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Compartmentalisation in aquaculture production systems

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Summary

Compartmentalisation is a new tool for disease management within a country. In aquaculture, the successful application of compartmentalisation is largely dependent on the system of production and the epidemiology of the disease(s) for which the compartment is being defined. Therefore, compartmentalisation may not be universally applicable across all systems and diseases. The paper examines the implementation of the concept, providing examples of specific industries, and discusses the application of hazard analysis and critical control points (HACCP) to the biosecurity of the system. The role of compartmentalisation in the management of aquaculture disease emergencies is also discussed.

Keywords

Aquaculture – Biosecurity – Compartmentalisation – Disease management – HACCP – Risk analysis.

Introduction

Zoning and compartmentalisation are disease management strategies that pursue the same objective; both aim at establishing animal populations with a distinct health status based on effective separation of these populations and application of biosecurity measures to prevent the reintroduction of the infection. Zoning relies more heavily on geographic factors such as natural or man-made barriers, while compartmentalisation focuses more on management and biosecurity within the establishments that comprise the compartment to ensure the maintenance of the health status (33). The key difference between both concepts is that in zoning the application of control measures is under the direct responsibility of the competent authority, while in compartmentalisation biosecurity measures are the responsibility of the management of the compartment. Therefore, to achieve international recognition of compartments, it is essential that the competent authority establishes an audit and certification process in close coordination with the management of the compartment.

Although the term 'compartmentalisation' is relatively new for the purpose of international trade, many disease control programmes have applied it historically. Traditional control programmes for diseases such as bovine tuberculosis and brucellosis have relied on certificates of disease-free herds (4, 5) as the building blocks leading towards eradication.

The concept of a disease-free herd is the basis for compartmentalisation. The current interpretation of a compartment extends to all the epidemiologically linked units of a production system (27). In vertically integrated industries, such as the poultry, swine and some aquaculture industries, compartmentalisation allows the recognition of all the production units, including the slaughterhouses or packing plants, as having a uniform animal health status, ensuring the uninterrupted flow of animals, vehicles and goods between the different units within the compartment.

Aquaculture production systems pose a particular challenge for the application of compartmentalisation. The high potential for contact with pathogens through water means that the effective separation between compartments, essential to maintain the integrity of the system, can only be guaranteed under specific production conditions.

The Australian Aquatic Veterinary Emergency Plan (AQUAVETPLAN) categorises aquaculture production systems into four groups (7):

– open systems: systems where there is no control of either host movement or water flow, e.g. wild caught fisheries

– semi-open systems: systems where there is control of host movement but no control of water flow, e.g. net pen culture, sea cages, mollusc rack culture

– semi-closed systems: systems where there is control of host movement and some control of water flow, e.g. land-based farms with tanks, ponds or raceways

– closed systems: systems where there is good control of both host movement and water flow, e.g. aquaria, recirculating farms in a building on land.

Compartmentalisation is ideally suited for closed and semi-closed systems. Some industries such as salmon farming may have a combination of systems ranging from closed systems to semi-open systems. In this case, a mixed approach of zoning and compartmentalisation may be appropriate.

Implementation of compartmentalisation

A compartment free of a specified disease is expected to thoroughly document all the procedures supporting its disease status claim. Scott *et al.* (27) identified seven factors for the successful implementation of compartmentalisation:

– definition of the compartment

– epidemiologic separation of the compartment from potential sources of infection

– documentation of factors critical to the definition of the compartment

– supervision and control of the compartment

– surveillance for the agent or disease

– diagnostic capabilities

– emergency response, control, and notification capability.

The specific details pertaining to each factor will not be repeated here, but their application will be demonstrated below, using a shellfish or shrimp hatchery as an example. It is important to stress that, as in zoning, the burden of proof lies with the disease-free compartment. It is the responsibility of the compartment to implement all the appropriate measures that guarantee the integrity of its status.

Certification and biosecurity

A compartment must identify all the potential pathways for the introduction of infection. The critical points for the most significant pathways must be addressed in a comprehensive biosecurity programme and documented in a biosecurity plan. For international trade purposes, the recognition of compartments necessarily involves a process of official certification by the appropriate governmental authority, i.e. the competent authority, in accordance with the World Organisation for Animal Health (OIE) *Aquatic Animal Heath Code* (33).

This certification requirement implies that the biosecurity programme and all the measures applied within the compartment must be auditable and transparent. Biosecurity measures must be subjected to a control and verification process based on hazard analysis and critical control points (HACCP) methodology, which includes the following seven steps (9):

– conduct a hazard analysis

– determine critical control points

– establish critical limits

– establish monitoring procedures

– establish corrective actions

– establish verification procedures

– establish record-keeping and documentation procedures.

The evaluation of biosecurity measures using the HACCP methodology is described in a later section of this article, using a salmon farm as an example.

Surveillance

Continuous surveillance within and outside the compartment will be the ultimate proof that the biosecurity measures aimed at preventing the introduction of infection are effective. Internal surveillance must be maintained and directed not only to the pathogen for which the compartment has been defined, but also towards other pathogens of importance, particularly those that cause diseases that are listed by the OIE.

