The Role of Risk Analysis and Epidemiology in the Development of Biosecurity for Aquaculture

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ABSTRACT

Biosecurity is a management strategy to minimise the risk of disease introduction, and is critical to development of a successful aquaculture industry. In this paper, it is argued that the combination of epidemiological research and risk analysis methodology is required to develop appropriate biosecurity programmes. Risk analysis ensures that a logical, transparent approach is adopted to identify and prioritise disease hazards and pathways of introduction and exposure. In aquaculture, it has been mainly used to assess risks of disease introduction at a country or regional level, and has been little used at the farm level. Risk analysis is only as good as the data it uses, and primarily, epidemiological data is required. Epidemiological investigations that underpin risk analysis fall into two main categories: disease outbreak investigations and structured observational studies. The outbreak investigation and risk factor studies for infectious salmon anaemia (ISA) are used to illustrate how risk analysis and epidemiological investigations can be combined to develop improved biosecurity. It is argued that the development of biosecurity programmes for other diseases could benefit from similar epidemiological studies. Finally, it is shown that risk analysis can identify critical gaps in the data needed for the development of biosecurity, and, therefore, direct future epidemiological investigations.

INTRODUCTION

Biosecurity is the protection of a country, region or farm against the introduction of exotic pathogens. It is an essential element of a farm's disease control programme. Preventing disease introduction is more cost-effective and easier than control and elimination of an introduced pathogen. A sound biosecurity programme is only possible if founded on a thorough understanding of the disease and its epidemiology. Epidemiology is the study of the frequency, determinants and distribution of disease (Martin *et al*., 1987). The purpose of veterinary epidemiology is highly pragmatic, i.e., the resolution of animal health problems. Risk analysis can be considered an applied area of veterinary epidemiology. It is a method to assess the probability and consequences of undesirable events. Risk analysis methods were originally developed by the nuclear and space industries; in the last few years, risk analysis have been applied in the field of animal health (anon., 1993), and only recently in aquaculture (Rodgers, 2001). Risk analysis makes systematic use of the available information as an aid to decision making. It has the potential to be used in a number of areas of aquatic animal health, including: a) analysis of disease transmission between farmed and wild

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populations, b) the potential transmission of pathogens via the use of composted or ensiled fish waste and c) the risk of disease introduction at the farm, region or country level. To date, the main application of risk analysis in the animal health field has been stimulated by the Agreement on the Application of the Sanitary and Phyto-sanitary Measures (the SPS Agreement) of the World Trade Organization (WTO) (WTO, 1994). This has focused on risks associated with trade in animal and animal products and is known as import risk analysis (IRA). The SPS Agreement requires an IRA to justify levels of protection greater than those provided by international agreement. The advantages of risk analysis are that it is rigorous, transparent and produces defensible results. It forces a thorough and logical approach to be adopted in considering the likelihood of undesirable events, and takes into account not only the likelihood but also the consequences of the event.

In this paper, it is argued that an understanding of epidemic theory, epidemiological research and the application of risk analysis methodology are essential for developing efficient and cost-effective biosecurity programmes.

INHERENT RISK AND BIOSECURITY

Aquaculture sites have an inherent risk of disease introduction. Sites that use spring or borehole water, or recirculation systems carry an inherently negligible risk of disease introduction. Mariculture and freshwater sites using river water carry a significant risk because of contact with wild fish populations and the proximity of other aquaculture facilities. The level of this risk is approximately proportional to the density of farming upstream or within the proximity of the farm. This inherent risk cannot be completely eliminated. However, a range of biosecurity measures can be employed to reduce other risks of disease introduction associated with the purchase of live fish, contact with other farms, etc. The major risks of disease introduction are associated with the purchase of live fish and contact with other aquaculture sites. A good understanding of the epidemiology of disease and the application of risk analysis methods can assist the farmers in focusing their biosecurity programmes on the main risks.

EPIDEMIC THEORY

When designing biosecurity programmes, the principal concern is transmission of disease between farms. Different processes lead to different patterns of disease transmission. In the marine environment, passive exchange is likely to be limited by tidal excursions around marine farms. Freshwater farms are at risk from pathogens emanating from farms upstream. This spread can be effectively limited by sufficient physical separation between farms, but will increase with farm density. Epidemic diseases passing through wild populations can affect farmed fish populations. Natural or anthropogenic vectors may spread disease between farms. This pattern of spread is largely independent of farm density and farmed populations may play little part in the epidemiology of the disease. Natural vectors include birds or wild fish that may travel between farms. Natural vectors may be mechanical carriers, e.g., sea gulls with infectious pancreatic necrosis (IPN) viruses in their guts (McAllister and Owens, 1992), or true carriers excreting the pathogen, e.g., sea trout carrying ISA virus (Nylund and Jakobsen, 1995). Anthropogenic vectors include boats, other equipment or personnel, e.g., divers that travel between farms. An understanding of the spread of disease has resulted in the development of area management plans for Scottish salmon farms.

