of market factors, including sale price and demand. Increased competition can exert downward pressure on SPF sale prices, resulting in lower profit margins for shrimp farmers. The demand for Hawaii's SPF products depends on the preservation of the SPF-label and disease-free image.

Hazard identification

The State of Hawaii is a protective haven for a variety of agricultural products; however, its biosecurity is compromised by the introduction of invasive species and foreign animal diseases. Viral pathogens threaten the productivity and survival of Hawaii's local shrimp industry. Isolated occurrences of infectious hypodermal and hematopoietic necrosis virus (IHHNV) and white spot syndrome virus (WSSV) outbreaks have been reported on Oahu and Kauai, signaling that Hawaii's shrimp and prawn aquaculture industry may be in imminent danger. Aquatic diseases such as IHHNV and WSSV are hazards that threaten shrimp production and bring about financial consequences.

Risk assessment for WSSV

Based on existing literature and the beliefs of local aquaculturists, frozen commodity shrimp (FCS) were identified as the hazard of interest for investigating WSSV import risks.

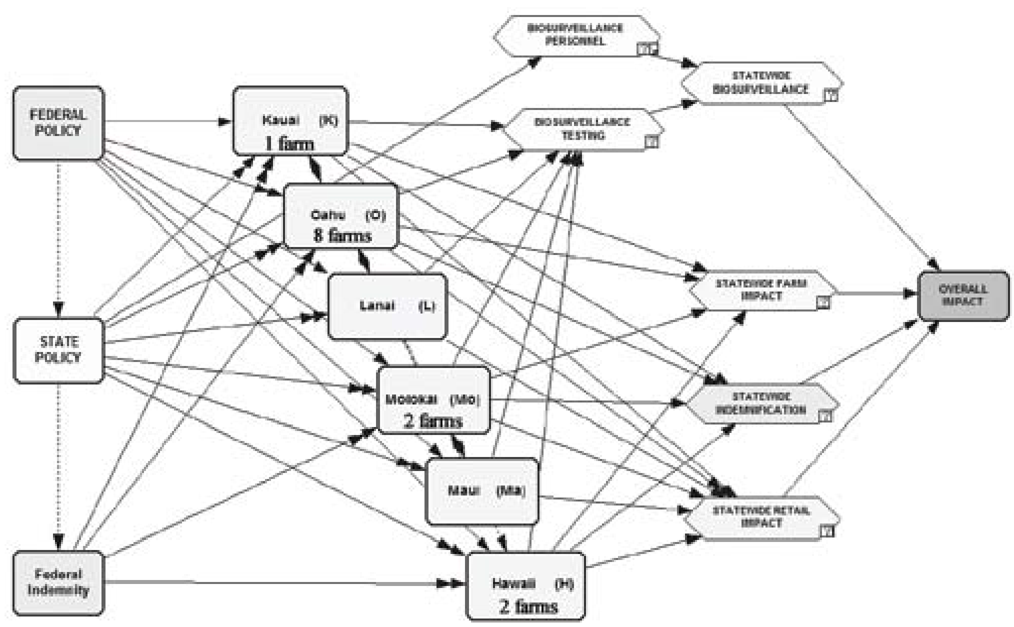
Methodology

A "test-action" biosecurity risk framework was developed that translates biosecurity decisions into tests and actions for the purpose of analysing biosecurity risk. From a decision-theoretic point of view, decisions are viewed as having action aspects that reduce consequences and/or test aspects that gather information (Jensen 2001, Korb and Nicholson 2004). This perspective on decision-making offers an accounting method for biosurveillance measures, particularly the value of information resulting from test decisions. The framework was used to fulfil the research objectives for investigating WSSV import risk associated with frozen commodity shrimp (FCS):

1) developing a Bayesian decision network (BDN) to model WSSV import risk,
2) determining the "best" policy networks (i.e. combinations of policy decisions) and
3) estimating the value of biosurveillance for mitigating WSSV import risk.

A BDN is a specific type of influence diagram that can be used for modelling causality, defining preferences based on expected utilities and incorporating uncertainty for decision-making using Bayesian calculus. A BDN was created based on the test-action biosecurity risk framework to model the impact of WSSV biosecurity policies,

FIGURE 1
Full white spot syndrome virus (WSSV) biosecurity import risk Baysian decision network (BDN). (Numbers located on each island submodel reflect the number of active shrimp farms assumed)



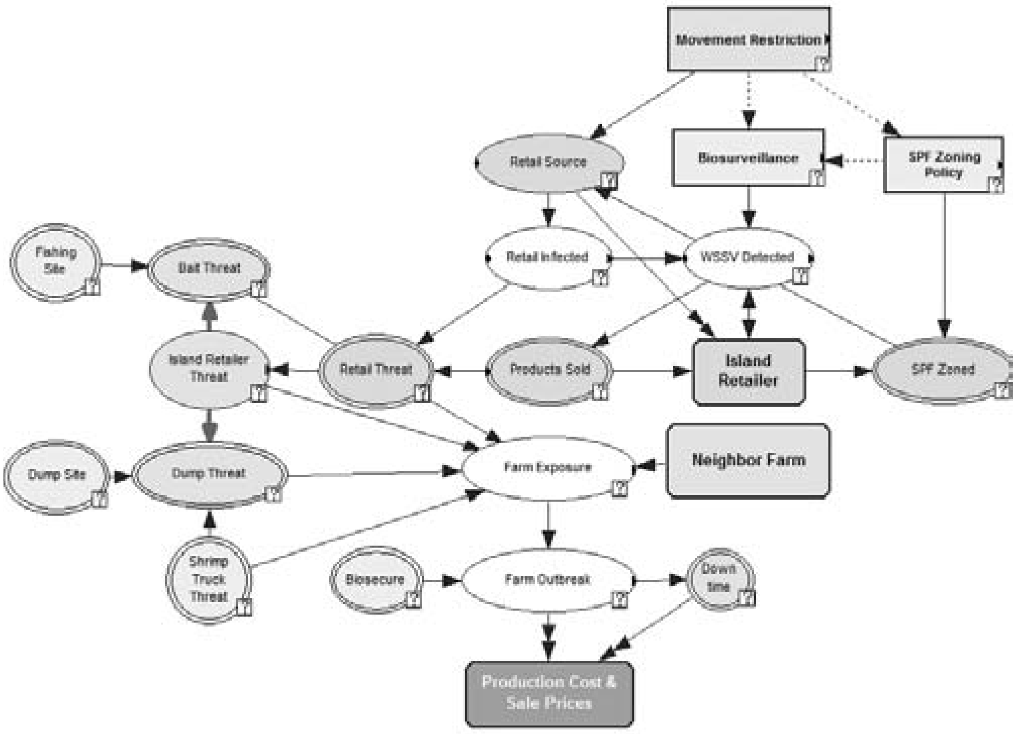
including a national movement restriction, biosurveillance and SPF zoning for FCS retailers (Figure 1).

Release assessment
According to trade data and country disease status, an estimated 32 percent of Hawaii's FCS products are infected with WSSV. The primary pathway of exposure was identified as contamination from imported FCS that are either sold for consumption or as fishing bait. According to the WSSV epidemiological pathways assumed (Kam 2006), both humans and animals were considered to be vectors for transporting infected FCS products from dump sites, fishing sites and shrimp trucks. Unavoidable environmental risk (e.g. WSSV-carriers live in the ocean) was also included in the model to account for uncertainty. When no intervention is taken, the retail threat is equal to the Hawaiian FCS disease prevalence of 32 percent.

Exposure assessment
Farm WSSV exposure depends on a farm's location. Infected products sold by retailers can reach a dump site, becoming a dump threat to a nearby farm (Figure 2). Similarly, infected bait shrimp sold by retailers can be left at fishing sites, posing a bait threat to a nearby farm. The infected products can reach a shrimp farm by human or animal vectors. The average farm in the 13-farm statewide model had a 15.9 percent probability of WSSV exposure based on the complex interaction of environmental threats surrounding each farm. The probability of farm exposure would be higher for farms with a higher-than-average combined environmental threat.

Consequence assessment
The probability of a farm outbreak depends on a farm's exposure to WSSV and the farm's level of biosecurity. For the average farm included in the model, the probability of a farm outbreak was estimated at 14.0 percent. Farms with above-average levels of biosecurity would have a lower probability of an outbreak.

FIGURE 2
Baysian decision network (BDN) example for single farm exposure



Farm outbreaks depend on farm characteristics, including environmental threats and farm biosecurity. Environmental threats (fishing bait threat, dump threat, truck threat and retail threat) increase a farm's potential exposure to WSSV. For a given level of WSSV-exposure, farms with higher levels of biosecurity have a lower probability of an outbreak.

Risk management

Thirty-two central policy combinations of SPF zoning, biosurveillance levels and national movement restrictions were examined using the WSSV biosecurity import risk BDN. The 32 management strategies (or "policy networks") were compared based on farm profit, retail profit, state expenses for biosurveillance and the factors combined. According to the expected value for each strategy, the policy that maximized the overall impact (retailer profit and farm profit, less biosurveillance expenses) was a United States movement restriction that prohibits the import of FCS from WSSV-positive regions. Without factoring in any direct costs due to a movement restriction or economy-wide aspects, a movement restriction resulted in an overall increase of \$12.21 million (20.4 percent of the baseline overall impact of \$60.04 million). Since no costs directly associated with the movement restriction were considered, the \$12.21 million also represents the value or maximum amount we would be willing to pay for the benefits of the movement restriction policy.

When a movement restriction was simulated, retail profit increased to \$66.22 million and farm profit increased to \$6.04 million from the baseline values of \$56.8 million and \$3.24 million, respectively. While additional SPF zoning and biosurveillance generally benefit the farm, retail profit decreases because retailers must purchase higher-cost SPF shrimp locally (Figure 3).

In the WSSV import risk model, the cost of a United States movement restriction was not specified. However, the results of the simulation experiments suggest that the

FIGURE 3
Comparing retail profit, farm profit, and state expenses under a national movement restriction policy

movement restriction was worth $12.21 million based on the cost assumptions. If a United States movement restriction is considered too prohibitive, the next best policy was statewide SPF zoning. A statewide SPF zoning policy resulted in an increase of $4.62 million in the overall impact. Under statewide SPF zoning, farmers increased profit by $30.23 million due to the additional sale of SPF shrimp that served as a

FIGURE 4
Comparing retail profit, farm profit, and state expenses under state policies (no movement restriction)

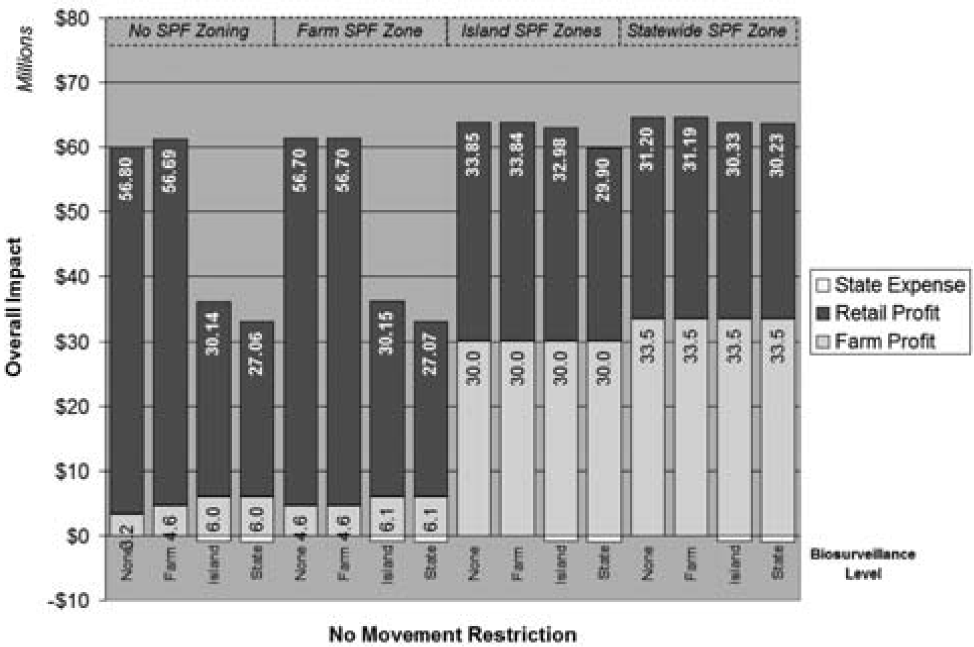


TABLE 1
Effect of a specific pathogen free (SPF) farm zone policy

Assessment endpoint	Baseline	Farm SPF zone policy
Epidemiologic		
Retail infected	31.86%	31.74%
WSSV detected	0.00%	0.00%
Retail threat	31.86%	31.72%
Farm exposure[1]	15.88%	8.78%
Farm outbreak[1]	13.97%	8.26%
Financial		
Farm profit	$ 3 235 770	+1 412 100[2]
	5.4%	+2.35%[2]
Retail profit	$ 56 804 400	-102 800[2]
	94.6%	-0.17%[2]
Overall impact	$ 60 040 170	+1 309 300[2]
	100.0%	+2.18%[2]

[1] Average value.
[2] Increase (+) or decrease (-) from baseline value.

substitution for local FCS consumed. The result suggests a policy trade-off because retailers would incur a loss of $25.61 million due to lower profit margins due to higher-cost SPF shrimp (Figure 4).

Additional biosurveillance was an inferior policy. When no movement restriction was considered, biosurveillance had a negative effect and under any level of SPF zoning. The negative consequences resulting from biosurveillance were due to two types of costs. The first consequence was the direct cost of statewide biosurveillance, estimated at $69 000, $972 000 and $1.07 million for farm-level, island-level and statewide biosurveillance, respectively. The second consequence was due to the small possibility of WSSV-positive test findings, resulting in non-saleable products and a loss for retailers.

SPF zoning requires that the local shrimp aquaculture industry supply retailers with SPF shrimp products. Farm production would have to increase by 13x the current level of production for island-level SPF zoning and 15x for statewide SPF zoning in order to satisfy FCS consumption. The increase would mean either an increase in production by existing farms, the establishment of new farms or both. However, it is unlikely that the Hawaiian industry could grow to the size necessary to satisfy the estimated FCS consumption levels.

Consequently, in order to efficiently manage WSSV import risk, policy-makers may consider farm-level SPF zoning. The baseline level of farm production can satisfy the estimated level of FCS retail sales within the one farm-zone located on Oahu. Farm-level SPF zoning mainly benefits the three farms located in the zone where WSSV exposure is potentially high. Even with the protection of the SPF zone, the model considers the risk of infected retail products coming from outside of the SPF farm-zone. Therefore, after considering the retail threat from outside of the zone, the SPF farm-zone resulted in a $1.31 million increase in the overall impact, 2.18 percent of the baseline overall impact (Table 1). Since the volume of retail products sold in the SPF zone was quite small, the retailers only lost 1.71 percent of the baseline overall impact, equal to a loss of $102 800. In contrast, farm profit increased by $1.41 million due to the decrease in WSSV exposure in the SPF zone. A farm-level SPF zone was estimated to reduce the average farm exposure and farm outbreak to about half of the baseline values, to 8.8 percent and 8.3 percent, respectively.

Only the direct costs of biosurveillance were considered in this risk analysis. Costs for a national movement restriction, SPF zoning and other economy-wide impacts could give a complete picture of the overall benefit of central policies aspects were not considered. While additional costs of SPF zoning are not considered, the analysis of the effects of the SPF farm-zone tells us that such a policy would be worth $1.31 million based on the WSSV import risk BDN assumptions. Since retailers experience a loss of $102 800, policy-makers or farmers could consider compensation for the retail loss by offering subsidies or a discount on SPF products sold by farms to retailers within the farm-zone.

In the biosecurity import risk model, the retailer was designed to experience a negative impact due to a biosurveillance policy that prohibited the sale of the proportion of products that test positive for WSSV. Clearly, retailers would be wary of such an unfavourable biosecurity policy. The risk of expected losses resulting from biosurveillance, however, could serve as incentive for retailers to comply with SPF zoning or to purchase products from WSSV-negative regions. As observed in Figures 3 and 4, biosurveillance was only marginally beneficial at the farm-zone level. Therefore, SPF zoning and more generally, retailers' compliance with purchasing pathogen-free products may be preferred over other forms of biosecurity strategies.

ANNEX II

PARTIAL BUDGET ANALYSIS EXAMPLE

Using a partial budget to compare marketing strategies for different size farms

Hawaii's ornamental aquaculture products are held in high regard among producers and aquarists worldwide. Aquaculture ornamentals branded "Made in Hawaii" often evoke a mystique of rare, exotic and natural products. Their desirability is partly due to Hawaii's pristine tropical environment, which supports year-round production and is conducive to producing disease-free, healthier and higher quality fish.

Despite the positive reputation of Hawaii's ornamentals, the local aquaculturists find it difficult to compete in the global niche market. Asian competitors leverage low prices and product variety to penetrate the United States market. In 1992, the Los Angeles port, which is used by most Asian wholesale ornamental fish distributors, was the destination port for 39 percent of all United States ornamental aquaculture imports (Chapman *et al.* 1994). Hawaii's ornamental aquafarmers could tap the United States mainland West Coast market, which is predominantly served by Southeast Asia and Florida wholesalers. Wholesalers provide a value-added service, creating additional layers in the ornamental fish distribution network. Wholesalers often operate in tandem, where secondary wholesalers sell their products to primary wholesalers, who distribute products directly to retailers. Each of these layers in the distribution network cuts into an ornamental aquafarmer's potential profits.

Optimal product mix

A spreadsheet model was used to determine the ornamental product mix that maximized net sales based on farmgate price, water consumption, pack density and overpack allowance. The species in the product mix were selected based on their ability to contribute to the farm's profit. Each product line's contribution to farm profitability is affected by the profit on the sale of each fish, stocking density and pack density for each product. The optimization model maximizes profit by varying the farm's product mix, while constrained by the maximum and minimum number of species, harvestable capacity, supply (minimum) and demand (maximum). A description of each of the constraints appears below in Table 1.

In general, a farm will want to produce highly valued fish that are in demand. High-value fish, however, are usually stocked and harvested at densities lower than fish of less value, utilizing more of a farm's production capacity. In addition, pack density is typically lower for highly valued fish than for less valuable fish, resulting in increased shipping costs per fish and the landed price of each product. Restricting demand for each product prevents an enterprise from overproducing highly valued fish that earn

TABLE 1
Constraints used in the ornamental product optimization worksheet

Parameter	Constraint
Product lines	*minimum ≤ no. of products ≤ maximum*
Harvestable capacity	gallons harvested ≤ harvestable capacity The harvestable capacity (in gallons) was assumed to be 25% of the total water capacity of the farm based on the 3 to 4-month production cycle.
Supply	*specie production quantity ≥ minimum production quantity* The minimum production quantity for a selected product line (default of one case per month).
Demand	*specie production quantity ≤ maximum production quantity* The maximum product quantity for a selected product line (default of one case per buyer-week).

TABLE 2
Summary of key farm characteristics

Farm characteristics	Small farm	Large farm	Co-op farm
Total water capacity (gal)	27 000	180 000	540 000
Maximum harvest capacity (gal)	6 750	45 000	135 000
Average number of fish per week	2 677	16 186	48 980
Average number boxes per weekly order	2	5	5
Fish product variety	8	26	40
Estimated number of customers	5	10	30
Average shipping weight per weekly order (lbs)	59	144	148

high profits after taking into consideration its landed price. All of these factors are incorporated in the optimization of a product mix.

The optimal product mixes for three farm scenarios were based on a secondary wholesaler analysis in which air cargo shipping fees and box charges were passed onto a primary wholesaler distributing to Washington State retailers (see Kam, Leung and Tamaru 2006 for details). The freshwater ornamental product mixes, yielding annual farmgate sales of US$ 57 649, $227 066, and $703 732 for small, large and co-operative farms, respectively, were used in the partial budget analyses. Selected factors differentiating the three farm scenarios are exhibited in Table 2.

Partial budget analysis

A partial budget reflects the additional costs and revenues that result from a shift in business strategy, in this case, direct marketing to retailers (or primary wholesaling). The net change in income (difference between positive and negative impacts) is an estimate of the net effect of making the proposed change from farmgate sales to direct marketing to retailers. A positive difference indicates the potential increase in income if the change in strategy is made. Conversely, a negative difference is an estimate of the reduction in income if the change to direct marketing is adopted. Costs considered in this partial budget analysis included changes to shipping, marketing and risk associated with United States mainland West Coast distribution.

The results of the partial budget analysis was used to determine the feasibility for farmers to direct-market their products to the United States and to distribute products through United States mainland wholesalers are given in Tables 3 and 4, respectively. Direct-marketing was found to be profitable for the large and co-op farm sizes. Wholesaling to mainland distributors was not a profitable strategy for any of the produce scenarios. Break-even analyses exhibited in Tables 3 and 4 were used to determine the minimum-mark-up on farmgate prices in order for the change in strategy to be beneficial (i.e. to achieve a positive net change in income).

TABLE 3
Summary of direct marketing (primary wholesaling) partial budget and break-even analyses (all figures in US$)

Partial budget analysis	Small farm	Large farm	Co-op farm
Wholesale revenue	$151 264	$602 810	$1 863 247
Farmgate revenue	57 649	227 066	703 732
Total positive impacts (change in revenue)	93 615	375 743	1 159 515
Shipping and handling	36 091	145 998	456 489
Marketing costs	37 933	94 148	172 114
Reduced returns (Non-payment and excess mortality)	22 690	90 421	139 744
Total negative impacts	96 714	330 567	768 346
Net change in income (NCI), assuming a 200% farmgate markup[1] (67% gross margin)[2]	(3 100)	$45 176	$391 169
NCI as a % of change in net sales	-3.31%	12.02%	33.74%
Break-even Analysis			
Wholesale markup on the farmgate price[1]	207%	174%	135%
Gross margin on sale price[2]	67%	64%	58%

[1] In this analysis, markup refers to the percentage calculated using the difference between sale price and farmgate price, divided by farmgate price: markup = (sale price – farmgate price)/farmgate price.

[2] The gross margin refers to the percentage calculation based on the difference between the sale price and farmgate price, divided by the sale price: gross margin = (sale price – farmgate price)/sale price.

TABLE 4
Summary of secondary wholesaling partial budget and breakeven analyses (all figures in US$)

Partial budget analysis	Small Farm	Large Farm	Co-op Farm
Wholesale revenue	$76 866	$302 755	$938 309
Farmgate revenue	57 649	227 066	703 732
Change in revenue	19 216	75 689	234 577
Shipping and handling paid by retailer	21 405	68 760	213 534
Total positive impacts	40 622	144 449	448 111
Shipping and handling	24 291	82 818	256 820
Marketing costs	33 257	74 566	114 197
Reduced returns (Non-payment and excess mortality)	13 670	52 290	81 050
Total negative impacts	71 219	209 673	452 068
Net change in income (NCI) assuming a 33% farmgate markup[1] (25% gross margin)[2]	($30 597)	($65 224)	($3 956)
NCI as a % of change in net sales	-159%	-86%	-1.7%
Break-even Analysis			
Wholesale markup on the farmgate price[1]	101%	70%	34%
Gross margin on sale price[2]	50%	41%	25%

[1] In this analysis, markup refers to the percentage calculated using the difference between sale price and farmgate price, divided by farmgate price: markup = (sale price – farmgate price)/farmgate price.

[2] The gross margin refers to the percentage calculation based on the difference between the sale price and farmgate price, divided by the sale price: gross margin = (sale price – farmgate price)/sale price.

Social risks in aquaculture

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ABSTRACT

Social risks are challenges by stakeholders to companies' business practices due to real or perceived business impacts on a broad range of issues related to human welfare – for example, working conditions, environmental quality, health or economic opportunity. The consequences may include brand and reputation damage, heightened regulatory pressure, legal action, consumer boycotts and operational stoppages – jeopardizing short- and long-term shareholder value. This definition of social risk can be suitably adapted for aquaculture at the sector, industry, company, farmer group or individual farm level. The definition provides a departure to the concept of origin of risk. To bring social risk analysis to a degree of simplification and system, one should start by defining aquaculture's spheres of social responsibility; identifying the stakeholders to which it has to be responsible and drawing from codes of conduct, codes of practices, ecolabeling and certification schemes, labor standards, food safety standards and environmental standards a list of hazards that could turn into social risks. This review borrows from ecological risk assessment to illustrate the process of social risk estimation, the practical application of which is to predict the types of challenges and their degrees of severity so that an early and cost-effective response can be devised to address them. Another point of difference between social and other risks is that social risks are strategic risks. For strategic risks, in contrast to traditional compliance or hazard risks, risk and opportunity are two sides of the same coin. This makes it necessary and desirable to adopt an integrated approach to strategic risk management. A strategic risk that is anticipated early and mitigated well can be converted into a new market, a competitive advantage, a stock of goodwill or a strategic relationship. An aquaculture risk data bank could be created in which all possible hazards and risks are classified as to their nature, causes, consequences, impacts, severity of impacts, likelihood of occurrence and other characterizations. Among other applications, this could be, a helpful tool for risk analysis and reference for commercial insurers and governments. The review concludes with the proposition that a social risk-free environment that is predicated on socially responsible behaviour promotes sustained growth and development.

INTRODUCTION

A literature search on social risk analysis has indicated the following state of the art: (i) the practice of assessing and managing social risks is common among corporate bodies, especially multinational corporations; (ii) it is widely used in project risk analysis for which guidelines have been developed (i.e. risk analysis and management for projects) or are being developed (social risk and opportunities tool kit); and (iii) social risk management and protection is a relatively new concept in addressing poverty and welfare issues among the poor and vulnerable by such institutions as the Asian Development Bank (ADB) and the World Bank (WB) (Holzmann, 2001; ADB, 2003).

In terms of risk management, the difference between social risks and technical risks such as pathogens is that the latter focuses on point solutions. These are specific actions to mitigate particular sources or impacts of risk. On the other hand, the approach to social risk, because of its complex origins and impacts, is integrated management (Bekefi, Jenkins and Kytle, 2006). This is probably one of the reasons for the lack of any standardized, widely accepted method, guidance or manual on social risk analysis, apart from those developed for project risk analysis in which social risk is incorporated. There is as yet no formal guideline or agreement issued or arrived at by the Food and Agriculture Organization of the United Nations (FAO), Asia-Pacific Economic Cooperation (APEC) or other organization, on social risk analysis that is comparable to those on food safety, pathogen, ecological and import risks.

DEFINITION OF SOCIAL RISK IN AQUACULTURE

This review takes the perspective of the corporate sector on social risk, i.e. "*Social risks are challenges by stakeholders to companies' business practices over social consequences*" (Kelly, 2005); and, with perceptions factored in, "*Social risks are challenges by stakeholders to companies' business practices due to real or perceived business impacts on a broad range of issues related to human welfare – for example, working conditions, environmental quality, health, or economic opportunity. The consequences may include brand and reputation damage, heightened regulatory pressure, legal action, consumer boycotts, and operational stoppages – jeopardizing short- and long-term shareholder value*" (Bekefi, Jenkins and Kytle, 2006). The emergence of social risk is characterized by four components in combination: an issue, a stakeholder or group of stakeholders, a negative perception about the company and the means to do damage, as illustrated in Box 1.

BOX 1

Components of social risk

- **Issue** – Social and environmental issues like climate change, disease pandemics and mass urbanization.
- **Stakeholder** – In addition to traditional stakeholders, includes civil society organizations, international agencies and even individuals.
- **Means** – Mobilize large (or small but strategic) networks of allies; communication over the Internet; influence public opinion; boycotts, protests; court action, etc.
- **Perception** – Information about companies from official news sources, the Internet, word of mouth and the company itself; can be accurate or inaccurate.

Source: Bekefi, Jenkins and Kytle, 2006.

These essentially similar definitions of social risk made from a corporate viewpoint can be suitably adapted for aquaculture at the sectoral, industry, company, farmer group and individual farm levels as: *Social risks in aquaculture are challenges by society to the practices of the sector, industry, company or farm over the perceived or real impacts of these practices on issues related to human welfare.*

The "polluter pays" principle demonstrates this definition. A farmer compensates society through a tax or a license fee for the cost of repairing damage from his pollution; or he assumes the cost by investing in a system to prevent his operation from causing pollution. Otherwise, the farm could become the target of challenges from the harmed community or from other interest groups that perceive the harm and act on behalf of the community. For instance, the government could impose a penalty or an activist group could file a legal action.

This definition also suggests three spheres of social responsibility, which for the purpose of this review are classified as internal, external and global. The internal sphere would encompass responsibilities to the farmer, his/her family and the farm workers (as well as the cultured animals!); the external sphere would be responsibility to the community in which it operates, other users of community resources and the most proximate players in the value chain such as suppliers, buyers and processors; and the global sphere would include responsibility to the rest of the stakeholders, especially consumers but also aquaculturists in other countries (Box 2).[1]

BOX 2

Spheres of social responsibility of the aquaculture sector

1. Internal social responsibilities
- farmer
- household
- workers
- cultured animals

2. External social responsibilities
- community stakeholders
- suppliers
- product buyers
- processors
- traders

3. Global social responsibilities
- consumers
- aquaculture industries in other countries
- mass media
- civil society organizations
- activist groups

HAZARD IDENTIFICATION

The broad and usually interlinked social and economic impacts of risks include loss of livelihood, loss of income, loss of market, loss of assets and loss of capacity to work productively. From this perspective, just about any hazard has the potential to translate into a risk that has social impact. For instance, a natural disaster that not only wipes out the crop but also destroys farm assets and erodes the topsoil or silts up the pond will result in loss or severe and prolonged disruption of livelihood for the farmer and unemployment for the workers.

