Aquaculture Readiness Data Phase II

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1 Executive summary

1.1 BACKGROUND

Protection of New Zealand's natural resources and primary industries from the impacts of unwanted organisms requires a high degree of preparedness and planning. The need to be prepared invokes all aspects of New Zealand's biosecurity system from surveillance and prevention of incursions, to incursion responses and pest management. Pests and diseases can spread rapidly, so the ability to detect early and act swiftly to eradicate or contain them is important. An essential prerequisite to such action is prior knowledge of the location of likely hosts, suitable habitats and vectors of spread.

1.2 METHODS

Phase I consited of data collection in a suitable format to underpin effective surveillance, incursion investigation and response, and biosecurity readiness work for cultured and enhanced aquatic species. The data collected in Phase I are used in Phase II to create 'defined areas' in which aquacultured organisms have a similar likelihood of exposure to a pest or disease. A three-stage approach was used to derive the defined dispersion areas. In the first stage, we reviewed relevant examples of disease and pest preparedness work/research. This guided our development of dispersion areas in the second stage, in which GIS layers representing the geographical distribution of aquaculture facilities and vectors of disease and pest movement were established. Potential vectors include hydrodynamic features of aquacultural areas, anthropogenic vectors, and other relevant environmental factors, such as habitat types that are likely to influence transmission of pests and diseases. The third stage integrated hydrodynamic layers to derive the proposed dispersion areas. Input from MAFBNZ and other stakeholders to the process was sought at workshops held in Nelson and Auckland in late 2010. The consensus was that the simplest modelling option for marine farms should be adopted and applied nationwide – i.e. dispersion would be modelled on the basis of tidal advection. Modelling of dispersion by downstream drift in rivers used flow rates (mean, mean annual maximum, and mean annual low flow) to derive downstream dispersion distances, assuming 1–3 days infectious life. This included land-based facilities that discharge into waterways.

1.3 RESULTS AND DISCUSSION

In total, 55 freshwater and 40 marine dispersion areas were defined. The results presented in this study are influenced by a number of modelling assumptions and simplifications. The use of a 24-hour timeframe for the modelling was constrained by resources and by the lack of more complex (i.e. producing useful predictions over longer periods) models for many parts of the coast. Wind and barometric forcing also drive currents, however, and under certain conditions (e.g. strong winds or storms), dispersal may be far greater than predicted by tidal currents alone.

Dispersion of pathogens and pests by water movements occurs over relatively small spatial scales and long-distance dispersion (for example, from the top of the North Island to the South Island) is unlikely over the period during which the pathogen remains infectious. Human-mediated movements of aquaculture stock and equipment, in contrast, are capable of transmitting pathogens over much larger distances and shorter time-frames. Information on movements of aquaculture stock and equipment was collected as part of Phase I and has been plotted in GIS to illustrate the aquaculture species moved, the sources and destinations. Due to limited data of uncertain quality, it is not currently possible to incorporate these anthropogenic movement data into defining dispersion areas. If the defined dispersal zones concept is to be implemented, this is a key data need to be addressed.

Stakeholders identified a number of actual or potential vectors for the transfer of pathogens and pests that are not currently included in the movement database. One particularly important observation was that movement information is not held by individual farmers in an easily accessible form, and varies widely by sector.

1.4 RECOMMENDATIONS

1.4.1 Database maintenance

Maintenance of the location dataset will require the following:

- addressing information noted as missing and other errors identified during stakeholder consultations;
- updating information on ownership and contact details;
- adding information on new farms and other facilities;
- adding information on changes in use, including closure and changes in species farmed or processed;
- adding information on changes in area of farms or other facilities.

1.4.2 Refining of dispersion modelling

Hydrodynamic models are regularly used to manage development of aquaculture throughout New Zealand, commissioned by the industry or by regulatory bodies such as regional councils and the Ministry of Fisheries (MFish). For example, MFish has recently commissioned studies of the feasibility of finfish farming in the inner Hauraki Gulf, the Marlborough Sounds and Tasman/Golden Bays. This work involved particle tracking models to predict the spread of waste and of propagules of marine pests from potential farm sites. Sharing of such information among farming and regulatory organisations will create opportunities for modelling of pathogen dispersion to be improved progressively.

1.5 GENERAL CONCLUSIONS

There was general agreement among stakeholders consulted that the defined-areas approach is useful and worthwhile. In this approach marine farms need to be considered in association with customary, commercial and recreational wild harvest and movement, and of wild populations. There is a strong need for a good database of information and it needs to be decided how the data would be obtained, refined and who would hold and manage it. The relative merits of continually updating this improved database versus just updating the contact list needs to be assessed.

There is a clear need to educate the industry on the effects of disease outbreaks and how this approach can help minimise potential impacts. This is a good time to do this because the recent outbreak of oyster herpes virus is fresh in the industry’s mind. When developing industry support for response plans, a disease-based approach would be better than a pest-based one in terms of industry understanding its importance.

Development of dispersion zones (defined areas) on the basis of types of organism (infectious life-span, etc., the approach taken to date) would overcome the difficulty in predicting the species that may arrive and cause problems. Later modelling could take into account other characteristics of the pathogens than just life-span, such as whether they are passive or actively motile and whether they rely on a secondary host.

2 Glossary

Term	Definition
Aquaculture management area	A coastal marine area described as an aquaculture management area under the Resource Management Amendment Act (No. 2) 2004
Biosecurity	A set of preventive measures designed to reduce the risk of transmission of infectious diseases, pests, invasive alien species or living modified organisms.
Catchment	A natural land drainage area.
Epidemiological unit	A group of animals or plants that share approximately the same likelihood of exposure to a pathogen. This may be because they share a common environment (e.g. animals in a pond), or because of common management practices. It may apply to the stock on a particular farm or stock sharing a communal animal handling facility. The epidemiological relationship may differ from disease to disease, or even strain to strain of the pathogen. (World Organization for Animal Health (OIE) definition)
Farm	A facility for the rearing and growing of stock organisms for commercial use. Note that under the Fish Farming Regulations 1983, “fish farm” does not include any hatchery established and operated by an acclimatisation society (now Fish and Game New Zealand), MAF or the Department of Internal Affairs (now the Department of Conservation).
Geodatabase	A database designed to store, query, and manipulate geographic information and spatial data – may be incorporated into a geographic information system (GIS).
Hatchery	A facility for rearing stock from hatching.
Host	An organism that carries a parasite, disease or pathogen.
Hydrodynamics	The study of liquids in motion, including tidal and wind-driven currents in the sea and river flow.
Incursion	The entrance into, or invasion of, an area or territory by a pathogen, pest, invasive alien species or living modified organism.
Ongrowing site	A farm, area or water body where juveniles are grown to market size.
Pathogen	A disease-causing organism
Pond	A stock holding facility.
Preparedness	Developing operational systems and capabilities before an emergency happens. This includes self-help and response programmes for the public, as well as specific programmes for emergency services.
Processing facility	A facility for processing stock organisms for commercial sale.
Spat catching	Collection of juvenile bivalves (‘spat’) as they settle out of the water column and metamorphose from their planktonic larval form to their adult form.
Stock organism	A valuable aquatic animal or plant reared for commercial purposes.
Surveillance	The systematic ongoing collection, collation, and analysis of information related to animal health and the timely dissemination of information to those who need to know so that action can be taken.
Transfers	The conveyance or removal of aquaculture stock/equipment from one place to another.

3 Introduction

3.1 BACKGROUND

Protection of New Zealand's natural resources and primary industries from the impacts of unwanted organisms requires a high degree of preparedness and planning. The need to be prepared invokes all aspects of New Zealand's biosecurity system from prevention of arrival to surveillance, incursion responses and pest management. Pests and diseases can spread rapidly, so swift action to eradicate or contain them is important. An essential prerequisite to such action is prior knowledge of the location of likely hosts, suitable habitats and vectors of spread (Inglis et al. 2006; Floerl et al. 2008).

Aquaculture is one of New Zealand's most important aquatic industries. Aquaculture in particular is growing rapidly. The aquaculture industry has set itself ambitious growth targets (NZAC 2006), and a Technical Advisory Group convened by the government has made a series of recommendations to help advance aquaculture development in New Zealand (Aquaculture Technical Advisory Group 2009).

While keen to expand, the aquaculture industry is fully aware of the need for growth to be demonstrably sustainable and secure from biosecurity threats. Recent outbreaks of disease, such as ostreid herpesvirus-1 (OsHV-1) in New Zealand and abalone virus ganglioneuritis in Australia, have left the New Zealand aquaculture industry in no doubt about the threats that unwanted organisms pose to the commercial success of their operations. There have also been several recent incursions of non-indigenous pests with the potential to adversely affect the industry, such as the seasquirts *Styela clava* (Gust et al. 2006), *Didemnum vexillum* sp. (Denny 2008) and *Eudistoma elongatum* (Morrisey et al. 2009), and the tube worm *Sabella spallanzanii* (Inglis et al. 2008).

While aquaculture is at risk from biosecurity failures, it can also be an exacerbator of biosecurity risks by spreading pests and diseases through stock and equipment movements. Thus, there is a need for proactive systems to limit the likelihood of entry and subsequent spread of pests or diseases. Currently, New Zealand has strict import controls in place to limit the potential for pest or disease introductions. However, such systems are not infallible and preparation is required to ensure (1) early detection of any incursion and (2) that there are widely understood response actions that can be implemented quickly when an incursion is detected. MAF, in recognising the biosecurity needs of the aquaculture industry, has commissioned research (the Aquaculture Readiness Data project) to support developing a readiness system for aquaculture.

Phase I of this research was designed to obtain fundamental information on New Zealand's aquaculture and fisheries enhancement industries.. Phase I produced (1) a geodatabase of aquaculture facilities (land, marine and freshwater based) from publicly available information, (2) information on the movement of stock and equipment between facilities based on a survey of the industry and, (3) a report on the current spatial knowledge of New Zealand's aquaculture operations.

Phase II was designed to develop, in consultation with stakeholders, defined areas based upon the concept of an epidemiological unit. Aquacultured organisms in each defined area have a similar likelihood of exposure to a pest or disease. In the context of disease and pest management, these areas may serve as surveillance zones for the early detection of incursions, act as predefined movement control areas, or serve as zones to re-establish trade during or after an outbreak, in addition to providing spatial information about farmed or enhanced species for general animal health management. The World Organisation for Animal Health (OIE 2011) has described the concept of an epidemiological unit as "a group of animals that share approximately the same *risk* of exposure to a *pathogenic agent*". Creating defined areas based upon the concept of the epidemiological unit will underpin biosecurity activities in response and readiness work, which stakeholders both agree with and understand the benefits of having.

3.2 AQUACULTURE IN NEW ZEALAND

3.2.1 Species farmed

The species of marine and freshwater organisms that may be farmed in New Zealand (Appendix 1: Table 1) were gazetted in 2006 under the Freshwater Fish Farming Regulations 1983[1].

At present, however, very few of these species are commercially farmed and production is overwhelmingly dominated by (in order of production) Greenshell™ mussels (33,296 tonnes exported in 2008: information from Aquaculture New Zealand), king (or quinnat) salmon (3,479 tonnes) and Pacific oysters (1,873 tonnes). Blue mussels, Bluff oysters and paua (abalone), Koura, and Macrobranchium are also farmed. Species still in the research or pre-commercial stages include eels, European perch, sea cucumbers, kina, rock lobsters and groper/hapuka (source of information: Ministry of Fisheries[2]).

No marine algae are currently farmed in New Zealand (Wendy Nelson, NIWA and Jill Bradley, Seaweed Association of New Zealand, pers. comm. to Mike Page, NIWA).

3.2.2 Aquaculture in the regions

The principal regions for marine farming in New Zealand are: Northland, Auckland, the Coromandel, Tasman and Golden Bays, the Marlborough Sounds, Canterbury and Stewart Island (Table 2). Freshwater and land-based aquaculture facilities are scattered around New Zealand.

Table 2 Major marine farming regions, major species cultivated and percentage of total production for the three dominant species in 2008

Region	Greenshell™ mussels	King salmon	Pacific oysters	Dredge oysters	Paua	Other
Northland			47%			
Auckland	3%		26%			
Coromandel	22%		21%			
Tasman and Golden Bays	3%		1%			Scallop, cockles, spat catching
Marlborough	68%	75%	5%	Yes	Yes	
Canterbury	1%	6%			Yes	
Stewart Island	3%	19%		Yes		

Source: www.aquaculture.org.nz

[1] see http://fs.fish.govt.nz/Page.aspx?pk=24&tk=450
[2] see http://fs.fish.govt.nz/Page.aspx?pk=24&tk=349

The regional coastal plans of some regional councils and unitary authorities currently restrict the range of species that may be farmed in their coastal marine area. Waikato Regional Council and Tasman District Council, for example, only allow shellfish farming and prohibit other types of aquaculture (even experimental). These restrictions for the Waikato Region and Tasman District are, however, under revision.

Summaries of the current status of aquaculture in each region of the country, and developments currently in progress (website Government of New Zealand 2011). These are described below.

Northland: Currently 704.9 ha of marine farms, mostly oysters with some mussels. An aquaculture research facility (operated by NIWA) and land-based paua farm are located at Bream Bay. The regional council is in the process of proposing a plan change to provide for aquaculture growth in the region.

Auckland: Currently 326 ha of marine farms, mostly oysters and some mussel farms. There has been a rapid increase in applications for aquaculture development since 2000, especially in the Firth of Thames. Hearings on new Aquaculture Management Areas (AMAs) are on hold since 2006, pending consultation on proposed aquaculture policy framework and aquaculture-exclusion areas.