OBSERVATIONAL EPIDEMIOLOGICAL STUDIES

Observational epidemiological studies in support of biosecurity falls into two main categories: (a) disease outbreak investigations and (b) structured observational studies of disease risk factors.

Epidemiological investigations of aquatic animal disease outbreaks

Investigations of disease outbreaks are usually designed to identify the cause of the outbreak and routes of transmission. The application of epidemiological approaches to investigating disease outbreaks is illustrated with reference to ISA in Scotland and infectious haematopoietic necrosis virus (IHNV) in British Colombia, Canada.

Infectious salmon anaemia in Scotland

ISA was first recognised in Norwegian farmed Atlantic salmon (*Salmo salar* L.) in 1984 (Thorud and Djupvik, 1988). The causal agent was proven to be a virus (Dannevig, Falk and Namork, 1995), and subsequently shown to be an enveloped RNA virus of the family *Orthomyxoviridae* (Falk *et al*., 1997). ISA outbreaks have been confirmed in Canada (Mullins *et a*l., 1998; Lovely *et al*., 1999), Scotland (Rodger *et al*., 1998), Chile and the Faeroes and in the USA (Bouchard et al., 2001). It is listed under “diseases notifiable to OIE”. Fish affected with ISA suffer anaemia and are often observed swimming near to the surface of the water swallowing air. A high level of mortality is common, 80 % mortality occurred in the first outbreak in Norway (Jarp and Karlsen, 1997). Investigations of the ISA outbreak in Scotland identified the use of well boats, for moving and harvesting fish, as an important factor in the spread of the disease (Murray, 2002). This finding led to a risk analysis of harvesting techniques (Munro *et al*., 2003). These investigations are being used to develop improved biosecurity measures, e.g., a code of practice for well boat operators. Following the outbreak, a code of practice for salmon farmers “to avoid and minimise the impact of ISA” was developed based on experiences of the ISA outbreak and good fish health management (anon., 2000a).

Infectious haematopoietic necrosis virus in British Colombia

IHNV is a rhabdovirus that primarily causes disease in the genus Oncorhynchus. It was first isolated in the Pacific northwest region of the USA, where it is endemic in wild sockeye salmon (Onchorhychus nerka) (Wolf, 1988). Epidemics have occurred on the west coast of North America among farmed stocks of chinook salmon (O. tschawytscha) and rainbow trout (O. mykiss) (Winton, 1991). Since 1987, the disease has been detected in several European countries (Bovo, Ceschia and Giorgetti 1991; Enzmann *et al*., 1992; Hattenberger-Baudouy *et al*., 1988), and Asia (Wang *et al*., 1996). In 1992, the virus was isolated for the first time from Atlantic salmon in seawater sites in British Colombia, Canada (Armstrong *et al*., 1993). In 1996, companies farming salmon in British Colombia implemented a management plan for the control of disease. An investigation of an IHNV outbreak in British Colombia and the impact of the management plan has been published (St-Hilaire *et al*., 2002). The spatial and temporal analysis of the outbreaks and the genetic similarity of the virus isolates demonstrated that virus was spread from farm to farm, and wild salmon were not an important source. The research also established that fallowing was an effective means of reducing disease outbreaks.

Risk factor studies

It is well established that disease occurrence is the outcome of the interaction between the pathogen, host and environment. Some epidemiologists find it more useful to consider the pathogen as a component of the environment (Martin *et al*., 1987). However, fish health research has focused on isolating and investigating the pathogen, at the expense of studies of host and environmental factors (Smith, 1999). Well-designed observational epidemiological studies can make an invaluable contribution to identifying and quantifying environmental and host risk factors for disease. The results of these studies can be used to develop hypotheses that can be further tested in the field or laboratory for biosecurity and disease control strategies. The few published risk factor studies of aquatic animals have been reviewed by Georgiadis *et al*. (2001). In Table 1, the results of risk factor studies for diseases of farmed salmon are summarised. ISA provides an excellent example of the potential contribution risk factor studies can provide to both the identification of route of introduction and establishment of the disease (Table 3). The risk factors identified by Jarp *et al*. (1994) and Vagsholm *et al*. (1994) clearly indicated that currents or tides from an infected farm or slaughterhouse physically transported the virus to neighbouring farms. Other routes of transmission between farms also appeared important, including mechanical transmission by divers visiting many sites (Hammell and Dohoo, 1999) or other members of the workforce who moved between sites (Vagsholm *et al*., 1994), and boats delivering feed (Hammell and Dohoo, 1999). Other management factors identified may have contributed to the establishment of the disease on the farm once it was introduced, e.g., intra-peritoneal vaccination, mixing year classes (Vagsholm *et al*., 1994) and high fat feed (Hammell and Dohoo, 1999).