Civil unrest, threats to peace and order and widespread poverty and social inequalities are by themselves social hazards. But these are not results of socially or environmentally irresponsible practices of aquaculture. A farm or a company deciding to locate in an area considered high-risk because of social unrest is expected to make a decision analysis on the basis of an already known hazard that could threaten the viability of its operations. Similarly, farms or enterprises located in an area where risks of a social nature or origin are imminent or suddenly occur would need to weigh management options, i.e. pull out and avoid the risk or stay and initiate risk management actions. This falls under project risk management. But it is relevant – project risk assessments include a social risk assessment, which could be a useful method to adopt for analysis of risks to aquaculture. It is instructive in that an evaluation of social risks to a project includes their impacts on project costs and viability (see Box 3).

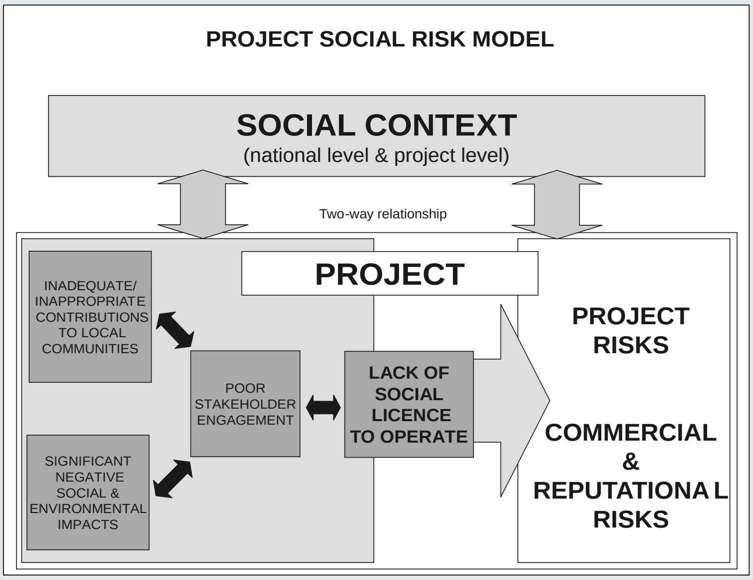
Furthermore, aquaculture or any other economic sector has nothing to do with spawning the most serious hazard of all, bad government, although opportunistic behaviour from the industry could abet it. However, there are actions that farmers and industry can adopt to improve the sector's management and governance, including voluntary or self-management measures and co-management arrangements, forging

[1] In this review, civil society organizations, mass media and activist groups are classified under the category of external responsibilities because their functions are to report, articulate and interpret issues or act as watchdogs on behalf of society in general or of certain groups of stakeholders. A significant portion of the efforts from corporate bodies and industries to manage strategic risks consists of dealing with these groups. The likelihood of a perceived social risk being noticed and broadcast has increased with the proliferation of empowered stakeholders in the global environment, particularly nongovernmental organizations (NGOs) and new forms of media whose own justification for operation depends on their capacity to demonstrate impact (Kelly, 2005).

BOX 3

A model for social risk assessment and management for projects

Projects located and run in unstable environments could inadvertently trigger or sustain violence or become the focus of resentment. Violent conflict represents a threat to life, security, growth and prosperity for affected communities. Conflict also undermines decades of economic development and destroys the social harmony of a locality, country or region. In the context of a project (such as establishing a mining operations), social risks and opportunities are essentially related to a project's local stakeholders and their perceptions and interactions with the project and the organizations delivering it (i.e. the client and their contractors). Social risk can often be visualized as the gap between the boundary of responsibility that these organizations acknowledge and that perceived by their stakeholders. A project social risk assessment model (from Anon., 2006) that could be adapted for aquaculture is illustrated below:



The two-way interactions between a project and the economic, political, socio-cultural and security context in which it is constructed and operated will shape the social risks facing that project: just as a project will be affected by the local and national context, the project itself will also have an impact on this context. To understand and identify social risks, it is important to first understand the context and this two-way relationship. The model outlines how the interactions between a project and its context and stakeholders may generate social risk and opportunities for the project. The diagram provides a basic model of these interactions. In particular, it highlights the link between a lack of "social license to operate" and the generation of risks to the project that would impact on its commercial viability as well as reputation.

alliances with each other as well as with other stakeholders such as the science and technology sector, and organizing into well-run professionalized farmers' associations. Below is a list of social, economic and political hazards to any economic activity:

- civil unrest or civil strife,
- social tension,
- political instability,
- rampant poverty (a proxy to weak government),
- high unemployment (an indicator of horizontal inequality between groups),
- social exclusion (highly defined inequality in access to services and resources),
- tendency of government to solve social conflicts by military action,

- lack of independent judiciary (for dispute resolutions),
- insufficient regulatory system,
- excessive regulation,
- poor or weak governance, and
- economic crisis.

The essence of the definition of social risk – i.e. a challenge by society to a practice or the practices of an entity – precludes these aforementioned situations in risk analysis. This does not mean they should be ignored; their potential impacts can be very severe and they are abetted by improper practices in the sector. Small farmers, who are most vulnerable to these risks, need to be assisted to deal with them.

Another category of hazards consists of those that tend to prevent farmers from adopting, or to make risk-averse ones reluctant to adopt, strategies (such as crop diversification or intensification) or practices (such as an effluent treatment system) that improve their livelihoods or management. Examples are ill-defined property rights, lack of protection of assets, seasonality or unreliability of labour, perception of loss of profitability and a number of those listed above.

Economic hazards that are spawned in the market and industry, such as changes in consumer preferences and tastes, appearance of substitutes, development of competitive products and market volatility, invariably translate to social risks. The most extreme consequence would be the collapse of a commodity industry and closure of farms, resulting in widespread unemployment and the loss of livelihoods or income opportunities for communities and service sectors dependent on the commodity industry. This group of hazards, to be sure, is not perpetrated by practices within the aquaculture sector; but failure to identify them could be attributed to a variety of reasons within the industry or sector, such as lack of foresight, wrong interpretation of market trends or plain lack of capability for market intelligence.

In view of the above discussion, this review will concentrate on hazards that potentially provoke a challenge that has a social impact on a farm, an industry or the sector. Based on the definition and using the spheres of social responsibility as basis for identifying hazards, these would include those listed below (Table 1) as examples.

The above examples of hazards are in fact strategies, practices, facilities or substances the uses of which are meant to improve productivity and profitability. Their improper practice or misuse, whether inadvertent or deliberate, could result in adverse impacts on stakeholders. In the case of technologies (obviously useful by themselves), the introduction of devices that displace workers in a social setting that is poor and where there is excess labour could reflect adversely on the reputation the farm. It could breed resentment from the community because of lost job opportunities (a similar challenge could be provoked by hiring practices). The same applies to technology that requires higher skills, which would displace unskilled or lower workers. A farm or corporate body that neglects to train its workers and finds it more convenient or more efficient to replace them could generate the same response of resentment or direct hostile action from the community.

Worker relations and hiring and purchasing practices pose a social risk to the farm if these were seen by the community as discriminatory, exploitative or opportunistic. There can also be the case of offering "competitive salary structures or wages" to undercut competitors in the labour market. This could result in other sectors losing their work force to the sector or being forced to compete. The latter would have a positive effect on the community's labour market but could result in adverse impacts on other industries and a general feeling of ill will from the business sector towards the aquaculture farm or company. On the other hand, a business strategy such as consolidation, merger or acquisition that is meant to create value for owners and stockholders – and could result in workers being made redundant – cannot be considered as a hazard, notwithstanding this possible consequence.

TABLE 1
Examples of hazards that could turn into social risks

Internal social responsibilities	Hazards
People • Farmer • Household • Workers	• Workplace conditions • Pest and disease control operations • Technology that might displace labor • Technology requiring higher skills
Cultured animals	• Feed ingredients (e.g. melamine) • Pollution hazards • Drugs and chemicals • Stocking density • Harvest and (for live animals i.e. aquarium fish) transport practices
External social responsibilities	**Hazards**
Community and the environment	• Location of farm • Use of common natural resources like water • Containment of cultured organisms • Waste and effluent disposal systems • Employment practices • Purchasing practices • Predator eradication practices • Introductions of species for farming
Suppliers, product buyers, processors, traders	• Buying practices • Feed and additives use • Drugs and chemicals use
Global social responsibilities	**Hazards**
Consumers	• Feed and additives use • Drugs and chemicals use • Feeding practices (e.g. use of trashfish)
Aquaculture industries in other countries	• Subsidies • Species and production targets • Marketing practices

The siting of farms, farm management practices such as effluent treatment and discharge, and other aquaculture practices carry social and environmental impacts to the community. Environmental impacts invariably translate to social impacts. Conflicts can arise because people's access to the shore is blocked by aquaculture installations, salination of crop lands, encroachment or decline in fish catch because of various aquaculture impacts that include fish kills on the wild fishery (FAO, 2006). A classic example of a social hazard is the siting and practices of brackishwater shrimp farms in India, which were cited by activists in their petition to the Supreme Court of India to shut down the sector in 1997 (Patil and Krishnan, 1998).

The use of inputs such as feed, drugs and chemicals is a great source of social hazards, not so much to the farm as to the industry or the sector as a whole. A scare caused by a tainted product invariably gives the industry a bad press potentially resulting in consumer resistance or boycott, importing countries' burning of containers of the product and perhaps change in product or product-supplier preference, all of which lead to loss of market. Loss of market could jeopardize the viability of the sector and the welfare of workers and people dependent on it for a living. The burning or return of shipments of shrimp from Viet Nam found with unacceptable levels of residues of banned drugs also severely impacted on the livelihoods of poor agricultural communities dependent on shrimp aquaculture (MoF/NACA, 2005). The ingestion or exposure of a farmer and/or farm workers to toxic substances from chemicals and drugs because of poor or lack of safety precautions can reach the media and become a serious local or national issue, with the potential of escalating into such challenges as lawsuits, community action against the farm or consumer resistance to the product.

The process of identifying hazards with social consequence includes posing the critical question "What challenges to the industry can be expected from society or certain stakeholders if something went wrong?" Answers to "What could go wrong?" which should be the first question, can be found or inferred from:

- codes of conduct
- principles of good aquaculture
- codes of practice
- good aquaculture practices
- international agreements
- certification schemes
- ethical and fair trade standards
- animal welfare and free range
- labour standards
- rules and regulations
- International Standards Organization (ISO) standards
- others

These instruments can be used to identify hazards, i.e. to assess what could go wrong. Beyond this, aquaculture needs to know what challenges can be expected from any sector of society if something goes wrong. For example, introduced species that become pests or that carry pathogens have in some cases caused the collapse of fisheries and aquaculture operations, resulting in massive losses in revenue and severe implications for farmers, fishers, post-harvest industries and human health (APEC, 2003). The risk analysis methodologies used for alien or introduced species are well established and the methodology to evaluate their economic, environmental and social impacts have been developed. It is the likely challenges to aquaculture as a whole (or, for example, the ornamental fish industry, if it were the source of the alien) that their impact would incite that need to be identified, assessed and mitigated.

The hazards that could provoke challenges from industries in other countries are those with potential impacts from a country's policies (i.e. subsidies) or a sector's targets (i.e. species and production targets) and marketing practices (e.g. dumping). Subsidies, as well as protectionism, could cause harm to a similar industry and its workers in another country. Over-production and flooding the market thus depressing prices would hurt competitors in poorer areas or countries, and dumping can create a lot of economic backlash on an industry or commodity sector.

A study of shrimp farming in Latin America and the Caribbean by Wurmann, Madrid and Brugger (2004) provides an example with an interesting perspective. The study focused on two sources of competition: producers in importing countries (such as the United States shrimp fishing industry) and producers in other regions, particularly Asia. The study viewed the anti-dumping case in the light of its negative impacts on national shrimp industries. It predicted that after the completion of the exercise (anti-dumping charges and imposition of countervailing tariffs, and countercharges), "things would go back more or less to where they were at the outset, but not before causing disruptions in producing countries, and financial collapse of traders, importers and distributors". It also viewed the Asian competition largely from the expansion of white shrimp production (*Litopenaeus vannamei*) as initially disruptive to the industry in Latin America but concluded that it will compel the latter to become more efficient in the long term. The anti-dumping action probably did not affect the shrimp industries of concerned countries as seriously as the study predicted, but it did create disruptions. On the other hand, there was no challenge based on this issue from Latin America to Asian competitors (particularly those producing *L. vannamei*).

In summary, an action within the aquaculture sector that tarnishes its reputation for social responsibility has the potential to provoke challenges from society. Codes of conduct and practices, certification schemes (especially ecolabeling) and standards of food safety, chemical use and labour are useful guides to identifying hazards that could turn into social risks.

SOCIAL RISK ASSESSMENT

Assessing the likelihood of a hazard turning into a social risk may or may not follow the stepwise release, exposure, consequence and estimation procedure designed for import risk analysis (pathogen risk analysis). Risk assessment of introduction of species would follow exactly the standard procedure up to assessment of its social, environmental and economic consequences. To then assess its social risk, key questions would be:

- What is the likelihood that a challenge is provoked from adversely affected parties or groups taking up their cause?
- What kind of challenge could be expected, from whom or which interest group(s)? and
- What are the likely consequences of a challenge to the aquaculture sector or the industry?

The critical question is what would be the most serious consequence from the challenge? Would it be simply an annoyance, would it breed resentment from the community, would it provoke hostile action such as a blockade against the farm or destruction of its structures and equipment, would it result in loss of market, or would it lead to the closure of a farm or an industry?

A negative report or public criticism in the local or national media from some person or group would at first glance seem a mild reaction that can be responded to by a media release or a public relations campaign. However, this could readily escalate into (a) a greater issue, say, of human rights, environmental irresponsibility or anti-poor, or (b) a suite of interlinked issues that could be more intractable and expensive to respond to, or (c) a class action. For example, what started as public criticism from an environmentalist in India on a single issue – water abstraction – ended in the Supreme Court ordering the closure of brackishwater shrimp aquaculture.

In this connection and in the context of risk analysis, the study of Patil and Krishnan (1998) on the social impacts of shrimp farms in Nellore, Andhra Pradesh illustrates an important step in the process of social risk assessment. They identified and ranked the severity of six social impacts of shrimp farming on 26 villages located adjacent to shrimp farming clusters as perceived or felt by the affected parties. The impacts included blocked access to the beach, salination of well water, salination of agricultural land, difficulty in gathering fodder and fuel wood, unemployment or under employment and poor health. They found that for the 17 fishing villages, blocked access to the beach was a very severe problem, well water salinity a severe problem, crop land salination and underemployment were moderate problems, poor health was problematic and difficulty in gathering fodder and fuel wood a nuisance. The study found no problem or combination of problems that caused a social crisis. It also found that different occupational groupings ranked the problems differently, as illustrated below in Table 2.

The value of this kind of study to risk assessment is the identification and assessment of the impacts and their relative severity, which thus gives an indication of likely consequences and the impacts of a practice. For risk management, it offers government

TABLE 2

Severity ranking of social impacts in fishing and farming villages

Ranked Impacts[1]	Ranked by Fishing Villages	Ranked by Farming Villages
Well water salinity	2	4
Blocked access	1	3
Agricultural land salinity	3	2
Un/under employment	4	5
Poor health	5	6
Fodder & fuel wood	6	1

[1] "1" is most severe.

Source: Patil and Krishnan 1998.

and industry a guideline for addressing the root cause/s of the risks. The study was able to expose the nature of each social impact and determine its magnitude to enable the development of effective legislation and other means to regulate and mitigate shrimp farming impacts. The science-based guidelines became a credible response to the environmental activists' challenges.

Consequence scenario

The complexity of origins, the relationships between risks or among several risks, and the many possible consequences of a social risk make it extremely difficult to establish a social risk consequence scenario, as is sharply illustrated by the Supreme Court of India's order to close the brackishwater shrimp industry. Other challenges such as consumer boycotts and resistance are difficult to assess, although an indication that such challenge might be mounted could be gauged from the severity and visibility of the impact. For example, food poisoning, discovered and widely reported drug residue on shipment and its being burned, mass lay off of workers, massive pollution and massive mortality of cultured and wild fish are unmistakable signals of severity that can catch the industry off guard. On the other hand, importing country actions such as bans, return or destruction of shipment, and trade sanctions are essentially notified and, because of specific provisions in World Trade Organization (WTO) or bilateral trade agreements, could be anticipated. Examples of possible challenges and likely consequences of these challenges are listed in Table 3.

The following steps could be followed in risk assessment with the ultimate aim of determining the likelihood of its occurrence and the seriousness of its consequence/s. For several risks, the exercise would aim at ranking their relative seriousness so that responses could be prepared and set into priorities.

1. **Assessment**. To provide an example of an assessment matrix for social risks, we pick the farm worker and the "community" as resources under threat. A column on modifying factors, i.e. what could reduce or aggravate the risk, is introduced (Table 4).
2. **Quantification** of social risks allows proper comparison and prioritization against perhaps more easily quantifiable technical risks. It also allows a proper decision as to which risk or set of risks justify and are amenable to more detailed analysis and evaluation. For aquaculture, a risk evaluation matrix could be developed using a rating system for the severity of the consequence of a challenge and its likelihood of occurrence, as in the example given in Table 5.

The information on severity of impact and likelihood of the risk happening could be derived from historical experiences and expert views. Descriptors for severity of social risks are provided as examples in Table 6.

3. **Descriptors** of likelihood of occurrence could be as given in Table 7.
4. **Ranking.** The result enables a ranking of risks so that responses could be also prioritized. Table 8 illustrates this step.
5. **Developing a risk table.** The next step is to rank the issues, assign an issue according to its rank under one of six categories and develop a risk table such as the one show in Table 9.

This process should be completed for each of the identified issues with a risk ranking developed and the rationale for assigning these rankings recorded. The actual risk assessment is not just the scores generated during the assessment process. It should include the appropriate level of documentation and justification for the categories selected, as illustrated in Table 10.[2]

[2] Another guide for risk rating is "HPSS guidance on analysis of risk/risk rating matrix" (www.hsspsni.gov.uk/guidance_on_analysis.pdf).

TABLE 3
Some examples of direct and indirect consequences of social hazards

Internal social responsibilities	Hazards	Consequences and Likely challenges from society
Workers	• Technology that might displace labour • Technology requiring higher skills • Workplace conditions • Pest and disease control operations	• Unemployment – management–labour conflict, human rights and welfare issue, work-related injury or illness, cessation of operations due to labour unrest, bad press, negative report, public criticism, lawsuit
Cultured animals	• Feed ingredients (i.e. melamine) • Pollution hazards • Drugs and chemicals • Stocking density	• Animal welfare issue – bad press, boycott, ban • Negative report or public criticism
External Social Responsibilities	**Hazards**	**Consequences**
Community and the environment	• Location of farm • Use of common natural resources like water • Density of farm structures • Containment of cultured organisms • Waste and effluent disposal systems • Employment practices, terms • Purchasing practices • Predator eradication practices • Introductions of species for farming	• Access to source of livelihoods barred or made difficult –conflict with community • Contamination of water resources, loss of livelihoods from wild fishery – capture-culture conflict • Conflict with common users of resources • Local resentment at missed job opportunities leads to elements of the local community blockading the site • Accidental damage to wild fishery or farm crops – bad press, conflict with fishers • Spread of disease, pests or predators – bad reputation; negative report; public criticism
Suppliers, product buyers, processors, traders	• Buying practices • Feed and additives • Drugs and chemicals • Perceptions of product quality	• Loss of trust – loss of market, tarnished product or farm reputation, blacklist
Global social responsibilities	**Hazards**	**Consequences**
Consumers	• Feed and additives • Drugs and chemicals • Perceptions of product quality • Feeding practices (use of trashfish)	• Loss of market; tarnished product image and sector reputation – bans, boycotts, lawsuits, product avoidance • Environmental action
	• Appearance of cheaper substitutes, development of competitive products, change in preferences and tastes	• Loss of profitability, competitiveness and market
Aquaculture industries in other countries	• Subsidies • Species and production targets • Marketing practices	• Market access issues: bans, boycotts, antidumping measures, countervailing tariffs – loss of market. • Harm to livelihoods of farmers in other countries – trade related challenges (i.e. anti-dumping), higher tariffs – loss of market access

TABLE 4
An example of an assessment matrix for social risks

"Resource" Under Threat	Threats to resource	Causes	Consequences	Modifying factors (reduce (–) or aggravate (+) risk)
farm labour	• Displacement • Injury or illness	• Labour-saving technology • Unsafe, unsanitary working condition, lack of protection; lack of knowledge of safety measures	• Lawsuit • Bad press • Community resentment • Strike	• Skills training (–) • Cutting corners on employee safety (+) • Investment in training and safety devices (–)
Community goodwill or cooperation	• Pollution of water bodies, croplands • Perceived exploitative practice	• Leaks, spills, discharge of effluent • Unfair labour terms or unethical hiring practices	• Community hostile action • Lawsuit • Bad press	• Water treatment system (+) • Forced labor (+) • Child labour(+) • Illegal wage structure (+)

SOCIAL RISK MANAGEMENT

Concepts and definitions

Risk management is the process of bearing the risk you want to bear, and minimizing your exposure to the risk you do not want. This can be done in several ways: **not doing things** that carry a particular risk; **hedging,** which involves deliberately taking on a new risk that offsets an existing one, such as your exposure to an adverse change in an exchange rate, interest rate or commodity price; and **diversification,** which means not putting all your eggs in one basket (having a portfolio in which you hold several different shares and assets helps to reduce risk; and buying insurance (in economic terms, anything used to reduce the downside of risk. In its most familiar form, insurance is provided through a policy purchased from an insurance company. A fuller definition would include, for example, a financial security (or anything else) used to hedge, as well as assistance available in the event of disaster. The latter could be provided by the government in various ways, including welfare payments to sick or poor people and legal protection from creditors in the event of bankruptcy.[3]

TABLE 5
Example risk evaluation matrix

Severity	Likelihood of Occurrence
0- Negligible	1- Remote
1- Minor	2- Rare
2- Moderate	3- Unlikely
3- Severe	4- Possible
4- Major	5- Occasional
5- Catastrophic	6- Likely

Source: FRDC Australia, 2004

TABLE 6
Examples of descriptors for severity of social risks

Severity Level	Social risk consequence
Negligible (0)	General – insignificant impacts to aquaculture at any level (farm, industry or sector); unlikely to be measurable or to cause challenge from any sector.
Minor (1)	Challenges likely to be a nuisance and can be addressed or responded to with minimum of effort and expense.
Moderate (2)	Challenges will likely impact on reputation of farm, industry or sector with one or a few consequences; can be addressed before it escalates into a major challenge.
Severe (3)	Challenge will place the reputation of an entire commodity industry at stake; has the potential of escalating into a major challenge; could result in an abrupt loss of market access and profitability.
Major (4)	A major challenge or sets of challenges from various empowered stakeholders that will have very costly and several interlinked consequences such as bans, boycotts, hostile action, lawsuits, blacklist etc; could jeopardize welfare of people in the sector; response is needed from the sector as a whole and will entail much expense and effort; recovery can take a few years.
Catastrophic (5)	Closure; bankruptcies, widespread collapse of the industry; long-term recovery period.

TABLE 7
Descriptors or likelihood of occurrence

Likelihood	Definition
Remote (1)	Never heard of but not impossible
Rare (2)	May occur in exceptional circumstances
Unlikely (3)	Uncommon but has been known to occur elsewhere
Possible (4)	Some evidence to suggest it is possible to occur
Occasional (5)	May occur
Likely (6)	Expected to occur

Source: FRDC Australia, 2004.

Arrangements and strategies

The next section largely borrows from Holzmann (2001). The concepts and examples would appropriately but not exclusively apply to poor and small farming households.

Social risk arrangements

Arrangements to deal with vulnerability fall into three main categories: (i) informal, (ii) market based and iii) public arrangements on a large scale. In an ideal world with

[3] "Economics from A to Z", www.economist.com.

TABLE 8
Quantifying social risks by severity and likelihood of occurrence, an example

Consequences and likely challenges from society	a. Severity of impact	b. Likelihood of occurrence	Score (A x b)
1 Unemployment: management–labour conflict	4	6	24
2 Human rights and welfare issue	3	3	9
3 Work-related injury or illness	4	5	20
4 Cessation of operations due to labour unrest	4	6	24
5 Bad press, negative report, public criticism	2	6	12
6 Lawsuit	4	3	12
7 Animal welfare issue – bad press, boycott, ban	2	2	4
8 Negative report or public criticism			
	2	5	10
9 Access to source of livelihoods barred or made difficult: conflict with community	4	4	16
10 Contamination of water resources, loss of livelihoods from wild fishery – capture-culture conflict (with other stakeholders)	4	5	20
11 Conflict with common users of resources			
12 Local resentment at missed job opportunities leads to	4	3	12
elements of the local community protesting or blockading the site.	3	5	15
13 Accidental damage to wild fishery or farm crops – bad press, conflict with fishers			
	5	3	15
14 Spread of disease, pests or predators – bad reputation; negative report; public criticism			
	4	3	12
15 Unethical buying/marketing practice; bad product: loss of trust, loss of market, tarnished product or farm reputation, blacklist	5	3	15
16 Market access issues: bans, boycotts, antidumping measures, countervailing tariffs – loss of market.	4	5	20
17 Harm to farmers in other countries – trade related challenges (i.e. anti-dumping, higher tariffs – loss of market access)	4	6	24

TABLE 9
Example of risk table

		Consequence					
Likelihood		Negligible	Minor	Moderate	Severe	Major	Catastrophic
		0	**1**	**2**	**3**	**4**	**5**
Remote	**1**	**0**	**1**	**2**	**3**	**4**	**5**
Rare	**2**	**0**	**2**	**4**	**6**	**8**	**10**
Unlikely	**3**	**0**	**3**	**6**	**9**	**12**	**15**
Possible	**4**	**0**	**4**	**8**	**12**	**16**	**20**
Occasional	**5**	**0**	**5**	**10**	**15**	**20**	**25**
Likely	**6**	**0**	**6**	**12**	**18**	**24**	**30**

Source: FRDC Australia, 2004.

perfectly symmetrical information and complete and well-functioning markets, all risk management arrangements can be market based. In reality, all risk management arrangements will play important roles that could change over time.

- **Informal –** With no or incomplete market institutions and public provision of support, households and small farms respond to risk by protecting themselves through informal and personal arrangements. Credit from relatives and self-help group arrangements are examples.
- **Market based –** Where available and affordable, smallholders and households take advantage of the financial products offered by insurance companies and banks. Because formal market institutions have difficulty to lend or provide insurance to small farms without secured earnings and improved access to information,

TABLE 10
Risk ranking definitions and reporting requirements

Risk	Reporting		Management response
Negligible	0	Short justification only	Nil
Low	1	Full justification needed	None specific
Moderate	2	Full performance report	Continue current arrangements
High	3	Full performance report	Probable increases to management
Extreme	4	Full performance report	Substantial additional management needed

micro-credit and insurance are potentially interesting instruments for social risk management.[4]

- **Public – This category** takes various forms. When informal or market-based risk management arrangements do not exist (there is no insurance), the government can provide or mandate social insurance programmes for risks such as unemployment, work injury, disability and sickness, and compensation schemes for catastrophes or unusually large damages to assets and crop. Additionally, governments have a whole array of instruments to help farms cope after a shock hits, such as social assistance, subsidies on basic goods and services and public works programmes. Through legislation, government is also able to introduce prevention strategies such as zoning, safety standards, property rights and protection of rights to assets. Many government programmes (in health, education and infrastructure) also play an important role in social risk prevention.

SRM strategies

Social Risk Management (SMR) consists of three strategies: prevention, mitigation and coping.

Prevention strategies are those that reduce the probability of the risk occurring. Measures that could apply to aquaculture include:

- skills training or job function improvement to reduce the risk of un/under-employment or low wages that are probably man-made;
- optimizing macroeconomic policies to reduce the shocks of financial crisis, such as oil price surges or unpredictable market moves on currencies;
- for natural disasters and environmental degradation, deploying a networked pre-warning system or sustainable, renewable and environmentally friendly ecosystem management strategies and practices to minimize the impact of the consequences, such as flooding, earthquakes, drought, global warming and soil acidity or salinity;
- in human and animal health care, focus is on the preventing epidemics and the introduction of pathogens by awareness and educational programmes, responsible movement of live animals, quarantine, certification etc.; and
- for social security, establishing a farm mutual to compensate for loss of assets, disability or chronic illness.

Mitigation strategies focus on reducing the impact of a future risk event. Common practices include:

- diversifying to a reasonable level that is commensurate to the resources and management skills of the farmer, to spread the risk[5] as well as reduce shock from a crop wipeout;

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4 A hybrid programme for insurance by which, broadly, insurers cover insurable perils and the government covers the social risk that insurers normally do not cover, was proposed at the FAO/NACA/APRACA Regional Workshop to Promote Aquaculture Insurance in Asia held in Bali, Indonesia on 30 April–2 May 2007. A draft guideline, discussed at the workshop, was being finalized.

5 A study in India by Brugere (2003) noted that at the village level, crop diversity increases with risk, up to a point, then decreases, which contradicts the assumption of crop diversification as a strategy to decrease risk. It concluded that with limited resources, crop diversification may increase income but does not reduce risk.

TABLE 11
Strategies and arrangements of social risk management: examples for aquaculture

Arrangements/ Strategies	Informal	Market-based	Public
Risk Prevention and Reduction			
	• Self-help grouping or association of farmers • Better farm management practices • Less risky production – low tech-low input; non-diversified • Off-farm employment	• Food safety certification • Environmental standards • Market-driven labour standards • Market information access	• Labour standards, regulations • Child labour reduction interventions • Gender policies • Skills training
Risk Mitigation			
	• Self-help grouping • Diversified enterprise • Savings • Investments in human, physical and real assets • Investment in social capital	• Credit • Crop and assets insurance • Life, accident, health insurance	• Property rights • Support for credit and insurance • Green subsidies
Risk Coping			
	• Sale of real assets • Borrowing from relatives	• Sale of financial assets	• Social assistance • Compensations to damages

Source: Adapted from Holzmann, 2001.