Waikato: Currently 1,003 ha of marine farms, mostly mussels and some oysters in the Firth of Thames and Coromandel areas, together with land-based paua farms. An additional 520-ha AMA in the Firth of Thames (Wilson Bay Area B) will be consented in 2010. At present, the regional coastal plan prohibits most aquaculture outside existing locations and the Wilson Bay zone, but this may be lifted as a result of current aquaculture law reform. Assessment of environmental effects of farming of ‘additive species’ (i.e. species for which material is added to the water column or directly to stock, including feed and therapeutants) in the inner Hauraki Gulf is currently in progress.

Bay of Plenty: Currently 9.6 ha of oyster farms in Ohiwa Harbour and a a small, land-based paua farm at Te Kaha. Permits for mussel farms at Te Kaha (size?) and offshore from Opotiki (3,800-ha) have been approved but not yet developed and an application for a 4,009-ha mussel farm off Otamaraku is being processed.

Gisborne: There are no AMAs or coastal permits for aquaculture in the district at present, but there is a land-based paua farm at Nuhaka.

Hawke’s Bay: There are currently no operational marine farms in Hawkes Bay, but a consent has been granted for a 2,469-ha offshore mussel farm at Waipatiki Beach (the permit allows other species to be trialled). HBRC have identified the Waipatiki beach site and a 4-ha area off Mahia Peninsula as AMAs in the region.

Taranaki: Demand for aquaculture space is currently limited and the only facility is Fish and Game New Zealand’s salmon hatchery at Hawera.

Manawatu-Wanganui: There are currently no marine farms in this region.

Wellington: There has been little aquaculture development in the region to date, with only 4.3 ha of small marine farms used for trials of a range of species and a small number of land-based farms.

Marlborough: Currently 3,056.4 ha of marine farms, mostly mussels but also includes salmon, oysters and trials of new species. There are also a few consents for land-based farms for a range of species, including shellfish.

Nelson: There are currently no marine farms but there are several land-based consents for salmon, oyster, and paua facilities, including the Cawthron research facility at Glenhaven. A new research facility is currently under development near Glenhaven and, like the Cawthron facility, will draw water from the adjacent sea.

Tasman: At present there are a total of 6,086 ha of marine farms in the district, for mussel farming and mussel and scallop spat catching. Of this, 2,637 ha are in Golden Bay and 896 ha in Tasman Bay, of which 96 ha are zoned for mussel farming only, 52 ha for mussel spat catching only, and 598 ha for both mussel farming and spat catching. The remaining area is under application for spat catching. A further 2,000 ha has been approved or potentially approved for development. Assessment of environmental effects of farming of 'additive species' (species for which material is added to the water column or directly to stock, including feed and therapeutants) in Golden and Tasman Bays is currently in progress.

West Coast: Currently, there is only one mussel farm of 45.6 ha in Jacksons Bay, and a number of consents for freshwater salmon farms.

Canterbury: Currently, 179.4 ha of marine farms, mainly mussels but also salmon and paua, around Banks Peninsula. Further consents have been granted but not yet developed, including a 2,695-ha mussel farm in Pegasus Bay.

Otago: To date, there has been very little aquaculture development in Otago and planning for aquaculture management is on hold pending review of the Regional Plan: Coast. There are a small number of freshwater or land-based farms for salmon and koura.

Southland: Currently 285.9 ha of marine farms for mussels and salmon in Big Glory Bay, Stewart Island. Marine and land-based culture of a range of species in Bluff Harbour.

4 Creating defined areas

Selection of an appropriate method for deriving defined areas was based on review of relevant examples of disease and pest management programmes, and on discussions with stakeholders and MAFBNZ to identify priority aquaculture species, pests and diseases. The selected method was then applied to the database of aquaculture facilities throughout New Zealand created in Phase 1. Each of these steps is described in the following sections.

4.1 EXISTING HYDRODYNAMIC APPROACHES TO DISEASE MANAGEMENT

Stewart (1998) reviewed the rationales and likely effectiveness of mandatory or suggested separation distance among salmon farms for the purpose of disease management in Canada, Chile, Ireland, Norway and Scotland. Stewart concluded that none of the proposed distances (between 1-3 km) was adequate to provide protection against the spread of infectious diseases. This was largely because definition of separation distances was not based on hydrodynamic considerations of the individual sites. The review concluded that definition of sites for the purpose of management of diseases must be based on patterns of mixing of the water bodies around the aquaculture facilities, and coined the maxim “share the water, share the disease”. Consequently, a modelled simulation of particles (representing a pathogen) by tidal excursion was developed for Passamaquoddy Bay (New Brunswick, Canada). The patterns of dispersion of the particles identified three potential management areas within the bay “which it might be possible and advisable to manage as separate units to cope with health problems”.

This initial attempt to define management areas was based on one tidal cycle but the report acknowledged that resolution of management areas should take into account the survival times of pathogens, which can exceed 45 days, and that models should therefore be run over a much larger number of tidal cycles and with continuous release of pathogens (the initial run used a single release). Despite this the hydrodynamic-based approach has gained wide acceptance as a way of planning aquaculture management areas (Murray et al. 2005) and the present review focuses on programmes that have used this approach.

4.1.1 Coastal catchment zone management to avoid and minimise effects of infectious salmon anaemia in Scotland

Following an outbreak of infectious salmon anaemia (ISA) in Scotland in 1998, the Scottish Executive’s Joint Government/Industry Working Group on Infectious Salmon Anaemia established a system of hydrographically-defined management areas to tackle the outbreak (Scottish Executive 2000). In 2000, the Working Group reviewed approaches to definition of disease zones and areas in other countries, including Canada, Chile, Ireland, Norway and Scotland (Scottish Executive 2000). It reached similar conclusions to Stewart (1998), and recognised the importance of basing separation distances and management areas on water movement rather than specific distances.

The management areas were based on earlier methods for controlling sea lice and furunculosis, and can be used to deal with any water-borne disease. In the absence of more sophisticated hydrodynamic models for the farmed areas, management areas were derived using maximal tidal current speeds for each farm site (Murray et al. 2005). These were used to estimate tidal excursion distances around each farm (i.e. the distance water would travel from a farm over a spring tidal cycle). Where the tidal excursions of adjacent farms overlapped, the farms were assigned to the same management area, with the objective of minimising the likelihood of rapid transmission of disease from one area to the next. Addition of tidal excursions for shellfish farms to the mapping process for salmon farms generally made little difference to the proposed management areas (i.e. shellfish farms rarely occurred in areas where they could act as links between adjacent management areas). The mapping process was based on a 1-km grid. The derived areas must be reviewed on a case-by-case basis in the event of a disease outbreak to account for factors that vary over time (such as occupancy of farms) and local conditions (such as patterns of water movement).

4.1.2 Modelling dispersion of sea lice in Scottish sea lochs

A three-dimensional (3-D) hydrodynamic model of the dispersion of sea lice from a point source has been developed for sea lochs on the west coast of Scotland (Murray & Gillibrand 2006, Amundrud & Murray 2009). Output from the model is used to drive a particle tracking model which follows statistical representations of sea lice through the planktonic stages of a louse life cycle. By including maturation and mortality, the model can be used to predict the dispersion and transport of infectious sea lice from a point source and can be used to produce maps of infectivity under varying environmental conditions. Results highlight the importance of the wind-driven circulation for larval lice transport; local wind conditions can lead to formation of lice concentrations in coastal areas several kilometres from the source and can have considerable impact on the probability of sea lice infection spreading between wild and farmed fish populations. Idealised constant wind simulations have been used to locate areas that larval lice may potentially reach from given source locations.

4.1.3 Co-ordinated local area management systems (CLAMS) for aquaculture development in Ireland

The Department of Marine in Ireland developed a system for management of sea lice infestations on salmon farms in the early 1990s, operating at the scale of individual embayments that has resulted in significant and sustained improvements in lice control on farmed fish (Department of Marine 2011). Crucial elements in the success of this plan include separation of generations of fish, annual fallowing of sites, strategic application of therapeutants, good fish health management, and close cooperation between farms. CLAMS integrates the elements of single bay management into a coordinated local aquaculture management system. It provides a concise description of the bay in terms of physical characteristics, history, aquaculture operations and potential environmental or fish-health problems. It also allows various codes of practice to be customised and integrated to the aquaculture industry operating in the bay. The system also provides a framework for aquaculture management and development planning in the bay and acts as a focus group for the community. This, in turn, provides an information channel from local to national level and vice versa.

4.1.4 Conclusions

The review of existing methods for identifying management areas identified several important points:

- Defensible definition of management areas should be based on consideration of water mixing among aquaculture sites. This is most cost-effectively achieved by hydrodynamic modelling;
- Simple tidal excursion models were used successfully as part of an eradication of a pathogen (ISA) with a short infectious half-life after leaving its host (ca 24 hours) (Murray et al. 2005);

- Dispersion of longer-lived pathogens is better modelled using a more sophisticated model that incorporates tidal advection currents, residual advection currents and turbulent diffusive currents combined with a particle-tracking model parameterised with relevant biological properties of the pathogen (period of shedding by infected hosts and lifespan in the water column) (Murray et al. 2005);
- Pathogens with infectious periods of several days or more are only adequately modelled by coupling particle-tracking models with more complex hydrodynamic models that incorporate wind-driven mixing (Murray et al. 2005);
- Attempts to apply modelling to management of an outbreak of ISA in Scotland in 1998 were constrained by a lack of information on a) infectious periods of the pathogen and b) hydrodynamic information on the Scottish coast. These constraints are likely to apply to other types of pathogen and availability of hydrodynamic information for the New Zealand coastal marine area is as limited as it is in Scotland (Phil Gillibrand, NIWA, pers. comm.). Whereas adequate information is available on tidal excursion for the entire coast and more detailed models are available for limited areas, such as Cook Straight (including Golden and Tasman Bays);
- Given the resource and information constraints on the present study, we concluded that it would be most appropriate to begin the process of defining dispersion areas by using a simple tidal-excursion model and that this be proposed to stakeholders for comment.

4.2 STAKEHOLDER CONSULTATION

Consultation meetings in Nelson (26 August 2010) and Auckland (8 October 2010) took the form of presentations by members of the MAFBNZ and NIWA project teams to provide information on the background and methods for the study. These were followed by general discussions to solicit opinions on the issues raised, in particular the range of pathogens and hosts that the study should consider and the type of modelling to employ in the light of their associated life-cycle characteristics.

4.2.1 Scoping of pathogens

The potential representative pathogens identified were (depending on the modelling option chosen):

- Sea lice (finfish parasite);
- A generic shellfish parasite;
- Salmon rickettsia (representing a viral or bacterial disease of finfish);
- Abalone viral ganglioneuritis (AVG);
- Ostreid herpes virus;
- *Marteilia* (protozoan parasite of bivalves).

4.2.2 Scoping of modelling

- New Zealand's Northeast Shelf and Cook Straight are regions of focus for coastal model development and these overlap with aquaculture areas, including the Marlborough Sounds and Golden and Tasman Bays. Model resolution in these areas is relatively fine (tens to hundreds of metres) and uses local-area models;
- Given the coarseness of modelling that is likely to be possible with available hydrodynamic data, the most practical approach to selecting target pathogens may be to categorise them by behaviour and life cycle (i.e. factors that affect dispersion), and select representatives of shellfish and finfish diseases in each category, rather than focus on specific pathogens;

- Options for modelling include:
  - applying a simple model (e.g. based on tidal excursion) to aquaculture areas throughout New Zealand, or;
  - applying a more detailed model to one or more areas for which sufficient hydrodynamic information is available (including density-driven and wind-driven flows, for example, the Marlborough Sounds or Golden Bay) and comparing the results with the simple option. This would represent a case study and identify information gaps, and the approach could later be extended to other regions as information and resources allow. It would be necessary to determine how feasible it would be to extend the detailed approach developed in areas with relatively large amounts of hydrodynamic information to other major aquaculture areas where fewer data are available.

4.2.3 Selection of the method for deriving defined areas

Following stakeholder meetings in Nelson and Auckland the consensus was that the simplest modelling option for marine farms should be adopted and applied nationwide – i.e. dispersion would be modelled on the basis of tidal advection. It was noted that a detailed focus on a particular area might identify issues of concern that appear to be specific to that area from the perspective of anyone not familiar with the context of the modelling exercise.

We later decided to include diffusion in the modelling to add randomness to the trajectory of the particles, simulating the effect of turbulence. This increases dispersion around farms where tidal currents are weak, but has only a minor effect on farms where currents are strong. Movement of pathogens is entirely passive (i.e. they do not actively swim). This seemed the best approach at this stage of developing a response capability, in that it best fits the original brief, is applicable to pathogens known to be of concern to industry (both finfish and shellfish), and will provide a good illustration of the process for stakeholders (without the risk of singling out a particular region for detailed study and risking making it look like there were potential problems specific just to that region).

Modelling of dispersion of particles by downstream drift in rivers used flow rates (mean, mean annual maximum, and mean annual low flow) to derive downstream dispersion distances, assuming 1–3 days infectious life. This included land-based facilities that discharge into waterways (this information is in the geodatabase produced during Phase I). In the case of aquaculture facilities in lakes, it is possible to model dispersion of pathogens using data on average current speeds and directions of the water body, where these are known. Realistically, however, each lake is probably best treated as a single epidemiological unit because once an outbreak occurs somewhere within it there is a high probability that the disease will appear everywhere in the lake sooner or later (Colin Johnston, MAFBNZ, pers. comm.). Modelling may still need to consider dispersal out of the lake via streams, and interconnectedness of lakes and streams over the time scale in question.