Table 1. Stages of an import risk analysis.

Stage	Description
1. hazard identification	identification of the major exotic aquatic diseases
2. release assessment	description of pathways necessary for introduction
3. exposure assessment	description of pathways necessary for the exposure of host aquatic species to the introduced exotic pathogen, and the spread or establishment of the hazard.
4. consequence assessment	identification of the consequences of disease introduction and establishment
5. risk management	policies to reduce likelihood of introduction and mitigate the consequences (e.g., biosecurity programme)

The majority of risk factor studies have been of Atlantic salmon production, and in particular ISA. The recent study by Corsin *et al*. (2001) of factors associated with white spot syndrome virus (WSSV) in shrimp is the exception. The study generated a number of interesting results, including associations between using a commercial feed and proximity to seawater, that have resulted in further investigations.

RISK ANALYSIS

Risk analysis methods, known as IRA, in the field of aquatic animal health have mainly been used to assess the risks of introducing exotic diseases into a country. A search of the literature has identified ten published IRA for aquatic animals at a country level (Anon., 2000b; Beers and Wilson, 1993; Bruneau, 2001; Kahn *et al*., 1999a, 1999b; MacDiarmid, undated; Manfrin *et al*., 2001; Mortensen, 2000; Pharo and MacDiarmid, 2001; Stone *et al*., 2001; Wilson, 1993;). Four of these publication appeared as papers given at a conference sponsored by the Office des Epizooties (OIE) (OIE, 2001)). The remaining publications are reports produced by the Australian or New Zealand Ministries of Agriculture. Most of these studies were undertaken for trade or regulatory purposes. At a regional level the only published paper is by Paisley *et al*. (1999), who took a quantitative approach to assessing the risk of introducing Gryodacytylus salaris into an uninfected river (Tana) in Norway.

To date risk analysis has been little used at the farm-level, however, the methodology has great potential to be applied to assessing the risks of disease introduction and thus assist in developing biosecurity programmes at the farm level. The five stages of an IRA (Table 1) (Rodgers, 2001) provides a logical and transparent framework to identify all the data needed

Table 2. Data required for an import risk analysis.

Pathogen characteristics
route of infection
infectious dose
carrier state / subclinical infection
tissues affected in clinically affected individuals / carriers
survivability (i.e. susceptibility to temperature, dessication)
reproductive ratio (R0) (i.e., rate of transmission)
Characteristics of farmed aquatic animal
species, strain or genotype and age of the host species
vaccination and treatment history
Characteristics of live fish introduced into the farm
volume of live fish introductions
number of sources of live fish and their health status
age of introduced fish
period of quarantine after introduction
species, strain or genotype and age of the host species
vaccination and treatment history
water source where reared (borehole / spring / river)
water temperature and salinity of water where reared
Other routes of introduction
contact with other fish farms, e.g., shared personnel, delivery lorries / boats
contact with wild fish populations
proximity to slaughterhouses discharging waste
proximity to other aquaculture facilities

Table 3. Risk factors for aquatic diseases of farmed Atlantic salmon.

Disease	*Risk factor associated with increased level of disease*	*Reference*
IPN (post smolt) (hatchery)	mixing smolts from many freshwater hatcheries	(Jarp *et al*., 1994) [1]
	new site (<1 yr old)	
	late season transfer of smolts	
	fjord zone (vs. coastal zone)	(Jarp *et al*., 1993) [1]
	migration of anadromous fish into freshwater supply	
	of the hatchery	
	sharing personnel with other farms	
	high concentration of infected farms near hatchery	
ISA	within 5 km of a salmonid slaughterhouse / number	(Jarp and Karlsen, 1997; Vagsholm *et al*., 1994) [1]
	of adjacent slaughterhouses	
	within 5 km of an ISA infected farm / number	
	of infected adjacent holdings	
	high number of hatcheries delivering smolts	
	high density of fish markets near the farm	(Jarp and Karlsen, 1997) [1]
	divers visiting multiple sites	(Hammell and Dohoo, 1999) [2]
	shared workforce	(Vagsholm *et al*., 1994) [1]
	reared in seawater	
	return of salmon from slaughterhouse	
	intra-peritoneal vaccination	
	retarded growth	
	moist feed not fed after transfer	(Hammell and Dohoo, 1999) [2]
	feed delivered by boat by feed company[3]	
	high fat feed fed	
	mixed year classes	
Spinal deformaties	low smolt weight	(Vagsholm and Djupvik, 1998) [1]
	fjord sites (compared with oceanic)	
	an increase in 3 months between vaccination and	
	seawater introduction	
	slow growth rate	
	slaughter from August to March	
Skin lesions	an increase in 3 months between vaccination and	(Vagsholm and Djupvik, 1998) [1]
	seawater introduction	
	plant oil vaccine adjuvant (vrs. mineral oil)	
	lower weight at slaughter	
Abdominal adhesions	mineral oil vaccine adjuvant (vrs. plant oil)	(Vagsholm and Djupvik, 1998) [1]
	epithiolocystis	
	decrease in the number of days at sea	
	fjord sites (compared with oceanic)	
	low smolt weight	
Cataracts	spring compared with autumn entry (increased	(Ersdal *et al*., 2001) [1]
	severity)	
	southern (vrs. northern counties)	
	low smolt weight	