- micro-financing to smallholders; and
- insurance.

Coping strategies are designed to relieve the impact of the risk event once it has occurred. Usual measures are:

- issuing government relief and rehabilitation funds for very serious risks such as disasters or epidemics;
- immediate compensation schemes for serious damages to crops and assets caused by intentional or accidental pollution or acts that result in extensive damage; and
- alternative and emergency employment such as work-for-food programmes.

Table 11 lists examples of social risk management strategies through informal, market-based and public arrangements. Among small-scale farmers, being organized into a self-help group or a formal association would increase their capacities to prevent and mitigate, as well as cope with, social risks. Large corporate farms joined into alliances (such as the Global Aquaculture Alliance (GAA)) are able to deal with strategic risks, many of which are challenges to the (shrimp) industry from various parties. Strategic management of social risks is discussed in the next section.

Strategic and integrated risk management

The complexity of impacts and difficult-to-pinpoint origins of social risks reinforce the need for integrated approaches to strategic risk management. Strategic risks can scale rapidly in geographic terms: what looks like a local public relations issue could turn from a one-time cost and simple response into an issue involving a sector's, industry's, company's or farm's reputation.

For strategic risks, in contrast with traditional compliance or hazard risks, risk and opportunity are often two sides of the same coin. A strategic risk that is anticipated early and mitigated well can be converted into a new market, a competitive advantage, a stock of goodwill or a strategic relationship (Bekefi, Jenkins and Kytle, 2006). The introduction of new technology could be an opportunity to upgrade the skills of the workforce (rather than laying off workers) through in-house training or an industry-wide skills upgrade programme and thus improve labor efficiencies and enhance goodwill. Competition for freshwater by an aquaculture sector such as shrimp farming with the community could be an opportunity to educate the community on water-saving techniques, demonstrating water-recycling and re-use measures, develop a market-based water-pricing mechanism with the local government, and introduce sanitation and health programmes to the community.

The aquaculture sector is familiar with a number of social risks. Certification and ecolabeling schemes, developing alliances with various sectors and working with stakeholders to build or re-build trust and reputation in order to avoid or limit the damage or to engage on the issues to prevent future incidents are strategic responses that the sector could make. The Code of Conduct, International Principles for Sustainable Shrimp Aquaculture, and other codes (some developed by the industry, such as the Federation of European Aquaculture Producers' (FEAP), Code of Practice and GAA's Code of Conduct) provide guides by which aquaculture farmers can understand and address the range of social and environmental issues that affect them and on which they can have an impact. There have been initiatives that go beyond understanding the issues to identifying and engaging other stakeholders in those issues. FEAP routinely engages researchers and scientists (i.e. with the European Aquaculture Society) as well as the mass media (i.e. AQUAMEDIA) in discussing various issues that impact on the industry and by communicating its opinions to the concerned bodies such as the European Commission (Hough and Bueno, 2003).

Building relationships can help farms or a commodity sector gain freedom from stakeholder challenges to their management and business practices. It can contribute to a reputation for good behaviour (i.e. by adhering to a code of conduct, better management practices (BMP), good aquaculture practices (GAP) or eco-label certification) that could give an industry or a farm advantage with ethical consumers and investors. Strong relationships with stakeholders that are maintained over time can be an insurance: they buy time and patience from those with the power to challenge the farm or the sector when it causes a negative social impact. These relationships can be good sources of sensing emerging risks and opportunities. They can help to identify the issues, understand the dynamics behind them and track them as they evolve. These relationships may form the basis of more collaborative operational partnerships with stakeholders actively helping the industry mitigate risks and capture new opportunities (Bekefi, Jenkins and Kytle, 2006).

For the aquaculture sector, alliances with consumer groups, supermarket chains, researchers and technology developers, and civil society organizations with social agenda are examples. The sector should build relationships that are conducive to managing the risks and opportunities arising out of the issues in which both parties have common stakes, such as food quality and safety, eco-labeling and development of certification standards, as well as fair trade. Ultimately, it is a farm's commitment to its customers and to socially responsible farming that assures a lasting relationship.

SOCIAL RISK COMMUNICATION

The aim of risk communication usually is to avoid or correct misperceptions of a risk. It goes without saying that the source of the message must be able to understand the sources and causes of anxieties and perceptions of stakeholders. In short, there has to be a common understanding between the communicator and the public about the elements of the risk. Communication is a tool for risk management. One important arm of "corporate social responsibility" (CSR) is a public affairs or public relations unit with the capabilities and expertise to manage strategic risks stemming from social (and environmental) issues. In the aquaculture sector, with the obvious absence of a CSR body for small, widespread or independent farms, the alternatives have included organizing into associations and federations (e.g. FEAP) and alliances (e.g. GAA and Shrimp Producers Association of Thailand) that include suppliers of inputs and processors/exporters). The "CSR function" or parts of a CSR unit's functions are performed to some extent and in a disinterested manner consistent with their mandates, by organizations like the Network of Aquaculture Centres in Asia and the Pacific (NACA), the South East Asian Fisheries Development Center (SEAFDEC), INFOFISH and FAO. They develop with other stakeholders guidelines for responsible farming and strategies for communicating, sharing and promoting awareness and adoption.

In the context of communicating social risk, a "CSR" action (whether by the industry itself or in cooperation with development organizations) contributes through two means: (i) providing intelligence, awareness and insight about what those risks are, and (2) offering an effective means to respond to them. The key to both is managing stakeholder relationships (Bekefi, Jenkins and Kytle, 2006).

An equivalent activity to managing stakeholder relationships in a sector with many small, poor farmers is getting organized into self-help groups or more formal associations and cooperating with suppliers, buyers, support services, civil society organizations, government and regional and international development organizations. Information flows between stakeholders and the sector can form the base of knowledge about social issues and the nature of those problems (Kytle and Ruggie, 2005). Among the key questions that can be answered by engaging with stakeholders on a particular social issue are:

- What is the issue or problem?
- How complex is it?
- What is its scope?
- Who else has an interest in the problem?
- What is working and not working in the current approach?
- What would be accomplished by engaging others in the dialogue?

A process for internal and external risk sensing, reporting and monitoring should be employed. By partnering with other social actors including civil society organizations, the aquaculture sector can also improve the conditions that pose emerging risks for them in the first place. As an example, global and national companies now collaborate to build greater social capacity to respond to shared challenges like epidemics and the HIV/AIDS crisis, drugs, trafficking, child labour, and other social issues.

CONCLUSIONS

Social risk analysis in aquaculture can benefit from the methodology developed for biological (i.e. pathogen) risks, up to a point. The complexity of the origins of social risks and the difficulty of establishing a hierarchy among numerous possible consequences make it extremely difficult to establish causal relationships. Table 12 illustrates this constraint.

TABLE 12
A matrix illustrating the complex nature of the origins and impacts of social risks

Consequences	Challenges	Possible origins
• Loss of market that leads to… • Loss of viability that may lead to... • Closure of farm or industry that will mean… • Loss of employment of workers in the farm or the industry including ancillary… and • Loss of livelihood of the farmer and/or a lot of other people	• Public exposure (news and criticism) • Court action • Boycott of product • Trade challenges – antidumping, non-tariff barriers (NTBs) • Hostility to farm or company • Introduction of a cheaper or preferred product substitute • Competition from an industrial-scale and more efficient farm • Change in consumer tastes and preferences	• Residues found in product • Mass fish kills (cultured and wild) • Accidental or intentional discharge of pollutant (pollution, salinization) • Conflicts with common users of resource • Conflicts with community in general • Government action • Loss of competitiveness • Introduction and spread of pests and/or diseases • Cost-price squeeze • Civil unrest

The definition adapted for social risk provides a departure to the concept of origin of risk.

It essentially says that a social risk is the result of a provocation by the sector, industry or farm on society. The provocation, which could simply be based on a perception, results in a challenge. The challenge constitutes the risk, which has myriad possible consequences with various degrees of severity. To bring risk analysis to a degree of simplification and system, it is suggested that one starts by defining aquaculture's spheres of social responsibility; identifying the stakeholders to which it has to be responsible; and drawing from codes of conduct, codes of practices, ecolabeling and certification schemes, labour standards, food safety standards and environmental standards a list of hazards that could turn into social risks. It would be useful to develop a methodology for social risk estimation, the practical application of which is to predict the types of challenges and their degrees of severity so that an early response could be devised to address the challenge. The insurance sector could provide the tools for developing a social risk estimation methodology.

An aquaculture risk data bank, which is akin to a risk register in project risk analysis and management (RAMP, 2004), in which all possible hazards and risks are classified as to their nature, causes, consequences, impacts, severity of impacts, likelihood of occurrence and other characterizations would be a helpful tool for risk analysis and reference for commercial insurers and governments, the latter for devising social insurance programmes. A risk register lists all the identified risks and the results of their analysis and evaluation. Information on the status of the risk is also included. The risk register is continuously updated and reviewed throughout the course of a project. A risk register is best presented as a table for ease of reference and should contain the following information:[6]

- risk number (unique within register),
- risk type,
- author (who raised it),
- date identified,
- date last updated,
- description,
- likelihood,
- interdependencies with other sources of risks,
- expected impact,
- bearer of risk,
- countermeasures, and
- risk status and risk action status.

FUTURE CHALLENGES AND OPPORTUNITIES: SOCIAL RISK AND SUSTAINED GROWTH

If the industry, a farm or the sector as a whole adheres to socially responsible practices, it is fair to expect it would face very little challenge and none that is serious. The need therefore is to enable the farmers, processors, traders, input suppliers and others in the chain to adopt the codes, adhere to better practices and comply with regulations. A particular challenge is how to prevent free-riding, rent-seeking and corruption and other opportunistic behaviours that would surely invite challenges to the sector. This shifts the focus of the issue to governance mechanisms, particularly the effectiveness of various mechanisms of governance (mandatory, market-based and voluntary) instruments. The other side of the issue is the ability of farmers to comply with an increasing number and stringency of requirements without jeopardizing their profitability; the challenge is for farmers to see as sensible to business to adopt and

[6] The Green Book. www.greenbook.treasury.gov.uk

comply with all these requirements. A number of pilot studies and initiatives offer evidences of the effectiveness of such strategies as organizing into farmer groups or more formal associations and adopting BMPs (Bueno *et al.*, 2007a, 2007b).

The opportunities presented by these challenges are many and varied: a small list would include making it attractive for insurers to insure aquaculture operations, particularly the numerous small farms; developing a hybrid insurance approach that combines the market-oriented and social (public) insurance schemes; and a better system for micro-financing (FAO/NACA/APRACA 2007). The demand-side opportunities would include organizing farmers and promoting adoption of better practices. The broader challenge and opportunity is the strengthening of national farmer servicing systems that cater to the numerous small farmers. The greatest opportunity is to let the farmer know, and to assure the sector, that a social risk-free environment, which is predicated on socially responsible behaviour, translates to sustained growth and development. Finally, a possible framework by which analysis of various genera of risks (natural, physical, environmental, economic and social) might be integrated is outlined in **B**ox 4.

The five livelihood assets are linked through an asset pentagon (Figure 1) that allows comparison of status before and after an intervention; in short it enables assessment of changes. The pentagon allows the change in each angle to be shown in terms of an increase or decrease in the assets; the shape of the pentagon of assets plotted is more important than the absolute magnitude. The livelihood outcome is the result of an analysis of livelihood strategy and assets. One livelihood outcome is the loss of it. Threats to a means of livelihoods to any of the five livelihoods assets could thus

BOX 4

Sustainable livelihoods analysis:
a possible integrative framework for risk analysis

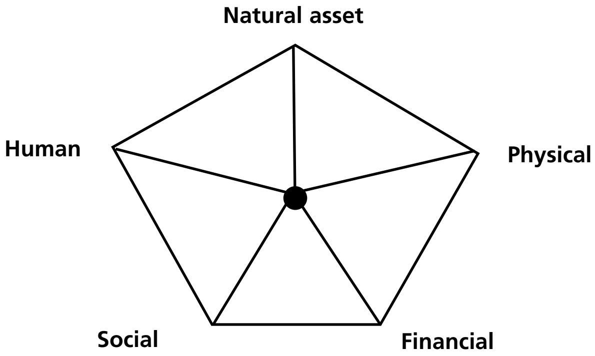
The Department for International Development (DFID)[7] has been promoting a framework for livelihoods analysis, based on the concept that *"a livelihood comprises the capabilities, assets, and activities required for a means of living"* and the proposition that *"a livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base".* Based on this concept, Rakodi and Lloyd-Jones (2002) identified five livelihood assets, as follows:

- *Natural:* the natural resource stock, which is derived for livelihood use; includes land, water, forest and other natural resources.
- *Physical*: the stock built by humans; basically an infrastructure, such as an irrigation system, transportation system, pond system, pen-culture and cage-culture installations.
- *Human:* includes what is generally known as labour and knowledge. Labour has qualitative and quantitative dimensions. Quantitative refers to the number of household and hired labour, and qualitative refers to the level of education, skill and the health status of labour. Technology that is learned and utilized is part of this human asset.
- *Financial/economic:* is associated with income, expenditure, savings and loan (it includes all kinds of production investment).
- *Social:* refers to the social networks, group relationship and access to wider institutions of society.

[7] http://www.livelihoods.org/info/guidance_sheets_pdfs/cover.pdf

be described and assessed using this framework. A risk is an intervention, albeit unplanned. Adopted for risk analysis, the same framework could be used for assessing the impacts of various kinds of risk on each livelihood asset. This would give a holistic perspective of the consequences of various types of risks on the farm household.

FIGURE 1
The asset pentagon



Source: Rakodi and Lloyd-Jones, 2002.

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Aquaculture insurance industry risk analysis processes

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ABSTRACT

The aquaculture insurance industry's approach to risk analysis is wide ranging and thorough. It starts during the insurance arrangement process and carries on throughout the life of the insurance policy. The analysis process relies on information obtained through the completion of specially designed proposal forms that have to be completed by applicants seeking insurance. Different forms are used for different types of aquaculture. Information is gathered on every aspect of each farm, and questions must be answered in considerable detail. Answers must be correct and accurate, as a completed proposal form becomes a legal component of any policy that is issued, and any failure to provide information that proves to be material[1] can render the policy null and void. Once a policy is issued, risk analysis continues through special clauses and conditions in policies that mandate that details of changes to rearing processes, growing systems and management have to be reported to insurers, together with losses and possible losses. Risk analysis and management is thus carried on continuously through the life of every policy, with all changes being assessed as to their importance and potential impact on the safety or otherwise of the crop. Insurance policies are subject to deductibles (self-insure amounts carried by the farm itself) that rule out the many small losses but are also a technique used to modify insurers' exposure to specific risk and hazards that they regard as high, or to reduce premiums. Following risk analysis, they may also exclude specific high-risk perils. Insurers, therefore, do not become involved in the day to day mortalities from the small losses that are a fact of life in aquaculture, or in the very high-level risks that may be considered as inevitabilities. Site surveys are essential to risk assessment at all phases of the insurance process. These are carried out by skilled surveyors, each of whom is experienced in risk assessment appropriate to the type of operation involved and its component parts. This particularly applies to marine installations and operations that include electrical and mechanical life support components. Fish health surveys are also carried out by specialist experts. The process of risk analysis is carried on continuously, from the initial application for insurance, through the life of the insurance policy and

[1] In brief, information is considered "material" if it is information that would cause an insurance underwriter to decline to underwrite an operation or to apply different insuring terms and conditions.

in the aftermath of claim situations. It is very thorough and wide ranging. Above all, it is very effective; it has been responsible for reducing losses, lowering risk profiles and avoiding financial loss in all the areas of aquaculture in which it has been applied. Above all, it has contributed to a tangible increase in wealth in many areas and has the potential to do the same in those parts of the world to which it's practices have not yet spread.

INTRODUCTION

The aquaculture industry has many insurable interests that are the same or almost identical to the insurable interests of other industries. They may range from liabilities in certain areas, to the physical assets of the business. However, aquaculture has one very important insurable interest that is almost unique – its stock! Because its stock is grown in water and is, in most cases, totally dependant on water as a life-support medium, aquaculture stock is subject to a unique set of risks and hazards that are unlike those of almost any other industry. Additionally, aquaculture, through its stock and growing processes, may affect the environment and the society around it. Thus any risks associated with these effects are of concern to politicians, public administrators and the general public, and are not, as a general rule, of concern in the arrangement of insurance on the stocks of aquatic organisms. This paper, therefore, deals only with the risk analysis processes that the aquaculture insurance industry uses to directly assess the risks to aquaculture's stock.

EVOLUTION OF AQUACULTURE INSURANCE

The insurance market for aquaculture stock began operating in 1974, when the first insurance facilities were created in the Lloyd's of London and the London Insurance Market. Because it involves growing stocks of aquatic plants and creatures in either fresh or saltwater, aquaculture is a highly unusual industry and one, it might be thought, that would pose considerable handling difficulties for insurance markets. However, the insurance industry has a long track record of assessing and handling the risks of a very wide variety of vastly different industries and insurable interests. While growing stocks of aquatic plants and creatures in water presented some very unusual challenges, the insurance industry was able to fall back on its historical experience of assessing and handling risk in different situations and design an approach to aquaculture that took into account its "oddities".

OVERVIEW OF THE INSURANCE INDUSTRY'S GENERAL APPROACH TO RISK ANALYSIS

The insurance industry's approach to aquaculture is to protect it against risks that can cause severe losses, and not against those that cause minor ones. The analysis of risk that is constantly carried out by aquaculture stock insurers is similarly focused on the risks that can do the most harm. In order to put this approach into effect, standard aquaculture insurance policies carry substantial deductibles (self-insure amounts that are carried by the farm itself) that are designed to exclude the small losses that are a fact of life in the industry but are also used as an underwriting mechanism for modifying insurers' exposure to specific risk and hazards that they regard as high but not necessarily so high as to require exclusion from the cover provided. They can also be used as a mechanism for reducing premiums. Insurers, therefore, do not get involved in paying for the day to day mortalities and the small losses the industry incurs.

The insurance industry's general approach to risk analysis in "industrial" situations, of which aquaculture is an example, is very thorough and extensive, and generally follows a fairly standard path. It begins with a process of gathering information on the interest offered for insurance. Information is usually obtained through the completion of a proposal form that is specific to the business involved. Proposal forms request relevant facts and figures on all the different areas of the business that insurers identify as being important to their risk analysis process.

The initial analysis of proposal form information regularly results in insurers asking additional questions about issues they perceive to be important. However, once all information is provided to them, and providing the overall operation is satisfactory and meets their underwriting criteria, they will issue a premium quotation and an indication of the terms of coverage.

In many situations, however, insurers will require a survey to be carried out as part of the information gathering and risk assessment processes. Surveyors will be specialists in particular parts of industrial processes, such as the electrical, mechanical or chemical components, or expert in marine, fire, security and other more general aspects. Surveyors produce reports that generally contain recommendations as to how processes can be improved to achieve lower risk levels.

Information gathering having been completed and a terms, conditions and premium quotation produced that is acceptable to the farm's owner, a policy of insurance is put into effect. Policy wordings detail the contractual arrangement between the insurer and the insured, covering such issues as the amount of premium required, what the insured has to do in the event of a claim and many other issues. In aquaculture, the information gathering and risk analysis processes are perpetuated through the operation of policy wordings. These will normally contain conditions that require material changes and alterations to the operation to be reported to the insurer, who reserves the right to change the terms of the policy to reflect their introduction. Changes may either improve terms in response to improvements in risk or penalize the insured if they cause risks to increase.

A re-analysis of risk will also take place when a claim occurs. Indeed, when a serious risk that a loss may occur arises, it must, under the terms of the policy, be immediately reported to insurers. This prompts an urgent analysis of the situation by all parties, leading to all reasonable steps being taken to mitigate the situation.

Insurance policies normally run for a period of 12 months, unless the policy period is adjusted to accommodate a particular growing period. When a policy is renewed, the information gathering process is generally repeated either in whole or in part. A new proposal form will have been supplied that updates information on all issues, and another survey may also be carried out. Renewal information is once again analyzed by the insurers in a repeat of the initial acquisition process.

INSURANCE RISK ANALYSIS PROCESSES AS APPLIED TO AQUACULTURE

The risk analysis processes developed by the specialist aquaculture insurance market recognize one very important thing – no aquaculture operation stays the same! Farms change, their surroundings change, the people running them change and the fundamental production processes change. It is therefore very important to insurers that all material changes are brought into their analysis processes as they occur, enabling them to adjust their insuring terms and conditions and apply effective risk management strategies that each change prompts.

Insurers achieve a constant evaluation of risk and of the risks inherent in operational changes by developing relevant information at four points in the insurance cycle:

- when an operation applies for insurance;
- when a key change in the farming process takes place;
- when a claim occurs and
- at the renewal of the policy.

The acquisition of information during the initial underwriting process and at policy renewal relies heavily on the use of proposal forms and site surveys. Material changes, however, occur during the course of a policy term, and therefore there needs to be a structured system reporting and analysing them. Insurers achieve this through specific conditions in their policies that mandate that policy holders must report material changes to their operations and also give immediate advice of claims and potential claims.

The role of proposal forms

Proposal forms that have been specially designed for the industry are key to basic risk analysis in aquaculture insurance. These have to be completed when insurance is applied for, and generally when a policy is due for renewal. They must be signed by the insured signifying that their contents are true and accurate, and they are formally incorporated into the wording and conditions of the insurance policy.

Special forms (see Annexes 1 and 2) have been designed for fish in onshore and offshore situations, and also for operations that are different to conventional onshore gravity flow and offshore cage production profiles. Thus, operations with a very high pumping and recirculation content may merit their own specially designed proposal forms, and so too may molluscs grown on beds as opposed to on longlines and rafts.

Proposal forms gather information on every aspect of each operation, including:

- the species being farmed.
- the location(s) involved;
- the management and its skills and experience;
- the layout of production unit(s);
- the growing processes;
- loss history;
- disease history;
- health monitoring and
- the values involved.

Focused questions are asked in respect of the different sectors of the industry and their various organizational and structural arrangements. Thus, onshore proposals will go into the layout of ponds, tanks and raceways; the way water is moved around them; and the arrangement of pumping and aeration systems used. Offshore proposal forms will go into the exposure to wind, currents, plankton blooms, superchill and shipping movements, as well as into the structure of the cages and the arrangement and design of moorings.

All proposal form questions have to be answered in considerable detail, with answers being supported by maps, plans, photographs, feeding charts and personal curriculum vitae (CVs). As has already been noted, it is very important that all answers are correct and accurate; when insurance is put into effect, each proposal form becomes a legal component of the insurance arrangement, and any failure to provide information that proves to be material can render the insurance policy null and void.

The role of the proposal form is to provide insurers with an intimate overview of an operation at the time it is completed. It must provide them with sufficient information on the farm to enable them to analyze its inherent risks, develop an approach to managing them, and prepare fair and equitable terms and conditions for insuring them.

The role of site surveys

Aquaculture is an unusual business because it is carried on in water. This fact impacts on the many different risks that threaten the business. For example, stock control is very difficult in water, and it complicates both spotting diseases and treating them. Water can also carry pollution, flood sites and exercise massive forces on cages, rafts and mooring systems. The fact that it is carried on in water makes aquaculture a high-risk business!

The specialist aquaculture insurance market is widely familiar with the exposures the various types of aquaculture face and the losses they have suffered. It is very important to insurers, and fundamental to their commercial success, that they bring this experience to bear on reducing risks to the farms they insure. They see it as unsatisfactory to rely on a farmer completing a proposal form, to fully appreciate and describe all the risks to which his site is exposed. Insurers, therefore, regularly insist that surveys of farms are carried out by specialist surveyors.

The aquaculture insurance market has thus developed a significant survey capability, which it regularly employs as an adjunct to the proposal form information gathering process. It is a very important part of the risk analysis and management process in aquaculture insurance and has proved to be a very successful way of identifying, analysing and managing risks. The creation of a sophisticated surveying capability is one of the factors that has enabled the market to achieve reasonable underwriting profitability after many years of losses.

The aquaculture insurance survey facilities built up by insurers over many years are an extremely valuable asset, and one that could be much more widely used by the aquaculture industry, to whom it is fully available on a commercial basis. Some producers, however, argue that survey costs are too high and believe that they carry out their own surveys perfectly satisfactorily.

The counter arguments are that surveys are expensive because they have to be carried out by skilled professionals who command high fees, but the expense is very low when compared to the losses they can help to avoid. The cost of a survey can be amply repaid if it reveals just one risk that can be eliminated.

There is also much evidence that shows that owners and farm managers are very often "over familiar" with their operations, to the extent that they miss critical weaknesses. Few doubt farmers' genuine efforts to risk manage their operations, but it is difficult for them to spot flaws in systems with which they are intimately familiar, and independent surveyors, unfamiliar with the layout and workings of sites, are much more critical in their approach. As a result, they look much more deeply into all aspects of the structure, arrangement and operation; ask many "what if" questions; and thus discover shortcomings that farmers tend to miss.

The survey process

Surveys tend to fall into two groups. General risk assessment surveys cover at all aspects of an operation, checking that the proposal form information is correct and accurate, looking for any weaknesses in the production process and making recommendations as to how an operation can be better risk managed. Specialist surveys are designed to look at features of an operation that demand specialist attention. These would include surveys of cage groups by qualified marine surveyors, examination of biological husbandry by disease experts, and the inspection of key electrical and mechanical components by qualified engineers, especially when there is a heavy dependence on the latter for life support.

Surveyors will look very closely at the components of the farm that come within their area of competence. Thus in the case of a cage farm, a specialist surveyor would look very closely at the wave climate and wave characteristics, the storm exposure and the mooring designs needed to deal with them; he would also examine maintenance and replacement procedures. If a farm uses intensive pumping and aeration, the arrangement of such systems would be critically examined, including examining fail-safe backups, the arrangement of alarms and the response to them, equipment maintenance procedures and staff training on emergency procedures. All will be the subject of intense scrutiny.

Report and recommendations

A key outcome of a survey is the production of the Survey Report. These reports contain recommendations on to how the risks inherent in the farm and its processes can either be managed more effectively or avoided entirely. The recommendations surveyors make are an extremely important part of the survey process. They are regularly linked by insurers to the insurance policy through special policy conditions that require recommendations to be completed, usually within a specified period. Policy conditions may also specify that recommendations must be reported to insurers once completed, and it is not unknown for insurers to require a further visit by the surveyor to ensure that recommendations have been completed properly and that safety routines are being put into practice properly.

Ownership of survey reports

It might be thought that the farmer would automatically have full rights to see the contents of a survey report on his farm. In fact, this is not necessarily the case, and in practice he may only be allowed to see the recommendations that the report contains. This is because survey reports are owned by those who commission them, and this is generally the insurers who are being asked to insure the operation.

It is most important, from all points of view, that a surveyor has the freedom to deal with all issues he finds on a survey and that he is able to comment on them frankly and in confidence. If a farm is not up to a suitable standard, the surveyor must feel free to say so! However, he may be reluctant to do so if he knows that his comments are going to be seen by the owner. Insurers, therefore, tend to guarantee confidentiality to their surveyors. Though in theory this means that farmers are prevented from reading reports on their own operations, in reality, confidentiality is a fall-back position that is infrequently used, and report information is usually readily available. Farmers also respect the skills of surveyors, very much welcome their suggestions on how their farms can be improved and are generally keen to implement their recommendations.

Use of surveys and survey reports by insurers

Surveys and survey reports are an extremely important part of the underwriting process and of the on-going handling of risk analysis under aquaculture insurance policies. Insurers rely on them extensively when analysing the risks to which an operation is exposed and when deciding on the insurance terms and conditions they will offer. Insurers will frequently liaise closely with individual surveyors, seeking their comments and taking their advice on many issues, especially on changes and alterations to the farm. Insurers will also encourage farmers to consult surveyors in advance of making changes, and insurers will also request midterm surveys if they believe a farm has gone through radical change.

Cost of surveys

Survey costs are levied in different ways. They may be charged directly to the farmer or met by the insurer out of the premium. As to what costs are, these vary enormously. Survey fees depend on may factors, from the size of the farm, whether it may be one of several farms all being surveyed at the same time, to the nature and complexity of the operation. Suffice it to say that, historically, surveys have proved to be a very cost effective, hence their wide use.

On-going risk analysis through insurance policy conditions

Insurers recognize that change is a constant feature of aquaculture. They know that farmers are always trying to improve their systems and indeed, to make them safer. They also know that farms exist in a constantly changing environment and that the people who run them are also free to move to other opportunities. What is important to insurers is that they find out about changes, that they have the opportunity to analyze the risk associated with each change and that they can defend their commercial position when change alters the risk profile of a farm they are insuring.

Change in aquaculture can have a dramatic effect on risk levels, either raising or lowering them. It is a situation that is normal in insurance generally, although arguably it is of much greater significance in aquaculture because of both the incredible pace of change in the industry and because of its unique nature. With respect to the latter, aquaculture is is in a class of its own! The fact that is it conducted in water and that it utilizes such a wide range of species, growing systems and geographically different and challenging locations means that to be profitable, insurers have to exercise very tight control over change, and that means that they must have a way of monitoring it and responding to it.

The importance of analysing the risks associated with "change"
The process of monitoring, analysing, and in some cases actually controlling change is achieved by insurers through special conditions in their policy wordings. These conditions are used to achieve and control the following:

- mandatory reporting of material changes;
- stocking densities;
- reporting of losses and potential claims;
- rights of subrogation; and
- individual "warranties".

Mandatory reporting of material changes
"Materiality" is described in Footnote 1. Aquaculture policies contain reporting clauses that stipulate that all material changes must be advised to an insurer, who, under the terms of the same clause, reserves the right to alter or amend the terms and conditions of the policy, including/excluding coverage or even cancelling the policy. Some versions of the clause advise the policy holder to contact the insurer if there is any uncertainty as to whether a change is "material" or not.