It is possible that pathogens could spread from one aquaculture facility to another by horizontal transmission through wild populations of the farmed species or other vectors. This could potentially result in wider spread than would occur as a result of water movement, albeit more slowly, because it does not require that the pathogen remains infective for prolonged periods outside its host. This method of spread is, however, beyond the scope of this study.

4.3 DISPERSION MODELLING FOR MARINE SITES

The method employed to identify epidemiological units for marine farms is to conduct numerical simulations of tidal dispersal for tracers released from all present marine farm locations. A hydrodynamic model is used to calculate tidal currents over a period at spring tide. Tracer particles are released continuously from each marine farm, and their positions tracked over time. The particles are released over one tidal cycle (12.42 hours), and assumed to have a life span of 24 hours. Although 24 hours is a short time span, it follows work done in Scotland assessing an ISA outbreak (Murray et al. 2005). The Scottish study showed that 24 hours is a reasonable period over which pathogen numbers remain viable, and is an appropriate time-scale for considering tidal advection. Over longer time-periods, wind-driven circulation becomes increasingly important.

The particle tracks are used to determine what region is at risk of being infected by the source farm. A GIS polygon (outline) is created for each farm that encompasses all particle tracks originating from that farm. Relative risk of infection is defined in terms of these polygons, as described in the following section.

4.3.1 Identification of proposed particle dispersion zones

The process of defining areas based on particle dispersion is to first derive polygons that describe the area over which pathogens will be transported by tidal currents for each farm during a chosen lifespan (24 hours). All farm polygons are then over-laid. Farms that lie within the dispersion polygon of another farm are at high risk of becoming infected in the event that the other farm is infected. If a farm lies outside the dispersal polygon but the two polygons overlap, then we consider there to be a moderate risk of infection. This is a conservative approach in that while, under purely tidal conditions, it is unlikely that pathogens would reach the farm, other factors, such as a slightly longer pathogen lifespan, wind or other non-tidal forcing, could increase the distance that pathogens can travel. It also allows for some degree of uncertainty in the model predictions of tidal currents. We consider that if a farm is at moderate or high risk, then it will become infected and then act as a new source of pathogens. Thus, a group of overlapping polygons represent a single proposed management area. Polygons that do not overlap are considered to have a low risk of transmitting pathogens and form separate management areas. This is illustrated in Figure 1.

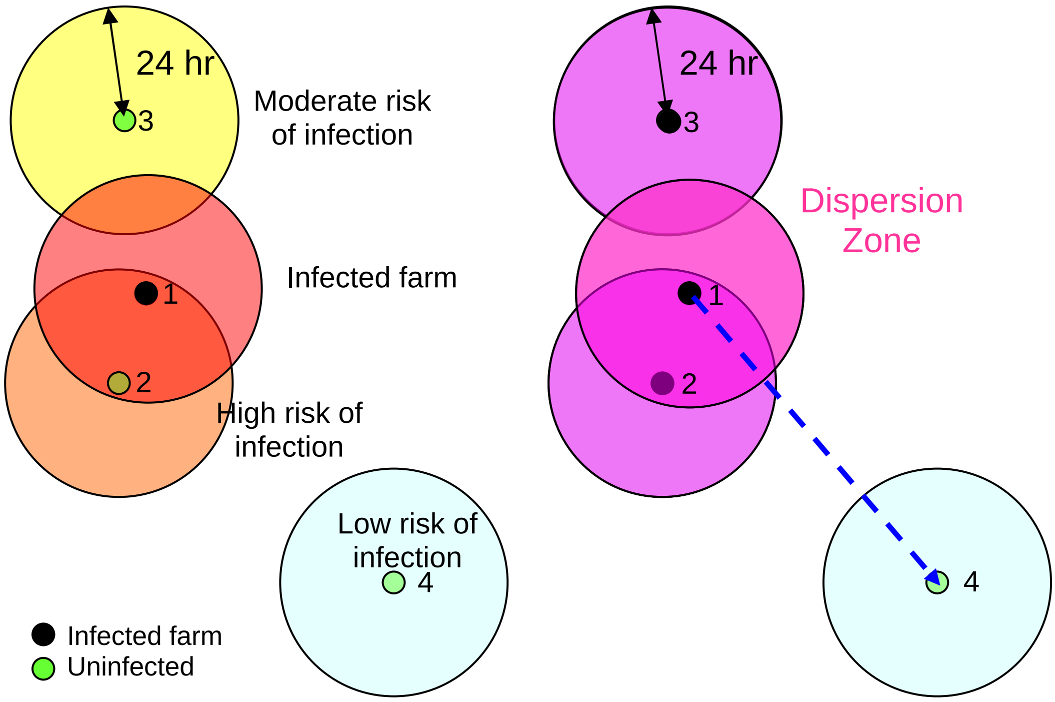

Figure 1 Representation of process by which proposed dispersion areas are defined. Left: farm 1 is infected. Farm 2 lies within the tidal excursion of farm 1, and is at high risk of infection.

The areas over which pathogens are transported are determined by simulating tidal currents with a numerical model, and using the modelled currents to transport particles released from each farm for their specified lifespan. The modelling process and the derivation of polygons that describe the area over which pathogens are transported are described in the following sections.

4.3.2 Hydrodynamic modelling

The numerical model used in this study is a general-purpose hydrodynamics model known as RiCOM (River and Coastal Ocean Model). The model has been under development for several years and has been evaluated and verified continually during this process (Walters & Casulli 1998, Walters 2005, Walters et al. 2010). The model solves the Reynolds-averaged momentum equations using finite element techniques and semi-implicit time stepping.

The model calculates water velocities over a grid consisting of triangular elements. The size of the elements vary over the grid, with smaller elements near the coastline and in regions of interest to give better resolution of flow, and larger elements offshore or in regions outside the area of interest to improve model efficiency. Two model grids were used for this study – a large grid covering the whole of New Zealand out beyond the EEZ region (Figure 2) and a smaller grid for the Cook Strait region (Figure 3). The separate Cook Strait grid was required because of the complexity of the coastline in the Marlborough Sounds, which required a large number of grid elements to resolve the coastline adequately.

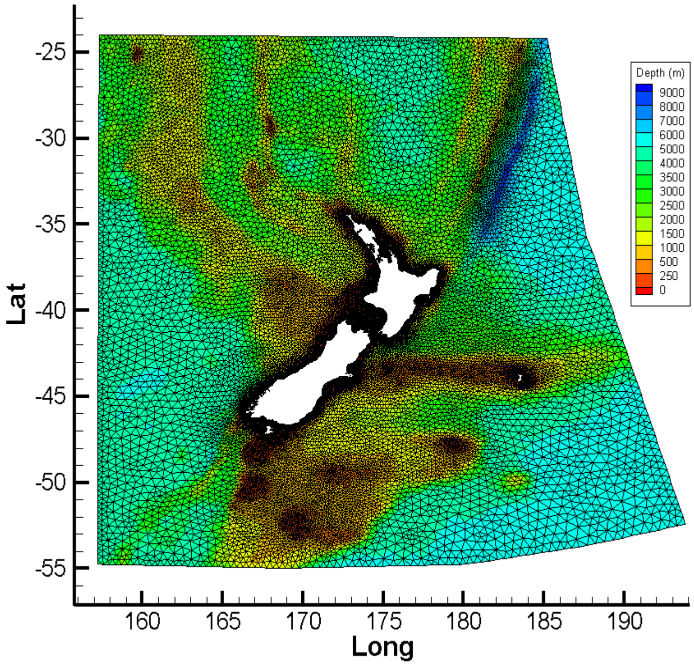

Figure 2 Overview of the grid used for hydrodynamic modelling around New Zealand.

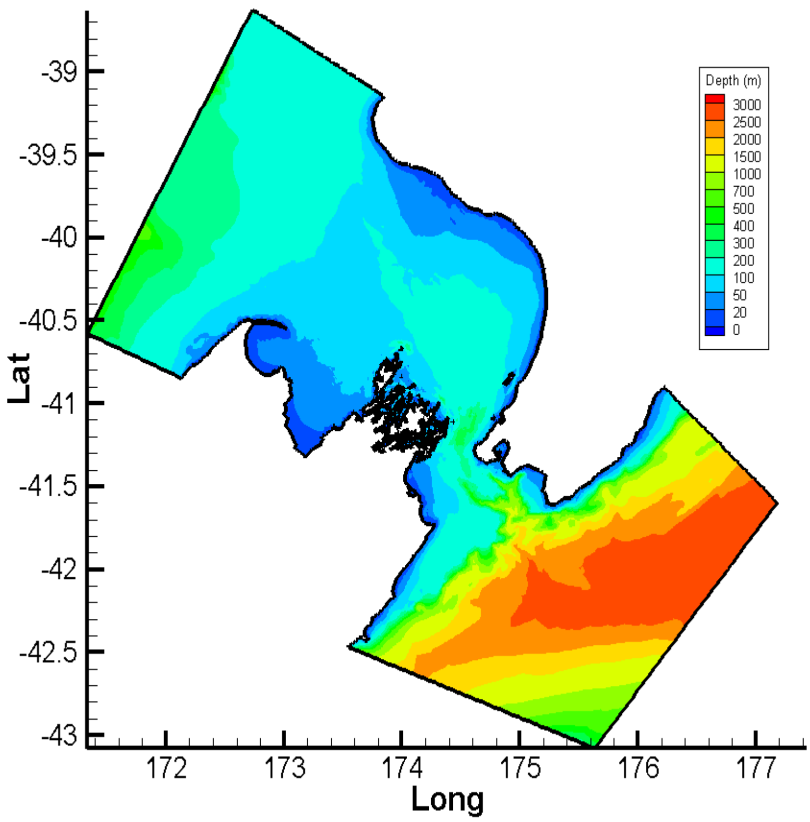

Figure 3 Overview of area covered by the grid used for hydrodynamic modelling in the Cook Strait region.

Tides are simulated by specifying the tidal variation in water level at the seaward extends of the model grid. These boundary conditions are calculated from the amplitude and phase of the six largest tidal constituents, which are the semi-diurnal (twice daily) M2, S2, and N2, and the diurnal (daily) K1, O1 and Q1 constituents.

Tidal simulations spanned the spring tide period from 8-10 October 2010. This period was selected because tides are larger than normal (but less than their astronomical maximum) and thus will drive stronger currents, leading to greater dispersal of particles from their release points. This results in a conservative (high) estimate of the likely dispersal of pathogens. Dispersal will be less at neap tides.

Simulations do not include the effect of winds, which will alter currents and increase dispersal. The modelling is 2-dimensional (2-D) and the currents are depth-averaged. The results do not, therefore, include the effects of variations in density, water speed and direction over the water depth.

4.3.3 Particle dispersal

Pathogens are treated as purely passive particles with no swimming, buoyancy or sinking. They are given a lifespan of 24 hours from the time of release. Pathogens are released continuously for 12.42 hours (one complete tidal cycle) from each farm. They are transported at each model time-step according to the velocity at their current location. Particle locations are written to file every 3 minutes. Particles are removed 24 hours after being released. The particle location file contains the co-ordinates of all positions that have been occupied by a particle during the simulation. Particles are identified according to the farm from which they were released. Tidal currents in smaller inlets can be very low, and in these regions dispersal will be caused mostly by wind-driven currents and mixing. These processes are not simulated directly. Instead, a random walk component was included in the particle path to simulate the effects of diffusion. Mathematically, the movement of a particle at each time step is described by:

$$x_{t+1} = x_t + u\Delta t + R\delta_{Hx}$$
$$y_{t+1} = y_t + v\Delta t + R\delta_{Hy}$$

where x_t and y_t are the easting and northing of the particle at the current time step, x_{t+1} and y_{t+1} the new position of the particle, u and v the east and north velocity component at the location of the particle (interpolated at each time step from the model), Δt the time step used in the model, and δ_{Hx} and δ_{Hy} represents horizontal diffusion.

Horizontal diffusion is simulated at each time step by:

$$\delta_{Hx} = R\sqrt{6K_H\Delta t}$$
$$\delta_{Hy} = R\sqrt{6K_H\Delta t}$$

where R is a random number between -1 and 1, and K_H is a horizontal diffusion coefficient. The value of the horizontal diffusion will be affected by wind, stratification, vertical and horizontal shear and in reality will be variable in both time and space. It is not possible to predict this variability, and instead a fixed value of $K_H = 1.0\ m^2\ s^{-1}$ is used. This value is within the range measured in the Marlborough Sounds (Stevens 2010). The effect of diffusion in the absence of tidal currents is illustrated in Figure 4, where diffusion of 10,000 particles over 24 hours was simulated using a diffusion coefficient of $K_H = 1.0\ m^2\ s^{-1}$. The histogram shows the distribution of the distances of particles from the origin. Diffusion produces a mean displacement of 523 m (S.D. ± 274 m).