The finding of another disease agent that shares one or more pathways of introduction may indicate a breach in the biosecurity that needs to be corrected immediately. For example, the detection of a boring sponge in the shells of trochus spat (*Trochus niloticus*) at a 'high-health' recirculating marine hatchery facility was of concern even though the sponge, of itself, was not causing mortalities; however, its presence indicated a breach of biosecurity which might allow entry of more lethal pathogens (J.B. Jones, unpublished data). External surveillance will indicate whether significant changes in the level of exposure have occurred and might trigger a review of the biosecurity measures applied, for example, a change in the prevalence of a disease outside the compartment may require a review of the sample strategy for surveillance for the disease within the compartment.

Uses of compartmentalisation

Compartments can be defined under two scenarios:

– as a disease management tool in an endemic but stable situation

– as a disease management tool in the event of an outbreak.

In countries or zones with endemic disease, compartmentalisation offers the possibility to direct resources more efficiently. Disease-free compartments can be defined and can continue to trade in situations where disease eradication at the country or zone level is not deemed feasible in the short term or in situations where infected wildlife or vectors are involved. In most situations, compartmentalisation will entail a significant investment and eradication of the infection should be the most cost-effective approach.

In the event of an outbreak, compartmentalisation can be used as a tool to limit the economic impact of the disease by allowing trade from disease-free compartments. Ideally, a country should define its compartmentalisation strategy as a precautionary measure before an outbreak as a way to expedite the resumption of trade. If compartments are defined and bilaterally agreed upon in 'peace time', in the event of an outbreak, disease-free compartments could resume trading once the situation has been demonstrated to be stable both in terms of incidence and geographic distribution. However, if the compartmentalisation strategy is established once the disease has been introduced, it will take a significant amount of time to define the compartments, conduct a thorough pathways analysis to identify potential routes of entry, set up biosecurity measures, and establish certification procedures, and the benefits of applying such a strategy may be lost.

Occasionally, a mixed approach combining zoning and compartmentalisation may be suitable. For example, the European Union, under Council Directive 91/67/EEC and subsequent decisions, recognises disease-free zones for two fish diseases (infectious haematopoietic necrosis [IHN] and viral haemorrhagic septicaemia) and two shellfish diseases (*Bonamia ostreae* and *Marteilia refringens* infections) (32). The zones are based on geographical characteristics, but one of the features of this programme is that there are also individual farms with disease-free recognition.

Compartmentalisation applied to 'high-health' shellfish or shrimp hatcheries

A 'closed system' such as a finfish farm using recirculated water or a shellfish or shrimp hatchery of 'high-health' status is the easiest form of compartment in which to apply management practices to achieve biosecurity. This is because all of the animals forming the subpopulation within the compartment are identifiable and it is possible to establish a clear epidemiological separation from other aquatic animals and other potential pathways for disease introduction. All of the perimeter inputs (water, air, personnel, feed, vehicles and stock) are under the control of an operator and are capable of being independently monitored and audited. The activities within the compartment can all be routinely monitored and tested such that deviations from normal can be identified and investigated. The example below is taken from a shellfish hatchery, but could be easily adapted to fit any building-based aquaculture ventures (such as fish farms operating with recirculated water).

Definition of the compartment

The subpopulation of animals within the compartment must be clearly defined, and there must be a means of identifying and tracing the aquatic animals. This step should be carried out in consultation with the competent authority and might, for example, involve a single hatchery or a group of hatcheries owned by a company, or a group of hatcheries belonging to an industry association. All of the aquatic animals within the compartment and those leaving the compartment will be identifiable by a method which enables trace-back to the hatchery of origin and the batch production date. Where a compartment is comprised of a number of establishments, these will share many common elements of the biosecurity plans, which together will form the criteria for the definition of the compartment.

Epidemiologic separation of the compartment from potential sources of infection

Animals in the compartment need to be recognisable through a clear epidemiological separation from other aquatic animals and all things presenting a disease risk. Therefore, potential sources of infection and the risk of spread of infection into the compartment must be assessed. Methods for performing a disease risk assessment are well documented elsewhere (2, 15, 31). In addition, HACCP analysis, with which business managers are often more familiar, can be invaluable for identifying processes, hazards, and critical control points (22). An example of an HACCP generic process flow diagram for a typical shellfish or shrimp hatchery is shown in Figure 1.

Documentation of factors critical to the definition of the compartment

For land-based hatcheries, the most common source of infection is through the incoming water supply, particularly if aquatic animals in that water supply may carry the diseases of concern. A secure water source (such as a well) is the preferred option, but for most hatcheries incoming sea water must be filtered to remove bacteria and other potential pathogens (1, 10). Filtration can be accompanied by protein fractionation and sterilisation (typically UV) where viruses are of concern.

The fish pathogen, *Amyloodinium ocellatum*, is the only aquatic pathogen that has been associated with airborne dispersal (26), but the air can also bring dust (for example, dust rich in iron promotes growth of *Vibrio* bacteria), birds (19, 29), insects, and aerosols which may include toxic chemicals from nearby industrial or agricultural sites (25). Toxic compounds negatively affect the immune-status of the stock. If an assessment of the risk requires it, air supply into a building or parts of a building can be controlled. For larger sites, bird-netting may suffice.