[1] Norway, [2] Canada, [3] delivery boats travelled between farms, IPN infectious pancreatic necrosis, ISA infectious salmon anaemia.

to assess the risk of a hazard, in this instance the introduction of a disease. Some data will be missing and thus one output of a risk analysis will be the prioritisation of future research. At the farm level epidemiological information from observational studies, such as risk factors studies as discussed above, is particularly important to identify potential routes of introduction and factors that may favour establishment of the disease. Risk analysis can integrate epidemiological data with other information (Table 2), including pathogen characteristics, the volume of movements of live aquatic animals and other movements (e.g., people and vehicles) on and off the farm.

The outputs of a risk analysis have other advantages for the production of a biosecurity programme. As a rule, only limited resources are available for the development of improved biosecurity. A quantitative risk analysis will quantify the risks of disease introduction and establishment presented by different routes, whilst a qualitative analysis will lead to a ranking. Outputs from both approaches provide a means to determine the priorities for biosecurity programmes.

In many instances a number of aquaculture facilities use the same water resource. Since many aquatic animal pathogens are able to survive outside their host, they can be carried between farms by currents or tides. Therefore, the development of regional biosecurity programmes, often known as area management plans, is crucial. Outbreaks of ISA in Scotland and IHNV in Canada have resulted in area management plans. In Scotland, area management plans are based not only on fundamental aspects of oceanographic conditions, but also on specific local conditions (anon., 2000). Epidemiological studies that take as the unit of interest the region, not the farm, can similarly contribute the development of area management plans.

In addition to using risk analysis to assist in producing a biosecurity programme, at a farm or regional level, epidemiological research may highlight specific areas where risk analysis can be applied to produce fish health policy recommendations. For example, the Scottish ISA outbreak investigation identified the movement of live fish by well boats as an important route of farm to farm transmission (Murray, 2002). Consequently, a risk analysis of harvesting methods, including the use of well boats, was undertaken (Munro *et al*., 2003) which resulted to recommendations for harvesting salmon to minimise ISA transmission..

DISCUSSION AND CONCLUSIONS

Veterinary epidemiology had evolved into a holistic discipline largely in response to the failure of traditional approaches to resolve a number of terrestrial animal health problems, mainly of intensive livestock production (Schwabe, 1982). Today many aquaculture production systems face serious disease problems, e.g., ISA and IPN in salmon production, WSSV in shrimp aquaculture. Epidemiology provided a new way to approach terrestrial animal health problems, and it has the same potential in aquaculture. In this paper the importance of epidemiology and risk analysis in the development of biosecurity programmes has been argued. Epidemiological theory discussed at the outset of this paper provides a conceptual framework on which to build biosecurity programmes to minimise the risk of disease introduction. Epidemiological studies can help identify potential sources of infection, routes of introduction and factors associated with the likelihood of establishment. There have been relatively few observational studies of aquatic animal disease, ISA is the notable exception. Epidemiological investigations have contributed greatly to our understanding of ISA and the development of biosecurity programmes to reduce the risk of its introduction. The development of control programmes, including biosecurity, for other diseases would also undoubtedly benefit from similar epidemiological studies. Risk analysis has only recently been applied in aquatic animal health, and predominantly to assess the risk of disease introduction at the country level. However, it is also highly pertinent for use at a farm or regional level. Risk analysis methods can integrate the results of epidemiological studies with other data to quantify or rank the importance of different routes of entry. This provides the basis for the development of a biosecurity programme.

The introduction of new pathogens into a farm can cause severe financial hardship, and may lead to the failure of the business. In the future, the threat of disease introductions will increase with the inexorable rise in international trade in livestock products and people, and the extension of aquaculture into new territory. Governments and the aquaculture industry have responsibilities to minimise the risk of disease introductions. There is an onus on the farmer to take the precautions necessary to minimise the risk of disease introduction at the farm level. Extension and researcher workers have a responsibility to establish partnerships with farmers to undertake the necessary research, and use the results to produce cost-effective biosecurity programmes. Risk analysis can be used to both develop biosecurity programmes and identify critical gaps in the existing information, and thus influence the direction of future research.

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