The effect of these material change clauses is that the process of risk analysis is carried on throughout the life of the policy. The clause is designed to cause every material change to be reported to insurers so that they can evaluate it in the light of their experience and analyze the impact it may have on risk levels.

Insurers recognize that change does not automatically translate into increased risk, and indeed that the aquaculture industry has made enormous strides, not to mention huge investments, in changing to reduce the risks it faces. So the approach of insurers in wanting to know about changes to farms should not be seen in a negative light. In using their experience to analyze the affect on risk that change brings about, aquaculture insurers should be judged to be making a very positive contribution to the on-going success of the industry.

Control of stocking densities

Stocking density is a key factor in the husbandry of all types of organisms. It is particularly important in aquaculture, again, because of the wide diversity of the environmental conditions in which the industry operates and the wide range of organisms that it farms. As far as insurers are concerned, it is a vital factor, and one that must be very carefully controlled because any increase in stocking density directly increases the risk to stock from disease. The higher the stocking density, the greater the risk of the development of disease, the extent to which it spreads and the speed with which it does so.

Stocking density levels also impact on the general ability of stock to withstand stress. Stress can arise from a very wide range of factors, from extreme water temperatures, exposure to pollution and plankton blooms, to the effects of storms. The severity of losses following on from such events can be directly related to the stocking density at which the stock was held at the time of the event. Insurers, therefore, set stocking density limits in their policies that insureds must adhere to at all times. If the density on a farm increases (it rarely decreases!), insurers must be advised, and if the increase is significant, they will be entitled to amend their insuring terms accordingly.

Reporting losses and analysing threatening situations

As has been emphasized, all changes in circumstances in aquaculture need to be analyzed from a risk point of view. However, never is this more important that in the case of the occurrence or threat of a loss of any kind! It is crucial to analyze both the level of the threat and the opportunities for mitigating the effect it may have. The standard loss reporting clauses in aquaculture policies all stipulate that insurers must be advised as soon as fish start dying or when an event occurs that puts stock in jeopardy.

Insurers have a great deal of experience in handling aquaculture losses of every conceivable kind. They are, therefore, very well positioned to analyze threatening situations and to advise their insureds on the best course of action to take to save their stock. Their interests and those of their insureds are almost completely in tandem! Both parties stand to lose if a serious loss occurs; the assured through the substantial deductibles (self-insured factors) that will inevitably apply, and the insurer because they will have to pay the largest portion of the loss.

The loss reporting process should, once again, not be seen in a negative light. The immediate involvement of insurers in loss situations is an extremely positive aspect of being insured! Insurers can bring to bear levels of experience and practical support that the farmer is very unlikely to find anywhere else. This is a very valuable by-product of being insured and one that, over many years, has resulted in massive savings to the industry.

Rights of subrogation

This clause does not actually constitute part of the risk analysis process, but the effect it can have "after the fact" is very important. However, it is a largely ignored part of the risk analysis picture.

Subrogation rights are reserved for insurers, in a specific policy condition. This gives the insurer the automatic right to benefit from the insured's right to take legal action against a third party who is responsible for losses to the insured's stock. In other words, if a claim has been paid, the insurer can take over and exercise the insured's right to sue any party responsible for the damage. The classic case is when a third party is responsible for the death of stock by polluting the watercourse a farm draws from. The insurer will seek to recover by suing the polluter in the name of the farm owner.

As far as the analysis of risk is concerned, the point to be made is that the potential for third-party pollution to cause losses may well be have been recognized during the pre-insurance risk analysis processes. Recognition, however, led to the conclusion that the risk was not significant, because if pollution actually occured, insurers would be able to recover from the responsible party by using the subrogation provisions in the policy.

Subrogation is an important consideration in a number of risk analysis issues in aquaculture. These include the risk of the introduction of disease through bought-in juveniles, the risk of loss from contaminated feed, the risk of failure of equipment such as pumps and aerators, and indeed the risk of basic design failure. As far as the latter is concerned, a question increasingly asked by insurers is – Who designed the farm? The objective behind the question is to identify who is responsible for design, so that recovery can be instituted against them if a basic design failure causes a loss.

One aspect of insurance that is rarely recognized is the benefit that the effect of being insured can have on the way the farmer is treated by third parties who are outside his influence but who can do him damage. In the eyes of a large potential polluter, for example, a farmer on his own is much less of a concern than a farmer who is insured! Forced to defend himself using his own resources, the farmer may well be at a distinct disadvantage as the injured party because the financial resources he can use to prosecute a polluter are inevitably limited. Potential polluters know this and tend to behave accordingly. A farmer who is insured, however, is a totally different proposition, and one who potential polluters will treat with much more respect. They know that the farmer has behind him the resources and expertise of his insurers, and that, for them, is a much more formidable proposition.

The ability of insurers to recover from third parties is an important part of the whole picture, and while it may not be relevant to the analysis of the extent and likely occurrence of risk generally, it is a very relevant factor in analysing the potential cost of risk.

The application of individual conditions to policies

In addition to relying on standard clauses, insurers also design specific one-off conditions, applying them to individual policies to meet individual situations. An example might be to make it a condition of a cage-farm policy that navigation warning lights be located on cages to warn marine traffic of their position. Such individual policy conditions very often stem from the recommendations surveyors make in their survey reports. Indeed, there are a wide range of circumstances in which insurers, having analyzed risks of a situation, decide that it can be improved if a particular action or series of actions is taken. They will then apply a special condition to the policy accordingly.

The importance of underwriting experience in risk analysis

The aquaculture insurance market has over 30 years' experience of the aquaculture industry's losses and of paying for them! This long experience is very important and is a key element in its risk analysis processes and a reason why they are so successful. Individual insurers are able to bring considerable experience to bear on analysing risks, and they understand very well the vulnerabilities of the industry in its many configurations. Their experience also enables them to make sound assessments and judgements on new systems and species that are offered to them. Equally, the techniques insurers have developed for analysing risks and managing them have grown in sophistication over the years, and the routines involved are now backed by in-depth knowledge and considerable practical experience.

CONCLUSIONS

The process of risk analysis in insurance is carried on continuously, from the initial application for insurance, through the life the insurance policy, at renewal, and in the aftermath of claim situations. It is very thorough and wide ranging. It is supported by experienced professionals in many spheres and has a track record of saving the aquaculture industry vast amounts of money, having been responsible for reducing losses, lowering risk profiles and avoiding financial loss in all the areas of aquaculture in which it has been applied. Above all, it has contributed to a tangible increase in wealth in many areas and has the potential to do the same in those parts of the world to which it's practices have not yet spread.

ANNEX 1

EXAMPLE FISH FARM PROPOSAL FORM
FOR HATCHERY AND LAND-BASED SITES

Sunderland Marine
Mutual Insurance Company Limited

Fish Farm Proposal Form
(Hatchery & Land based Sites)

Aquaculture
Risk (Management) Ltd

1.

PROPOSER'S NAME:

CONTACT NAME:

POSITION WITHIN COMPANY:

MAILING ADDRESS:

POSTCODE:	**TEL NO:**	**FAX NO:**

MOBILE NO:	**E-MAIL:**

SITE NAME:

SITE ADDRESS:	**POST CODE:**

SITE LOCATION (Latitude and Longitude):	**SITE LICENCE NO:**

TEL NO.:	**FAX. NO.:**	**E-MAIL:**

SITE MANAGEMENT PERSONNEL			
FIRST NAME			
SURNAME			
DATE OF BIRTH			
POSITION	MANAGER	ASS. MANAGER	
QUALIFICATIONS			
NUMBER OF YEARS EXPERIENCE			
NUMBER OF YEARS AT THIS SITE			
MOBILE NO:			
TOTAL NUMBER OF PRODUCTION PERSONNEL			

FOR OFFICE USE ONLY	**OBSERVATIONS**
RECEIVED	
REVIEWED	
INITIATED	

DATE SITE FIRST ESTABLISHED AND BY WHOM:

DATE SITE COMMENCED OPERATION UNDER PRESENT OWNERSHIP:

DETAIL ANY KNOWN OR POTENTIAL SOURCES OF RISK E.G. POLLUTION, DISEASE ETC. AT ANY LOCATION WITHIN 5 MILES OF YOUR SITE:

ARE THERE ANY OTHER PRODUCTION FACILITIES LOCATED ON THIS WATER SOURCE AND IF SO WHERE ARE THEY LOCATED:

PROVIDE INFORMATION ON THE PRIMARY WATER SOURCE IN THE TABLE BELOW:

WATER PARAMETERS		
WATER TEMPERATURE	MIN:	MAX:
D.O. LEVELS	MIN:	MAX:
pH LEVELS	MIN:	MAX:
SALINITY (Where relevant)	MIN:	MAX:
FLOW RATE	MIN:	MAX:

PROVIDE INFORMATION ON THE SECONDARY WATER SOURCE IN THE TABLE BELOW:

WATER PARAMETERS		
WATER TEMPERATURE	MIN:	MAX:
D.O. LEVELS	MIN:	MAX:
pH LEVELS	MIN:	MAX:
SALINITY (Where relevant)	MIN:	MAX:
FLOW RATE	MIN:	MAX:

IF THERE IS A TERTIARY WATER SOURCE THEN PLEASE INCLUDE DETAILS OF THIS SOURCE AT THE END OF THIS FORM.

PROVIDE DETAILS OF FILTRATION SYSTEMS USED ON INTAKE e.g.

PROVIDE DETAILS OF INFLUENT WATER TEMPERATURE MANIPULATION, IF ANY

PROVIDE DETAILS OF AERATION / OXYGEN SYSTEMS

IS THE UNIT SUBJECT TO ANY FORM OF RECIRCULATION

WATER MONITORING: **FREQUENCY**

METHOD

STATE ANY WATER QUALITY PROBLEMS PAST & PRESENT:

WHAT IS THE SOURCE AND TYPE OF FEED USED:

IS FOOD FED AUTOMATICALLY OR BY HAND:

STOCK – CURRENT							
SPECIES	DATE OF TRANSFER TO SITE	NUMBER AT TRANSFER TO SITE	WEIGHT AT TRANSFER TO SITE MAX/MIN	SUPPLIER	PROJECTED MORTALITY TO HARVEST/ TRANSFER OFF SITE	PROJECTED HARVEST/ TRANSFER WEIGHT OFF SITE	PROJECTED HARVEST/ TRANSFER DATE OFF SITE
Atlantic Salmon							
STOCK – FUTURE (WITHIN THE NEXT 12 MONTHS)							
SPECIES	DATE OF TRANSFER TO SITE	NUMBER AT TRANSFER TO SITE	WEIGHT AT TRANSFER TO SITE MAX/MIN	SUPPLIER	PROJECTED MORTALITY TO HARVEST/ TRANSFER OFF SITE	PROJECTED HARVEST / TRANSFER WEIGHT OFF SITE	PROJECTED HARVEST TRANSFER DATE OFF SITE
Atlantic Salmon							
OVERALL MAXIMUM STOCK VALUE: CURRENCY AMOUNT							
COVER REQUIRED: YES☐ NO☐							

2.

EQUIPMENT:

TYPE: TANKS, PONDS, RACEWAYS ETC	DIMENSIONS	MANUFACTURER/ BUILDER	YR OF MANUFACTURE	MATERIAL	NUMBER	VALUE
COVER REQUIRED: YES ☐ NO☐						

ATTACH AN ANNOTATED PLAN OR PROVIDE A DIAGRAM OF THE SITE:

SHOW:

1. NUMBER & FULL CONSTRUCTION DETAILS OF ALL TANKS OR HOLDING SYSTEMS.
2. PATH OF WATER FLOW, FROM SOURCE TO DISCHARGE / RECIRCULATION.
3. DETAILS OF ALTERNATIVE WATER SUPPLIES IN THE EVENT OF MAIN SUPPLY FAILURE & PERCENTAGE REUSE IF APPLICABLE.
4. DETAILS OF PUMPING WATER (IF ANY).
5. DETAILS OF FILTRATION AND AERATION (IF ANY).
6. DETAILS OF ALARM SYSTEMS INSTALLED (IF ANY) INCLUDING DETAILS OF THE FACTORS MONITORED (E.G. WATER TEMPERATURE, WATER FLOW RATE, WATER LEVEL ETC) AND THE METHOD OF SIGNALLING A SYSTEM FAILURE.
7. STATE REQUIRED MINIMUM FLOW RATE AND DURATION OF SUPPLY AT THIS MINIMUM RATE.
8. DETAILS OF ALL PRODUCTION PLANT, PUMPS, TREATMENT APPARATUS, GENERATORS ETC.
9. IF THIS SYSTEM WAS PURPOSE BUILT PLEASE ADVISE DATE OF COMMISSION / CONSTRUCTION, DESIGNOR, CONSULTANTS USED & COPY OF ORIGINAL PLANS.

3.

MAXIMUM STOCKING DENSITY: Kg/m2 or Kg/m3	WHEN THIS OCCURS:

STOCK HEALTH RECORD (DETAIL ANY PROBLEMS DURING THE LAST 5 YEARS)

CAUSATIVE AGENT	DATE	TREATMENT	FREQUENCY	OUTCOME

DETAIL DISEASE MONITORING & LABORATORY FACILITIES:-

ON SITE:		
OFF SITE:		
VETERINARIAN USED: NAME	TELEPHONE NO.:	
FREQUENCY OF HEALTH CHECKS:		
BY WHOM	NAME	QUALIFICATIONS
EXPERIENCE		

SECURITY

GENERAL				
ALARMS				
GUARD PATROL	**YES** ☐	**NO** ☐	IF YES 24 HOURS	**YES** ☐ **NO** ☐

IS ALL MECHANICAL PLANT, INCLUDING PUMP AND ALARM SYSTEMS, THE SUBJECT OF MAINTENANCE CONTRACTS? IF SO PROVIDE DETAILS:

EMERGENCY AVAILABILITY OF STAFF ON SITE **YES** ☐ **NO** ☐ PROXIMITY TO SITE:

IS THE SITE EXPOSED TO ANY OF THE FOLLOWING

PARTICULAR RISKS:	YES	NO	IF YES STATE PREVENTATIVE/REMEDIAL MEASURES
STORM	☐	☐	
TSUNAMI	☐	☐	
DISEASE	☐	☐	
BLOOMS (ALGAL,PLANKTON)	☐	☐	
POLLUTION	☐	☐	
PREDATION	☐	☐	
WATER SUPPLY FLUCTUATION	☐	☐	
WATER QUALITY	☐	☐	
DEBRIS EXPOSURE AT INTAKE etc.	☐	☐	
THEFT	☐	☐	
OTHER (DETAILS)	☐	☐	

4.

PREVIOUS LOSS HISTORY DURING THE LAST 10 YEARS (WHETHER OR NOT THE SUBJECT OF A CLAIM)
STOCK

DATE	CAUSE OF LOSS	SPECIES	NUMBER	AVERAGE WEIGHT	GROSS LOSS	NETT SETTLEMENT
		Atlantic Salmon				
		Atlantic Salmon				
		Atlantic Salmon				
		Atlantic Salmon				
		Atlantic Salmon				
		Atlantic Salmon				
		Atlantic Salmon				
		Atlantic Salmon				
		Atlantic Salmon				
		Atlantic Salmon				

NAME OF PRESENT INSURERS:
RENEWAL DATE:

NAME OF ANY PREVIOUS INSURER:

IN RESPECT OF THE PROPERTY, THE SUBJECT OF THIS PROPOSAL, HAS ANY INSURER:

(A)	**DECLINED:**	**YES** ☐	**NO** ☐
(B)	**CANCELLED COVER:**	**YES** ☐	**NO** ☐
(C)	**IMPOSED RESTRICTED TERMS OR ADDITIONAL PREMIUMS:**	**YES** ☐	**NO** ☐

IF YES, PROVIDE DETAILS:

PLEASE PROVIDE ANY OTHER INFORMATION WHICH YOU FEEL MAY BE RELEVANT:

SIGNING THIS FORM DOES NOT BIND THE PROVIDER OR INSURER TO COMPLETE THE INSURANCE, BUT IT IS AGREED THAT THIS PROPOSAL SHALL BE THE BASIS OF THE INSURANCE CONTRACT ENTERED INTO WITH THE COMPANY.

I HEREBY DECLARE THAT THE PARTICULARS AND ANSWERS GIVEN IN THIS PROPOSAL ARE IN EVERY RESPECT TRUE AND CORRECT AND THAT I HAVE NOT WITHHELD ANY INFORMATION CALCULATED TO INFLUENCE THE DECISION OF THE COMPANY IN REGARD TO THE UNDERWRITING OF THE RISKS TO WHICH THIS PROPOSAL RELATES.

FAILURE TO DISCLOSE ALL RELEVANT FACTS MAY INVALIDATE YOUR POLICY.

INSURERS SHOULD IMMEDIATELY BE ADVISED OF ALL MATERIAL CHANGES OR ALTERATIONS OF THE INFORMATION PROVIDED IN THIS PROPOSAL. A MATERIAL CHANGE IS ONE WHICH WOULD INFLUENCE THE JUDGEMENT OF A PRUDENT INSURER IN SETTING THE TERMS OR PREMIUMS OR DETERMINING WHETHER TO CONTINUE ACCEPTANCE OF THE RISK.

SIGNATURE:	**DATE:** DD/MM/YY
PRINT NAME:	**POSITION:**
COMPANY:	
COMPANY ADDRESS:	

Managers

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Risk analysis in aquaculture – experiences from small-scale shrimp farmers of India

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ABSTRACT

The Network of Aquaculture Centers in Asia and the Pacific (NACA), in association with the Marine Products Export Development Authority (MPEDA) has been implementing a collaborative programme for the last several years to support shrimp farmers in India to adopt better management practices (BMPs) for disease control, coastal management and sustainable farming. This programme was started with a longitudinal epidemiological study to identify hazards (disease, food safety, social, environmental and financial) and

assess risks in small-scale shrimp farms in Andhra Pradesh (2000–2001). The "risk factors" identified using epidemiological tools provided an understanding of the disease causation and possible risk management options (i.e. BMPs) for reducing the likelihood of shrimp disease outbreaks and low pond productivity. Formulation of BMPs was followed by a village demonstration programme (2003–2006) that successfully organized small-scale farmers into self-help groups for adoption of BMPs. The success of the village demonstration programme generated considerable enthusiasm among the aquaculture farming community, and there are now more requests from many quarters for conducting such programmes in the different regions of India. As a result, aquaclubs/aquaculture societies have been established in the maritime states for reducing disease risks and effective communication of risk management strategies with a participatory approach. In order to sustain the work initiated by the MPEDA-NACA project and provide a thrust to sustainable aquaculture development, MPEDA has established a separate agency – the National Centre for Sustainable Aquaculture aimed to provide technical support to the primary aquaculture societies and build capacity among small farmers to reduce risks and to produce quality shrimp in a sustainable manner. Although the programme was carried out in five coastal states of India (Andhra Pradesh, Tamilnadu, Gujarat, Karnataka and Orissa), the findings have wider application to other coastal shrimp farming areas in India.

BACKGROUND

The Network of Aquaculture Centers in Asia and the Pacific (NACA) in association with the Marine Products Export Development Authority (MPEDA) has been involved in supporting small-scale shrimp farmers in India to adopt better management practices (BMPs) for shrimp disease control, improved management of coastal environments and sustainable farming. The initial work was not formally planned to follow the risk analysis (RA) approach, but the approach adopted eventually mirrored some of the requirements of a more formal risk analysis, and the experiences may provide valuable lessons in the application of risk analysis in small-scale aquaculture farming.

The aim of the MPEDA/NACA project was to develop strategies for reducing the risk of shrimp disease outbreaks and improve farm productivity through formation of "aquaclubs" (cluster, farmer self-help groups) to tackle shrimp disease problems more effectively. The demonstration programmes were successful in organizing small-scale farmers into self-help groups for adoption of BMPs. The demonstration of risk management practices in cluster farms gave promising results, with improvements in both profits and productivity during the period of demonstrations. In farms adopting better shrimp health management recommendations, returns shifted from a loss in 80 percent of the ponds to a profit in 80 percent of the ponds, a good indication of the viability of the management measures resulting from the study. The success has now led to an increasingly wide application of the approach in India and elsewhere in Asia.

HAZARD IDENTIFICATION AND RISK ASSESSMENT

The MPEDA/NACA collaboration started with the conduct of a longitudinal epidemiological study to identify hazards (disease: horizontal and vertical transmission of diseases in selected shrimp farming areas, including investigation of hatcheries and broodstock, food safety, social, environmental and financial aspects) and assess risks of key hazards in small-scale shrimp farms in Andhra Pradesh during 2000–2001. The epidemiological study, which covered a total of 385 ponds in two districts of Andhra Pradesh, identified the hazards (or "what can go wrong") at the farm level as (a) shrimp disease outbreaks and (b) low pond productivity, for further analysis. The risk of the occurrence/impact associated with these hazards was then analyzed using an epidemiological approach, and a range of risk factors were identified (e.g. presence of whitespot syndrome virus (WSSV) in shrimp seed, shrimp pond depth, soil conditions, etc.) that were significantly associated with these outcomes. Using epidemiological analysis, these "risk factors" provided an understanding of white spot disease (WSD) causation and possible risk management options for reducing the likelihood of shrimp disease outbreaks and low pond productivity.

In aquaculture systems, a risk factor is a crop-related factor that simply increases or decreases the probability of occurrence of an adverse event happening during a specified time period. For example, WSD is an adverse event during the shrimp-cropping period. If a high prevalence of WSSV in seed batches stocked in ponds increases the probability of occurrence of WSD, then the high prevalence of WSSV in seed batches is called a risk factor to WSD. Epidemiology investigates the statistical and biological significance of the relationship between the adverse event and the hypothesized risk factor to determine whether the hypothesized risk factor is a risk factor or not. The risk factor study of the MPEDA/NACA project considered shrimp disease outbreak and poor production as adverse crop events for the epidemiological analyses.

In total, the study covered 365 ponds in the state of Andhra Pradesh (MPEDA/NACA, 2003). The ponds were selected randomly. WSSV has been established as the "necessary cause" of WSD. However, presence of the necessary cause alone will not lead to a WSD outbreak in a pond. In a farm situation, a number of "component causes" (risk factors) along with the "necessary cause" might become "sufficient cause" to produce WSD outbreaks. The MPEDA/NACA study clearly shows that WSD is not caused by any one factor. Rather a number of risk factors influence the occurrence of WSD in the farm. These risk factors occur throughout the shrimp cropping cycle and in general terms, fall into the following categories during the different stages of the crop cycle:

- season of stocking;
- pond preparation;
- pond filling and water preparation;
- seed quality and screening;
- water management;
- pond bottom management;
- feed management; and
- disease treatments.

The risk factors at each stage of the cropping cycle and their relationship to WSD outbreaks are illustrated below in a "web of disease causation" in Figure 1.

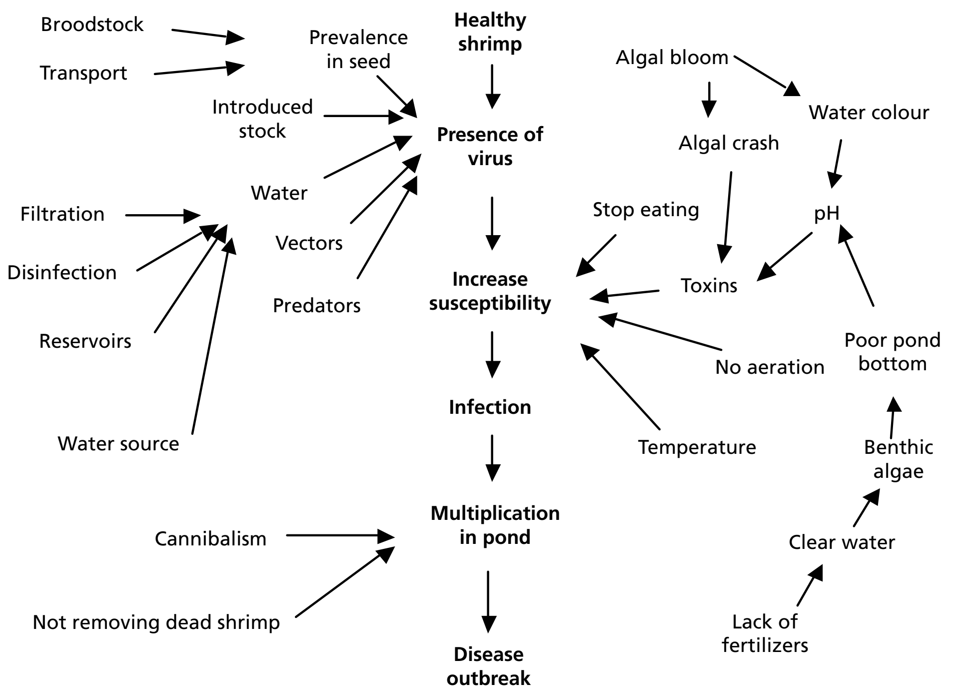
The following summarize the main points shown in the "web":

- A WSD outbreak is the end result of a series of actions or changes from healthy shrimp through to disease outbreak.
- At each stage of the cropping cycle, a number of factors influence the development of the disease in individual animals and also in the population of shrimp in each pond.
- WSSV can enter the shrimp and pond through different routes, including shrimp seed, water, carrier animals and transfer of infected animals and farm equipment from one farm to another.
- Adverse environmental factors combined with a high prevalence of infected shrimp among the pond population are necessary for a mass disease outbreak to occur.

Management factors can be used to control environmental factors and reduce risks of WSD occurring in the pond. To be successful in controlling shrimp disease, one has to manage all potential risks at different stages of the cropping cycle.

The results from the shrimp disease risk factor study clearly show a number of significant factors that influence shrimp disease outbreaks and shrimp yields at the pond level, many of which can be managed at the farm level. The risk factor study

FIGURE 1
Causes of white spot disease



Source: MPEDA/NACA, 2003.

clearly demonstrates that WSD is not caused by any one factor but by a number of factors that interact and influence the occurrence of the disease. Thus, an integrated management and extension approach is necessary to deal with the key factors that contribute to disease occurrence.

The findings provide a strong foundation for reducing shrimp disease losses to farmers, improving farm-level capacities and skills in shrimp health management, minimizing the risks of spread of shrimp diseases to other areas and improving shrimp farm productivity and profitability (MPEDA/NACA, 2003).

RISK MANAGEMENT

The risk management objective was to develop practical measures for containing/ preventing shrimp disease outbreaks that should specifically cover identification of shrimp disease risk factors, diagnosis of problems and management strategies to control disease in farms. The results of the epidemiological study provided the basis for the project team to work closely with farmers and scientists to identify practical farm-level risk management interventions. Eventually two key areas were identified:

- Better management practices (BMPs) that are practical farm-level interventions to address the key "risk factors". These were subsequently expanded to include all relevant shrimp disease risk factors, plus food safety and environmental risks.
- Farmer organization/self-help groups/clusters to address social and financial risks associated with farming and allow effective dissemination of the BMPs among group members.

The BMPs used were good pond preparation, good quality seed selection, water quality management, feed management, health monitoring, pond bottom monitoring, disease management, emergency harvest, harvest and post-harvest, food safety and environmental awareness. The BMPs were disseminated through communication channels involving farmer meetings, regular pond visits, training of extension workers and publication of ten brochures on steps of BMP adoption and booklets on shrimp health management and extension.

The BMPs were implemented through farmer groups and clusters, a cluster being a group of interdependent shrimp ponds situated in a specified geographical locality and typically being comprised of the farmers whose ponds are dependent on the same water source. The cluster concept makes it practical to communicate risks and risk management to farmers more effectively to reduce risks and maximize returns.

RISK COMMUNICATION

The risk management measures (BMPs) have to be simple and practical but science-based. Promoting their adoption requires an understanding of the farmers and their culture systems. Involvement of local institutions is also very important in this process. Communication with all stakeholders was therefore important in the promotion of BMP adoption by farmers in clusters.

Risk communication involved conducting training and demonstration of appropriate shrimp disease control measures, which should especially include demonstration of efficient farm management practices for containing viral and other diseases in selected farms through cooperation and self-help among shrimp farmers in affected areas.

A village demonstration programme for effective communication of risks, promoting adoption of risk management measures (BMPs) and capacity building of farmers was started in Mogalthur Village of West Godavari District of Andhra Pradesh during 2002, and has been very successful in forming a participatory movement of farmers across the country. The demonstration programmes were successful in organizing small-scale farmers into self-help groups for adoption of BMPs. The success of the village demonstration programme generated considerable enthusiasm among the aquaculture farming community, and there are now more requests from many quarters for conducting such programmes in the different regions of India. As a result, aquaclubs/aquaculture societies have been established in the maritime states for community management with a participatory approach (MPEDA/NACA, 2005.). In order to continue the work initiated by the MPEDA-NACA project and to provide the much needed thrust through institutional and policy changes to the extension work in coastal aquaculture development, MPEDA has established a separate agency, the National Centre for Sustainable Aquaculture (NaCSA), with the approval of the Government of India.

PROGRESS

The project has made significant progress, increasing from five farmers who adopted the cluster farm approach in 2001 to 730 farmers (813 ha) in 28 aquaclubs in five states (Andhra Pradesh, Karnataka, Orissa, Gujarat and Tamilnadu) in 2006 (Figure 2). The production of BMP shrimp through the programme has increased from 4 tonnes in 2001 to 870 tonnes in 2006. The success of the project led to the establishment of NaCSA in March 2007, which will facilitate links between aquaculture stakeholders, strengthen farmer societies and enable farmers to formulate common policies, strategies and voluntary guidelines.

LESSONS LEARNED

While not a formal risk analysis, the approach used by the project led to significant benefits to the participating farmers. The project reduced disease risks in cluster farms significantly. The prevalence of disease in the demonstration farms was reduced from 82 percent in 2003 to 17 percent in 2006 in Andhra Pradesh, while in non-demonstration ponds the reduction in disease prevalence was limited during the same period, as shown in Table 1 below.