Feed is a common source of pathogens. The risk of pathogen introduction can be controlled by using processed foods such as pellets, crumbed feeds or algal pastes. Live, freshly dead, or frozen feeds are more problematic. For shellfish this is usually overcome by using azenic algal culture, keeping bacterial counts to below 2×10^6 cfu/ml (18). In shrimp hatcheries, care must be taken to ensure that feed does not become infected with

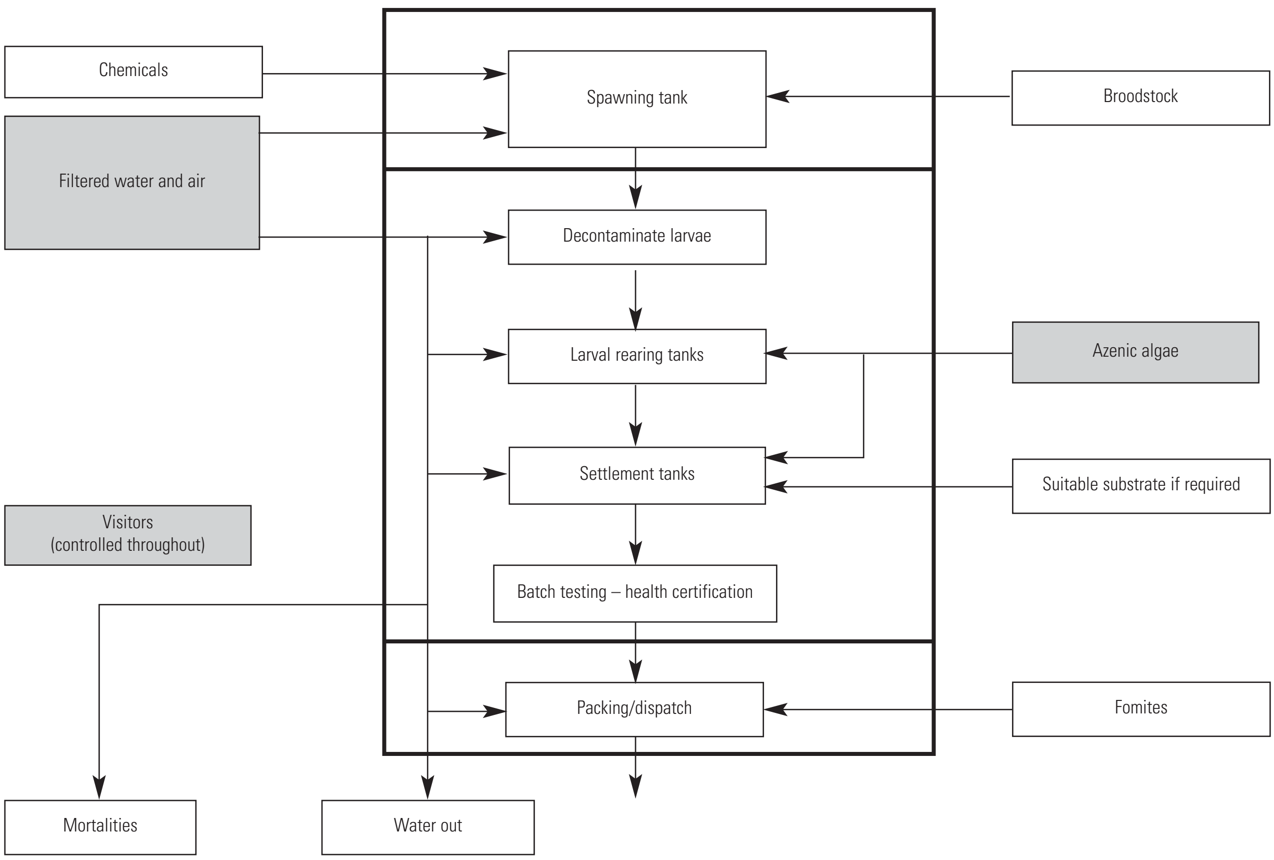

Fig. 1
An example of a generic hazard analysis and critical control point process flow diagram for a typical shellfish or shrimp hatchery
The compartment is shown within heavy lines, the three sections have separate biosecurity. The shaded boxes indicate the critical control points in the process

shrimp pathogens such as white spot syndrome virus (30). The use of fresh or frozen crustacean tissues to condition broodstock should be avoided.

Other supplies coming onto the site can be a potential source of infection. These include fomites such as transport crates, settlement slats and netting; and other at-risk items such as non-food grade plastics that may lead to toxic insults (14), especially in mollusc hatcheries, that result in immune suppression and consequent infection by pathogenic organisms.

Water leaving the compartment should also be treated to prevent the escape of individuals and/or pathogens into the environment. Such a breach may affect the status of other compartments and the environment.

Contingency plans should be in place to ensure continuity of power supply, particularly to pump, heat or aerate water. Utility staff might travel from one establishment to another, representing a potential biosecurity hazard that should be assessed.

A full set of daily records should be kept of all production figures, sources of supplies and feed (16). Daily records for each tank should be maintained for water quality parameters, stock movements, feeding schedules, morbidity and mortality, and medications. A record should also be kept of the due dates and completion dates of all maintenance and cleaning work for tanks, pipe work and associated infrastructure. If the hatchery has a 'dry out' or fallowing period in the production cycle, then that too must be documented.

As well as addressing all of the above potential pathways for the introduction of pathogens into the facility, the biosecurity plan of a compartment must include the following elements:

– a risk assessment and the management measures required for each risk
– production and stock records
– feed sources
– surveillance results
– visitor logbook
– morbidity and mortality history
– medications
– vaccinations
– training documentation
– any other criteria necessary for risk mitigation.