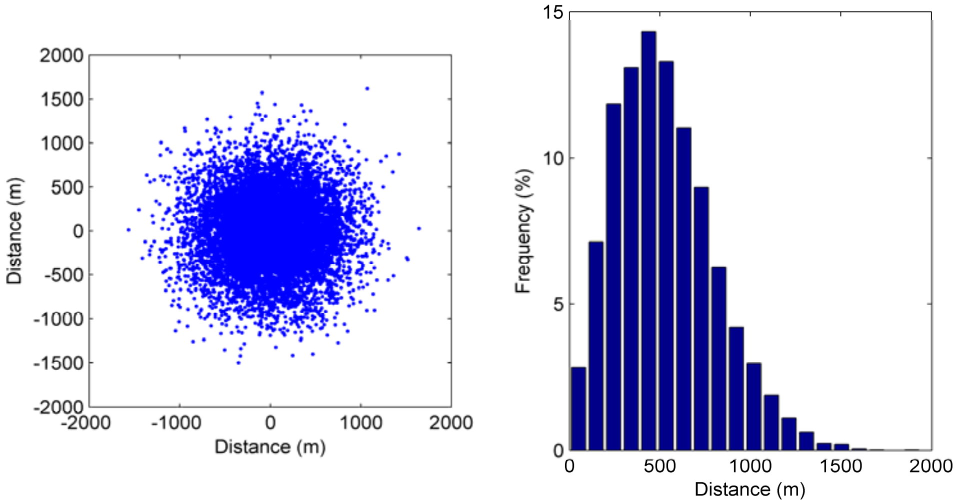

Figure 4 Scatter plot of particle distribution from random diffusion of 10,000 particles over 24 hours with K_H = 1.0 $m^2 s^{-1}$ (left), and histogram of net particle displacement from the starting position after 24 hours (right).

After the simulation has been completed, the particle tracks of all particles released from each individual farm are used to construct a polygon that encompasses the region traversed by particles released from that farm. A convex-hull algorithm is used to create a polygon that encompasses all the points where particles released from the farm were recorded.

Figure 5 shows an example of the particle tracks generated by the model for a farm located in Port Ligar, Pelorus Sound (Marlborough Sounds). The red line shows the boundaries of a polygon fitted using a convex hull algorithm. This polygon is considered to represent the limits of the region in which particles are likely to travel during their projected 24-hour lifespan. Figure 5 also demonstrates how diffusion increases the area over which pathogens are dispersed, although dispersion by the tide has the largest effect.

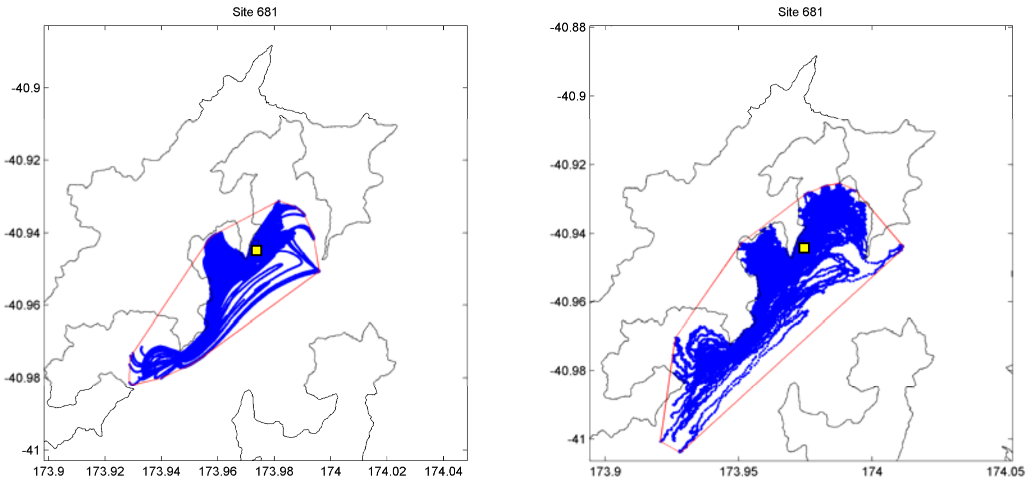

Figure 5 Example of pathogen dispersal from a marine farm located in Port Ligar, Pelorus Sound with no diffusion (left) and with diffusion (right). Red line shows the fitted polygon

Polygons were manually modified in cases where the convex-hull fitting included large areas that were not traversed by particles during the simulations. This occurred for sites in Tory Channel (Marlborough Sounds). The simulated tidal currents carried particles westward to the junction of Tory Channel and Queen Charlotte Sound, and also north-east around the tip of

Arapawa Island (Figure 6). The convex-hull polygons include Queen Charlotte Sound to the north of Arapawa Island when no particles travelled through this area. Tidal currents are weak in Queen Charlotte Sound to the north of Arapawa Island and it is unlikely that tidal currents alone would transport pathogens from the Tory Channel into this region within 24 hours. Dispersion is shown at spring tide for pathogens released continuously for 12.42 hours with a 24 hour life span. The 2-D simulation includes diffusion ($K_H = 1.0\ m^2\ s^{-1}$) but not wind.

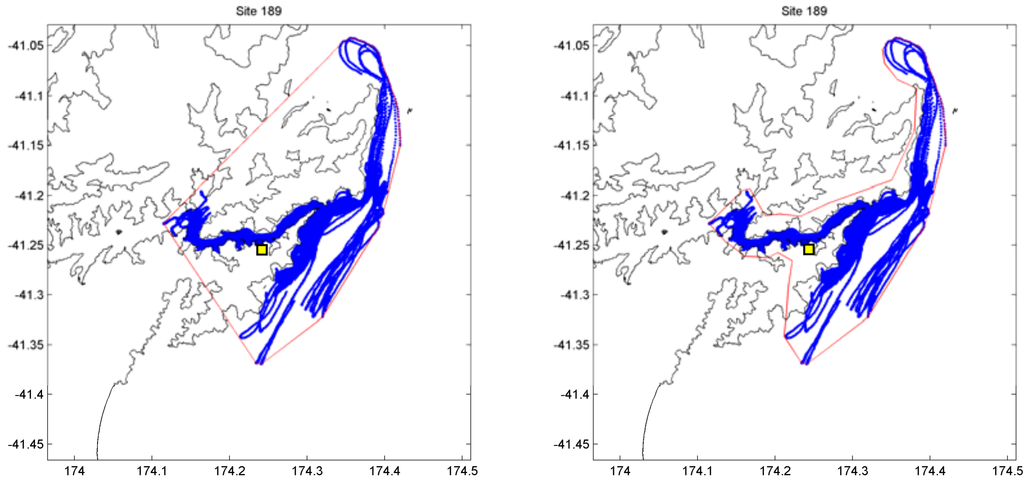

Figure 6 Example of original (left) and modified (right) polygons (red line) for 24-hour pathogen dispersal from a farm in Tory Channel, indicated by the yellow box in each figure.

4.3.4 Outputs for marine sites

In total, 40 marine dispersion areas were defined (Table 4).

4.3.4.1 Northern New Zealand

Marine farms are located in many bays and harbours around northern New Zealand. Not all of the bays containing marine farms could be resolved in the model due to insufficient bathymetric data. We propose that, in such cases, each area is considered a single dispersion zone as it is likely that dispersion will rapidly spread pathogens throughout each bay.

In the following sections, maps of pathogen dispersion zones (Figure 7) and 24-hour pathogen dispersal (Figure 8) are shown for Houhora Harbour as illustrative examples. Equivalent maps for other regions are shown in Appendix 2.

Parengarenga and Whangaroa Harbours could not be modelled due to insufficient bathymetric data. We propose that each harbour be treated as a single dispersal zone. Separate zones can be defined for Houhora Harbour, Houhora Bay, and Rangaunu Harbour (Figure 7), based on dispersal distances (Figure 8). Dispersal zones in have been coloured by area in Figure 8 to help distinguish between different farms, with smaller zones plotted on top of larger ones.

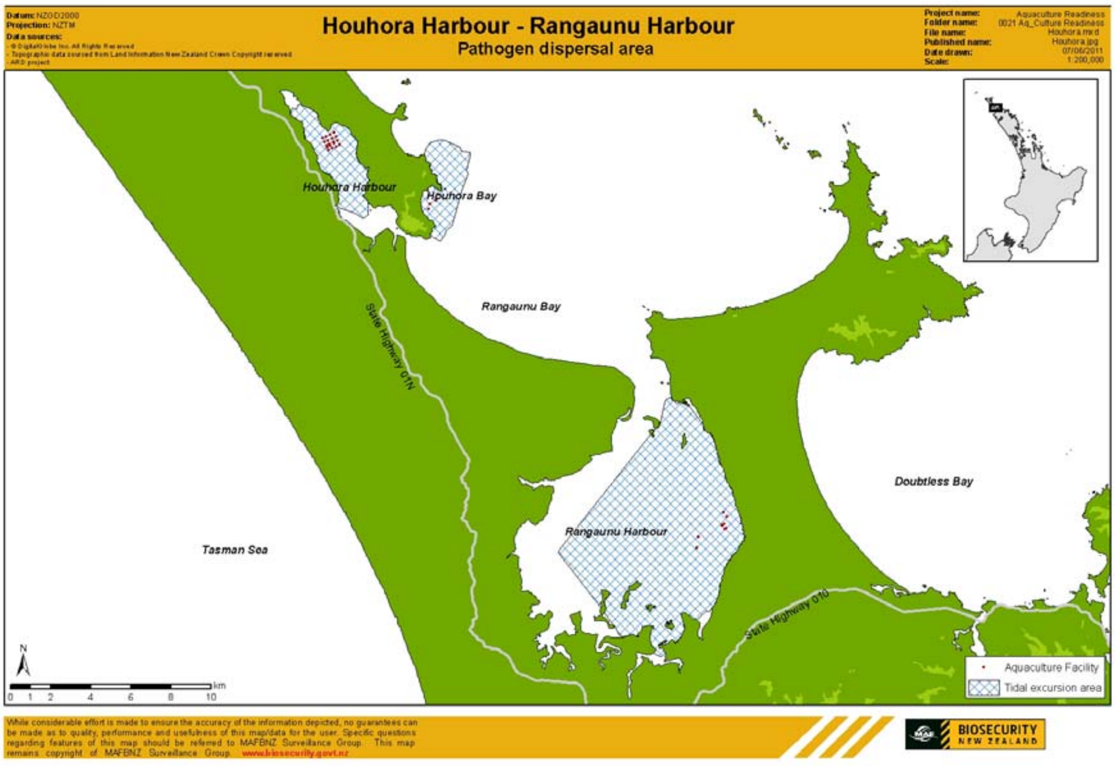

Figure 7 Proposed pathogen dispersal zones in Houhora Harbour, Houhora Bay and Rangaunu Harbour

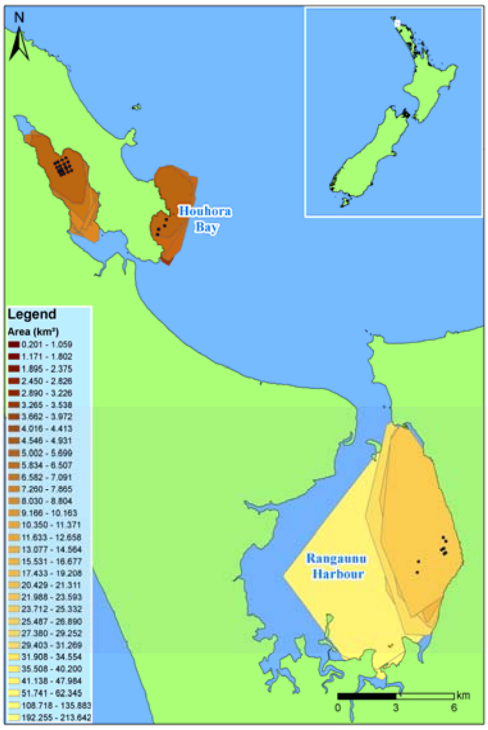

Figure 8 Overview of 24-hour pathogen dispersal from marine farms in Houhora Harbour, Houhora Bay and Rangaunu Harbour.

Three dispersal zones are defined for the Bay of Islands (Figure 10): a southern zone extending from near Russell and including Waikare Inlet, a northern zone from Moturoa Island, including Kerikeri Inlet and Te Puna Inlet, and a smaller zone covering Paroa Bay. The individual dispersal areas are shown in Figure 11.

The two marine farms identified in the Hokianga Harbour have overlapping excursion zones (Figure 12). Hokianga Harbour can be considered a single dispersal zone (Figure 13).

In the Kaipara Harbour, farms in the branches of the Otamatea River (including the Whakaki and Arapaoa arms) all have overlapping dispersal zones (Figure 14). There is also connection with excursion zones from farms in the southern Kaipara Harbour. While the model does not show a connection with farms located in the Oruawharo River arm, this may be an artefact of bathymetry or model resolution, and we suggest that a single, large dispersal zone (Figure 13) be defined for Kaipara Harbour until more detailed studies are conducted.

4.3.4.2 Auckland and Hauraki Gulf

The widely-separated marine farming areas of the Hauraki Gulf north and east of Auckland have non-overlapping excursion zones (Figure 15) and are considered separate dispersion areas (Figure 16). Although not all excursion zones for sites around Waiheke Island overlap (particularly the sites in Putiki Bay and near Taniwhanui Point), the separation with other sites is small. Conservatively, Waiheke Island should be treated as a single zone.

4.3.4.3 The Firth of Thames and the Coromandel

All marine sites on the eastern side of the Firth of Thames have overlapping dispersal zones (Figure 15) and may be considered a single zone (Figure 16). The sites on the western side form a separate cluster. The bays on the eastern side of the Coromandel Peninsula are sufficiently spaced that tidal dispersion is unlikely to transport pathogens between them over a 24-hour period. Although not all excursion zones for sites around Waiheke Island overlap (particularly the sites in Putiki Bay and near Taniwhanui Point), the separation with other sites is small. Conservatively, Waiheke Island should be treated as a single dispersal zone.