Efficient use of resources such as feed, seed, fuel and finance resulted in minimizing the cost of production and maximizing profits. Compared to surrounding non-demonstration ponds, the crop highlights included:

FIGURE 2
Development of the NACA/MPEDA Project

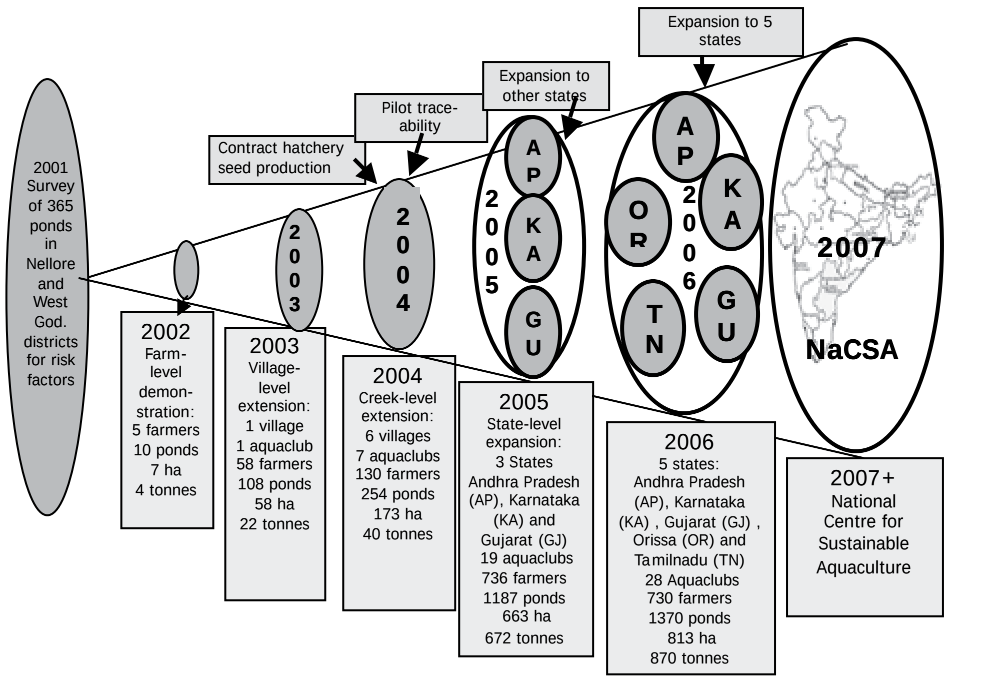


TABLE 1
Comparison of the prevalence (%) of disease in BMP and non-BMP shrimp ponds in from 2003 to 2006

Year	No. of BMP ponds	Disease prevalence in BMP ponds	No. of non-BMP ponds	Disease prevalence in non-BMP Ponds	Improvement
2003	108	82%	164	89%	+ 7%
2004	254	37%	187	52%	+20%
2005	1187	15%	517	42%	+27%
2006	1370	17%	901	44%	+27%

- 30 percent increase in production;
- 8 percent increase in size of shrimp;
- 30 percent improvement in survival; and
- 31 percent reduction in disease prevalence.

Economic analysis clearly demonstrates that farmers adopting BMPs have higher profitability and lower cost of production, and are able to produce quality and traceable shrimp without using any banned chemicals. In the demonstration ponds in Andhra Pradesh, for every Rs1000 (US$25) invested by a farmer, around Rs520 (US$13) was earned as profit in 2006. This was a substantial increase compared to the Rs250 (US$6) profit made by non-demonstration farmers during the same period.

The programme led to reduction in other aquaculture-related risks. The environmental risks were also reduced by the decrease in pollution resulting from reduced use of chemicals, antibiotics and limited discharge of sediments and water exchange. Food safety risks were reduced substantially by discouraging the use of banned chemicals in cluster BMP ponds. Around 45 random shrimp samples from 29 clusters examined for the presence of banned antibiotics during the summer crop of 2006 tested negative. The shrimp produced in the demonstration farms were traced through a pilot-scale traceability programme in which the produce from a pond was identified by an eight digit number comprising State, District, Mandal, Village, Farm and Pond details. Based on backward linkage, the source of seed (including the mother prawn) was traceable and presently, work is underway to establish forward linkages with exporters.

The social impacts are reduction in risks to livelihoods and improved awareness of biosecurity and environment among cluster farmers.

SUSTAINING THE PROCESS

The risk analysis approach and the management measures adopted from the analysis show that BMPs and group management are promising models for farmers to work together to reduce disease, food safety, environmental, financial and social risks and earn their livelihood by helping the industry to meet customer demand through adoption of sustainable and environmentally friendly farming practices. The establishment of NaCSA is expected to further strengthen the BMP programme and give a boost to farmer societies. NaCSA will assist farmer societies to implement BMPs, participate in traceability and certification programmes and access premium international/domestic markets. The following steps are being taken by NaCSA to sustain the process:

Promoting BMPs to improve aquaculture productivity and profits

One of the most significant outcomes of the MPEDA/NACA project is the significant reduction in disease prevalence and improved productivity and profitability in aquaclub farms through adoption of BMPs. Successful implementation of BMPs reduced disease prevalence and increased the number of planned (normal) harvests, leading to better crop outcomes. NaCSA will continue to expand the process through formation of more self-help farmer societies and widespread promotion of BMPs through the aquaculture sector.

Capacity-building and empowerment of primary producers

Over the past five years the MPEDA/NACA village demonstration programme has contributed to significant awareness and capacity building among farmers in the aquaclubs. Increased interaction among farmers, improved community dialogue and more opportunities for mutual help has helped to create good will among farmers and enabled capacity building and empowerment. Cooperation among farmers and a collective approach has empowered farmers to obtain high-quality farm inputs (seed, feed, lime, etc.) at competitive prices. Cooperation and a collective approach have also enabled shrimp farmers to be more responsive to environmental concerns and forged strong unity in dealing with common problems (e.g. desilting of drains). NaCSA will continue to expand the process through formation of more self-help farmer societies in all the shrimp farming states of India.

Facilitating improved service provision to the sector

Provision of improved inputs to the sector through the facilitation of sector-servicing initiatives could help to further strengthen and sustain the industry. Such an initiative would encompass all forms of service including finance, microcredit, diagnostics, insurance, quality inputs, technical inputs, etc.

Connecting farmers to markets for realization of better price

NaCSA will work towards bringing processors and farmers together to improve harvest and post-harvest practices to further increase the quality of shrimp supplied to the processing plants and seek to obtain premium prices for farmers for quality product. NaCSA will work to explore opportunities for facilitating certification programmes and implement traceability schemes. Further, the implementation of BMPs by the farmers groups can result in better value realization for the products, which can also create a niche for such products in the global market. The branded products are value earners in the international market.

Food security and sustainable livelihoods

The development of coastal aquaculture in the country has enhanced the socio-economic condition of the rural communities. Direct as well as indirect employment opportunities have improved the livelihood condition in the villages. Through the formation of aquaculture societies, self-empowerment of farmers is also programmed. The ways and means to reduce the cost of production will be explored. Implementation of BMPs by an organized farming sector would contribute to food security and also ensure sustainable livelihoods for the small-scale farmers involved.

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PART 2

PROCEEDINGS OF THE FAO/NACA EXPERT WORKSHOP ON UNDERSTANDING AND APPLYING RISK ANALYSIS IN AQUACULTURE

Rayong, Thailand, 7–11 June 2007

Proceedings of the FAO/NACA Expert Workshop on Understanding and Applying Risk Analysis in Aquaculture

Rayong, Thailand, 7–11 June 2007

BACKGROUND

As a food-producing sector, aquaculture has surpassed both capture fisheries and the terrestrial farmed meat production systems in terms of average annual growth rate. However, it has a number of *biosecurity concerns* that pose risks and hazards to both its development and management, and to the aquatic environment and society.

Aquaculture faces risks similar to those of the agriculture sector. However, as aquaculture is very diverse (in terms of species, environments, systems and practices), the range of hazards and the perceived risks are complex. In general terms, "risk" is defined as "*a combination of the likelihood (or possibility) of occurrence of undesired outcomes and the severity (or magnitude) of consequences*"; while a "hazard" is "*the presence of a material or condition that has the potential to cause loss or harm*". No matter how well managed a system is, there will always be associated risks and hazards.

Multiple objectives are driving the application of risk analysis to aquaculture. Foremost is for *resource protection* (human, animal and plant health; aquaculture; wild fisheries and the general environment) as embodied in international agreements and responsibilities. The other drivers of risk analysis are: (i) food security, (ii) trade, (iii) consumer preference for high quality and safe products, (iv) production profitability and (v) other investment and development objectives.

FAO initiatives in risk analysis for aquaculture and aquatic species

FAO has been actively involved in the area of risk analysis for the safe movement of aquatic animals in cooperation with the Asia-Pacific Economic Cooperation (APEC) and the Network of Aquaculture Centres in Asia and the Pacific (NACA), through the APEC FWG 01/2002 "Capacity and Awareness Building on Risk Analysis (IRA) for Aquatic Animals" and the FAO Technical Cooperation Project (TCP) TCP/RLA/0071 "Assistance to health management of shrimp culture in Latin America," which jointly trained, in 2002, about 130 participants representing 37 countries comprised of regulatory authorities, administrators and aquatic animal health specialists responsible for trade of aquatic animals and produced a Manual on Import Risk Analysis (IRA) In the same area, a number of TCPs have small components aimed to build capacity on risk analysis: TCP/BZE/3003 "Strengthening the Biosecurity Framework", TCP/LAT/3001 "Improving Aquatic Animal Health and Quality and Safety of Aquatic Products", TCP/IND/2902 "Health Management in Shrimp Aquaculture in Andhra Pradesh", TCP/BIH/3101 "Strengthening Capacity of Aquaculture Health Management" and TCP/RAS/3101 (A) "Sustainable Aquaculture Development in Pacific Micronesia."

Since 2001, FAO has supported GESAMP Working Group 31 (WG31) on its specific task on Environmental Risk Assessment and Communication in Coastal Aquaculture, and facilitated the preparation of a related background and discussion paper for WG31.

GESAMP WG31 held a scoping and planning meeting in 2003 and in November 2006, it held a workshop at the FAO Headquarters to discuss and finalize its study report on Environmental Risk Assessment and Communication in Coastal Aquaculture, which contains six case studies on the application of environmental risk assessment and communication methods in six different contexts of coastal aquaculture. The work of WG31 has benefitted from contributions by experts of the ICES Working Group on Environmental Interactions of Mariculture.

FAO also completed a world review of aquaculture insurance and recognizing the importance of risk management in aquaculture and responding to needs for advice on this subject that have been expressed mainly in Asia, organized a regional workshop on the promotion of fisheries and aquaculture insurance for sustainable development of the sector, held in Bali, Indonesia, from 29 April to 3 May 2007.

There is also an on-going effort in the development of Technical Guidelines on Genetic Resource Management in Aquaculture with a section on risk assessment and monitoring. As well, FAO's contribution to the risk analysis work (including capacity building activities) in the realm of food safety in fish and fishery products within the Codex Alimentarius framework is well recognized.

The current project: "Application of risk analysis in aquaculture production"

Responding to requests emanating from the second and third Sessions of COFI's Sub-Committee on Aquaculture (SCA) (SCA II, Norway, 2002; SCA III, India, 2006) to undertake studies on risk assessment, with funding from the our Regular Programme and under FAO's New Cooperation Agreement with Norway, the current project was undertaken to: (1) review the (a) current state of knowledge and understanding on the risks involved in aquaculture development and management, and (b) application of risk analysis (hazard identification, risk assessment, risk management and risk communication) in aquaculture; (2) to prepare and compile a technical document that will provide practical guidance for policy-makers and interested individuals on the use of various types of risk analysis in aquaculture as a useful decision-making tool for the sustainable development of the sector; and (3) organize an expert workshop to contribute to the process of better understanding the various risks involved in aquaculture so that they can be communicated well, more accurately assessed, and risk management measures appropriately identified to reduce the vulnerability of people who depend on aquaculture for their livelihoods and so that improvement in sector sustainability, profitability and efficiency can be achieved.

Seven major risk sectors in aquaculture have been identified. These are: (i) pathogens, (ii) food safety and public health, (iii) ecological risks (pests and invasives), (iv) genetic issues (v) environmental issues, (vi) financial risks and (vii) social risks. While the hazard and risk elements in some of the sectors are clearly recognized (i.e. pathogens and food safety) and methodologies (as well as standards) for their assessment have been developed and applied, the hazards and risks in many of these areas of concern are still vaguely understood and methods for their assessment are not yet clearly defined. Nevertheless, all these sectors are *inextricably linked* and pose serious biosecurity threats if the risks are not reduced and managed responsibly. Therefore our attempt to "demystify" the concept first before being discouraged by the anticipated complexity of the process requires a good *cross-sectoral* and an *inter-disciplinary* approach to better understand the risk analysis process and how it can be applied to sustainable aquaculture development.

The current *global focus on biosecurity* is driven by such factors as: (i) increasing volume and diversity of trade, (ii) changing agricultural practices and climate, (iii) changing human behaviour and ecology, (iv) greater demands for public health and preserving environmental integrity, (v) increasing public perceptions on food safety and quality and (v) more sophisticated detection and management of hazards. Fisheries and aquaculture are now considered as an *"emerging new agriculture"* and will be affected by major development issues such as trade, international property rights, global diseases, climate change, etc. Enhancing biosecurity through cross-sectoral and multi-thematic/disciplinary coordination of the application of risk analysis and risk management measures will benefit the aquaculture sector and in general terms lead to the following benefits: (i) sustainable development of the sector, (ii) improved food safety and quality, (iii) improved human health, (iv) environmental protection, (v) increased trade, (vi) minimized impacts on biodiversity, (vii) genetic improvement and (viii) freer market access.

FAO is cognizant of initiatives by a number of national, regional and international institutions tackling the various risk issues affecting aquaculture. FAO's intent is to *begin the process* of bringing together these *parallel initiatives* in a consultative and participatory way aimed at a productive outcome. It is expected that this project through the desk study, the expert workshop and the outcomes of such initiatives will further elaborate on: (i) which risk sectors can be analysed using the RA framework as used for biological hazards and which cannot, (ii) what other appropriate approaches can be used or are already being used, (iii) which risk sectors are lacking in methodologies for their assessment, and (iv) which risk sectors require development of methods for assessment or need to be analyzed differently beyond the pathway analysis approach of the RA framework used for biological hazards.

TECHNICAL WORKSHOP

The FAO/NACA Expert Workshop on Understanding and Applying Risk Analysis in Aquaculture was held in Rayong, Thailand from 7 to 11 June 2007.

Purpose

The objectives of the expert workshop were:

(a) to present the desk-top study of the same title focusing on seven major risk sectors:
- pathogen risks,
- food safety and public health risks,
- ecological (pests and invasives) risks,
- genetic risks,
- environmental risks,
- financial risks, and
- social risks.

(b) to discuss the unifying principles for analysis of the various risks and identify:
- the inherent differences in approaches between sectors, and
- what risk analysis methodologies/procedures are available for the particular hazard/s being addressed; and

(c) to provide a platform for better understanding the hazards, vulnerabilities, uncertainties and risks affecting the aquaculture sector, as well as the connections between the different risk events and patterns and to identify integrated approaches to risk management and perspectives on how to share risks and responsibilities.

Participation

Forty-two aquaculture experts (policy-makers, risk analysis practitioners and technical experts in various aspects, e.g. diseases, food safety, genetics, environment, socio-economics, aquaculture insurance) representing various international, regional and national organizations and institutions in Asia, the Pacific, Oceania, Europe and North America, participated in the expert workshop. The list of experts and their profiles are presented as Annex 5.1.

Process

Annex 5.2 provides the programme of work during the workshop.

Opening session

The opening session was held in the afternoon of June 8. The opening speakers were Prof. Sena de Silva, Director General of NACA and Dr Rohana Subasinghe, Senior Fishery Resources Officer, FAO Rome.

Presentation highlights

Dr Melba Reantaso (FAO) presented a backgrounder on risk analysis (RA), its various definitions, its application outside of aquaculture and the drivers for risk analysis in aquaculture. She presented the main objectives of the current project, which included: (i) to review the current state of knowledge and understanding on the risks involved in aquaculture development and management; (ii) to review the application of risk analysis in aquaculture and (iii) to prepare a technical document that will provide practical guidance to policy-makers and interested individuals on the use of various types of risk analysis in aquaculture as a useful decision-making tool for the sustainable development of the sector. She emphasized the need to demystify the whole process and produce a 'simple and crisp' technical document.

Dr J. Richard Arthur (FAO Consultant) examined the definitions and nature of risk, with a focus on the nature of hazards. He examined the different components of risk analysis and emphasized the need to factor in uncertainty. He then provided a series of general principles to risk analysis, including the use of common sense, precaution, transparency, consistency, stakeholder consultation, stringency, minimal risk management, unacceptable risk and equivalence.

Dr Iddya Karunasagar (FAO) emphasized that FAO is recommending the *food chain approach* that encompasses all sectors from primary production to final consumption, with emphasis on preventive steps. Risk analysis is an important tool to determine the level of risk against often statutorily accepted thresholds for food safety. Risk analysis has three components, namely: (i) (quantitative) risk assessment, (ii) risk communication and (iii) risk management. Food safety RA has four specific steps: (i) hazard identification, (ii) exposure analysis, (iii) dose-response analysis and (iv) risk characterization. He then looked at the different levels of risk assessment, e.g. qualitative, semi-quantitative and quantitative risk assessment.

Dr Melba Reantaso (FAO) considered what a pathogen RA is, the drivers and principle components of a pathogen RA. She went through the different steps in risk analysis in some detail. She also looked at other issues, including pathway analysis and scenario diagrams, the principles of acceptable level of risk (ALOR) and appropriate level of protection (ALOP), the precautionary principle (*cautious interim measures*) and future challenges and opportunities (especially the high levels of uncertainty involved). She presented the OIE approach to risk analysis. She concluded that despite the best risk analysis and risk mitigation measures, serious pathogens will be introduced and cause major disease problems. This is due to limitations in diagnostic techniques, existence of cryptic pathogens, and the ability of "benign organisms" (normally non-pathogenic) to become pathogenic when introduced to new hosts and environments. Therefore, good disease surveillance, reporting and well- designed emergency plans will be necessary. Disease is considered a risk sector with high uncertainty. Especially in developing countries, where there is a general lack of basic knowledge on the ecology and pathogens of aquatic animals, it is necessary to establish appropriate research capacity and to conduct targeted studies and particularly, research that will support aquaculture biosecurity.

Dr Eric Hallerman (Virginia Polytechnic Institute and State University) started looking at scoping of risk analysis, the processes of harm (consequence) and hazard identification, various likelihood assessments (release, exposure and harm resulting from exposure). He then looked at risk management (focusing on confinement and operational management), risk communication and future challenges (e.g. understanding of some fundamental issues, incompleteness of quantitative risk assessment, especially regarding likelihood of harm given exposure to hazard, etc.). In closing, he identified the following future challenges in dealing with genetic issues in aquaculture. On risk assessment, there is a need for more genetic risk analysis case studies, especially in the aquaculture context; better understanding of the fundamental issues (e.g. likelihood of outbreeding depression, fitness of transgenics) and development of quantitative risk assessment methodologies. On risk management, there is a need to develop and demonstrate cost-effective confinement for small aquaculture operations. Since most of the theories on risk analysis are already established, what is needed now is to apply it. The adaptive management framework would be appropriate in most cases, not only for genetic risk issues. Communication of risk analysis principles and application is needed, as well as capacity building, especially in the public sector.

Dr Kenneth Leung and Dr David Dudgeon (University of Hong Kong) presented the guidelines on Ecological Risk Assessment (ERA) by the US Environmental Protection Agency and proceeded with listing the seventh ecological risk associated with aquaculture activities, i.e. introduction of exotic species; the other six include habitat alteration/destruction, organic pollution and eutrophication, chemical contamination, infection with disease organisms, genetic risks of escaped cultured animals and depletion of wild fish stocks to provide food for cultured carnivorous fish. He emphasized the importance of understanding the processes of introduction, establishment and spread of an exotic species in aquaculture industries before beginning risk analysis. Future challenges include conducting biological and ecological studies on new cultured species; making risk assessment of biological invasion a legally binding procedure in aquaculture industries and improving international network and surveillance systems for the prevention and control of invasive aquatic species through aquaculture. The presentation was concluded with a note that aquaculture activities are important pathways for the introduction of exotic aquatic organisms. Implementing risk assessment before introduction will reduce the invasion risk and minimize ecological/economic impacts. More effort and funding should be channelled towards basic biological and ecological research, better biological invasion information systems and education of both consumers and industries.

Dr Michael Phillips (NACA) presented three major points, namely: the purpose of environmental risk analysis for aquaculture, its applications and environmental issues. Many environmental hazards overlap with those considered by other papers; the challenge therefore is to integrate these overlaps and complementarities into the manual. Environmental interactions in aquaculture include impacts of environment on aquaculture, impacts of aquaculture on the environment and impacts of aquaculture on aquaculture. Impacts can both be positive and negative; aquaculture heavily relies on a healthy aquatic environment. If broadly applied, risk analysis can support sector development. He then presented the eight principles for responsible shrimp farming (i.e. farm siting, farm design, water use, broodstock and postlarvae, feed management, heath management, food safety and social responsibility). With regard to risk communication, he noted that the most important issues are: ownership, building trust, stakeholder knowledge and priorities, transparency, dealing with "grey areas" and acceptable levels of change, clear communication of results to users for decision making and implementation; and lastly, the risk analysis "jargon" as a major communication concern. The presentation was concluded by listing a number of implementation challenges, e.g. uncertainties – the lack of science-based information for many aquaculture systems, widely scattered data, large number of small-scale farmers, the need for cost effective systems for risk analysis, the need for skilled people and resources for doing risk analysis, communications, institutional responsibilities and implementation of management measures.

Dr Rohana Subasinghe (FAO) gave the background to the IMO/FAO/UNESCO-IOC/WMO/IAEA/UN/UNEP/UNIDO Joint Group of Experts on Scientific Aspects of Marine Environmental Protection or GESAMP. GESAMP is an advisory body consisting of specialized experts nominated by Sponsoring Agencies; it establishes Working Groups that are tasked to review given issues and themes. Working Group 31 looks at the environmental impact of coastal aquaculture. He described the ongoing work of GESAMP Working Group 31, which is developing an integrated risk assessment/communication protocol that fits within a risk analysis structure for resource management. He then briefly enumerated the six case studies, drawn from temperate and tropical coastal aquaculture activities concerned with salmon, shrimp and bivalve culture, which were developed to illustrate the use of the risk assessment protocol. The case studies were: (i) fish farming effects on benthic community changes due to sedimentation; (ii) risk assessment of the potential decrease of carrying capacity by shellfish farming; (iii) risk analysis of the potential interbreeding of wild and escaped farmed cod; (iv) risk analysis of the decline of laminariales due to fish farming waste; (v) risk analysis of the soil salinization due to low-salinity shrimp farming in central plain of Thailand; and (vi) risk analysis of coastal aquaculture: potential effects on algal blooms.

Dr Marnie Campbell (co-authored with Dr Chad Hewitt, both of the National Center for Marine and Coastal Conservation, Australian Maritime College) in her presentation on Introduced Marine Species Risk Analysis – Aquaculture, explained the term marine biosecurity, which deals specifically with marine introduced species (includes animals, pathogens and diseases, plants and protests) and pre-border (quarantine and import health standards) and post-border (surveillance, monitoring and incursion response) measures. The basic risk analysis framework includes identifying the endpoint(s), identifying the hazards, determining the likelihood, determining the consequences and calculating the risk. In the risk analysis process, the following core values need to be included: environmental, economic, social and cultural values. The presentation was concluded with a note that: (i) the marine biosecurity risk framework is consistent with international standards; (ii) because of significant data limitations in the marine environment, semi-quantitative and qualitative assessments remain more tractable; (iii) the target species Organism Impact Assessment has proven extremely useful in identifying management options, even following an incursion event, however, the ability to predict which species will invade or the potential impact of a species once it is introduced remains poor and (iv) the use of non-native food stocks as live, fresh or frozen material represents the 'silent sleeper' of aquaculture-related invasions.

On behalf of Mr Colin Nash (NOAA), Mr Phillip A.D. Secretan briefly presented NOAA's Guidelines for the Ecological Risk Assessment of Marine Fish Aquaculture. He explained the purpose of the paper, which was to exemplify a basic set of guidelines for risk managers and other decision-makers to use all information available to assess the different ecological risks of marine fish aquaculture in a variety of marine ecosystems. He then presented the ten areas of substantive risk in the interaction between marine fish aquaculture perceived by the public and public administrators to be of most concern. These are: increased organic loading, increased inorganic loading, residual heavy metals, transmission of disease organisms, residual therapeutants, biological interaction of escapes with wild populations, physical interaction with marine wildlife, physical impact on marine habitat, using wild juveniles for grow-out, and harvesting industrial fisheries for aqua-feeds. Three examples were presented (i.e. increased organic loading, transmission of disease organisms, biological interaction of escapees) for their degree of potential adversity, together with its mitigation, in an identical step-by-step process. A flowchart helps identify the biological end points or entities and their attributes, both locally and far field, that might be affected for that respective area of risk. It also identifies appropriate methodologies that can be used for measuring or monitoring the effects of exposure to each specific risk.

Dr Lotus Kam and Dr Pingsun Leung (University of Hawaii), in a joint paper entitled Financial Risk Analysis in Aquaculture, introduced the topic by saying that in aquaculture, financial risk refers to the potential loss associated with an aquaculture investment. Aquaculture investments may be public or private and made on behalf of stakeholders, including individual farmers, shareholders, farm enterprises, financial institutions, and/or government institutions. Two types of sources of financial hazards, i.e. production uncertainty (e.g. environment/weather, equipment failure, disease outbreak, pest infestation, etc.). and market uncertainty (e.g. price, demand, availability of input, etc.) were presented. Financial risk analysis methods were compared with the standard components of a risk analysis (hazard identification, risk assessment, risk management and risk communication). She emphasized that methodologically, the linkage between financial risk and traditional risk analysis is weak. While many studies and techniques are available to analyze financial risk in aquaculture, the methods are not necessarily linked to the traditional components of a risk assessment. While the structure presented in this paper is not commonly used in assessing financial risk in aquaculture, it highlights the relationship between financial risk and biological, ecological, and environmental hazards in aquaculture. The presentation was concluded with a remark that financial risk analysis relies on financial analysis principles; utilizes the release and exposure methods for other disciplines; incorporates financial, economic and socio-economic criteria; considers farm-level, industry-level and regional impacts and mature quantitative evaluation methods; and integrates analytic methods into commercial software packages.

Mr Pedro Bueno (NACA) started his presentation on "Social Risks in Aquaculture" with an adapted definition that social risks in aquaculture are challenges by society to the practices of the sector, industry, company or farm over the perceived or real impacts of these practices on issues related to human welfare (e.g. working conditions, environmental quality, health or economic opportunity) and the consequences, which may include brand and reputation damage, heightened regulatory pressure, legal action, consumer boycotts and operational stoppages – jeopardizing short- and long-term shareholder value. Such a definition of social risk can be suitably adapted at the sector, industry, company, farmer group or individual farm level. He then proceeded with elaborating on the components of social risks, i.e. issues, stakeholders, perceptions and means. He defined aquaculture's spheres of social responsibility (internal, immediate external, global) and identified the stakeholders to which it has to be responsible. From, codes of conduct, codes of practice, ecolabeling and certification schemes, labour standards, food safety standards and environmental standards, he drew up a list of hazards that could turn into social risks. Borrowing from ecological risk assessment, he illustrated the process of social risk estimation, the practical application of which is to predict the types of challenges and their degrees of severity so that an early and cost-effective response can be devised to address them. He emphasized that the difference between social and other risks is that social risks are strategic risks. The presentation was concluded with the proposition that a social risk-free environment that is predicated on socially responsible behaviour promotes sustained growth and development.

Mr Phillip A.D. Secretan (AUMS Limited, Aquaculture Underwriting and Management Services) provided an overview of the insurance risk analysis in aquaculture that focussed on stock insurance. An underwriter's approach to risk analysis is not scientific and very arbitrary, He emphasized an important factor to bear in mind, i.e. insurers use substantial deductibles of 10, 15, 20 and even 30 percent (in some cases) of the total amount of risk. The risk analysis process in the insurance industry is an ongoing process during a policy's term because farms, their surroundings, people and farming processes all change. The analysis process relies on information obtained through the completion of specially designed proposal forms that have to be completed by applicants seeking insurance. Different forms are used for different types of aquaculture. Site surveys are essential to risk assessment at all phases of the insurance process. These are carried out by skilled surveyors, each of whom is experienced in risk assessment appropriate to the type of operation involved and its component parts. This particularly applies to marine installations and operations that include electrical and mechanical life support components. Fish health surveys are also carried out by specialist experts. The processes involved are professionally applied, thorough, on-going and enforced through policy conditions. He concluded the presentation by emphasizing that the end results of insurance are reduced losses, empowered risk profiles, reduction of financial loss (and thus hardship) and increase in wealth.

Mr N.R. Umesh (MPEDA/NACA) in a presentation on "Risk analysis in aquaculture – experiences from small-scale shrimp farmers of India" presented the outcomes of a project aimed at supporting Indian small-scale shrimp farmers in adopting better management practices (BMPs) for sustainable fish farming. The 10 BMPs used include: good pond preparation, good quality seed selection, water quality management, feed management, pond bottom monitoring, health monitoring/biosecurity, food safety (no use of antibiotics), better harvest and post-harvest practices, record keeping/traceability, and environmental awareness. Although the initial work was not planned to follow a formal risk analysis approach, the experiences gained provided valuable lessons in the application of risk analysis in small-scale aquaculture farming. Epidemiological studies lead to the identification of risk factors (infected seed, stocking at different periods, soil conditions, use of chemicals etc.), while epidemiological tools measured the statistical associations (= risk assessment) between the identified hazards and the risks (= bad outcomes). Risk management constitutes the application of BMPs. Lessons learned included reduced disease risk, increased profit, increased cooperation among farmers, food safety, enhanced financial support (through good access to bank credit and insurance), and reduced risks to small farmers livelihoods.