Supervision and control of the compartment

Staff and visitors entering and leaving the site(s) are a biosecurity risk. Personnel should not visit 'at-risk' sites prior to arrival for work and should, where practicable, not enter and leave multiple times during the day – especially where a compartment is surrounded by high risk factors. Visitors, particularly if they have visited other establishments, may also pose a biosecurity risk. Mud and other biological contaminants on vehicles and vessels entering and leaving the site are also a biosecurity risk which must be evaluated and managed. It is important to keep a visitor book, to record all visits and visitors to the site to enable a swift and effective trace-forward and trace-back in case of disease.

The management of broodstock is a major problem and a major source of contamination in shellfish and shrimp hatcheries. Broodstock, particularly shellfish and mollusc broodstock, may have an unknown disease history (3). Since many aquatic pathogens may yield false-negative results in non-sacrificial tests, broodstock, their faeces and water and any fomites associated with their arrival should be treated as a potential source of infection. The holding and conditioning facilities for broodstock should be physically separated from the larval rearing areas, all equipment should be segregated and kept in the broodstock area, the water supply should be separate and staff should not move freely from broodstock to larval areas without application of risk mitigation procedures.

Within the farm or hatchery, it is good practice to subdivide the space into areas based on activity and risk, for example, larval grow-out areas should be separate from broodstock areas, feed preparation areas should be separate from administration areas, and workflow should, where practical, go from clean activities to dirty areas and then staff should exit the facility. Many establishments separate work areas through the use of internal partitions and require the use of foot baths and hand washing facilities between work areas.

Egg production and fertilisation should be carried out in a way that ensures that fertilised eggs are washed and do not carry adhering pathogens into the larval area (3). Egg batches should be kept separate where possible and be tested for pathogens of concern as soon as practical. Many aquatic pathogens can persist in aquatic populations at prevalences far below those assumed by standard sampling methods. For this reason, routine testing of stock may not detect disease. In such cases, if broodstock are destroyed after spawning, they should be tested for vertically transmitted diseases of concern, and if positive, the offspring should be assumed to be infected, even if testing using standard sample sizes provides negative results.

Equipment in the facility should undergo regular maintenance and testing to ensure that it is operating within acceptable parameters. For example, refrigerator or heating unit motors may appear to be working, but may not be operating at the specified temperature.

A compartment must be auditable. The biosecurity plan should define the relationship between the relevant enterprise/industry and the competent authority and their respective responsibilities, including the processes for oversight and independent audit of the operation of the compartment by (or on behalf of) the competent authority.

Surveillance for the agent or disease

A testing regime is an essential part of the concept of a compartment. Testing should be planned, regularly carried out and encompass both disease surveillance and hygiene issues (for example, shellfish hatcheries routinely monitor bacterial loads in pipelines, which should be below 10^4 bacteria/ml for larvae [18], and changes to normal bacterial plate-counts can give an early indicator of filter failure). Surveillance for pathogens of concern should occur regularly on larvae in the facility, in accordance with a sampling plan approved by the competent authority.

Finally, whether required by the competent authority or not, all larvae leaving the facility should be tested for pathogens of concern by an independent laboratory. This is as much about ensuring the reputation of the establishment as it is about the quality of the larvae, and can avoid expensive disputes should mortalities subsequently occur.

Diagnostic capabilities

Most hatcheries will routinely monitor larvae for condition and growth, and also for bacterial loading in tanks, pipes and on surfaces. Commercial test kits for common pathogens are being increasingly used. However, it is essential for compartments, in consultation with the competent authority, to have ready access to a well-equipped diagnostic laboratory and to appropriate veterinary assistance. This will speed the implementation of control measures, should a health problem be present.

Emergency response, control, and notification capability

In addition, the biosecurity plan should have a section on what to do if a disease emergency occurs in the vicinity of the establishment, in the broodstock area, or in the larval area. This should be detailed, and include responsibilities of staff, isolation of affected areas, sample collection for diagnostic purposes, phone numbers to call for notification to the competent authority and for diagnostic assistance (including after-hours contact details) and action sheets to tick as tasks are completed. The biosecurity plan should be an officially approved document with relevant sections laminated and readily available to staff in wet areas, and with copies available to relevant personnel off-site.

The biosecurity plan should include a section on disaster recovery (it should contain, for example, details of where stocks of veterinary drugs can be obtained, where emergency generators can be leased, and where tonnes of dead fish can be disposed of).

An example of the evaluation of biosecurity measures on salmon farms using the HACCP methodology

The cornerstone of compartmentalisation is the establishment of an auditable biosecurity plan. The following example illustrates the steps required to apply a HACCP approach to biosecurity.

Salmon farming can be divided into two general phases: the fresh water and the saltwater stages. The fresh water stage comprises all the production steps from spawning, to fry production, to the production of smolts that are ready to be transferred to the ocean. The saltwater stage starts with the introduction of smolts into sea pens and finishes at harvest. In some operations, the broodstock (i.e. adult fish that will be spawned) are kept in a separate saltwater facility, but for the purposes of this example the broodstock are extracted directly from the saltwater farm.

Within these two broad stages, there are several intermediate steps intended to reproduce the natural life cycle of salmonids. Often the transition between intermediate steps involves moving the fish to and from different physical units, increasing the risk of spread of infectious diseases among separate production units.