4.3.4.4 Marlborough Sounds

Dispersal zones for farms in the Marlborough Sounds region are shown in Figure 17. There is continuous swath of zones through Pelorus Sound, indicating that pathogens could travel relatively quickly among farms. Pelorus Sound is therefore treated as a single dispersal zone (Figure 18). Tidal currents are strong in the entrance to Pelorus Sound and pathogens released near the entrance may reach farms in Forsyth Bay and Guards Bay. There is a small separation between farm dispersal zones in Anakoha Bay and Guards Bay, but conservatively we consider these bays to be connected.

Pathogens released from farms in Tory Channel will travel large distances due to the strong currents in the channel. Pathogens from Tory Channel farms are capable of travelling around the eastern tip of Arapawa Island almost as far as Cape Jackson, and as far south as Fighting Bay on the east coast. There is a separation between the Tory Channel defined area and Port Underwood. However, strong winds may drive currents that could carry pathogens as far south as Port Underwood.

Overlapping dispersion zones have been combined to identify nine defined dispersion areas, shown in Figure 18.

4.3.4.5 Tasman and Golden Bay

Aquaculture facilities in Tasman Bay and Golden Bay are concentrated into a few areas (Figure 18). Of the three sites in Tasman Bay, the two western sites lie within overlapping 24-hour tidal dispersal zones but the eastern site is separate (Figure 19). The two sites identified near Collingwood in Golden Bay (both in the block known as AMA 1) form a single dispersal zone (Figure 19). The excursion zones of the two other sites to the south in Golden Bay (in the block know as AMA 2) do not overlap. However, the separation is small and it is appropriate to treat these conservatively as a single dispersal zone (Figure 18).

4.3.4.6 Banks Peninsula

Farms between Port Levy and Little Akaloa Bay show overlapping dispersal zones (Figure 20), and are considered to form a single dispersal zone. Dispersal zones for all farms in Akaroa Harbour also overlap, and form a second dispersal zone (Figure 21).

4.3.4.7 Southland

Tidal excursion links all marine farms located in Bluff Harbour (Figure 22) and a single dispersion zone is proposed (Figure 21). Similarly, all farms in Big Glory Bay (Stewart Island) also form a single dispersion zone (Figure 21). Single aquaculture facilities in Horseshoe Bay and near Ruapuke Island lie outside the tidal dispersal zones of other farms (Figure 22).

4.4 DISPERSION MODELLING FOR FRESHWATER AND LAND-BASED SITES

Identification of defined areas for freshwater aquaculture facilities was based on modelled dispersal of pathogens by water movement over 24 hours, as for the marine facilities. Water movement information was derived from NIWA’s River Environment Classification database, and was used to model downstream dispersal distances from aquaculture facilities based on various flow scenarios. The process is described in the following sections.

4.4.1 Site identification

The locations of freshwater aquaculture sites were obtained from the database compiled for MAF Biosecurity New Zealand as part of the Phase 1 study. Many of these sites are no longer active and, as described in the report on Phase 1, there was uncertainty over the precise location of some sites. However, all sites in the database have been included in this study.

4.4.2 River Environment Classification database

The River Environment Classification (REC) is a database and digital network of all stream reaches in New Zealand. The REC database includes information on climate, source of flow, geology, land-cover, network position and valley land form, as well as stream flow statistics which are based on model predictions. The average length of reaches in the REC is 700 m.

Every freshwater aquaculture site was mapped to the nearest REC reach. A downstream trace was run from this reach to establish the sequence of downstream river reaches from the aquaculture site to the sea. For each reach, the predicted mean flow, mean annual maximum flow, and mean annual low flow were obtained. The model predictions have been calibrated against gauged river flows, but the values for mean annual maximum and mean annual low flow are valid only for rivers that have no large upstream lakes or artificial flow control.

4.4.3 Modelling dispersal of pathogens by river flow

The speed at which pathogens are likely to be transported at each of these flows were estimated using empirical relations between velocity and flow developed for New Zealand rivers (Jowett 1998). Jowett (1998) gives both ‘downstream’ and ‘at-a-station’ relationships to describe the variation of hydraulic geometry (water surface width, mean depth and mean velocity) with discharge within a reach. The ‘downstream’ relations describe how hydraulic geometry changes along the length of a river at mean discharge. ‘At-a-station’ relations describe how the hydraulic geometry at a reach changes with flow. Although the ‘downstream’ relations were developed for changes in hydraulic geometry along a river length, they are only applicable at mean flow. We have therefore used the 'at-a-station' relations as these were developed by comparing hydraulic geometry at different flows.

The velocity (m/s) in each reach is estimated as:

$$V = kQ^m$$

where $k = 0.24$ and $m = 0.427$ (Jowett 1998), and Q is the flow at the reach (m^3/s). The mean velocity is calculated at mean annual flow (Q_M) mean annual maximum (Q_{MAM}) and mean annual 7-day low flow (Q_{MLF}).

This mean velocity is used to estimate the time taken for water to travel the length of each reach. These travel times are then used to establish how far pathogens are likely to travel at each flow (mean, mean annual maximum and mean annual low flow) over 24 hours.

4.4.4 Lakes

Lakes generally have mean residence times ranging from a few days to years, depending on the lake volume and the inflow/outflows. However, wind, stratification, morphology and currents can lead to short circuiting such that a substance introduced to a lake may be discharged at much shorter time-scales than indicated by the mean residence time. While it is technically possible to conduct hydrodynamic modelling of lakes, this is an expensive and data intensive process beyond the scope of this study. Furthermore, experience suggests that outbreaks of disease at a location in a lake will eventually spread to the whole lake (Colin Johnston, MAFBNZ, pers. comm.). Consequently, lakes were treated as a pathogen buffer zone or trap. Pathogens that reach a lake are assumed to remain within the lake over the 24-hour period of interest. However, the entire lake is considered to be infected.

4.4.5 Outputs

In total, 55 freshwater were defined (Table 3). Plots of dispersal distances under different flow conditions (mean annual low flow, mean flow and mean annual maximum flow) show that even under mean annual flow (green lines) pathogens are likely to reach all of the stretches of the river below an infected facility within 24 hours (facilities in the lower North Island are shown in Figure 9 as an illustrative examples and other regions are shown in Appendix 3).

Consequently, under mean or higher flow, it seems appropriate to identify all reaches of a waterway downstream of an infected facility as the pathogen dispersal zone. This rule could, potentially, be refined in the case of some facilities (for example, those in Figure 23 E), if infections occur during low flow conditions. To do so would, however, assume that no rainfall occurs for 24 hours after the outbreak occurs. It seems simpler and more conservative, therefore, to treat all downstream reaches as the defined area in all cases.

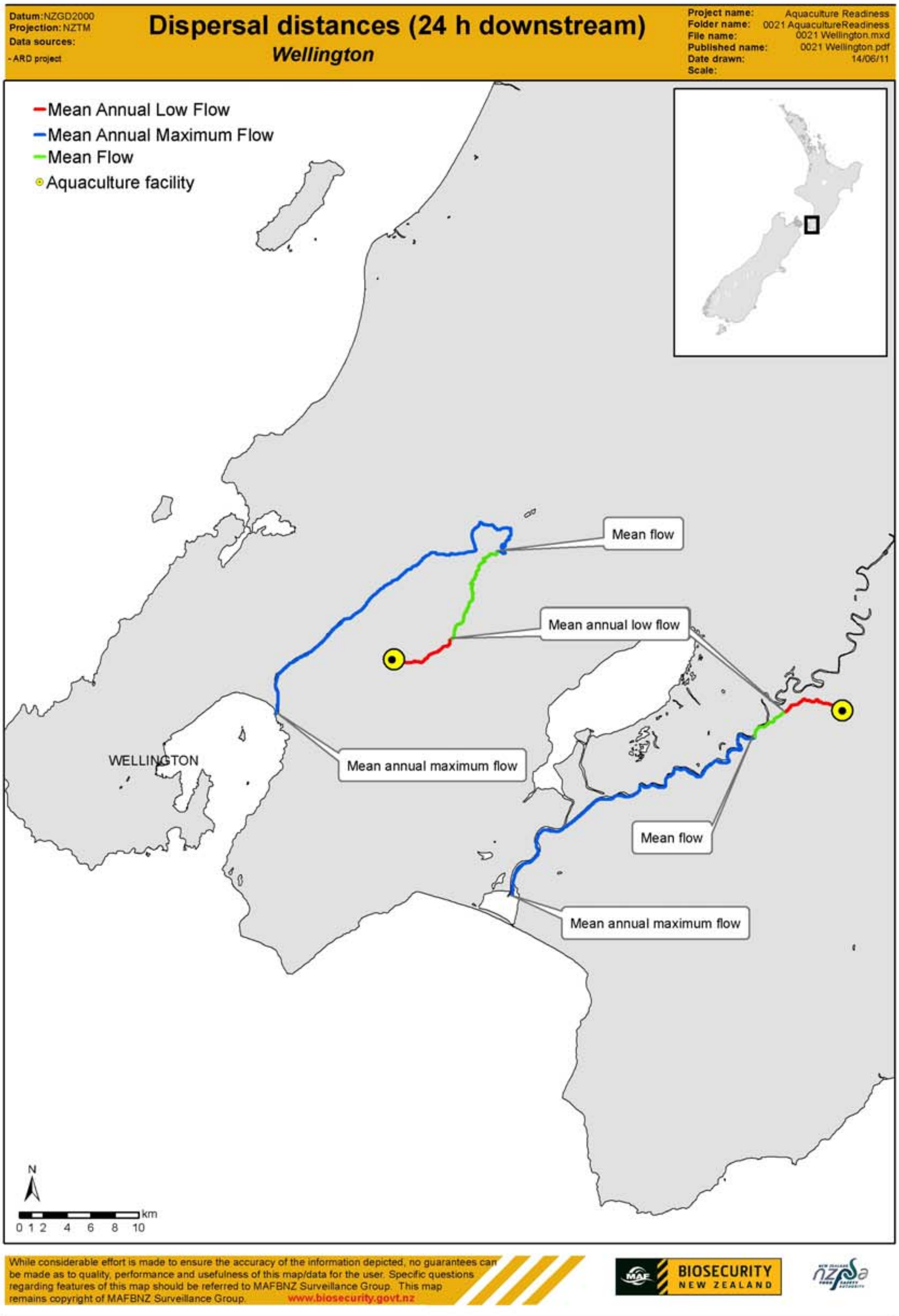

Figure 9 Estimated dispersal of pathogens from freshwater and land-based aquaculture facilities in the lower North Island over 24 hours under three different flow regimes.

4.5

4.6

5 Discussion

5.1 LIMITATIONS OF THE MARINE MODELLING APPROACH

The results presented in this study are influenced by a number of modelling assumptions and simplifications:

- The use of a 24-hour timeframe for the modelling was constrained by resources and by the lack of more complex (i.e. producing useful predictions over longer periods) models for many parts of the coast. There are robust, verified models for some aquaculture areas, including the Firth of Thames and Golden/Tasman Bays.
- The model does not clearly address the interface between freshwater and saltwater, where freshwater pathogens may potential cause problems for estuarine aquaculture.
- Only tidal currents at spring tide were simulated. Dispersal is likely to be less at neap tide.
- Wind and barometric forcing also drive currents and will alter dispersal. Under certain conditions (e.g. strong winds or storms), dispersal may be far greater than predicted by tidal currents alone.
- 2-D modelling was performed. This was necessary given the large spatial scales covered in this study, but means that differences in water speed and direction over water depth were not accounted for. This can be particularly important where winds drive circulation, and where there are variations in salinity and temperature over the water depth.
- Passive particles were simulated, ignoring any swimming, sinking or buoyancy behaviour of pathogens.
- Not all of the bays containing marine farms could be resolved in the model due to insufficient bathymetric data, which are required to calibrate the hydrodynamic model. An approximation could be used to estimate bathymetry (such as assuming an constant slope of the seabed between the closest known depth contour and the shore). Because the bays concerned were all small, however, a more conservative, and possibly realistic, approach is to assume that dispersion will spread pathogens to all parts of the bay within 24 hours.

Further limitations of the model were identified by stakeholders:

- The model does not distinguish among different species farmed at the same location (although it could be made to do so). Potential interactions among different types of aquaculture are context-dependent, such as the transfer of salmon pathogens by movement of stock or gear from nearby mussel farms.

5.2 LIMITATIONS OF THE FRESHWATER MODELLING APPROACH

There are a number of sources of possible error in the modelling approach used:

- Flow predictions for each reach are derived from predictive models. Mean flow is predicted from a rainfall water balance. Mean annual maximum is derived following McKerchar and Pearson (1989) who analysed rivers where there were no significant lakes or storage management upstream, and the catchment area doesn't span too many different climate/weather generation regions. The mean annual 7-day low flow is derived from unpublished methods and subject to the same caveats as mean annual maximum.
- Velocities within reaches are estimated from an empirical relationship (Jowett 1998). This relationship was developed from a combination of regression analysis and hydraulic simulation of 73 river reaches. A 'best-fit' relationship of this form will not allow for local characteristics of every reach. For example, velocities may be higher than predicted where river width is constricted such as within gorges.
- Longitudinal diffusion is not accounted for. The empirical model predicts a mean velocity for the reach. Velocity will vary across and along the reach, as well as with depth. This

difference in velocity, along with the action of turbulence, results in spreading of any substance released in the river. The predicted dispersion distances are a mean travel distance at that flow.

- Many of the locations in the database for freshwater aquaculture facilities appear to be either out of date or possibly wrongly located. For example, some of the locations are not near any stream, may be located in dense bush, or in towns.
- Canals are not resolved in the REC. For sites located in canals, dispersion has been routed to the first downstream lake via the nearest river channel in the REC.