Working group session

Dr Melba B. Reantaso (FAO) presented the guidelines for the working group discussion, after which the participants were divided into three working groups that tackled the following themes:

- Working Group 1: Development of the contents of the *Manual on Understanding and Applying Risk Analysis in Aquaculture*
- Working Group 2: Identification and grouping of hazard and assessment methodologies

- Working Group 3: Hazard identification with emphasis on social, financial/ economic and cultural hazards aspects

Two full days were spent on working group discussions and presentations. The outcomes of the working group discussions are presented in section 3; general and specific recommendations are presented in section 4.

Closing session

The closing session was held at 1300 hours on 11 June. Representatives of FAO and NACA thanked the participants and their institutions for an extremely productive workshop. The spirit that pervaded the exercise was marked by the collective desire and a strong commitment to accomplish an important and, it was felt, a challenging task; a large part of the challenge was to produce a practical guide and get it to be adopted.

WORKING GROUP FINDINGS

Working Group 1: Development of the contents of the *Manual on Understanding and Applying Risk Analysis in Aquaculture*

Working Group 1 reviewed the draft concept document for the preparation of a *Manual on Understanding and Applying Risk Analysis in Aquaculture*, and in light of the presentations and associated summary documents commissioned by FAO and prepared by the various experts, to attempt to develop an integrated approach and outline for the manual.

Working Group 1 members: Peter Applesford, Cheng Wo Wing, Jason Clay, Tim Huntington, Iddya Karunasagar, Zorana Mehmedbasic, Philip Secretan, Putt Songsangjinda and N.R. Umesh

Working Group 1 recommended that the outline of the manual should contain five major sections (Box 1) the contents of each section are briefly described in Table 1.

Working Group 2: Identification and grouping of hazard categories and risk assessment methodologies

Working Group 2 considered the "hazard identification" step for the manual. They were to identify hazards in coastal/marine aquaculture, group them as far as possible into hazard categories, list/identify methodologies that should be included for hazard identification, identify inherent similarities and differences between hazard identification sectors, and time permitting, to start to identify what risk assessment methodologies/procedures are available for the particular hazards being addressed and to identify examples of risk assessments that have been conducted.

Working Group 2 members: Richard Arthur, Puttharat Baopraserkul, Ingrid Burgetz, Marnie Campbell, Jim Chu, Eric Hallerman, Matthias Halwart , Chad Hewitt, Kenneth Leung, Graham Mair, Sena de Silva, Yin Kedong, C.V. Mohan, Thuy Nguyen, Michael Phillips, Ben Ponia, Temdoung Somsiri, Rohana Subasinghe, Sanin Tankovic and Varin Thanasomwang

The Working Group divided itself into four subgroups dealing with (i) pathogens/ disease risks (ii) food safety and public health risks, (iii) genetic risks and (iv) environmental and ecological risks.

BOX 1
Table of contents of the Manual on Understanding and Applying Risk Analysis in Aquaculture

Working Group 2.1 Pathogen/disease risks

Since the procedures for pathogen or import risk analysis are well established (OIE, 2007; Arthur *et al.*, 2004) and there are a number of relevant import risk analysis materials available (see Bondad-Reantaso and Arthur, this volume), Working Group 2.1 on pathogen/disease risks concentrated on listing actions for minimizing/managing risks associated with the following: (1) importation of live aquatic animals (import permitted following a risk analysis), (2) importation of aquatic animal products (import permitted following a risk analysis), (3) domestic movements of live aquatic animals and farm-level operations, (4) pathogen risk communication relevant to all of the above (Table 2) .

Working Group 2.2 Food safety and public health

Working Group 2.2 discussed the three steps in risk assessment for food safety and public health, i.e. (1) hazard characterization, (2) exposure assessment and (3) risk characterization; and the risk management framework using the Codex Principles for Risk Management and provided three examples of food safety and public health risks related to aquaculture.

(1) Hazard identification. Important considerations in the hazard characterization step is given in Table 3 below; while Table 4 shows three examples from the aquaculture sector.

TABLE 1
Suggested contents of the different sections of the Manual

Section title	Contents
1. Introduction	
1.1. Concepts of risk analysis	What is risk? Why is risk analysis used? When is risk analysis conducted? Who typically uses risk analysis (wider than just aquaculture)? Emphasis on the process being science-based and appropriately precautionary Relevance to aquaculture
1.2 General framework of risk analysis	Introduce the four steps: (1) hazard identification, (2) risk assessment, (3) risk management and (4) risk communication (cross-cutting) Provide examples of typical tools used (short and referenced to literature) Discuss uncertainty and the use of proxies
1.3 Purpose of the manual	Users: define target users as decision-makers but should consider regional, national, corporate and community levels (policy, investment, corporate) Scale: for use by FAO member countries; should contain both generic as well as specific information to be useful; the manual should serve as a high-level guiding document with resources to enable further development and provide guidance on the use of qualitative and quantitative approaches; need to cover site-specific risks vs cumulative risks, separately if appropriate Need to mention that risk analysis if still unknown in many countries, that there are many unique problems and scales of development occurring at different levels – all these have implications for the end use of the manual and its contents
1.4 Scope of the document	Introduce the seven “risk sectors” Present the structure of the manual Provide the boundaries of the manual, i.e. it addresses both the impacts of aquaculture to the environment (environmental, social and economic) and vice-versa Many of the hazards identified will be at the policy level, but will need to factor these hazards into the operational elements. For example, farm-level risk assessment will include development of better management practices (BMPs).
1.5 Definitions	Important terminologies used in the document
2. Operating Environment	
2.1. Overview of the regulatory frameworks	May include international and regional agreements; statutory frameworks; voluntary frameworks (e.g. codes of practice, BMPs, etc.) Examples: Pathogen risks (e.g. as elaborated in OIE, SPS Agreement, ISO) Food safety and public health risks (e.g. Codex, SPS, HACCP, TBTs, GMOs, ISO) Ecological (pests and invasive species) risks (e.g. CBD, CCRF, SPS, IPPC, WTO) Genetic risks (GMOs, Cartagena Protocol) Environmental risks (CCRF, CBD, ISO) Financial risks (WTO, Codex?) Social risks (ILO) (e.g. 1st Nations issues)
2.2 Overview of the key risk categories	Pathogen risks, food safety and public health risks, ecological (pests and invasive risks, genetic risks, environmental risks, financial risks and social risks Examples of national and local constraints (New Zealand Biosecurity Act) Review of the literature
3. Risk analysis process for aquaculture	Need to separate the risk against the mitigation options; latter need to be selected at an early stage and have to go through a cost-benefit analysis (note – costs might not be just monetary) Manual to be based on the four steps to risk analysis of GESAMP as this is still a reasonably robust approach; there might be slight variations, but this may be also just terminology issues.
3.1 Hazard identification	Environmental, economic, social/cultural hazards (to be informed by WGs 2 and 3) Prioritization of relevant hazards – need to categorize and aggregate hazards/risks using a hierarchichal process that will allow screening and methodology decision-making, mainly focused by data availability and scope requirements Forward thinking of hazard mitigation (e.g. an environmental hazard may result in an economic or social consequence; thus includes a time-scale issue (i.e. what happens now has consequences much later) To include boxes, e.g.: Box 1: Pathogens: VHS in finfish (or EUS in Botswana?) Box 2: Carbon miles (including fish feeds) Box 3: Mangrove usage Box 4: Social Box 5: Economic Boxes provide a snapshot. They should be short and referenced.

TABLE 1 (continued)
Suggested contents of the different sections of the Manual

3.2. Risk assessment	Qualitative, quantitative, scale, uncertainty Precaution in application (to reflect different perspectives and used in the context of lack of knowledge) Use of controls and baseline
3.3 Risk management	Prioritization Need to focus on key issues
3.4 Risk communication	Stakeholder engagement and consensus building General principles Risk analysis process Hazard identification Risk assessment Risk management Dissemination of results and outcomes Sectoral stakeholders External stakeholders (including transboundary responsibilities)
4. Synthesis	
5. Next steps	Implementation (especially at small-scale level) Information collection and management Capacity (knowledge, skills and attitude)-building needs, both in terms of numbers and skills availability. Needs to address risk analysis (access to skills and relevant (and often multidisciplinary) knowledge and on-going risk management (in-house expertise and capacity) capability. identification of sources of available knowledge and ability to distribute and share experience/information/knowledge.
Appendix 1	References
Appendix 2	Risk analysis case studies

(2) Exposure assessment. Exposure assessment is the qualitative and/or quantitative evaluation of the degree of intake likely to occur. It considers the level of the pathogen/ chemical agent at the time of consumption and the quantity of particular food consumed. Table 5 below lists the relevant questions to be asked and the sources of information that may be useful.

Dose response assessment determines the relationship between the magnitude of exposure and the magnitude and/or frequency of adverse effects.

- Theoretical Maximum Daily Intake (TMDI) is based on the MRLs, and estimates of commodity intake are made based on a global diet. This calculation is known to greatly overestimate the exposure and is conducted for screening purposes. If the TMDI exceeds the ADI, the Estimated Maximum Daily Intake (EMDI) is calculated based on global and regional diets and may include correction factors to improve the accuracy of exposure estimates. For example, data on the edible portion of the food and the fate of residues during processing may be used to make a more accurate calculation of exposure.

Production to consumption pathway takes into account the relevance and concentration of the biological agent or the chemical agent. In aquaculture, the various sources of the biological or chemical agent (e.g. water, sewage contamination, feed, fertilizers, intermediate hosts (in the case of some parasites) and considered as well as the effects of various aquaculture practices on the biological or chemical agent (e.g. effect of sanitizers on pathogens, diatom blooms affecting bacterial pathogens).

(3) Risk characterization. The Codex Alimentarius defines the risk characterization step as the process of determining the qualitative and/or quantitative estimation, including attendant uncertainties of the probability of occurrence and the severity of the known or potential adverse health effect in a given population based on hazard

TABLE 2
List of risk management actions for minimizing risks of pathogens

Importation of live aquatic animals (import permitted following risk analysis)	Importation of fishery products (import permitted following risk analysis)	National movements and farm-level operations	Pathogen/disease risk communication
• legislation to support establishment and operation of quarantine facilities; • registering of importers; • setting up and registering of quarantine facilities (government or private); • ensuring that quarantine facilities meet biosecurity requirements; • allowing importation only with a valid health certificate issued by the exporting country; • ensuring that the imported stock (consignment) is held in quarantine for the specified period; • testing stock for World Organisation for Animal Health (OIE) listed or national-listed pathogens, as appropriate; • releasing imported stock only to an approved facility (e.g. a farm); • setting up surveillance programmes (active and/or passive, as appropriate) and using the OIE and national pathogen lists, as appropriate; • establishing mechanisms (e.g. stock destruction, farm closure, restrictions on stock movement) to deal with the pathogen in the event of its detection during active and passive surveillance; and • notifying the OIE and following other regional disease reporting mechanisms if the disease in question is listed.	• registering importers; • approving importer facilities (e.g. processing plant, handling facility); • assuring that the processing facility meets hazard analysis critical control point (HACCP) or other (e.g. Better Management Practices (BMP), International Standards Organization (ISO)) requirements; • ensuring safe and effective disposal of effluents and wastes from the importer's facility (e.g. processing plant); • allowing importation of products only with valid health certificate from the exporting country; • conducting random checks on imported products for OIE or nationally listed pathogens, as appropriate; • ensuring implementation of appropriate measures in the event that samples test positive (e.g. from frozen product to cooked product); and • notifying the exporting country or OIE, as appropriate.	• registering farm facilities; • approving farm facilities (e.g. physical facility, sanitary conditions, biosecurity measures); • implementing or facilitating record keeping to ensure traceability; • ensuring implementation of active surveillance for pathogens listed in OIE and national pathogen lists, as appropriate for the cultured species; • ensuring establishment of mechanisms to gather disease information from all culture systems (passive surveillance); • ensuring implementation of better health management practices by the hatcheries and farmers (e.g. Good Aquaculture Practices (GAP), Codes of Conduct (CoC), BMPs); • setting up mechanisms (e.g. destruction, farm closure, restrictions on stock movement) to deal with disease outbreaks (active and passive surveillance); and • following OIE and other regional disease reporting mechanisms if the disease in question is listed.	• informing all stakeholders (e.g. importers, exporters, farmers, government) about hazards (e.g. diseases listed by the OIE and on national disease lists); • following the communication channels to provide and obtain all the information required for the purpose of conducting risk analysis and for taking decisions on national movements (adopting risk communication channels identified in typical risk analysis processes (e.g. OIE)); • communicating risk mitigation measures to be adopted to quarantine officers, processing plants, officers dealing with fishery products etc, in the event of detection of listed pathogens; • communicating (extending) better aquatic animal health management practices to farmers (e.g. on prevention and control methods); • implementing early warning systems for communicating risks to farmers, trading partners etc.; and • implementing notification systems (e.g. reporting to OIE).

identification, exposure assessment and hazard characterization. Risk assessments may be:

- qualitative: e.g. low, medium, high.
- quantitative: e.g. number of human illnesses likely to occur due to the biological or chemical agent per defined number of population.

Risk reduction scenarios include:

- Effect of mitigation steps (e.g. prevention of sewage contamination; treatment of intake water; growing shellfish in category A water; regulating number of bacteria in water, shellfish meat etc) on number of cases.
- Number of cases of illness which can be averted?
- Effect on aquaculture (e.g. water treatment costs, use of alternate feeds)?

Assumptions and uncertainties and data gaps must be documented.

TABLE 3
Hazard characterization for food safety and public health risks

	Key factors for these hazards	
	Biological agents	**Chemical agents**
In the hazard characterization step, a qualitative description is made of the severity and the duration of the adverse health effect that may result from the ingestion of a microorganism, a toxin or a chemical contaminant.	Ecology of the biological agent (natural habitat, likely mode of entry into aquaculture systems, probability of introduction). Virulence characters of the pathogen. Effect of food matrix on the organism at the time of consumption (factors of the food, e.g. high fat content that may protect the organism by providing increased resistance to gastric acids). Host susceptibility factors (immune-compromised individuals, pregnant women, AIDs patients). Population characteristics.	The chemicals in aquaculture products being considered include pesticides, polychlorinated biphenyls (PBCs), veterinary drugs and contaminants. They are often present in food at low levels – typically at a part per million or less. However, to obtain adequate sensitivity, animal toxicological studies must be conducted at high levels that may exceed, depending on the intrinsic toxicity of the chemical, several thousand parts per million. The significance that the adverse effects detected in high-dose animal studies have for low-dose human exposures is the major question posed in the hazard characterization of chemicals. Estimation of Provisional Tolerable Weekly Intake (PTWI) or Provisional Maximum Tolerable Daily Intake (PMTDI) is made, if possible. Maximum Residue Limits (MRLs) are estimated for individual pesticides in or on specific commodities. These MRLs are primarily based on the residue levels estimated in supervised field trials when the pesticide is used according to GAP.
	Wherever data are available, a dose response analysis is performed; data may come from outbreak investigations, human volunteer studies, vaccine trial studies or from animal studies	

TABLE 4
Examples of food safety and public health risks from the aquaculture sector

Examples from aquaculture	Characteristics
Vibrio parahaemolyticus in oysters eaten raw	Scientific data adequate for a quantitative risk assessment MRA conducted by the United Stated Food and Drug Administration (US FDA), FAO/WHO Management options: - cooling oysters immediately after harvest to prevent multiplication of *V. parahaemolyticus* (consider cost of this process) - control oyster harvesting based on levels of total *V. parahaemolyticus* in oysters at the time of harvest (what proportion of oysters have a high level of *V. parahaemolyticus*?) - subjecting oysters to high-pressure treatment - depuration (not very efficient for *V. parahaemolyticus*) - Food safety objective still under discussion (total *V. parahaemolyticus* 5 000/g?)
Listeria monocytogenes in smoked salmon	MRA conducted by US FDA, FAO/WHO (ready to eat products) Cases of listeriosis occur when foods with more than 10^6 *L. monocytogenes*/g are consumed. Control *L. monocytogenes* in smoked fish (100/g) Zero tolerance not practically achievable in smoked fish industry
Nitrofuran residues in prawns	Risk assessment conducted by Food Standards Australia and New Zealand Exposure (worst-case scenario in high consumers) is 1.5 percent of allowable daily intake (ADI) that existed earlier Public health and safety risk from nitrofuran residues in prawns very low No recalls ordered

With respect to risk management to food safety in aquaculture, the Codex Principles for Risk Management consisting of 8 principles are listed in Box 2.

Key reference documents pertaining to risk assessment for food safety and public health include:

- FAO/WHO 1995. *Application of risk analysis to food standards issues*. Report of Joint FAO/WHO Expert Consultation. 43 pp.

TABLE 5
Exposure assessment questions and information requirements

Exposure assessment questions	Information requirements
How many organisms are ingested by the consumer?	sources of contamination: frequency, concentration and an estimation of the probability and concentration that will be consumed
How often do they get ingested by the consumer?	distribution, growth, inhibition or inactivation from primary contamination, through processing, handling at retail and consumer preparation practices
	growth studies, predictive models
	food manufacturer data
	food surveillance data – primary processes and retail
	animal/zoonotic disease data
	food composition – pH, Aw, nutrient content, presence of antimicrobial substances and competing microflora
	population demographics
	consumption patterns

BOX 2
Codex principles for risk management

Principle 1: Risk management should follow a structured approach.
Risk evaluation,
Risk management option assessment,
Implementation of management decision, and
Monitoring and review.

Principle 2: Protection of human health should be the primary consideration in risk management decisions.

Principle 3: Risk management decisions and practices should be transparent.

Principle 4: Determination of risk assessment policy should be included as a specific component of risk management.

Principle 5: Risk management should ensure the scientific integrity of the risk

assessment process by maintaining the functional separation of risk management and risk assessment.

Principle 6: Risk management decisions should take into account the uncertainty in the output of the risk assessment.

Principle 7: Risk management should include clear, interactive communication with consumers and other interested parties in all aspects of the process.

Principle 8: Risk management should be a continuing process that takes into account all newly generated data in the evaluation and review of risk management decisions.

- FAO/WHO 2002. *Principles and guidelines for incorporating microbiological risk assessment in the* development of food safety standards, guidelines and related texts. 47 pp.
- FAO/WHO 2003. Hazard characterization for pathogens in food and water. Microbiological Risk Assessment Series No 3, 76 pp.
- Fazil, A. 2005. *A primer on risk assessment modelling: focus on seafood products.* FAO Fisheries Technical Paper No. 462, 62 pp.

Working Group 2.3 Genetic risks in aquaculture

Working Group 2.3 went through the whole process of assessing genetic risks in aquaculture starting from key questions which need to be asked to identify genetic hazards (Box 3), a process for prioritizing genetic hazards (Table 6), the risk assessment

BOX 3
Key questions for identifying genetic hazards in aquaculture

What are the hazards?
How do we identify genetic hazards in aquaculture?
What is the process for prioritization of genetic hazards?
What is the risk assessment process?
How do we identify or characterize the consequence of the hazard?

Key questions concerning genetic hazards from cultured organisms:
What is the organism being cultured?
Is it indigenous?
Is it being cultured in an environment with conspecifics or reproductively compatible species?
Is it genetically changed from local stocks?
Is it a composite of genetically distinct stocks?
Is it selectively bred?
Is it an inter-species hybrid?
Is it a genetically modified organism?
Is it triploid/sterile?

Key questions concerning genetic hazards from wild organisms:
What wild organisms are interacting with the cultured stocks?
Is it a reproductively compatible species?
Is it conspecific?

process using a conceptual approach for conducting assessment of the probability of gene flow from aquaculture systems into the receiving environment (Table 7), a matrix for identifying consequences and mechanisms for assessment of that consequence (Table 8), important considerations for risk management and risk communication, a case study example (Hallerman, 2008, this volume) and key references (Box 4).

The risk assessment process
Tools for risk assessment have been developed for transgenic fish (see references listed in Box 4). These can be readily adapted for characterizing the probability of gene flow from cultured stocks to wild stocks. The approach indicated below Table 8) can apply for assessing risks identified above that are related to gene flow, with the exception of the risk associated with the escape/release of sterile triploid organisms, which is related to loss of reproductive investment rather than gene flow[1].

Important considerations with respect to risk management (Table 9) and risk communication are provided below.

In the case of deliberate release of cultured stocks as part of a stock enhancement programme, it is necessary to effectively monitor and evaluate the impact of the stocking programme to ensure it is consistent with its objectives. Such objectives may include increased population size, yield to fisheries, maintenance of genetic diversity of the receiving population and fitness of the wild stock. The main risk management strategy in relation to stock enhancement is to adhere to genetic management guidelines in the foundation and subsequent maintenance of the hatchery stock.

Monitoring and evaluation would be required under both circumstances (accidental and deliberate release) to reassess risk likelihoods and severity of consequences. Control

[1] A separate conceptual approach can be developed for triploid organisms.

TABLE 6
A process for prioritization of genetic hazards

Hazard component	Degree of concern for genetic impacts			Genetic consequence
	Low	Med	High	
A. From cultured organisms				
Indigenous			X	Loss of adaptation Outbreeding depression Decreased Ne
Non-indigenous				
Reproductively compatible			X	Introgressive hybridization
Not reproductively compatible	X			None
B. From local stock				
Domesticated?	X			Loss of adaptation Outbreeding depression Decreased Ne
Selectively bred		X		Loss of adaptation Outbreeding depression Decreased Ne
Interspecific hybrid			X	Introgressive hybridization
Triploid/sterility	X			Loss of reproductive investment
GMO			X	Loss of adaptation Outbreeding depression Decreased Ne Unanticipated effects
C. From non-local stocks				
Composite of distinct stocks		X		Loss of adaptation Outbreeding depression Decreased Ne
Selectively bred		X	X	Loss of adaptation Outbreeding depression Decreased Ne
Interspecific hybrid			X	Introgressive hybridization
Triploid/sterility	X			Loss of reproductive investment
GMO			X	Loss of adaptation Outbreeding depression Decreased Ne Unanticipated effects
D. From wild organisms (reproductively compatible)				
Conspecific[1]		X		Loss of adaptation Loss of performance
Non-conspecific			X	Introgressive hybridization Loss of adaptation Loss of performance
Non-reproductively compatible	X			None

[1] Level of risk depends on the genetic status of the cultured stocks and the purpose of the operation. Invasion of wild or feral aquatic organisms into the culture system containing genetically improved stock carries higher risk than for facilities stocked with non-improved stock. Likewise the risks associated with invasion are higher in hatcheries than they are for grow-out systems.

actions need to be documented and continually assessed. Monitoring indicators need to be developed (e.g. regular sampling of threatened indigenous stocks for detection of introgression or stock assessment to determine impacts of releases) and monitoring implemented. Programme design and implementation may need to be adjusted.

With respect to risk communication concerning genetic risks, the following considerations are important: (1) actively engaging stakeholders' to agree on the scope of the risk analysis, (2) an educational component regarding principles and practices for evaluating and characterizing genetic hazard and consequences on genetic aspects of a project, (3) stakeholder agreement on hazards and validation of the prioritization of the hazards, (4) stakeholder agreement of consequences and validation of risk likelihood analysis, and (5) agreement on an acceptable level of risk and risk management options on a case-by-case basis.

BOX 4

Example of case study on a genetic risk analysis and key references

Case study

- Risk analysis for triploid oysters in Chesapeake Bay, United States of America (see Hallerman, 2008, this volume)

References

- ABRAC (Agricultural Biotechnology Research Advisory Committee) Working Group on Aquatic Biotechnology and Environmental Safety. 1995. *Performance standards for safely conducting research with genetically modified fish and shellfish. Parts I & II.* United States Department of Agriculture, Office of Agricultural Biotechnology. Document Nos. 95-04 and 95-05. (available at: http://www.isb.vt.edu/perfstands/)
- Kapuscinski, A., Sifa, L. & Hayes, K. eds. In press. Environmental risk assessment of genetically modified organisms, Vol. 3. *Building scientific capacity for transgenic fish in developing countries.* CABI Publishing.
- Mair, G.C., Nam, Y.K. & Solar, I.I. In press. Risk management: reducing risk through confinement of transgenic fish. *In* A. Kapuscinski, L. Sifa & K. Hayes, eds. *Environmental risk assessment of genetically modified organisms: methodologies for transgenic fish*. CABI Publishing.

TABLE 7

A conceptual approach for conducting assessment of the probability of gene flow from aquaculture systems into the receiving environment

Knowledge requirement	Action steps to be taken	Comments
Baseline data on escapees from aquaculture systems	Assess the probability of escape of sexually mature and immature organisms from aquaculture systems	If organisms are farmed in open aquaculture systems especially in an area where conspecifics live, an option is to assume escape will occur and focus assessment resources on next step.
Baseline data on the habitat conditions into which farmed fish are likely to escape	Assess the probability that immature escaped aquatic organisms would survive to sexual reproduction in the wild	If aquatic organisms can escape into habitat where conspecifics or closely related species survive and reproduce, an option is to assume some escapees will survive and focus assessment resources on the next step.
Baseline data on the population ecology of aquatic organisms in the receiving environment	Assess the probability of encounter between sexually mature escapes/ releases from aquaculture and reproductively compatible wild species	If cultured organisms can escape into an area where conspecifics (or reproductively compatible species) are known to exist, an option is to assume encounters will occur and focus assessment resources on the next step.
Baseline data on the reproductive behaviour of the species	Assess the probability of successful mating occurring between escapes/ releases from aquaculture and reproductively compatible wild species	
	Assess the probability of F1 offspring surviving and successfully reproducing	
	Assess the probability of survival and reproduction in the subsequent generations of introgressed stocks.	

Working Group 2.4 Risk assessment process for environment and ecology

Working Group 2.4. looked at the process which can be used for environmental and ecological risks. The process involves nine steps. This process can be applied for example to the release of effluent. Intensity, extent, geographical extent, frequency and duration must be assessed on a case-by-case basis with the particular circumstances

TABLE 8

Table identifying consequences of hazards from cultured organisms (risks from aquaculture) and from wild organisms (risks to aquaculture) and mechanisms for assessment

Risks from aquaculture			Risks to aquaculture		
Consequence of hazard from cultured organism	**Description**	**Mechanisms of assessment**	**Consequence of hazard from wild organisms**	**Description**	**Mechanisms of assessment**
Loss of adaptation	Loss of capacity of affected stocks to adapt to environmental changes/ challenges	Loss of population structure (identified through changes in genetic markers, which are used as proxies for fitness-related loci)	Interbreeding and loss of adaptation to culture conditions	The interbreeding of wild fish with cultured stocks in the culture environment, resulting in the partial loss of adaptation of the stock to the culture environment and/ or the benefits of genetic improvement	Loss of stock purity detected through analysis of genetic or phenotypic markers
Outbreeding depression	Loss of fitness upon interbreeding of differently adapted populations	Observation of reduced fitness upon interbreeding of cultured and wild stocks	Hybrid introgression of cultured stocks	The mixing of gene pools from two or more species under culture conditions, resulting in characteristics of pure species	Loss of species purity detected through analysis of genetic or phenotypic markers
Decreased effective population size	Reduction in number of breeding individuals contributing to the next generation. Also may result in increased levels of inbreeding	Detected through loss of rare alleles or by direct estimation of effective population size in suitably designed experiments	Of feed species & hitchhikers		
Introgressive hybridization	The mixing of gene pools from two or more species, resulting in change of characteristics of pure species.	Loss of species purity detected through analysis of genetic or phenotypic markers			
Loss of reproductive investment	The disruption of reproduction in natural stocks through the participation of non-fertile individuals in breeding. (especially triploid sterile males)	• Reduction in recruitment characterized through stock assessment • Reduction in number of breeding individuals contributing to the next generation; detected through loss of rare alleles • Experimental verification of participation of triploid/sterile in wild spawning			

of the production system and the surrounding environments (including biological components) being described and assessed in detail. Gaps in the available information on the surrounding environments and their biological components, trophic interactions etc. are inevitable. It may not be feasible to address these gaps in full or in part or within an acceptable time frame. This results in an increase in the uncertainty level for each determination.

TABLE 9
Important considerations concerning risk management and operations management of genetic risks

Risk management	Operations management
Acceptable level of risk needs to be defined on a case-by-case basis by consequence and informed by expert opinion and stakeholder consultation. The options for management of risk in relation to escapes from aquaculture are well defined (and published). They are: • Physical confinement - Physical barriers to escape - Geographic/physiological (e.g. tropical species in a temperate environment) • Biological confinement - Triploidy/sterility - Monosex • GURT (Genetic Use Restriction Technologies – currently only at R&D stage)	Activities consistent with goal of confinement (e.g. strong record keeping) Prevention of unauthorized access Regular inspection and maintenance of physical confinement systems Effective supervision of project personnel and implementation of policy Redundancy of measures is necessary to minimize probability of escape into the receiving environment

The steps involved in the process are:

1. Risk is derived from likelihood x consequence.
2. Once hazards are identified (hazard identification process for environment/ ecology issues) the risk assessment process begins (Stage II).
3. Identify likelihood using Table 10. Ask questions such as "is it likely that this farm will release effluent?" – this will determine the level/descriptor of likelihood. Likelihood may need to be determined from past records, expert input or through comparison with existing practices. Uncertainty at this stage should be captured as best possible by considering intensity, frequency and duration.
4. Develop a basic consequence matrix for the receiving environment (policy/ expert derived; e.g. Table 11). In this example, we are using an endpoint of disturbance to the surrounding environment from aquaculture practices.
   - Terminology within the consequence matrix must be defined and can be altered to meet stakeholder expectations
   - The consequence table must incorporate:
     – intensity or degree of change,
     – geographical extent, and
     – permanence or duration.
   - A basic consequence matrix (Table 11) can be presented to focus groups for threshold values to be determined and the matrix to be refined. This occurs following a heuristic process involving scientific experts (government, industry and independent scientists) and stakeholders' (including indigenes, government and industry representatives, conservationists, interested public) working groups.
     – The threshold values (percentages and levels within the consequence matrix representing categorical descriptors, e.g. "significant") were derived from legislative and policy obligations in the first instance, with subsequent adjustment through stakeholder consultation.