Briefly, the production cycle starts when the broodstock are selected from saltwater farm(s) and transported to freshwater ponds in the hatchery. The adult fish are spawned and the eggs are manually fertilised and transferred to incubation units. The hatched alevins remain in the incubators until their yolk sacs are consumed. As alevins become fry, they are transferred to (bigger) fry tanks usually located in the same facility, and after they reach a certain size, they are transported to open pens in large freshwater bodies such as lakes.

Salmon that are physiologically ready to migrate to saltwater are called smolts. They are moved as a cohort to floating pens usually located in protected bays or estuaries. After the fish reach a certain average weight (2.5 kg to 4.5 kg, depending on the species), they are transported in well boats to processing plants where they are slaughtered and processed for human consumption.

Most of the long-distance transportation of fish between production units is done in water tanks on specially designed hauling trucks, or in well boats, whereas the transfer within a production facility can be made using nets or containers or by diverting water flow.

Fish in different production stages are commonly graded and split into different tanks/cages based on size to obtain more homogeneous populations.

Depending on the country, region, and company/producer, the farming cycle may present many variations. For example, some countries allow for smolts to be grown in lakes, whereas in other areas smolts are only grown in ponds in-land; some operations will keep a separate broodstock, whereas others will gather the broodstock from the sea pens; fry can be grown in ponds in the hatchery or moved to fry facilities elsewhere. Also, depending on local regulations, slaughter can occur at the processing plant or at the sea site, in which case carcasses are placed in iced bins and transported to the processing plant (most regulatory agencies stipulate that blood and/or any fish parts cannot be released into the ocean after sea site harvest).

One important characteristic of the salmon farming industry is that companies are often vertically integrated. In other words, a single company manages the entire production cycle, from spawning to harvest. However, smaller companies may use external resources for some of the stages that require expensive inputs or technology. For instance, smaller operations may skip the freshwater cycle by buying smolts, or also outsource the harvest and processing of the food-size fish.

The aforementioned characteristics make disease management in farmed salmon complex, since populations are moved, mixed (i.e. graded and split), and fish in some stages are kept in open cages, facilitating the contact with wild fish populations, and the spread of diseases through water.

Compartments

Several stages of salmon farming occur in open systems (i.e. smolts in freshwater pens and adults in saltwater cages), making the definition of a compartment particularly challenging.

The hatchery stage may be defined as a compartment for one or more diseases if correct biosecurity measures are in place. For example, some modern facilities integrate the entire freshwater cycle – from spawning to smolts – in a single site, with constant surveillance for diseases of importance and tight biosecurity measures, including filtration and disinfection of incoming water supply, restricted access to personnel and vehicles, and routine sampling for economically important diseases such as infectious pancreatic necrosis (IPN), vibriosis and bacterial kidney disease (BKD). Even in highly controlled systems, the broodstock can be an important source of infection, so testing and culling of broodstock for relevant diseases such as IPN and BKD is common practice (12, 24). Since most testing methods do not return immediate results, egg batches are separated and only groups from siblings with undetectable or very low levels of the agent are kept for hatching.

Most agents causing OIE listed salmon diseases such as infectious salmon anaemia and IHN can be present in both the freshwater and saltwater stages of the fish. Hence, although a compartment can be established for a hatchery, this can only happen if the open cage stage is also assessed and included in the compartment.

Depending on the disease, the open stages in lakes and oceans could also be defined as compartments, if the disease is not known to be present in wildlife populations and if proper biosecurity measures, and surveillance of both wild and farmed populations, are in place.

The following section will exemplify the evaluation of biosecurity measures in the different production stages of a typical salmon farm, using the HACCP framework.

Biosecurity assessment

Zagmutt (34) used the HACCP framework to assess risk factors for the introduction and spread of IPN virus (IPNV) in salmon farms in Chile. Parts of this study are used to exemplify the use of the HACCP methodology to evaluate biosecurity measures.

The definition of the units of study and the evaluation of all the potential pathways for introduction and spread of diseases are two basic components of the assessment of on-farm biosecurity measures. Clearly defined pathways will greatly facilitate the identification and ranking of critical control points for disease introduction and spread, hence special care should be taken at this stage. Field visits are very helpful for identifying pathways, since the assessor can capture practices that may not be described in the company's management guidelines, or may be omitted by the experts consulted. For the following example, several field visits were performed at each production stage, and the pathways were reviewed and revised with experts.

Units of study

The different units to be studied will depend on the specific management of the industry or particular company to be assessed, and the epidemiology and ecology of the disease of interest. For this example, the salmon farming cycle was divided into four stages based on current management and production units, as follows (the weight ranges are for the Atlantic salmon [*Salmo salar*] cycle):

– hatchery: freshwater facility housing individuals from spawning to fry up to approximately 0.5 g

– fry: in-land facility housing fry from 0.5 g to roughly 20 g

– smolts: open-cage facilities housing fry from 20 g to smolts of approximately 100 g

– saltwater: open-cage facilities housing fish from smolt to harvest size (4.2 kg to 4.5 kg).

Flow diagrams

Diagrams showing the pathways for potential introduction and spread of pathogens to and from the different stages provide a good way of conceptualising different risk sources. For simplicity, only pathways for the hatchery and saltwater stages are shown in Figures 2 and 3, respectively.