5.3 LIMITATIONS OF THE SPATIAL DATABASE

A number of errors or limitations in the spatial database were identified during discussions with stakeholders such as:.

- The need for a national system of identification for aquaculture facilities was raised at several stages of the project.
- Farms are never monocultures, and always have wild populations of non-target species, either intentionally (e.g. crayfish) or unintentionally (e.g. wild populations of blue and greenshell mussels, scallops and *Undaria*). Some farms may hold small populations of experimental species, in addition to their main crop.
- The Marlborough Shellfish Quality Programme (MSQP: Marine Farming Association 2011) has accurate records of all active farms because the MSQP levy is based on this. Ongrowing farms are sometimes used to hold spat, but spat catching and holding facilities will not me included in the MSQP database unless some crop is also held.
- Other information is provided voluntarily only and the industry in general is not well enough informed to see the utility of having a more complete database. In the event of an outbreak of disease, farmers are more likely to try to manage it themselves. This is true for both marine and freshwater facilities.
- There are only 2 regional (i.e. between the levels of individual farmers and national organisations) farming organisation across NZ – MFA (top of the South Island) and the Coromandel Marine Farmers. Industry rationalisation may lead to fewer, larger farmers and more coordination in the future.
- Councils are unable to provide names and addresses of consent holders to third parties, only information about the consent.

5.4 INCORPORATING INFORMATION ON ANTHROPOGENIC MOVEMENTS OF STOCK AND EQUIPMENT

Dispersion of pathogens and pests by water movements occurs over relatively small spatial scales and long-distance dispersion (for example, from the top of the North Island to the South Island) is unlikely over the period during which the pathogen remains infectious. Human-mediated movements of aquaculture stock and equipment, in contrast, are capable of transmitting pathogens over much larger distances and shorter time-frames. One particularly common example is the transfer of mussel spat from Ninety-mile Beach in Northland to marine farms across the top of the South Island.

Information on movements of aquaculture stock and equipment was collected as part of Phase I and has been plotted in GIS to illustrate the aquaculture species moved, the sources and destinations. These maps (Appendix 4) are intended to be illustrative of the movements involved rather than to allow detailed identification of all sources and destinations.

Due to limited data of uncertain quality, it is not currently possible to incorporate these anthropogenic movement data into defining dispersion areas. If the defined dispersal zones concept is to be implemented, this is a key data need to be addressed.

5.4.1 Information gaps

Stakeholders identified a number of actual or potential vectors for the transfer of pathogens and pests that are not currently included in the movement database:

- Movement information is not held by individual farmers in an easily accessible form, and varies widely by sector.
- Movement of stock, particularly of Pacific oysters, to land-based facilities for grading, sorting and washing and then on for processing or return to the original or a different farm (sometimes in a different part of the country) was identified by stakeholders a transfer mechanism that has not been addressed in the present study. An associated unknown factor is the fate of washing water, mud and other potentially contaminated material from these land-based processing plants.
- Vessels servicing marine farms may have home ports, or ports to which they regularly travel for servicing, that are not identified as aquaculture facilities and are consequently not included in the database. Vessels may move throughout New Zealand, including between islands. This information would need to be gathered from individual farmers and incorporated into the movement database as a separate category.
- Culture and movements of ornamental species were excluded from the present study. However, goldfish may be a significant potential reservoir of several diseases and are moved within and between the North and South Islands, probably in large numbers (these movements are unregulated and unrecorded).
- Some poor-quality ongrowing sites are not registered with MAF Food Safety because they do not hold harvestable stock. They may, however, be used to catch or hold spat.
- Movements by natural vectors (such as birds),wild commercial harvest and transfer among wild populations (reseeding) are not addressed by the modelling. Ideally, the model would also map local populations, especially those of commercially-exploited species, since these can be transferred over large distances, such as the collection of scallop spat from the Marlborough Sounds and Tasman/Golden Bays and subsequent transfer to other commercial scallop areas in the North and South Islands. Customary translocation of toheroa from Northland to Hawkes Bay also occurs. Perhaps of particular concern is the translocation of paua for reseeding and farming, including customary reseeding.
- Farmers must declare harvesting of stock to MAF Food Safety in order to export the crop, but there is no requirement to report inter-farm movements or non-commercial (including recreational) movements. These unrecorded movements should perhaps be a priority for management of aquatic diseases, and approaches should include education of stakeholders because the risks are currently poorly understood.
- Some locations have disproportionate importance in the spread of diseases or pests because they act as movement hubs for stock and materials. Spat-catching sites are an example of such hubs because material may be transferred to locations throughout New Zealand. At present our understanding of the pattern of movements, including the identity of key hubs, is poor. A targetted study, using methods such as network analysis, would help to identify hubs.

5.5 DATABASE MAINTENANCE

Maintenance of the location dataset will require the following:

- addressing information noted as missing and other errors identified during stakeholder consultations;
- updating information on ownership and contact details;
- adding information on new farms and other facilities;
- adding information on changes in use, including closure and changes in species farmed or processed;
- adding information on changes in area of farms or other facilities.

Once missing facilities and incorrect locations (identified during stakeholder consultation) have been addressed in the database, the key requirement will be verifying and maintaining up to date ownership and contact information. It allows other information to be updated regularly or, in the event of an incursion, allows the relevant facilities to be contacted as quickly as possible. Individual farmers are likely to be the best source of up to date information, although industry organisations may have better overviews of the industry as a whole or sectors of it. They are also likely to be the only source of information on stocking densities and biomass, although this may not be forthcoming because of commercial sensitivity. During Phase I of the present study we were unable to obtain information on biomass from industry groups for this reason. Annual data collection is considered adequate because farm cycles tend to be 2-3-yearly. Although regional councils and unitary authorities cannot provide the name and address of consent holders to third parties, they can act as distribution hubs for requesting and collecting information

Marine farmers are legally required (under the Fisheries Act 1996) to provide or update this information in the Marine Farm Register whenever a new consent is issued or an existing consent is modified. Annual requests for updates are also sent out by MFish and must be completed and returned as soon as possible. These registrations provide some of the information required to update the location dataset, and linking the location dataset to the MFish register is a logical first step in maintaining the former. However, farmers are apparently not always diligent in filing applications for registration or variations to an existing registration. Further, the register does not include location coordinates for the facilities or information on numbers of weight of stock held or harvested. Consequently, information from the register will need to be supplemented (and cross-checked) from other sources.

A list of shellfish growing areas classified for harvest for human consumption is available from the MAF Food Safety website (New Zealand Food Safety Authority 2011a). The list provides authorisation numbers (lease, licence, permit or consent) for each facility in the area, grouped by geographical region (Northland, Auckland, etc.) and by numbered growing areas representing discrete coastal regions (bays, harbours, inlets. Because of licensing fees, unused areas are not registered by farmers, so the list provides an up to date list of areas currently in use. Authorisation numbers must be kept up to date or product from that facility may be rejected by overseas countries (Phil Busby, MAF Food Safety, pers. comm.). The MAF Food Safety website New Zealand Food Safety Authority 2011b) also contains lists of bivalve molluscan shellfish operators: commercial harvest operators; relay operators; sorting shed operators; depot operators; wet storage operators and transport operators. These sources were not cross-checked against the database during Phase I and may include facilities that were overlooked.

Equivalent information for freshwater or land-based facilities may be available from MFish's Freshwater Fish Farm Register. Again, coordinates of locations are not always recorded and information would need to be supplemented from other sources, such as resource consents.

The best approach to maintenance of the dataset of information on the location of aquaculture facilities is, therefore, to develop links between MAFBNZ, MAF Food Safety and MFish's Marine and Freshwater Fish Farm Registers to allow access to information on new or altered consents and to annual updates, and to obtain regular data summaries of new consents from regional councils and unitary authorities. Resource consents may not capture information on the species actually farmed (as opposed to potential farmed species for each site) but this information should be available from the Fish Farm Registers. Conversely, the latter may not include detailed farm locations but these will usually be recorded on consents.

In addition to being a source of information on the location and nature of marine farming facilities, resource consents may serve as a means of encouraging notification of marine pests or diseases. For example, Northland Regional Council now attaches and advice notice to all new marine farming consents placing the consent holder under a duty to inform MAF of the presence of "an organism not normally seen or otherwise detected in New Zealand" (Ricky Eyre, Northland Regional Council, pers. comm.).

Regular access to MFish's Freshwater Fish Transfer Authorisation database will allow updating of the movement database for freshwater and land-based farms. Updates on patterns of movement for marine farms is not available from any single source and is probably best achieved by regularly repeating the questionnaire-based survey used in the present study. Information should be sort from industry organisations, who have a broad overview of movements within their industry as a whole, supplemented and verified by more detailed surveys of selected companies within each sector of the industry.

Stakeholders emphasised that the first stage in setting up a response management plan for aquaculture diseases and pests should be to convince the industry of the need for the type of database discussed here, before attempting to collect information from farmers. Otherwise, the level of response is likely to be low. The industry is under-educated on the risks and consequences of diseases because, historically, it has had few problems and may worry that setting up response plans or other planning for disease events might create the impression that a problem could exist.

5.6 REFINING OF DISPERSION MODELLING

Hydrodynamic models are regularly used to manage development of aquaculture throughout New Zealand, commissioned by the industry or by regulatory bodies such as regional councils and MFish. For example, MFish has recently commissioned studies of the feasibility of finfish farming in the inner Hauraki Gulf, the Marlborough Sounds and Tasman/Golden Bays. This work involved particle tracking models to predict the spread of waste and of propagules of marine pests from potential farm sites. Sharing of such information among farming and regulatory organisations will create opportunities for modelling of pathogen dispersion to be improved progressively.

6 General conclusions

There was general agreement among stakeholders consulted that the defined-areas approach is useful and worthwhile. In this approach marine farms need to be considered in association with customary, commercial and recreational wild harvest and movement, and of wild populations. There is a strong need for a good database of information and it needs to be decided how the data would be obtained, refined and who would hold and manage it. The relative merits of continually updating this improved database versus just updating the contact list needs to be assessed.

There is a clear need to educate the industry on the effects of disease outbreaks and how this approach can help minimise potential impacts (see comments above re an initial presentation of how the response process works). This is a good time to do this because the recent outbreak of oyster herpes virus is fresh in the industry's mind. Industry organisations' annual meetings (the NZ Salmon Farmers Association, MSQP, etc.) would be appropriate places to present the concept. Presentations could involve role-playing exercises with industry members on how to respond to a disease incursion and could be organised via AQNZ. When developing industry support for response plans, a disease-based approach would be better than a pest-based one in terms of industry understanding its importance. Alignment of responsibilities from farm to central government is needed in order to ensure corrected data can be collected and managed. There may be opportunities for this resulting from recent outbreaks and new regulations and legislation. Early detection of disease outbreaks is essential in effective management.

Development of dispersion zones (defined areas) on the basis of types of organism (infectious life-span, etc., the approach taken to date) would overcome the difficulty in predicting the species that may arrive and cause problems. Later modelling could take into account other characteristics of the pathogens than just life-span, such as whether they are passive or actively motile and whether they rely on a secondary host. The life-span of the pathogen can also be increased where more sophisticated models are available. Although the tidal-excursion model can easily be extended to periods >24 hours, the results rapidly become unreliable because factors not included in the model, such as wind and density-driven currents, become increasingly important.