TABLE 10
Likelihood matrix

	Descriptor	Description
1	Rare	Event will only occur in exceptional circumstances
2	Unlikely	Event could occur but not expected
3	Possible	Event could occur
4	Likely	Event will probably occur in most circumstances
5	Almost Certain	Event is expected to occur in most circumstances

TABLE 11
Consequence example: effluent release from the farm to the surrounding environment

Level	Descriptor	Effluent release impacts
1	Insignificant	Biodiversity change is minimal (<xx%) compared to natural fluctuations in the ecosystem No significant change in nutrient levels detected If the effluent was removed, recovery is expected within a diel cycle
2	Minor	Biodiversity change is measurable (<xx%) compared to natural fluctuations in the ecosystem, and is apparent at point source Minor increase in nutrient levels detected (xx%) If the effluent was removed, recovery is expected within days
3	Moderate	Biodiversity reduction is <xx% compared to natural fluctuations in the ecosystem, and is apparent at point source and x km downstream Increase in nutrient levels are detected (>xx%) at x km downstream If the effluent was removed, recovery is expected in days to months
4	Major	Biodiversity reduction is <xx% compared to natural fluctuations in the ecosystem, and at x km downstream (<yy%). Eutrification has occurred near point source (>xx%) and nutrient levels are increased (>xx%) at x km downstream. If the effluent was removed, recovery is expected in years or generations
5	Catastrophic	Biodiversity reduction is <xx% compared to natural fluctuations in the ecosystem, and is apparent throughout the system Eutrification has occurred throughout watershed/system If the effluent was removed, recovery is not expected

– The exact threshold values are subject to adjustment within constraints of the legal and policy frameworks.
– Thus threshold values are based on consensus opinion and do not represent a fixed value but rather a perceived consequence at the scale of assessment (river, farm, region, country, etc).

5. Data collection occurs via literature review, heuristic process or undertaking monitoring, research etc. The steps for undertaking this analysis are as follows and can be applied singularly or in combination:
   • Undertake a literature review to ascertain available information. If information is lacking or incomplete, undertake a heuristic process.
   • The heuristic process captures input from experts to clarify information/data. If data are still lacking or incomplete, undertake further research.
   • Research can occur via extending existing monitoring or undertaking new research.
   • Data collection will inform the consequence matrix and identify uncertainty.
6. An estimated measure of risk is then derived by multiplying likelihood by consequence using Table 12.
7. The uncertainty must be determined at each level and data input. The degree of uncertainty may alter the risk matrix based on the application of the precautionary principle and stakeholder/expert perceptions and values.
8. Once risk is derived, risk management is applied. For consideration is the following example of possible approaches following the risk derivation (Table 13). The likely actions will be dictated by the level of acceptable level of risk (ALOR) (which is set through risk managers). Reporting will be case-by-case and aligned with national policies, international obligations, etc., as appropriate.

TABLE 12
Risk matrix (N = negligible; L = low, M = moderate; H = high; E = extreme)

	Consequence (impact)				
Likelihood event)	Insignificant	Minor	Moderate	Major	Catastrophic
Rare	N	L	L	M	M
Unlikely	N	L	M	H	H
Possible	N	L	H	H	E
Likely	N	M	H	E	E
Almost Certain	N	M	E	E	E

TABLE 13
Risk interpretation

Risk	Likely action	Reporting
Negligible	Nil	-
Low	None specific	-
Moderate	Specified management/science decision/activity required	+
High	Possible increases to science/management activities required	+
Extreme	Additional science/management activities required	+

Working Group 2 came up with Table 14 listing examples of different risks to aquaculture and from aquaculture under the 5 risk categories.

Working Group 2 also raised some issues and questions pertaining to hazard identification such as: socials risks can have environmental consequences; economic risks can have environmental and social consequences; social and environmental risk analysis need to be done early in the process and not after an industry has been

TABLE 14
Examples of different risks to aquaculture and from aquaculture under the five risk categories

Risk sectors	Examples	
	Risks to aquaculture	Risks from aquaculture
Pathogen risks	pathogens spreading from aquaculture to aquaculture	pathogens spreading from aquaculture to wild stocks
	pathogens spreading from wild stocks to aquaculture	multiplication of pathogens in wild stocks
Food safety and public health risks		food safety spreading of zoonotic pathogens to new areas chemical and drug contamination heavy metals biotoxins
Genetic risks	impacts of genetic improvement programmes risks from translocation of stocks	genetics and conservation trojan gene effects loss of reproductive investment hybrid introgression by mixing or domestication genetically modified organisms (GMOs) genetic changes of wild stocks
Ecological/environmental	changing/blocking water circulation/ current patterns harmful algal blooms changing risks over time with climate change risks to stocks during transportation	introduced species invasive species feed species hitchhiker species trophic cascades water quality, turbidity chemicals harmful algal blooms escapees ecosystem disruptions genetic introgression impacts on resident pathogens hazards to endemic species and/or species extinctions impacts on drinking water solid wastes watershed usage impacts of collection of seed from wild mangrove destruction alteration of currents/water flow patters
Social and economic risks	policy and planning aspects lack of capacity, information, education lack of legislation food security aesthetics and tourism	

established; how can social and environmental risks be quantified?; how can the different risk sectors be integrated into one complete risk analysis model?.

Considering the application of risk analysis at the farm level, the Working Group concluded that:

- risk analysis principles can be applied;
- application of release assessment and exposure assessment may be slightly difficult;
- risks can be identified and their likelihood assessed using other tools (epidemiological studies);
- risk can be prioritized;
- risk management measures can be developed around identified risks (better management measures);
- similar qualitative approach could be used for food safety, genetics and environmental risk assessments; and
- could be a good model for a research project.

Working Group 3: Hazard identification with emphasis on social, financial/economic and cultural aspects

Working Group members: Pedro Bueno, Jesper Clausen, Nihad Fejzic, Clayton Harrington, Lotus Kam, Thithiporn Laopraset, Pingsun Leung, Melba Reantaso, Susana Siar, Suda Tandavanitj and Montira Thavornyutikarn

Working Group 3 considered the definition of a "hazard" as an agent, event. material or condition that can cause potential loss or harm. Hazards include challenges by society to aquaculture practices.

The major outcomes of Working Group 3 include the following:

- free listing of social hazards to better understand the potential scope of hazards in aquaculture production that has a social dimension (Box 5);
- five major categorization of social-political hazards (Table 15);
- identification of factors which need to be considered when assessing social risks;
- identification of social hazards (Table 16); and
- identification of economic hazards (Table 17).

A number of factors need to be considered when assessing social risks. These include: (1) governance (e.g. clear property rights, presence of registration and licensing systems, governance indicators (e.g. using the human development index); (2) level of education and training (e.g. veterinary services, criteria for each indicator, how to measure knowledge and training). Social risk assessment methods (for projects) may be used.

Social hazards were identified and divided into 4 major areas as shown in Table 16 below. Cross-cutting issues which affect these broad categories include governance, political framework, legal framework and globalization.

With respect to social hazards, the Working Group came up with the following social hazards and examples of issues using four categories (resources, capacity, welfare and cross-cutting issues) categories (Table 17).

TABLE 15
Five major categorization of socio-political hazards in aquaculture

Category	Examples
Governance	poor governance, poor policies, unclear property rights, unsustainable national policies, lack of government support, widespread unemployment
Knowledge, education and information	low investment in human capital, poor people quality, negative views of aquaculture by consumers, lack of general education and training
Competition for resources	dislocation of some sectors
Civil unrest/terrorism	political/social instability
Globalization	

TABLE 16
Social hazards in aquaculture

Social hazard categories	Example of issues
Resources	access
	amenity value
	cultural values
	competition for use
Capacity	labour/skills (of people)
	services (institutional – government, private)
	infrastructure
	adaptation
Welfare	policy/regulations/permits (and changes within)
	equity
	essential resources
Cross-cutting issues	governance
	political framework
	legal framework
	globalization

BOX 5
Free listing of social hazards

- bad, poor or weak governance
- lack of knowledge/education/information
- terrorism
- poor policies, governance
- political/social instability
- widespread unemployment
- people quality
- lack of good education
- lack of labour adaptability
- lack of skilled labour
- lack of general education/training
- poor lifestyle/community living
- lack of national plans
- excessive regulation
- no clear property rights
- market functions
- lack of government support
- lack of political democracy
- globalization
- non-sustainable national policies
- negative views of aquaculture by consumers
- increasing population competing for resources
- lack of investment in human capital
- over-regulation
- competition for land, water and space
- infrastructure/industrial development
- dislocation of some sectors in the community
- civil unrest
- lack of formal contractual agreements/business ethics
- physical hazards
- biological hazards

TABLE 17
Economic hazards in aquaculture

Economic hazards	Examples
Production threats	Cost of production • cost of labour • cost of inputs (supplies): decreasing sales prices (prices of outputs); increasing production costs (prices of inputs); escalating interest rates; creditor instability
	Volume/yield • availability of inputs/services (seedstock low quality or limited availability; broodstock low quality or limited availability; lack/loss of skilled labour; limited availability of feed especially in extensive systems) • equipment/asset failure • siting • bioproduction (decreasing growth rates; disease spread) • detrimental environment weather
Market threats	Access • increasing food standards • credence, i.e. voluntary standards
	Price • competitors (decreasing market demand) • taxes • subsidies • substitutes

In deliberating on the category of financial risks, the Working Group noted that there are no financial hazards, but there are financial risks. Examples of economic hazards include market function, resource use, globalization, production infrastructure, taxation policy, market access, subsidies, interest rates, exchange rates and non-tariff barriers. The Working Group identified two major categories of economic hazards as shown in Table 17.

CONCLUSIONS AND RECOMMENDATIONS

Risk analysis methods as applied in the seven aquaculture sectors considered during the Expert Workshop have many commonalities but also many differences. An overriding feature of risk analysis as applied to all sectors is a firm foundation in drawing upon the results of scientific studies, the use of logic (deductive reasoning) in the risk assessment process and the application of "common sense" in assessing risk and applying risk management measures (e.g. separating the "probable" from the "possible"). General principles that apply to risk analysis for aquaculture include application of a precautionary approach when dealing with uncertainty, transparency of process, consistency in methodology, the use of common sense in assessing and managing risks, the use of stakeholder consultation (particularly when the risk analysis is undertaken by government), application of a high level of stringency (e.g. through the use of independent expert review), use of minimal risk management interventions needed to achieve an acceptable level or risk, the concept of unacceptable risk (and thus recognition that some "risky" actions cannot be managed and therefore should not be permitted under any circumstances), and the concept of equivalence (i.e. that alternate risk management measures achieving the required level of protection are equally acceptable).

The potential risks from aquaculture development to society and from the existing physical, social, and economic environment to aquaculture development and their impacts depend upon the species, culture system and operations management practices, and other non-technical factors such as human and institutional capacity. For some sectors, the likelihood of hazards becoming undesirable consequences is often difficult to quantify given present knowledge and the lack of appropriate tools. The wide range of hazards related to aquaculture requires a wide range of tools for risk assessment and skills among the people concerned. The effective use of risk analysis in aquaculture also requires effective communication among government and industry stakeholders and explanation of how risk analysis can be effectively applied to help resolve the issues and avoid possible conflicts.

Most risk analysis sectors make use of qualitative, semi-quantitative and quantitative methods (the exception being financial risk analysis, which uses only quantitative methods), depending on the complexity required for decision making. All methods are equally valid, however, qualitative risk assessment offers the advantages of rapidity and lower cost, and is applicable in most situations. Risk assessment also typically involves the use of project formulation, scenario (or probability) tree, diagrams, decision trees, pathways analysis and sensitivity analysis, an approach that allows investigation of the impacts of proposed risk management measures on the total risk estimate.

Individual risk sectors have widely differing approaches to the practical application of risk analysis. These include differences in philosophy, methodology and terminology that are well established for individual sectors. Sectors dealing with biological and physical hazards (e.g. pathogen risk analysis, genetic risk analysis, food safety risk analysis, ecological risk analysis and environmental risk analysis) have more similarities in approach with each other than they do to risk analysis as applied to social and financial risks. Never the less, they have significant differences in framework and terminology. An example is the use of the precautionary approach, which in ecological risk assessments of non-native species is employed by assuming that the species is "guilty until proven innocent" (assumption of harm), while in contrast, in pathogen risk analysis the species being imported is assumed to be "innocent" of potential to transmit serious disease until proven "guilty".

The process used to determine "acceptable risk" also varies among sectors. In some sectors this is clearly established by international standards enforced through government regulation (e.g. a Food Safety Objective for food products) or through a statement of national Appropriate Level of Protection, as is often the case in pathogen risk analysis. In other sectors (e.g. genetic, ecological, social and economic risk analysis) acceptable risk is often not fixed in advance and must be determined on a case by case basis by executive decision or general consensus (e.g. via agreement resulting from stakeholder consultation).

The application of a single risk analysis framework (e.g. that for pathogen risk analysis) across all sectors is neither possible nor desirable. It is more important that governments and the private sector give full consideration to possible risks in all these areas when considering proposals for aquaculture development (e.g. within the Environmental Impact Assessment (EIA) process). However, in general, this will involve a more in-depth and rigorous risk analysis process than that currently demanded by EIA protocols and existing international guidelines (e.g. ICES and EIFAC protocols).

Establishing appropriate national expertise and capacity to undertake risk analysis has become essential to meeting international trading standards and in allowing developing countries to obtain access to international markets. The Expert Workshop concluded that developing countries face many challenges in implementing risk analysis for the aquaculture sector.

New approaches are required to address the needs of developing countries. There are many opportunities for developing countries to obtain assistance in building expertise and capacity. These include bilateral programmes and assistance provided by WTO, FAO, OIE and national donor agencies, and regional agreements and programmes conducted by FAO, ASEAN and NACA, among others. The use of regional approaches that combine national expertise with the risk analysis expertise available in neighbouring countries may be the most cost-effective way for many countries to conduct risk analyses involving common and shared aquatic species. This approach will also involve sharing of databases and other sources of information. Particularly for introductions of exotic species into shared waterways, the sharing of risk analysis approaches and associated costs will be a practical action.

It is becoming increasingly recognized by government, private sector and the general public that "risky" practices in aquaculture development have led to major biological, social and economic impacts that have had long lasting negative impacts at the local, national and international levels. Risks in aquaculture need to carefully assessed and overly risky practices must be mitigated or prohibited in order for aquaculture to develop in a sustainable manner.

Application of the risk analysis process at the farm level is a challenging issue. In general terms, the risk analysis principles can be applied, risks can be identified and their likelihood assessed using, for example, epidemiological tools (for pathogen risks); however, the application of release assessment and exposure assessment may be slightly difficult. Risk management at the farm level can be developed around identified risks and can make use of better management practices (BMPs). BMPs, cluster management and the use of aquaclubs (or farmer societies) are promising approaches that will enable farmers to work together to identify and manage their own risks.

Specific recommendations arising from the seven risk sector papers presented during the Expert Workshop include:

For pathogen risk analysis

- Regional efforts should be made by developing countries to establish hatcheries and stocks with known health history, e.g. specific pathogen free (SPF) stocks, for the most frequently traded species (e.g. tilapia, marine shrimp, giant freshwater prawn, oysters).
- Greater attention should be given to generating information and knowledge essential to pathogen risk analysis.
- Appropriate research capacity and the ability to conduct targeted studies needed to address critical information gaps identified during sensitivity testing must be further developed.
- Studies in essential research areas such as the biological pathways for the introduction, establishment and spread of individual pathogens and information on trade are needed.
- For newly emerging diseases as well as some diseases in poorly studied aquatic animal species, basic studies on pathology and methods for rapid and accurate diagnosis are needed to facilitate accurate risk assessment and risk management.
- Increased surveillance of wild fish is needed to detect significant disease problems at an early stage.
- Improved disease reporting and well-designed contingency plans are also necessary.

For food safety and public health risk analysis

- The ability to undertake food safety risk analysis is essential to protect public health and promote international trade in food products, including products of aquaculture. For this sector, expertise in different fields such as food production (aquaculture), microbiology, epidemiology, food-processing technology and statistics is needed.
- Access to appropriate human and financial resources can be one of the major constraints for developing countries and thus needs to be addressed.

For genetic risk analysis

- Opportunities for informative case studies have been lost because of a lack of baseline data or because population monitoring was not begun until after a genetic harm was realized. Baseline data and case studies are thus needed to support genetic risk assessment.

- As background information useful as case study material is scattered across the scientific and grey literature and is not as well developed for aquaculture as for fisheries management, there is a need to identify and synthesize this literature.
- An understanding of some key issues (e.g. likelihood of outbreeding depression and fitness of transgenic fishes) is still emerging and thus further studies are needed.
- Studies to address the lack of knowledge of long-term impacts of genetic changes, the levels of variation needed to maintain viable populations over the long term and the relative risks posed by different classes of genetically modified aquaculture stocks are needed.
- Development of quantitative genetic risk analysis is very incomplete, especially with regard to estimating the likelihood of harm becoming realized given exposure to a hazardous agent.
- All these observations suggest the need for more genetic risk analysis studies, especially for nonsalmonid systems.
- For better management of genetic risks, more effort should be directed to developing and demonstrating cost-effective confinement systems for small aquaculture operations.
- To improve oversight of aquaculture by governments and non-governmental organizations, risk analysts need to apply the theory of genetic risk analysis, while drawing upon definitive case studies for guidance.
- As experience is gained, an adaptive approach to management of aquaculture systems is needed, not only for genetic risks, but also more generally for other types of risks.
- Effective communication of the principles and application of genetic risk analysis to organizations in both developed and developing countries is needed.
- There is a need for capacity-building in oversight bodies, especially in the public sector.

For ecological (pests and marine invasives) risk analysis

for pest risks

- Because anthropogenically driven deterioration of environmental conditions in aquatic systems can make conditions less congenial to native species and consequently favour exotic, robust species, risk assessors should take both ongoing and projected environmental changes and the ecological risk of introducing exotic species into account.
- The implementation of proper risk assessment schemes for screening the potential invasiveness of aquatic organisms before introduction will reduce the risk of importing invasive species and thereby minimize ecological and economic impacts. Qualitative assessment methods that are easy to use and do not require large amounts of resources or expertise can be readily adopted in Asia, which is the global centre of aquaculture production.
- The assessment method can be further developed and enhanced with advanced quantitative methods, if more relevant biological information on the taxonomic group of concern is available.
- As data and information availability has a huge influence on the quality and confidence of the risk assessment, more effort and funding must be dedicated to basic research on the life histories, population dynamics and ecology of cultured organisms.
- Better regional and international biological invasion information systems need to be established.
- Concerted efforts should be made to educate consumers and the private sector about the ecological risks and economic impacts of introducing invasive organisms,

and to establish mandatory application of legally binding species-specific risk assessments and risk management that will reduce the risks of biological invasion through aquaculture activities.

- More basic biological and ecological studies on new farming species (such as sea cucucmbers, sea urchins and sea squirts) in related to the predicted invasive sequence are needed.
- More efforts should be put into the development of economic instruments to give incentives to the aquaculture industry to follow relevant codes of practice and risk assessment protocols.

for marine invasive risks

- Target species Organism Impact Assessments are extremely useful in identifying management options; however, the ability to predict which species will invade or the potential impact of a species once it is introduced remains poor.
- Non-native food stocks such as live, fresh or fresh-frozen material may be the "silent sleeper" of aquaculture-associated invasions and can also represent a poorly managed pathway for pathogen invasion that can affect both cultured and wild stocks; thus risk analysis can be usefully applied to assessing the risks posed by these food stocks.

For environmental risk analysis

- As there are presently limited experiences and case studies associated with the more complex ecological risk analyses as applied to aquaculture, promotion of case studies and sharing of experiences are needed.
- The information on risk analysis that could be applied to aquaculture is scattered across the literature, from peer reviewed articles to the grey literature. A practical manual would be useful to assist risk analysis practitioners in the sector and to raise awareness on useful applications.
- The understanding of some key issues (e.g. risks associated with aquaculture and ecosystem functions, use of trash fish) is still limited. As far as possible, simple tools should be developed for the different hazards associated with aquaculture.
- A major challenge is to apply practical risk analysis methods to the small-scale aquaculture sector. The need to develop and demonstrate cost-effective risk management systems for small aquaculture operations is apparent.
- Capacity-building in all aspects of environmental risk analysis for aquaculture is needed.
- Risk analysis has a potentially important role in policy setting, but to be successful the institutional roles and responsibilities need to be carefully considered.

For financial risk analysis

- Aquaculture ventures are inherently risky and thus the need to conduct financial risk analyses to reduce the potential for financial loss is clear. Although a variety of rigorous methods for financial risk analysis are available, these need to be more widely put in practice.
- Education, software accessibility, training and assistance are needed in order for financial risk analysis to be widely adopted in aquaculture.
- Even if the financial risk problem is decomposed, sufficient data may not be available to estimate uncertainty and characterize the financial risk. Farm-level cost and production data and industry statistics are often difficult to obtain. In particular, aquaculture production data are not regularly collected in surveys conducted by agricultural ministries or are limited to highly aggregated values. Consequently, risk analysts are obliged to seek secondary or anecdotal information

to approximate the release, exposure and consequences associated with a hazard. There is therefore a need to improve collection and accessibility of financial data.
- It is vital that financial risk analysis methods be integrated in the early phases of hazard identification and risk assessment of traditional risk assessment methodologies in order to truly manage financial risk in aquaculture.

For social risk analysis
- If an industry, farm or sector as a whole adheres to socially responsible practices, it should face very little challenge, and none that is serious. The need therefore is to enable the farmers, processors, traders, input suppliers and others in the chain to adopt the codes of practice, adhere to better management practices and comply with regulations.
- To prevent free-riding, rent-seeking, corruption and other opportunistic behaviours that invite challenges to the sector, there is a need to improve governance mechanisms, particularly the effectiveness of various mechanisms of governance (mandatory, market-based and voluntary) instruments.
- There is a need to improve the ability of farmers to comply with an increasing number and stringency of requirements without jeopardizing their profitability; the challenge is for farmers to see as sensible to business to adopt and comply with all these requirements.
- There is a need to seek ways to make it attractive for insurers to insure aquaculture operations (particularly the numerous small farms).
- There is a need to develop a hybrid insurance approach that combines the market-oriented and social (public) insurance schemes.
- There is a need to establish a better system for micro-financing.
- There is a need to organize farmers, promote adoption of better practices and strengthen national farmer servicing systems that cater to small farmers.
- There is a need to assure the aquaculture sector that a social risk-free environment predicated on socially responsible behaviour will translate into sustained growth and development.

ANNEXES

Annex 1
EXPERTS AND EXPERT PROFILES

Name and contact details	Expertise/specialization
Peter Appleford Executive Director Fisheries Victoria Department of Primary Industries GPO Box 4440, Melbourne, Victoria, Australia 3001 Tel. No.: (61-3) 9658 4360 Fax No.: (61-3) 9658 4203 E-mail: peter.appleford@dpi.vic.gov.au	Extensive experience in fisheries and aquaculture regulation, management, research and education. Fisheries Victoria administers the *Fisheries Act 1995* (the Act) which provides for the management, development and use of Victoria's fisheries and aquatic biological resources in an efficient, effective and ecologically sustainable manner. This includes a requirement to protect and conserve fisheries resources, habitats and ecosystems, including the maintenance of ecology and genetic diversity. The Act also provides for industry development with a commitment to promote sustainable commercial fishing and viable aquaculture industries. More specifically, Fisheries Victoria leads State Government policy implementation to expand marine aquaculture, including the provision of more that 1 700 hectares of Crown land (offshore and land-based coastal) for the purpose of marine aquaculture development. In addition the DPI undertakes applied research, stakeholder consultation, policy development, the development of Biosecurity Codes, development of best practice aquaculture management plans, and the development of disease response structures and protocols for aquaculture. DPI's management response to a recent outbreak of abalone viral ganglioneuritis provides a case study of international significance particularly in the absence of definitive scientific information about the infectious organism and significant socio-economic loss to key industry stakeholders.
Richard Arthur FAO Consultant Box 1216, Barriere British Columbia, Canada V0E 1E0 Tel. No.: (1-250) 672 0221 E-mail: jrarthur@telus.net	Private consultant in international aquatic animal health issues based in western Canada. Career includes periods in Asia with IDRC as Fish Health Network Coordinator and as Fisheries Program Officer (Asia and Pacific), and in Canada, as a research scientist in aquatic parasitology with the Canadian DFO. Over the past 20 years, international experience has been primarily in Asia, but also in projects in Africa, Latin America, Eastern Europe and the South Pacific. During the past five years contracted as an expert in pathogen risk analysis for regional projects and short-term training courses funded by FAO, NACA, APEC and others. In 2004, led a team of five scientists who conducted pathogen and pest risk analyses for live crustaceans on behalf of the Secretariat of the Pacific Community. Lead author on a manual on risk analysis for the safe movement of aquatic animals and recently drafted the Technical Guidelines on *Health Management for the Movement of Live Aquatic Animals*, in support of FAO's CCRF. In 2007, completed an assignment as international consultant in aquatic animal health management for the World Fish Center as part of an Asian Development Bank funded project to create a pro-poor national strategy for aquaculture development for the Philippines. Currently contributing risk analysis expertise to an FAO-funded project to develop a national aquatic animal health strategy for Bosnia and Herzegovina.

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Fishery Biologist at Thailand's Department of Fisheries. Experience in genetic manipulation techniques (gynogenesis and sex reversal), molecular genetics and immunogenetics, particularly genes related to innate immune defenses and their expressions. Currently involved in biosecurity project and selective breeding program for giant freshwater prawn, and genetic diversity of aquatic plants.

P**edro Bueno**
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Currently Adviser to NACA, previously Director General and before that Information Specialist of NACA and the Regional Seafarming Development Project. Taught Development Communications courses in the University of the Philippines and was assistant scientist conducting training and research on farming systems at the International Rice Research Institute. Did research on diffusion of innovations, worked on rural development projects specializing on the use of various communications media to inform target audiences of the advantages and risks of adopting innovations in agriculture as well as aquaculture. Helped conceptualize and establish a network of rural educational radio stations in the Philippines based in agricultural universities. Undertook special training in agricultural project development, evaluation and management. Worked in various rural development, information and extension, and institutional development projects for UNESCO, UNDP, FAO, World Bank and UNOPS.

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National Analyst for Aquatic Biotechnology for Fisheries and Oceans Canada (DFO). Manages the federal Fisheries and Oceans Aquatic Biotechnology and Genomics Research and Development Program. This includes research focusing on regulatory research related to aquatic animals with novel traits, environmental risk assessment methodology research, investigation of the interaction between genotype and environment, and ecosystem effects of aquatic animals with novel traits, including transgenic aquatic animals. Involved, in conjunction with scientific specialists and regulators, in the identification of key gaps in scientific knowledge related to regulatory research and aquatic products of biotechnology. Prior to moving to DFO in 2006, Ingrid was a senior analyst of technology developments related to the regulatory system responsible for environmental risk assessment of novel plants, vaccines and microbial fertilizer supplements.

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An expert in marine biosecurity and ecosystem restoration, with more than 85 publications on various aspects of marine ecology, risk analysis, effects of fishing on the marine environment, ecosystem restoration and biosecurity management. Has given invited keynote and plenary presentations and been an invited panel member at more than 12 international fora. Marnie has worked in more than 14 countries as a biosecurity researcher with agencies such as CSIRO-CRIMP, the IMO GloBallast Programme, Biosecurity New Zealand and with the Australian Maritime College. Currently a senior lecturer and course coordinator for the National Centre for Marine and Coastal Conservation, Australian Maritime College. Co-founding member of the International Marine Biosecurity Education and Research Consortium, which provides biosecurity education and training opportunities across the Pacific Basin and Indian Ocean. Research interests have focused on elucidating human-mediated impacts on biodiversity in the marine environment and developing remediation and management options. Her career has maintained a balance between active science research and the interface with management/policy.

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Fisheries Officer of Agriculture, Fisheries and Conservation Department, China, Hong Kong SAR. Head of Fisheries Licensing and Enforcement. Expertise in marine finfish culture. Has been working on developing Good Aquaculture Practices and fish farm accreditation system. Currently involved in formulation of food safety management framework in China, Hong Kong SAR.

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An anthropologist by training, has taught at Harvard, worked in the US Department of Agriculture, and spent more than 20 years working with human rights and environmental NGOs. Has undertaken extensive research on the social and environmental impacts of shrimp aquaculture, and in 1999 created the Shrimp Aquaculture and the Environment Consortium that includes the WWF, World Bank, FAO and NACA, to identify and analyze better management practices that address the environmental and social impacts of shrimp aquaculture. Studied anthropology and Latin American studies at Harvard University, economics and geography at the London School of Economics, and anthropology and international agriculture at Cornell University where he received his Ph.D. in 1979. Author or co-author of 12 books (the most recent being *Global Agriculture and the Environment*, Island Press 11/03), and more than 300 articles. Has given numerous invited lectures and consulted with many international and national organizations and foundations, including the World Bank, the Asia Development Bank, USAID, UN FAO, UNCTAD, UNEP, UNDP, Ford Foundation, Rockefeller Foundation, Packard Foundation, MacArthur Foundation, Pew Charitable Trusts, and hundreds of international environmental, human rights and community-based NGOs.