In Figure 2, 'Eggs from outside supplier' come from outside sources, enter the facility, and then are placed in tanks for 'Eggs with eye-spots'. Dead fry/eggs (mortality) from each population unit exit the facility as 'carcasses'. Some farm management is specific to certain populations of fish (i.e. disinfection of eggs) whereas other routine management, such as cleaning, is applied to all populations in the farm (not shown in the figure).

In Figure 3, the farming unit is not an enclosed facility, but instead is a group of floating pens situated in the ocean. Hence, the system is naturally permeable since it shares the same environment and water with other aquatic species, such as wild fish and sea birds, that may carry disease-causing pathogens (6, 20, 21, 23, 28).

For compartmentalisation purposes, special attention must be placed on personnel and material (e.g. feed, vaccines, equipment, eggs, wild fish) entering and exiting the farm or sea site, since these are potential risk factors for the introduction and spread of disease agents among farms. Also, any movements within the farm are potential risks for the spread of disease within the facility.

Hazard analysis and critical control points

After performing field visits, obtaining expert consultation and reviewing the flowcharts, general critical control points for the introduction and spread of pathogens can be identified.

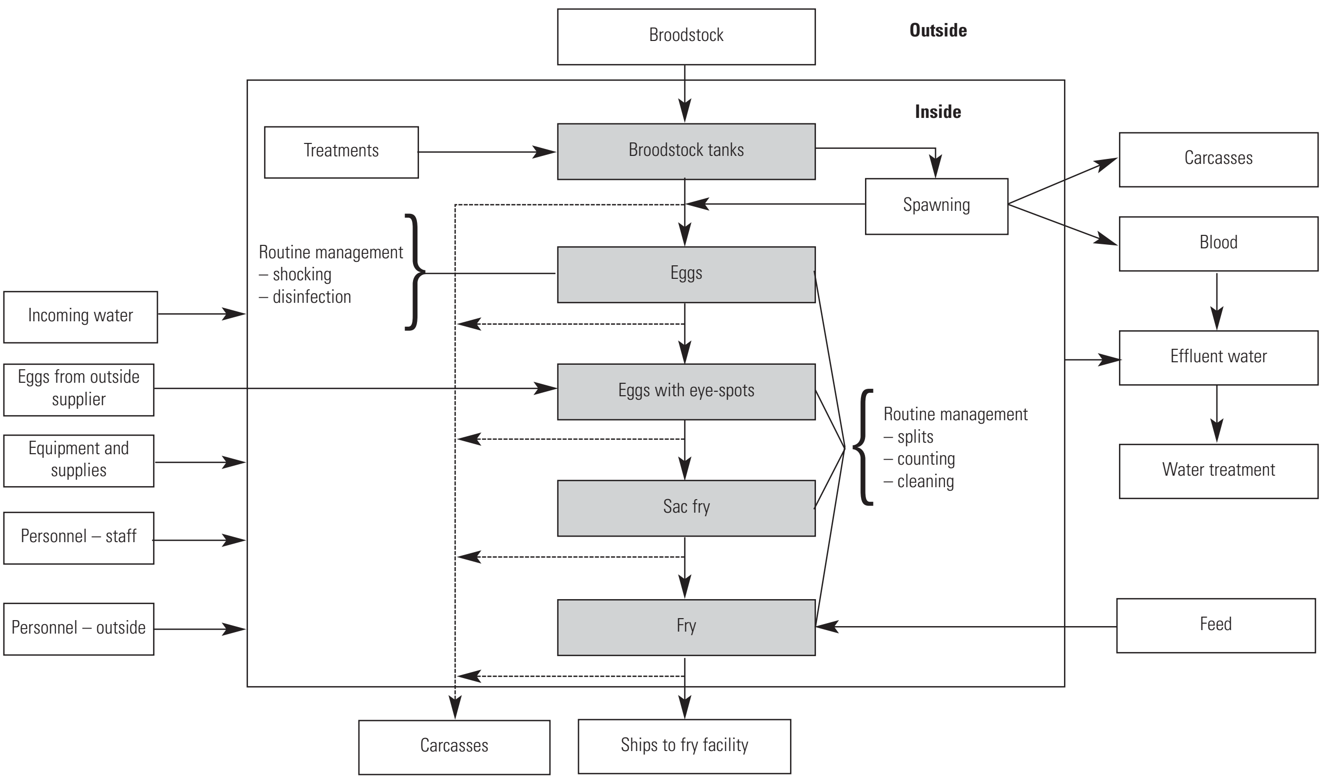

Fig. 2
Pathways for potential introduction and spread of pathogens in a hatchery
The larger frame represents the farm. The population units are represented by grey boxes. The solid arrows going into the larger frame represent potential sources of infection, and the discontinuous arrows indicate mortality removed from the system