7 Acknowledgements

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Appendix 1: Tables

Table 1 List of species that may be farmed in New Zealand

Common name (species)	Common name (species)	Common name (species)	Common name (species)
(1.1) Abalone or paua, being:	(iv) Sand flounder (*Rhombosolea plebeia*)	(1.28) Parore (*Girella tricuspidata*)	(ix) Red flabby sponge (*Crella encrustans*)
(i) Ordinary paua (*Haliotis iris*)	(v) Turbot (*Colistium nudipinnus*)	(1.29) Perch (*Perca fluviatilis*)	(1.42) Striped trumpeter (*Latris lineate*)
(ii) Virgin paua (*Haliotis virginea*)	(vi) Yellowbelly flounder (*Rhombosolea leporina*)	(1.30) Pipi (*Paphies australis*)	(1.43) Surf clam, being:
(iii) Yellow-foot paua (*Haliotis australis*)	(1.15) Freshwater crayfish or koura, being:	(1.31) Red gurnard (*Chelidonichthys kumu*)	(i) Deep water tuatua (*Paphies donacina*)
(1.2) Anemone, being:	(i) *Paranephrops planifrons*	(1.32) Rock shrimp (*Palaemon affinis*)	(ii) Fine dosinia (*Dosinia subrosea*)
(i) Common anemone (*Actinothoe albocinta*)	(ii) *Paranephrops zealandicus*	(1.33) Salmon, being:	(iii) Frilly venus shell (*Bassina yatei*)
(ii) Dahlia anemone (*Isocradactis magna*)	(1.16) Grey mullet (*Mugil cephalus*)	(i) Atlantic salmon (*Salmo salar*)	(iv) Large trough shell (*Mactra murchisoni*)
(1.3) Bass (*Polyprion moeone*)	(1.17) Hapuku (*Polyprion oxygeneios*)	(ii) Chinook or quinnat salmon (*Oncorhynchus tshawytscha*)	(v) Ringed dosinia (*Dosinia anus*)
(1.4) Blue cod (*Parapercis colias*)	(1.18) John dory (*Zeus faber*)	(iii) Sockeye salmon (*Oncorhynchus nerka*)	(vi) Silky dosinia (*Dosinia lambata*)
(1.5) Brine shrimp (*Artemia salina*)	(1.19) Kahawai (*Arripis trutta*)	(1.34) Scallops (*Pecten novaezelandiae*)	(vii) Small trough shell (*Mactra discors*)
(1.6) Butterfish (*Odax pullus*)	(1.20) King clam or geoduck (*Panopea zelandica*)	(1.35) Scampi (*Metanephrops challengeri*)	(viii) Triangle trough shell (*Spisula aequilateralis*)
(1.7) Carp, being:	(1.21) Koheru (*Decapterus koheru*)	(1.36) Sea cucumber (*Stichopus mollis*)	(ix) Tuatua (*Paphies subtriangulata*)
(i) Grass carp (*Ctenopharyngodon idella*)	(1.22) Leatherjacket (*Parika scaber*)	(1.37) Seahorse, being:	(1.44) Tarakihi (*Nemadactylus macropterus*)
(ii) Silver carp (*Hypophthalmichthys molitrix*)	(1.23) Lobster, being:	(i) Seahorse (*Hippocampus abdominalis*)	(1.45) Toheroa (*Paphies ventricosa*)
(1.8) Cat's eye (*Turbo smaragdus*)	(i) Packhorse or green lobster (*Jasus verreauxi*)	(ii) Spotted seahorse (*Hippocampus kuda*)	(1.46) Trevally (*Pseudocaranx dentex*)
(1.9) Crab, being:	(ii) Spiny or red rock lobster (*Jasus edwardsii*)	(1.38) Sea urchin (*Evechinus chloroticus*)	(1.47) Tropical freshwater prawn (*Macrobrachium rosenbergii*)
(i) Cancer crab (*Cancer novaezelandiae*)	(1.24) Mussel, being:	(1.39) Seaweed, being:	(1.48) Tuna, being:
(ii) Giant spider crab (*Jacquinotia edwardsii*)	(i) Blue mussel (*Mytilus galloprovincialis*)	(i) Agar weed (*Pterocladia lucida*)	(i) Bigeye tuna (*Thunnus obesus*)
(iii) King crab (*Lithodes murrayi*)	(ii) Freshwater mussel (*Hyridella menziesii* and *Cucumerunio websteri*)	(ii) Gigartina (*Gigartina atropurpurea* and *Gigartina circumcincta*)	(ii) Southern bluefin tuna (*Thunnus maccoyii*)
(iv) Paddle crab (*Ovalipes catharus*)	(iii) Green lipped mussel (*Perna canaliculus*)	(iii) Gracilaria (*Gracilaria chilensis*)	(1.49) Venus clam (*Ruditapes largillierti*)
(v) Red crab (*Chaeceon bicolour*)	(iv) Horse mussel (*Atrina zelandica*)	(iv) Small agar weed (*Pterocladia capillacea*)	(1.50) Watercress, being:
(1.10) Coarse dosina (*Dosina zelandica*)	(1.25) Octopus, being:	(1.40) Snapper (*Pagrus auratus*)	(i) *Nasturtium microphyllium*
(1.11) Cockle (*Austrovenus stutchburyi*)	(i) *Octopus huttoni*	(1.41) Sponge, being:	(ii) *Nasturtium officinale*
(1.12) Cooks turban (*Cookia sulcata*)	(ii) *Pinnoctopus cordiformis*	(i) Bath sponge (*Spongia manipulatus*)	(1.51) Whitebait, being:

Common name (species)	Common name (species)	Common name (species)	Common name (species)
(1.13) Eel, being:	(1.26) Mysid shrimp, being:	(ii) Finger sponge (*Callyspongia ramosa*)	(i) Banded kokopu (*Galaxias fasciatus*)
(i) Longfin eel (*Anguilla dieffenbachii*)	(i) *Mysidopsis* sp.	(iii) Grey sponge (*Ircinia sp.)*	(ii) Giant kokopu (*Galaxias argenteus*)
(ii) Shortfin eel (*Anguilla australis*)	(ii) *Tenagomysis nova-zealandiae*	(iv) *Latrunculia* sp.	(iii) Inanga (*Galaxias maculatus*)
(1.14) Flounder, being:	(iii) *Tenagomysis similes*	(v) *Lissodendoryx* sp.	(iv) Koaro (*Galaxias brevipinnis*)
(i) Black flounder (*Rhombosolea retiaria)*	(1.27) Oyster, being:	(vi) *Mycale* sp.	(v) Shortjaw kokopu (*Galaxias postvectis*)
(ii) Brill (*Colistium guntheri*)	(i) Dredge oyster (*Tiostrea chilensis*)	(vii) Pink conular sponge (*Chondropsis kirkii*)	(1.52) Yellowtail kingfish (*Seriola lalandi*)
(iii) Greenback flounder (*Rhombosolea tapirina*)	(ii) Pacific oyster (*Crassostrea gigas*)	(viii) *Raspailia agminata*	

Table 3 Location of freshwater and land-based aquaculture facilities included in the movements database, with notes on any problems encountered during modelling and mapping of dispersion of pathogens

Site ID	Name	District	Notes
2	Wairau River	Marlborough	OK – will reach sea at all flows
3	Wairau Valley	Marlborough	OK– all reach sea except MALF24
5	Lake Grassmere	Marlborough	Almost on coast. Assume reaches sea (only 2 reaches)
33	Ngongotaha Stream	South Auckland	Drains into Lake Rotorua
349	Waituna Creek	Westland	
353	Kumara	Westland	OK – will reach sea at all flows
354	Mill Creek	Westland	OK – will reach sea at all flows
357	Soldiers Creek	Nelson	Flows into Inangahua then Buller River. Likely to reach sea at all flows except MALF at 24 hrs
359	Coal Creek	Westland	OK – will reach sea at all flows
368	Invercargill	Southland	OK – will reach sea at all flows
369	Hermann Creek	Westland	OK – will reach sea at all flows
387	Takaka	Nelson	OK – will reach sea at all flows. Note site number might be 3875
393	Glenavy	Canterbury	OK – reaches sea at mean and MAM flows. Note site number 3934
614	Roscoe Falls	Otago	OK – will reach sea except 24hr MALF
615	Traquair Burn	Otago	OK – will reach sea except 24hr MALF
618	Leithen Burn	Otago	OK
619	Clutha River/Mata-Au	Otago	Map Mean72, MAM24 and MAM72 to Roxburgh Dam
620	Matau	Otago	Matau Branch of Clutha River. REC not likely to work here. Assume reaches sea at all flows
630	Bullock Creek	Canterbury	Mean24 and MLF24 MLF72 OK. MAM24, Mean72 and MAM72 will reach Tekapo River which is controlled. Assume that reaches Lake Benmore at these discharges
637	Tawhiti Stream	Taranaki	OK – reaches sea in under 24 hours except at MLF
841	Raupo	North Auckland	On Wairoa River which drains into Kaipara, only 1 reach. Could be tidal here?
844	Mahurangi River (Right Branch)	North Auckland	OK – drains into Mahurangi River
848	Taupo	South Auckland	Drains into Waikato River above Lake Aratiatia. Controlled river with large lake so flow data from REC model not appropriate. Need to use flow data from all Waikato stations below Lake Taupo
850	Pupu Springs	Nelson	Co-ordinates are wrong – gives position in Nelson rather than Pupu Springs. Same location as 860 and 862. When moved to real location at Pupu Springs, will reach coast at all flows.
851	Takaka	Nelson	
853	Waipupu Stream	Wellington	OK – near ocean only 1 reach
855	Mangaroa River	Wellington	OK
856	Karamea	Nelson	OK – will reach sea at all flows
859	Wairau Valley	Marlborough	
860	Nelson	Marlborough	Location is suspect. Same co-ordinates as 850 and 862
861	Hukarere	Nelson	OK – will reach sea at all flows except 24hr MALF
862	Nelson	Canterbury	Location is suspect. Same co-ordinates as 850 and 860 and no evidence of fish farm at that location
863	Hurunui River	Canterbury	OK – will reach sea at all flows except 24hr MALF. But Sisters Stream and Hurunui both feed from lakes so MAM and MALF could be inaccurate
864	Kaiapoi	Canterbury	OK
865	Christchurch	Canterbury	At Mcleans Island. Not clear where it drains to, but eventually to Waimakariri River
866	Rakaia	Canterbury	OK – will reach sea at all flows except 24hr MALF

Site ID	Name	District	Notes
870	Waituna Creek	Westland	OK – will reach sea at all flows
871	Ashburton	Canterbury	First reach very slow – have ignored this reach as site is likely part way along
872	Twizel	Canterbury	In Tekapo Canal. Route to Lake Pukaki
873	Twizel	Canterbury	In Ohau Canal. Route to Lake Ruataniwha. Comment – could reach Benmore, can not tell with this methodology
874	Twizel	Otago	At mouth of Lake Ruataniwha – route to Lake Benmore
875	Twizel	Otago	As above – this one shows on Google Earth
876	Ohau River	Canterbury	In Ohau Canal – Route to Lake Benmore
877	Kurow	Otago	OK
879	Waipuna Creek	Otago	Check this as goes through Clutha
880	Clutha River/Mata-Au	Otago	
883	Maitai River North Branch	Nelson	Appears to be located in bush above Maitai Dam – suspect location. Will ignore retention in Matai Dam given uncertain location. Will reach sea at all flows except MALF24
895	Martinborough	Wellington	OK
898	Nuhaka	Hawke's Bay	OK – all reaches sea
902	Seddon	Marlborough	Location is a street in Seddon – suspect location. Assume site is halfway along first reach (Starborough Creek above Awatere River). Will reach sea at all flow except MALF24
903	Gisborne	Gisborne	In Gisborne. If site is correct, will reach sea at mean and MAM
904	Balclutha	Otago	OK
906	Kaikoura	Marlborough	Single Reach
908	Outram	Otago	OK
910	Lincoln	Canterbury	Location is a house in Lincoln. Nearest reach is the LI/Liffey Stream in Liffey Reserve. Stop at Lake Ellesmere

Table 4 Summary of marine defined areas

Region	Defined areas	Figure number
Northland	Parengarenga Harbour	Not modelled (see text)
	Houhora Harbour	7
	Houhora Bay	7
	Rangaunu Harbour	7
	Whangaroa Harbour	Not modelled (see text)
	Te Puna Inlet/Kerikeri Inlet	10
	Waikare Inlet	10
	Paroa Bay	10
	Marotere Islands	Not shown
	Hokianga Harbour	13
	Kaipara Harbour	13
	Great Barrier Island	16
Auckland and inner Hauraki Gulf	Matakana	16
	Mahurangi Harbour	16
	Kawau Island	16
	Waiheke Island	16
The Firth of Thames and the Coromandel	Western Firth of Thames	16
	Eastern Firth of Thames	16
	Port Charles	16
	Kennedy Bay	16
	Whangapoua Harbour	16
	Whitianga Harbour	16
Marlborough Sounds	Waikawa Bay/Okuri Bay	18
	Admiralty Bay	18
	Pelorus Sound	18
	Waitui Bay/Port Gore	18
	Melville Cove (Port Gore)	18
	East Bay	18
	Tory Channel/Arapawa Island	18
	Port Underwood	18
Golden Bay	AMA1 Waikato	18
	AMA2 Puamakau	18
Tasman Bay	AMA3 Te Kumara 3A (north)	18
	AMA3 Te Kumara 3C (south)	18
Banks Peninsula	Port Levy – Little Akaloa Bay	21
	Akaroa Harbour	21
Foveaux Strait region	Bluff Harbour	21
	Big Glory Bay	21
	Horseshoe Bay	21
	Ruapuke Island	21

Appendix 2: Maps of pathogen dispersion zones and 24-hr pathogen dispersal for marine facilities

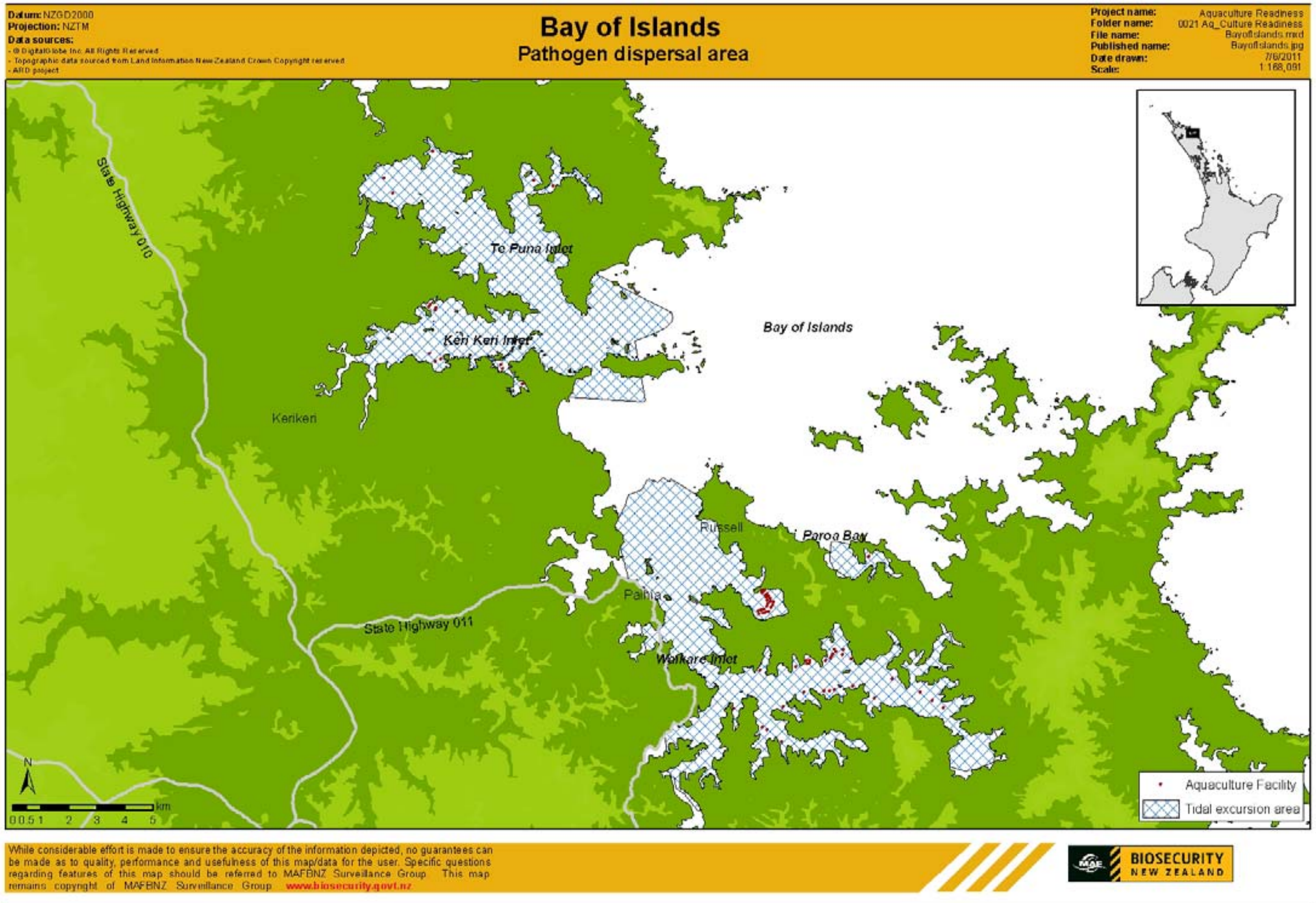

Figure 10 Proposed pathogen dispersal zones in the Bay of Islands.