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Worked with aquaculture in the Asian-Pacific region for 6 years and currently based at FAO Regional Office for Asia and the Pacific in Bangkok working with aquaculture and food safety. Before working for FAO, worked for NACA both in Thailand and in Vietnam, mainly on the Consortium on Shrimp Farming and the Environment, and for University of Copenhagen, Faculty of Life Science as project manager on the project Fishborne Zoonotic Parasites in Vietnam (FIBOZOPA). Main areas of experience and expertise are aquaculture and the environment, food safety aspects of aquaculture production and pre-harvest better management practices.

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Academic training mainly in biology (Texas A&M and Cornell Universities) with over 35 years of experience in aquaculture/natural resources management in Asia and globally. Work experience has been primarily with IDRC (International Development Research Centre of Canada) both based in Singapore and Canada and with Tokyo University of Fisheries/National Aquaculture Center in Japan. Founding member of the Asian Fisheries Society and currently a Senior Fellow with IISD based in Canada.

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Director-General of NACA and Adjunct Professor, Deakin University, Victoria, Australia. Over 35 years of experience in the academia, and aquaculture and inland fisheries management research and development Held academic positions in universities in Sri Lanka, Stirling, Scotland, National University of Singapore and Deakin University, Australia. Was responsible for developing and delivering post-graduate courses in aquaculture in the "distance mode". Internationally reputed researcher in finfish nutrition and reservoir fisheries, and expertise in fish introduction and biodiversity in relation to aquaculture. Author of three advanced texts and over 200 research publications in international journals. Serves on the editorial board of the journals Aquaculture International, Aquaculture Research, Fisheries Management and Ecology. Recipient of many awards, including the NAGA Award (ICLARM) in 1993, Deakin University Vice Chancellor's award for "Best Researcher", Asian Fisheries Society Gold Medal in 2004 and Honorary Life Member of the World Aquaculture Society (2005). Was a founder member of the Asian Fisheries Society and served in the Council for nine years.

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Deputy-Director of the State Veterinary Office (SVO) of Bosnia and Herzegovina (BiH), responsible for managing SVO, drafting of national animal health regulations, border veterinary inspections, coordination of network of diagnostic laboratories, training and education activities; National Project Coordinator of FAO/TCP/3101 Strengthening Capacity on Aquaculture Health Management. Current interests include disease control, introduction of live fish and fishery products, aquaculture health management.

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Professor and Head of the Department of Fisheries and Wildlife Sciences at Virginia Polytechnic Institute and State University. Research interests include population genetics of fish and wildlife species, genetic improvement of aquaculture stocks, and aquaculture biotechnology and related policy. Current projects include: environmental risk assessment for growth hormone transgenic Atlantic salmon, population genetic characterization of Virginia brook trout populations, and genetic stock structure of horseshoe crab populations. Author, coauthor or editor of three books, including one in press on risk assessment for transgenic fishes, and over 100 peer-reviewed papers in scientific journals, and is on the editorial advisory board of *Aquaculture*. Teaches Genetics for Aquaculturists, Conservation Genetics, and Advanced Conservation Genetics, and other courses as needed. Mentored eight M.S. and three Ph.D. students to completion, with two M.S. and three Ph.D. Students in progress. Shared his expertise with the National Research Council, the U.S. Department of Agriculture, the Food and Drug Administration, the Food and Agriculture Organization of the United Nations, and several private-sector firms.

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Fishery Resources Officer of the FAO Aquaculture Management and Conservation Service with main responsibility for aquaculture production and portfolio of activities ranging from technical project to normative policy-oriented studies and reviews covering topical areas of integrated agriculture-aquaculture and integrated irrigation aquaculture, cage aquaculture, aquatic biodiversity and organic aquaculture in Africa, Asia and Pacific, Latin America and the Caribbean and Europe. Besides project backstopping work, mainly in Asia and Africa, current major normative tasks include contributing to the Special Programme for Aquaculture Development in Africa (SPADA) and the NACA-like network for Africa as well as interdepartmental work in interdisciplinary groups on biological diversity, organic agriculture and integrated farming systems. An important component of the work programme is the lead responsibility for the organization, conduct of and follow-up to workshops and symposia related to the above technical areas – the most recent one being the proceedings of regional reviews and global synthesis on cage culture.

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Policy Officer at DAFF Australia. Involved in policy analysis, development and implementation of aquaculture policy in order to promote sustainable aquaculture in Australia and Asia-Pacific. Key projects include implementation of the Australian prawn farmers marketing and promotional levy; development of Australian ornamental fish strategy and research projects; Australia's National Pollutant Inventory in relation to aquaculture; European Union Prawn Working Group, maintaining market access for Australian prawns.

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Expert in marine bioinvasions science and management with over 100 publications in various aspects of marine ecology, risk determination and management of non-native species and vectors. Research interests focus on biological invasions at all stages of the process, including vector analyses and limitations to successful transport, inoculation and establishment success and impact analyses. Worked as a researcher in marine bioinvasions in the United States (University of Oregon, Oak Ridge National Labs and University of Tennessee) and Australia (CSIRO Centre for Research on Introduced Marine Pests –CRIMP) and as a senior official, Chief Technical Officer Marine Biosecurity, for the New Zealand government. Currently the Director of the National Centre for Marine and Coastal Conservation at the Australian Maritime College and has recently established the International Marine Biosecurity Education and Research Consortium with funding from the Australian Government. This Consortium provides Marine Biosecurity education and training opportunities in support of APEC across the Pacific Basin. Has worked at the interface between science and science application to policy and management providing a unique perspective on education and training needs.

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Director of Poseidon Aquatic Resource Management Ltd, a Europe and Australia-based fisheries and aquaculture consultancy. Specializes in developing policy, strategy and management solutions for environmentally sustainable aquaculture and capture fisheries. Has led a number of relevant studies for the FAO, World Bank, ADB and European Commission, including guidelines for aquaculture development in sensitive coastal areas (EC, 2005), evaluation of the impact of the use of feed fish in European aquaculture (FAO, 2006), assessment of environmental variables for inclusion in the Common Fisheries Policy (EC, 2003), environmental impacts of coastal aquaculture in Bangladesh (World Bank, 2001–2003), coastal zone management for aquaculture development in Belize (UNDP/GEF,1996) and a Strategy for Human Capacity Building in Fisheries (FAO, 2003–2004). He also regularly works as a fishery assessor to the Marine Stewardship Council 'Principles and Criteria for Responsible Fishing' standard.

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Post-doctoral researcher in Biosystems Engineering at the University of Hawaii. PhD in Communication and Information Sciences, dissertation work established a framework to develop a Bayesian decision network model of biosecurity import risk for Hawaii shrimp aquaculture. Previous research and publications include market studies, economic analyses, and enterprise financial and production models in aquaculture. Research employs a variety of decision-theoretic, simulation, operations research, and quantitative methods for conducting feasibility, cost-benefit and risk analyses, and the development of computer applications for managerial decision support. Her Master of Business Administration with emphasis in Management Information Systems enables her to provide a distinctive strategic business approach to using innovative technologies and results-driven performance metrics that inform policy and business decisions affecting aquaculture development.

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Has been working in the area of pathogens associated with aquatic animals for over 25 years and published over 150 papers in international journals. Has wide experience with both fish/shrimp pathogens causing disease in aquatic animals and human pathogens associated with aquatic animals, which affect the safety of fish to the consumer. Has been working very closely with FAO/WHO Microbiological Risk Assessment for Foods and was a member of Drafting Group for Risk Assessment of *Vibrio* spp. in seafood. He participated as an FAO Consultant on TCP "Strengthening National Capability in Fish Trade Including Risk Assessment and Traceability" in six countries in Asia. In recognition of his contribution for generating scientific data required for risk assessment, he was awarded the biannual "Research Contributor of the Biennium" Award by the International Association of Fish Inspectors at Sydney, Australia in 2005. In India, Dr. Karunasagar was conferred the position of "National Professor" by the Indian Council of Agricultural Research and received the prestigious "Rafi Ahmad Kidwai Award"from the Ministry of Agriculture. In May 2007, Dr. Karunasagar joined FAO as Senior Fishery Industry Officer (Quality Assurance) based in Rome.

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Associate Professor at the Australian Rivers Institute, a multi-disciplinary environmental oceanographer with an impressive academic record in marine ecology. Possesses an impressive comprehension of the dynamics of a coastal marine system and is an expert in interpreting the complex spatial and temporal variability of physical processes, nutrients and plankton in the water column. Over the years, has been working on dynamics of nutrients and plankton in a natural marine ecosystem. His study also focuses on eutrophication processes by examining how biological components respond to an input of nutrients, including anthropogenic nutrients. Research in the Pearl River estuary revealed that phosphorus is the most limiting nutrient to phytoplankton biomass production in the estuarine-influenced waters south of Hong Kong. He was chief environmental oceanographer for a large consulting project: Environment and Engineering Feasibility Study under the Hong Kong's Harbor Area Treatment Scheme. His scientific findings have made a significant contribution to the formation of the sewage treatment strategy in terms of the removal of inorganic nutrients. In this project, he has gained a great deal of knowledge on environmental risk analysis and risk communication. He is experienced in conducting large estuarine projects, as he is chief scientist for several large projects.

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Senior Fisheries Biologist, Aquatic Animal Health Research Institute, Thailand's Department of Fisheries (DOF). Early career on seed production of freshwater fishes and initiated pioneering work on monitoring of antibiotic residues in shrimp products. Since 1994 involved in fish disease work, completed MSc (Fish Pathology) from Stirling University. Has been doing research on fish disease particularly parasitic and fungal diseases, disease diagnosis, prevention and control for students, farmers, fisheries official staff and the private sector within the country and also for scientists and fish disease researchers from neighboring countries. Involved in setting up aquatic animal disease surveillance system, aquatic animal farm monitoring system, standardization and certification of live aquatic animal health for export, and setting up a quarantine system for aquatic animals imported to Thailand. Served as member of AAHRI newsletter and provided technical information and served as editorial team member of Thai Fisheries Gazette.

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Assistant Professor of the Department of Ecology & Biodiversity, the University of Hong Kong (HKU). Obtained B.Sc. in Applied Environmental Sciences at the University of Portsmouth in England and M.Phil. in Mariculture and the Environment at the City University of Hong Kong. In 2000, accomplished his PhD in marine ecotoxicology at the University of Glasgow in Scotland. Subsequently, took up a position as a Croucher Foundation Postdoctoral Research Fellow at Royal Holloway, University of London where he and his colleagues developed some practical, probabilistic approaches for assessing ecological risks of industrial chemicals in aquatic ecosystems. Research interests include aquatic toxicology, ecological risk assessments, derivation of water and sediment quality guidelines, biomonitoring and mariculture. Since 1999, published more than 40 SCI peer-reviewed articles in the field of ecotoxicology and ecological risk assessments. He is a founding member of the editorial board of the international journal *Integrated Environmental Assessment and Management,* which is published by the Society of Environmental Toxicology and Chemistry (SETAC). Serves as a regional representative for SETAC (Asia/Pacific) and Australasian Society for Ecotoxicology

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Professor at University of Hawaii in Manoa, Current research focus is in aquacultural and fisheries economics. Current teaching responsibility includes engineering economics, spreadsheet modeling, biosystems modeling, biosystems simulation and operations research for management. Serves as cooperating graduate faculty in the Department of Economics and the Department of Natural Resources and Environmental Management. Served as consultant to UN FAO, NACA, ADB, MRC, WFC and UNDP. Founding editor of Aquaculture Economics and Management and serves as a member of the editorial board of *Aquaculture*.

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Senior lecturer in aquaculture at Flinders University in South Australia and has recently taken on a major role as program leader for the Value Chain Profitability research program within the newly approved Australian Seafood Cooperative Research Centre. President of the Asian Pacific Chapter of the World Aquaculture Society. Prior to moving to Australia in 2004, worked for >15 years in S.E. Asia on a range of aquaculture genetics research projects in the context of aquaculture as a component of sustainable livelihoods. Experience across the whole research continuum from technical development through to upscaling, commercialization, dissemination and uptake/ impact assessment and thus has an appreciation of the varying levels of environmental and social risks posed by genetic improvement. Recently involved in the production of a book entitled *Environmental Risk Assessment of Genetically Modified Organisms, Volume 3: Building Scientific Capacity for Transgenic Fish in Developing Countries* to be published by CABI later in 2007 and was the lead author on a chapter covering the reduction of risk through confinement. This book covers a wide range of risk assessment and risk management issues that have broader relevance to genetically improved fish in general.

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Associate Officer of BiH SVO; working on development of veterinary legislation and other veterinary tasks for which SVO BiH is authorized as central veterinary authority, including aquatic animal health regulations, epidemiology, diagnostic veterinary laboratories and FAO/TCP/3101. Current interests include animal health control, introduction of live fish and fishery products to BiH and aquaculture health management.

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Coordinator of Animal Health Program of NACA. Specialized in the field of aquatic pathology. Since 1982, has been involved with aquatic animal health teaching and research at the College of Fisheries, Mangalore, India, and appointed Professor of Fish Pathology. Since March 2003, has been working in NACA as the Regional Aquatic Animal Health Specialist, managing the regional programme in 21 countries of the Asia-Pacific region. Expertise includes fish and shrimp diseases, epidemiology, surveillance and risk management. Over 20 years of teaching, research and development experience in aquatic animal health and has authored and coauthored over 60 papers in peer reviewed international journals.

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Coordinator of genetics and biodiversity programme of NACA. Expertise in molecular genetics and its application in phylogeny, broodstock management and conservation. Provides advice and training on the applications of molecular genetic techniques in relation to inland fisheries management and aquaculture development. Coordinates the Genes and Fish column in *Aquaculture Asia* magazine. Currently involved in the following projects: (a) development of broodstock and conservation plan for two indigenous fish species in Sarawak, Malaysia; (b) development of a conservation plan of the critically endangered Mekong giant catfish; and (c) taxonomy and genetic resources management of scallop species in Thailand.

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Environment Specialist and Program Manager (Research and Development), of NACA. Expertise in shrimp farming and environmental impacts of aquaculture. Has been working on environmental issues in Asian aquaculture for over two decades. In recent times, has been involved in tsunami rehabilitation work for fish farmers in Aceh and also played a major role in developing the "International Principles for Responsible Shrimp Farming," which received the "Green Award" by the World Bank in 2006. Considerable experience working with farmers and was instrumental in initiating and directing one of the most successful projects, in collaboration with the Marine Exports Development Authority, India, in reviving the livelihoods of small-scale shrimp farmers following the disease epidemics in 1997/98. Involved in leading the work on certification and standardization in aquaculture, a burning problem for small-scale farmers globally.

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Aquaculture Adviser of the Secretariat of the Pacific Community (SPC), a Pacific intergovernmental organization based in Noumea, New Caledonia. Manages the aquaculture program, which serves a regional focal point for the sector and provides a broad range of assistance to its member governments. Worked extensively throughout SPC's 22 Pacific Island member countries and is a strong advocate for forging professional linkages outside of the region, particularly to Asia. Prior to joining SPC in 2001, was the Director of Research at the Cook Island Ministry of Marine Resources. Is university educated in New Zealand, Hawaii, and Australia with a special interest in black-pearl farming (oyster physiology and lagoon water quality).

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Retired in 2000 as Senior Aquaculturist from the Philippine Bureau of Fisheries and Aquatic Resources, Monbusho scholar (1991–1995) and JSPS postdoctoral fellow (1998–1999). Joined FAO in 2004 as Fishery Resources Officer (Aquaculture), managed NACA's aquatic animal health regional programme (1999–2002); Research Pathologist at Maryland DNR's Cooperative Oxford Laboratory from 2002. Initiated pioneering work on pathogen risk analysis under APEC/NACA/FAO project, co-author of a manual and two commissioned studies on pathogen/ecological risk analysis for SPC; spearheaded the development of National Strategies on Aquatic Animal Health in Nepal, Myanmar, Philippines, Indonesia; led international emergency disease investigation task forces on suspected EUS outbreak (Botswana, 2007), koi herpes virus (Indonesia, 2002), and pearl oyster mortalities (Philippines, 1996). Currently Lead Technical Officer of the FAO-Norway funded project (B.1Objective) Risk Assessment and Management in Aquaculture and (D.1Objective) Support to National Biosecurity Initiatives/Policies to Countries facing High Risks of Diseases/Pests; and FAO TCP projects with biosecurity/risk analysis components (Belize, Latvia, Bosnia & Herzegovina). Presently involved in global assessment of freshwater seed resources in aquaculture, particularly small-scale aquaculture, GAL Source Book on Gender in Fisheries and Aquaculture, capacity building activities in aquaculture and aquatic animal health management and chief editorial responsibilities for *FAO Aquaculture Newsletter*.

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Managing Director of AUMS Ltd. Aquaculture Underwriting Management Services, of UK. Convenor of the biennial series of Aquaculture Insurance & Risk Management conferences, the 10^{th}, which was supported by FAO and held in Vigo, Spain, in April 2006. Has been closely involved in aquaculture insurance and risk management since 1974, when he was centrally involved in founding the insurance market for aquaculture stock mortality in Lloyd's of London and the international insurance market. Lectured widely on aquaculture insurance and risk management and has conducted numerous risk management surveys of individual operations and regional industries in many parts of the world involving many different species and growing systems.

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Fishery Industry Officer (Rural Development) at the Fishing Technology Service, FAO. From 1989 to mid-2004 she was connected with the Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC) in Tigbauan, Iloilo, Philippines, where she was involved in community-based coastal resource management, socio-economic surveys of fishing communities, and in training related to aquaculture development. Shortly before she joined FAO, she was working for the WorldFish Center in Penang, Malaysia as a regional coordinator and was involved in project management and coordination with research partners under the projects on fisheries co-management (Asia and Africa) and the dissemination and adoption of aquaculture technology in the Philippines. Her present projects and involvement include: Technical Cooperation Project on Capacity Building in Support of Cleaner Fishing Harbours in India; case studies on the social, economic and environmental impacts of beach seining; review of the current state of world capture fisheries insurance; pilot projects on establishing and strengthening organizations of women fish processors; pilot project on organizing sea safety groups; and case studies on the use of socio-economic and demographic information in community-based fisheries management.

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Currently head of the aquatic animal health research section of the Inland Aquatic Animal Health Research Institute, Department of Fisheries, Thailand. Expertise on fish and shellfish microbiology. Nearly 20 years experience, involved in disease diagnosis, disease control regime for both local consumption and exportation, involved with the governmental aquaculture policy and the registration of chemicals and micro-organisms used in aquaculture. Most recent research concerning Asiaresist project funded by the EU focused on three major subjects, including assessment of the extent of antibiotic resistance in aquaculture, assessment of the potential for antibiotic resistance transferring in aquaculture, and identification of critical control points to eliminate antibiotic resistance, especially chloramphenicol resistance in the Southeast Asian aquaculture environment. Outcomes of the project have been available among the partners and the information is freely accessible via the internet (www.medinfo.dist.unige.it/**asiaresist**/). Supervised MSc and Ph.D. students of Kasetsart University since 1995.

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Senior Fisheries Biologist, Thailand's Department of Fisheries. More than 20 years of research work in the field of aquaculture system management, particularly on environmental quality, aquaculture eutrophication, effluent treatment, recirculation system, material budget and modeling in marine shrimp production. Involved in the development of shrimp farm certification schemes of Thailand since 1999 and trained for the ISO and IEC guide for the quality system certifications, especially for the organic aquaculture production system. Invited as a lecturer in many topics related to the experience in development of shrimp farm certification scheme, mangrove friendly shrimp culture and shrimp farm management in many Asian countries by NACA, SEAFDEC and private companies.

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Senior Fisheries Resources Officer (Aquaculture) of the Fisheries and Aquaculture Department of FAO. Specialized in aquaculture, disease control and health management (with particular reference to microbiology and immunology). Has worked in all parts of the world, with most experience in Asia. Was responsible for many projects on aquaculture and aquatic animal health at national, regional and international levels. A former teacher of the University of Colombo and the Universiti Putra Malaysia, Rohana earned his PhD from Stirling University. Has been responsible for initiating major policy changes in aquatic health management in relation to aquaculture in the region and globally. Currently serves as Technical Secretary to the Sub-Committee on Aquaculture of the Committee on Fisheries of the FAO.

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Director of Samutsakhon Coastal Fisheries Research and Development Center, Coastal Fisheries Research and Development Bureau, Department of Fisheries. Earned a Bachelor Degree from Kasetsart University in 1977 in the field of aquaculture, Master Degree from Miyazaki University in 1986 and Doctoral Degree from Hiroshima University in 1989 in the field of Fish Pathology. Current work includes responsibility for all activities in the center, which includes administration, research and development, farm certification, inspection of drug residues in cultured shrimp and diagnosis of aquatic animal health; also involved in improvement of marine shrimp farm standard and preparing procedures of the certification body.

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Background is fishery biology. Worked as Head of the Antibiotic Residue Inspection Unit at Phuket Coastal Fisheries and Development Center from 1990–2003. During that period, involved in a number of researches on shrimp diseases, especially parasitic and viral diseases. Currently serving as Director of the Aquatic Animal Health Research Institute of Thailand's Department of Fisheries. Involved with the national aquatic animal disease control policy under the Animal Epidemic Act. Also appointed as a member of the National Fish Disease Committee as well as the Committee of the Antibiotic Control Plan.

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Senior Associate for Veterinary Public Health of the SVO of BiH. Involved in drafting of national animal health regulations; national residue control plan, veterinary sanitary conditions during import of live fish and fishery products into BiH, and other tasks related to SVO as central veterinary authority; participating in FAO/TCP/3101; currently interested in introduction of live fish and fishery products into BiH and aquaculture health management.

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Fishery Biologist at the Coastal Aquatic Animal Health Research Institute, Thailand's Department of Fisheries. Specialized in shrimp diseases. Since 2004, responsible for aquatic animal disease control and health management. Involved in epidemiology, surveillance and risk management, standard farm practices such as good aquaculture practice/code of conduct. Research focussed on herbs using in aquaculture. Fields of interest include epidemiology, surveillance and biotechnology.

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Fisheries postgraduate with more than 13 years of field experience in aquaculture projects in India (shrimp project for 5 yrs), Jordan (tilapia project for 6 yrs) and Ghana (IFC project in tilapia for 2 yrs). From 2006 working as Project Supervisor in the MPEDA-NACA village demonstration program, which is a collaborative project between MPEDA and NACA on shrimp disease control in India. Current job in the project is to organize small-scale farmers into self-help groups known as "Aquaclubs" for adoption of "BMPs" towards capacity building among the farmers; promoting better management practices to improve aquaculture productivity and profits in Aquaclubs/societies; capacity-building and empowerment of primary producers; facilitating improved service provision to farmers; connecting farmers to markets to receive a better price for quality product; technology transfer and diversification to other commercially important species; supporting improved food security and sustainable livelihoods in aquaculture communities. Current interests include formation of Aquaclub/Society as a promising model for farmers, especially small farmers to work together, solve their day to day farming problems and earn their livelihood by helping the industry to meet the customer demand.

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Fisheries Officer (Aquaculture Management) at Agriculture, Fisheries and Conservation Department (AFCD) in HKSARG. Current responsibility includes accredited fish farm scheme, baseline survey on local fish farms, oyster monitoring programme and food safety for seafood. Prior to joining AFCD in 1997, worked for 5 years in Ocean Park Corporation on a range of projects including Shark Aquarium, Ocean Theatre and Atoll Reef. Experience includes wetland management, marine conservation, environmental impact assessments and thus has an appreciation of environmental protection and sustainable development of aquaculture. Hasdedicated services in NGOs, including WWF, Friends of the Earth and Green Power. Obtained M. Phil. from the Chinese University of Hong Kong (1981) and Ph.D. from l'Univerite de Bretagne Occidentale, France (1985). Expertise includes fish and shrimp culture, oceanarium management and environmental impact assessment.

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Senior Fisheries Biologist at the Marine Shrimp Culture Research Institute, Thailand's Department of Fisheries. The institute has primary responsibility to carry out investigations for further advancement of technology in the fields of shrimp genetic selection and breeding technology, shrimp culture technology, coastal environment protection, shrimp farm management and shrimp farm standard practices. Involved in Food Safety Project (particularly for marine shrimp farms and products), in policies and planning on import and export of marine shrimp products and live aquatic animals, improvement of marine shrimp farm standards (procedure and regulation) and products quality control.

Annex 2
EXPERT WORKSHOP PROGRAMME

Date, Day and Time	Activities
Thursday, 7 June	Arrival of participants to Bangkok
Day 1: Friday, 8 June	
08:00-11:00	Travel from Bangkok to Rayong by car
11:00-14:00	Check-in and lunch
14:00-14:15	Opening remarks Dr Rohana Subasinghe (FAO) Dr Sena de Silva (NACA)
14:15-14:30	Presentation 1: Project purpose, participation, process, products Dr Melba Reantaso (FAO)
14:30-14:45	Self-introduction of workshop participants
14:45-15:15	Presentation 2: General principles of the risk analysis process and its application to aquaculture Dr J. Richard Arthur (FAO Consultant)
15:15-15:45	Coffee break
15:45-16:10	Presentation 3: Food safety and public health risk associated with products of aquaculture Dr Iddya Karunasagar (FAO)
16:10-16:35	Presentation 4: Pathogen risk analysis for aquaculture production Dr Melba Reantaso (FAO)
16:35-17:00	Presentation 5: Application of risk analysis to genetic issues in aquaculture (25 min) Dr Eric Hallerman (Virginia Polytechnic Institute and State University)
17:00-17:30	Discussion (30 min)
17:30-17:40	Day 1 and 2 announcements
19:00-	Welcome dinner
Day 2: Saturday, 9 June	
08:30-08:55	Presentation 6: Ecological (pest) risk assessment and management Dr Kenneth Leung and Dr David Dudgeon (University of Hong Kong)
08:55-09:20	Presentation 7: Environmental Risk Analysis Dr Michael Phillips (NACA) and Dr Rohana Subasinghe (FAO)
09:20-09:45	Presentation 8: GESAMP WG 31 Environmental risk assessment and communication in coastal aquaculture (work in progress) Dr Rohana Subasinghe (FAO)

09:45-10:10	Presentation 9: Marine invasive species risk analysis Dr Marnie Campbell and Dr Chad Hewitt (National Center for Marine and Coastal Conservation, Australian Maritime College)
10:10-10.40	Coffee break
10:40-11:05	Presentation 10: Guidelines for the ecological risk assessment of marine fish aquaculture Mr Colin Nash (NOAA) – to be presented by Mr Phillip AD Secretan
11:05-11:30	Presentation 11: Financial risks analysis in aquaculture Dr Lotus Kam and Dr Pingsun Leung (University of Hawaii)
11:30-11:55	Presentation 12: Social risks in aquaculture Mr Pedro Bueno (NACA)
11:55-12:20	Presentation 13: Insurance industry risk analysis process Mr Phillip AD Secretan (AUMS Limited)
12:20-12:45	Presentation 14: Better management practices in shrimp aquaculture: experiences in India Mr. Umesh NR (MPEDA/NACA)
13:10-14:30	Lunch break
14:30-15:30	Presentation of guidelines for the working groups and discussion
15:30-18:00	Parallel working group discussions Working Group 1 Working Group 2 Working Group 3
15:30-16:00	Coffee break
18:00	End of day
Day 3: Sunday, 10 June	
08:30-08:40	Day 3 Announcements
08:40-18:00	Continue parallel working group discussions Working Group 1 Working Group 2 Working Group 3
10:00-10:30	Coffee break
10:30-11:30	Reporting of working group progress
13:00-14:30	Lunch break
14:30-15:30	Parallel working group discussions Working Group 4 Working Group 5
15:30-16:00	Coffee Break
16:00-18:00	Parallel working group discussions Working Group 4 Working Group 5
18:00	End of day

Day 4: Monday, 11 June	
	Day 4 Announcements
09:00-10:30	Presentation 15: Working Group 1 and discussion (30 min)
10:30-11:00	Presentation 16: Working Group 2 and discussion (30 min)
09:30-10:00	Presentation 17: Working Group 3 and discussion (30 min)
11:00-11:30	Coffee Break
11:30-12:00	Presentation 18: Working Group 4 and discussion (30 min)
12:00-12:30	Presentation 19: Working Group 5 and discussion (30 min)
12:30-14:00	Lunch break
14:00-14:30	Final conclusions and way forward Dr Rohana Subasinghe (FAO)
14:30-15:00	Closing ceremony
15:00-15:30	Coffee break
15:30-	Participants depart for Bangkok
Tuesday, 12 June	
	Participants depart from Bangkok to home country

Annex 3
EXPERT WORKSHOP GROUP PHOTO

Forty-two aquaculture experts (policy-makers, risk analysis practitioners and technical experts in various aspects, e.g. diseases, food safety, genetics, environment, socio-economics, aquaculture insurance) representing various international, regional and national organizations and institutions in Asia, the Pacific, Oceania, Europe and North America, participated in the FAO/NACA Expert Workshop on Understanding and Applying Risk Analysis in Aquaculture held in Rayong, Thailand, from 7 to 11 June 2007.

Risk analysis is an objective, systematic, standardized and defensible method of assessing the likelihood of negative consequences occurring due to a proposed action or activity and the likely magnitude of those consequences, or, simply put, it is "science-based decision-making". Risk analysis has mainly been applied in assessing risks to society and the environment posed by hazards created by or associated with aquaculture development, e.g. risks of environmental degradation; introduction and spread of pathogens, pests and invasive species; genetic impacts; unsafe foods; and negative social and economic impacts. Risk analysis provides insights and assists in making decisions that will help avoid such negative impacts and allows aquaculture development to proceed in a more socially and environmentally responsible manner. An integrated approach to risk analysis will assist the aquaculture sector in reducing risks to successful operations from both internal and external hazards and can similarly contribute to protect the environment, society and other resource users from adverse and often unpredicted impacts. This could lead to improved profitability and sustainability of the sector, while at the same time improving the public's perception of aquaculture as a responsible, sustainable and environmentally-friendly activity.

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