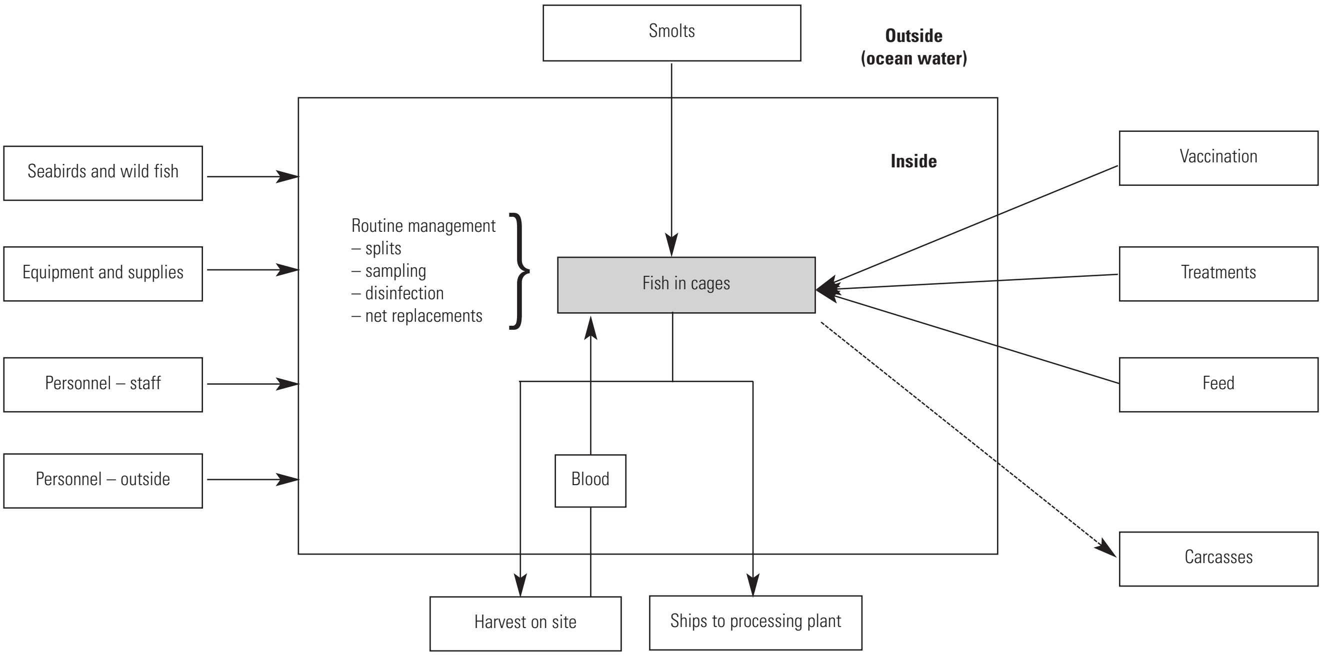

Fig. 3
Pathways for potential introduction and spread of pathogens in a saltwater farm
The larger frame represents the sea site. The solid arrows going into the larger frame represent potential sources of infection, and the discontinuous arrow indicates mortality removed from the system

For the IPNV example, the general critical control points for viral introduction can be classified as Outside Genetic Material, Personnel, Water, and Equipment and Supplies. Similarly, factors that may increase the risk of spread of the agent can be grouped as Routine Management, Personnel, Water, and Carcass Disposal.

Clearly, there are several options to assess in each risk group. For example, Outside Genetic Material can be imported or produced in the country, and genetic material can also come from the same company, or come from another company. Likewise, there may be different levels of risk depending on the water source and treatment. If a hatchery is supplied with UV-disinfected well water, the risk for introduction of infectious diseases will probably be smaller when compared to a hatchery with water supply from a river with native species that can harbour pathogens such as IPNV.

Given the wide variety of options and levels of risk, it is often impractical to measure the quantitative impact each risk has on the overall biosecurity of the farm. If risks can not be quantified, it may be possible to rank them or at least group them in broad categories such as high, medium and low.

One popular option for ranking risk factors is eliciting expert opinion. For example, Horst *et al.* (13) used experts to obtain different risk factors for the spread of contagious animal diseases, using conjoint analysis. The methodology is based on the principle that a product or event can be evaluated as a composition of attributes (8). Hence, instead of asking the expert directly for a specific risk factor, the expert is asked to rank a combination of factors. This avoids the potential bias and extreme answers that can happen when a single option is presented (11).

In the IPNV example, a similar methodology was used to assess the relative importance of different risk factors, and to evaluate the effectiveness of different biosecurity measures.

Table I shows the five risk factors the experts found most important for the introduction of disease into production facilities. Table II shows the five most important pre-emptive measures, as ranked by the experts.

The results from the expert consultation can help identify critical control points where biosecurity should be focused, and which pre-emptive measures may adequately avoid the introduction of diseases into, and spread within, a compartment. Nonetheless, the identification of critical control points should not rely solely on expert advice, but should also be based on the available scientific evidence and, where possible, be underpinned with sound risk analysis methodologies.

Table I
Ranked risk factors (first five) for the introduction of infectious pancreatic necrosis (IPN) virus, based on expert opinion

Order	Risk
1	Culture in waters with high prevalence of IPN
2	Equipment and supplies from other centres, no disinfection
3	Personnel entering facilities without proper clothing
4	Personnel entering facilities with proper clothing, not obeying biosecurity measures
5	Imported eggs and/or smolts

Table II
Ranked pre-emptive measures (first five) against the introduction of infectious pancreatic necrosis (IPN) virus, based on expert opinion

Order	Pre-emptive measure
1	No access to visitors or outside personnel
2	Properly disinfected equipment and supplies
3	New equipment and supplies
4	Domestically produced eggs and/or smolts
5	Personnel entering facilities with proper clothing, following biosecurity measures

Discussion

Increases in the variety and scale of global trade, together with international travel movements, have augmented the difficulties faced by competent authorities in maintaining country and zone freedom status. Thus, the concept of on-farm biosecurity is becoming more acceptable to the agriculture and aquaculture sectors, as there is growing awareness that on-farm biosecurity measures can provide another layer of assurance, complementing measures associated with country freedom and zone freedom and providing business security should country or zone measures be breached. It is also true that in contrast to achieving country or zonal freedom – which depends on control measures imposed by regulatory agencies and is subject to availability of public funding – compartmentalisation devolves the control (and costs) of farm biosecurity to a partnership between the competent authority and the individuals running the business.

With more aquaculture companies and individual farmers recognising the benefits of seeking disease-free compartment status, and with the costs and difficulties of proving country and zone freedom rising, it is likely that the recognition of compartments will become the dominant form of disease freedom certification for international trade.

The successful establishment of a compartment will be very dependent on the characteristics of the production system. The concept naturally applies to closed systems like the shellfish/shrimp culture or salmon hatcheries described in this article, whereas it can be more challenging to implement in open systems like salmon farming in sea pens.

Several reasons may make the implementation of a compartment in open systems difficult. For example, some agents causing OIE listed salmon diseases are present in both freshwater and saltwater stages of fish. Hence, a compartment for those diseases should not only include the hatchery but also the open cage stage. Open systems often share the same environment and water with other aquatic species, such as wild fish and sea birds, that may carry disease-causing pathogens (6, 20, 21, 23, 28), adding complexity to the establishment of the compartment. Nonetheless, if the disease is not present in wildlife populations and proper biosecurity measures and surveillance of both wild and farmed populations are in place, open stages in lakes and oceans could also be defined as compartments free of a particular disease.

Compartmentalisation allows continuation of trade by providing the necessary assurances that the spread of pathogens can be avoided. Some argue that compartmentalisation will be detrimental to competent authorities and surveillance systems, the main criticism being that the majority of the resources will be directed towards highly integrated companies with export markets, while smaller operations and family production systems would be of secondary importance. Additionally, critics of the concept claim that compartmentalisation will weaken the role of the competent authority by transferring too much authority and self certification responsibilities to the management of the compartment. Compartmentalisation should be viewed as a tool to allow trade while a country reaches disease freedom. Under certain circumstances where disease eradication is not deemed possible, such as when there is a wildlife reservoir or the infection is transmitted by vectors, compartmentalisation may be the only alternative. It is important to stress that the recognition of compartments by the competent authority of an importing country requires the direct involvement of the competent authority of the exporting country through providing certification of the health status of the compartments and certifying the particular commodity to be exported. Additionally, surveillance within and outside the compartment is mandatory to confirm disease freedom within the compartment and to understand the epidemiologic situation surrounding the compartment and thus, enable the adoption of appropriate safeguards to prevent the introduction of the infection.

Data is available to estimate the risk of spread of some diseases from the movement of processed fish (17).

However, more studies are needed to integrate such data into biosecurity assessments, particularly when establishing compartments in endemic areas.

The feasibility of establishing compartments is largely dependent on the system of production and the epidemiology of the disease(s) for which the compartment is being defined. Therefore, the concept may not be universally applicable across all systems and diseases.

Compartmentalisation provides an opportunity to develop and maintain strong operational relationships between the management of the compartments and the competent authorities. International trade is largely based on trust. However, trust cannot be achieved without transparency in the certification procedures used to document the health status of the compartment.

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La compartimentation dans les systèmes de production aquacole

C. Zepeda, J.B. Jones & F.J. Zagmutt

Résumé

La compartimentation est un nouvel outil de gestion des maladies au niveau national. En aquaculture, la réussite de la compartimentation dépend essentiellement du système de production aquacole et de l'épidémiologie de la ou des maladies par rapport auxquelles est défini un compartiment. En conséquence, la compartimentation n'est peut-être pas applicable universellement dans tous les systèmes, ni pour toutes les maladies. Les auteurs examinent la mise en œuvre de ce concept, à partir de plusieurs exemples concrets de production aquacole ; ils abordent également l'utilisation de l'analyse des risques et des points critiques pour leur maîtrise (HACCP), méthode visant à garantir la biosécurité du système. Le rôle de la compartimentation dans la gestion des urgences sanitaires affectant l'aquaculture est également examiné.

Mots-clés

Analyse des risques – Aquaculture – Biosécurité – Compartimentation – Gestion des maladies – HACCP.

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Compartimentación en los sistemas de producción acuícola

C. Zepeda, J.B. Jones & F.J. Zagmutt

Resumen

La compartimentación es una nueva herramienta para hacer frente a las enfermedades dentro de un país. En la acuicultura, su correcta aplicación depende en gran medida del sistema productivo y de la epidemiología de la(s) enfermedad(es) contra las que se conciban este tipo de medidas. No se trata, por lo tanto, de un método que pueda aplicarse universalmente a cualquier sistema productivo o enfermedad. Los autores estudian la aplicación práctica del concepto, ofreciendo ejemplos de varios sectores concretos, y reflexionan

sobre la aplicación del análisis de peligros y los puntos críticos de control (HACCP). Además, examinan la función de la compartimentación a la hora de afrontar emergencias sanitarias que afecten a las actividades acuícolas.

Palabras clave
Acuicultura – Análisis de peligros y control de puntos críticos – Análisis de riesgos – Bioseguridad – Compartimentación – Gestión de enfermedades.

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