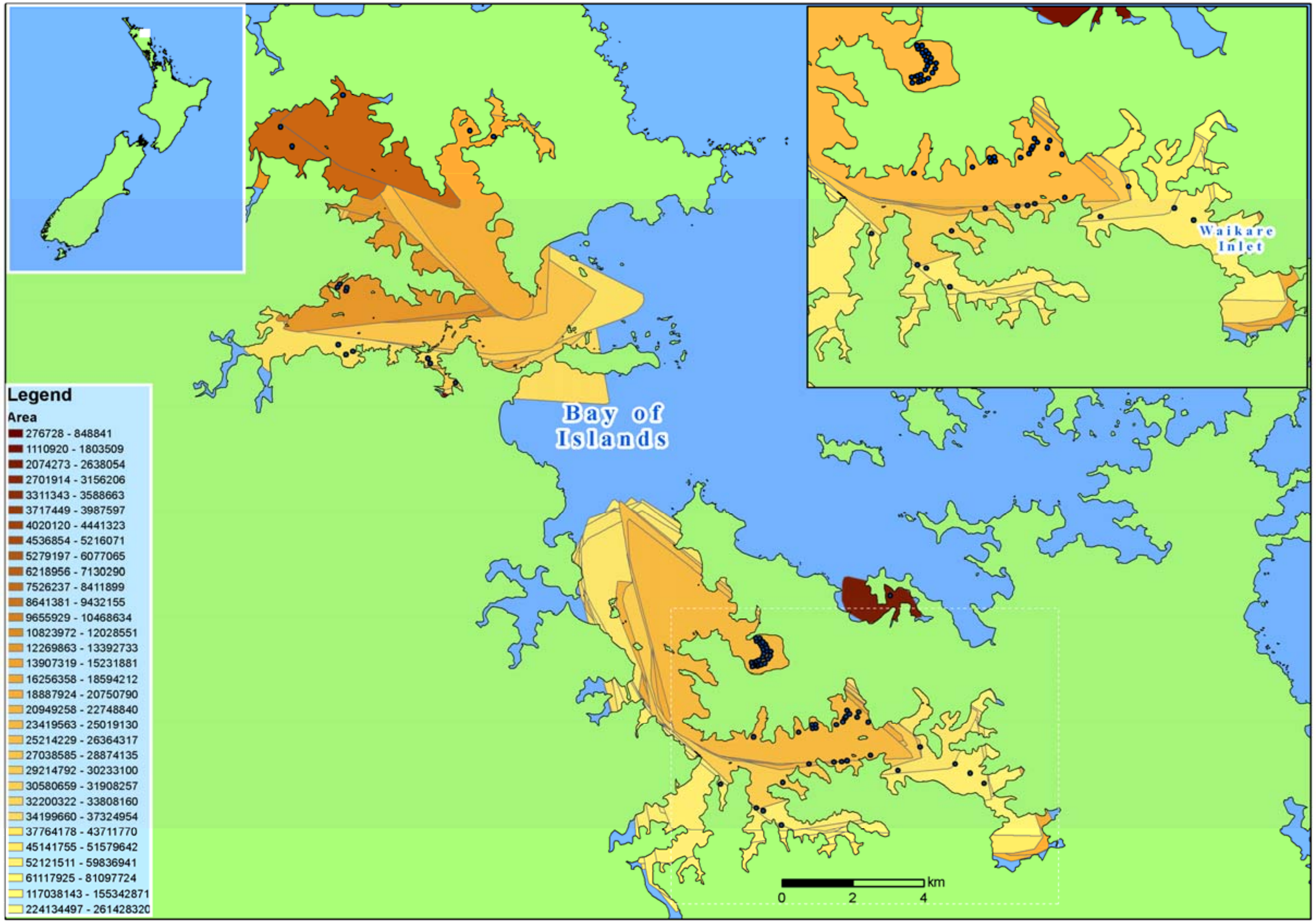

Figure 11 Overview of 24-hour pathogen dispersal from marine farms in the Bay of Islands.

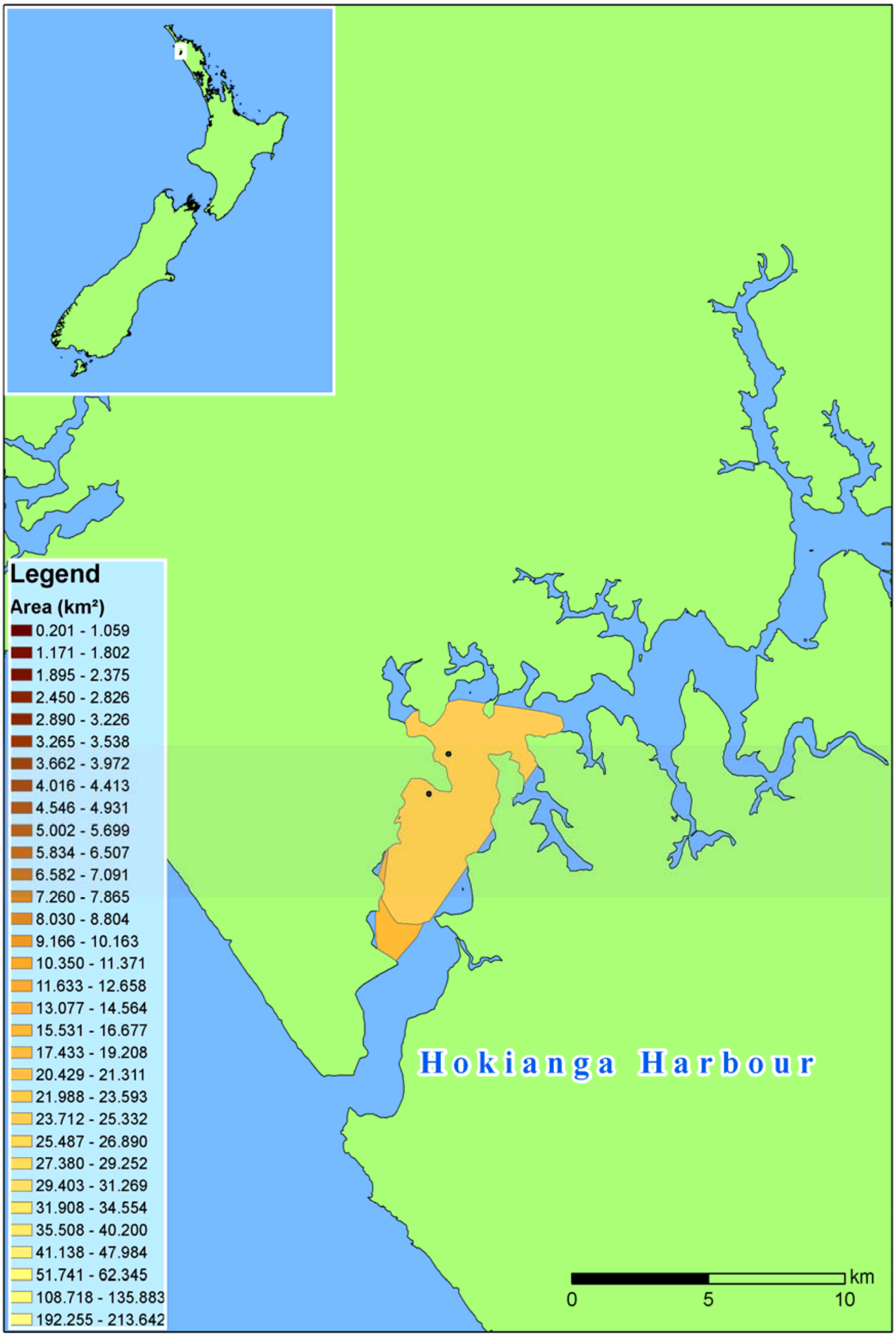

Figure 12 Overview of 24-hour pathogen dispersal from marine farms in the Hokianga Harbour.

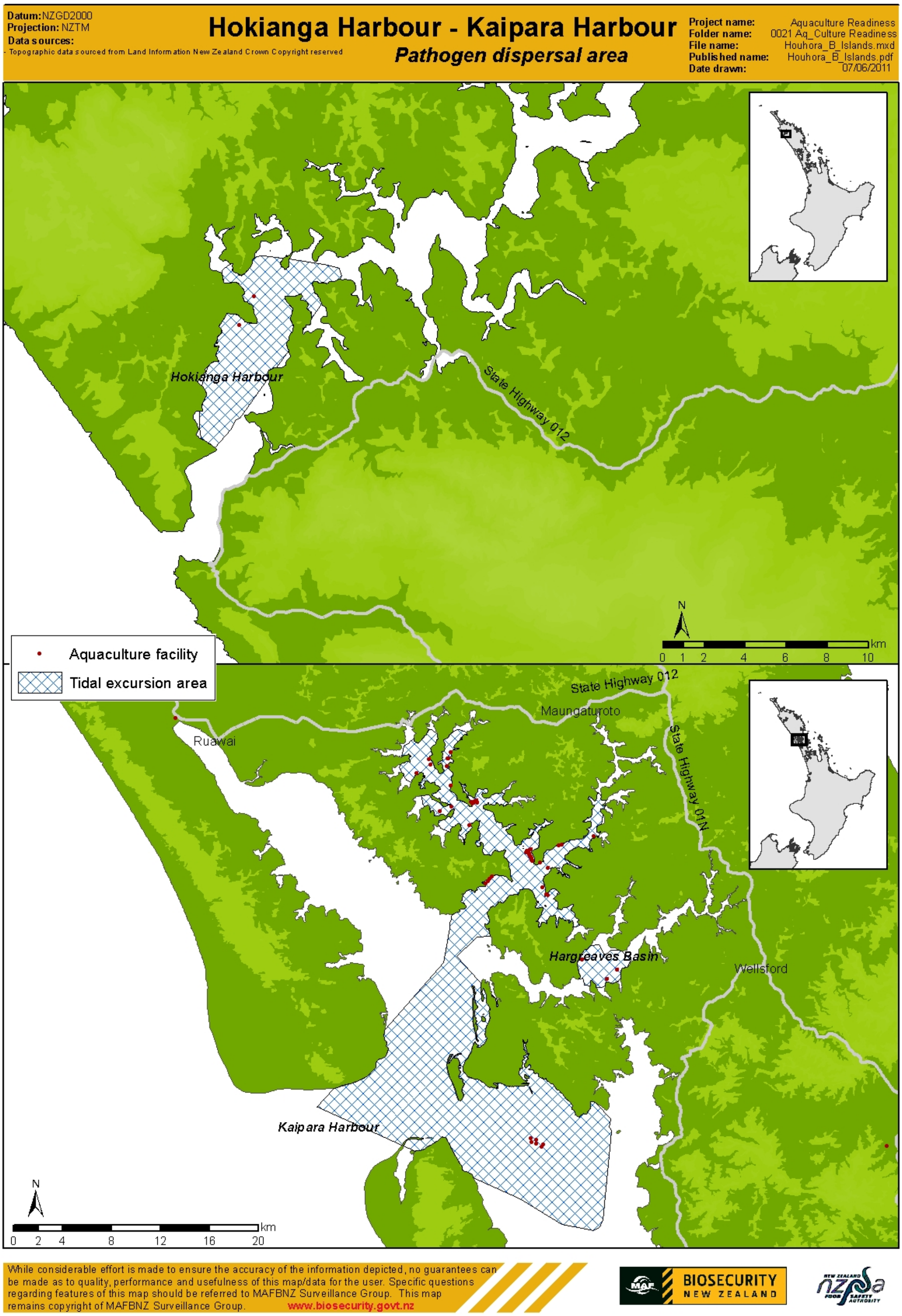

Figure 13 Proposed pathogen dispersal zones in the Hokianga and Kaipara Harbours.

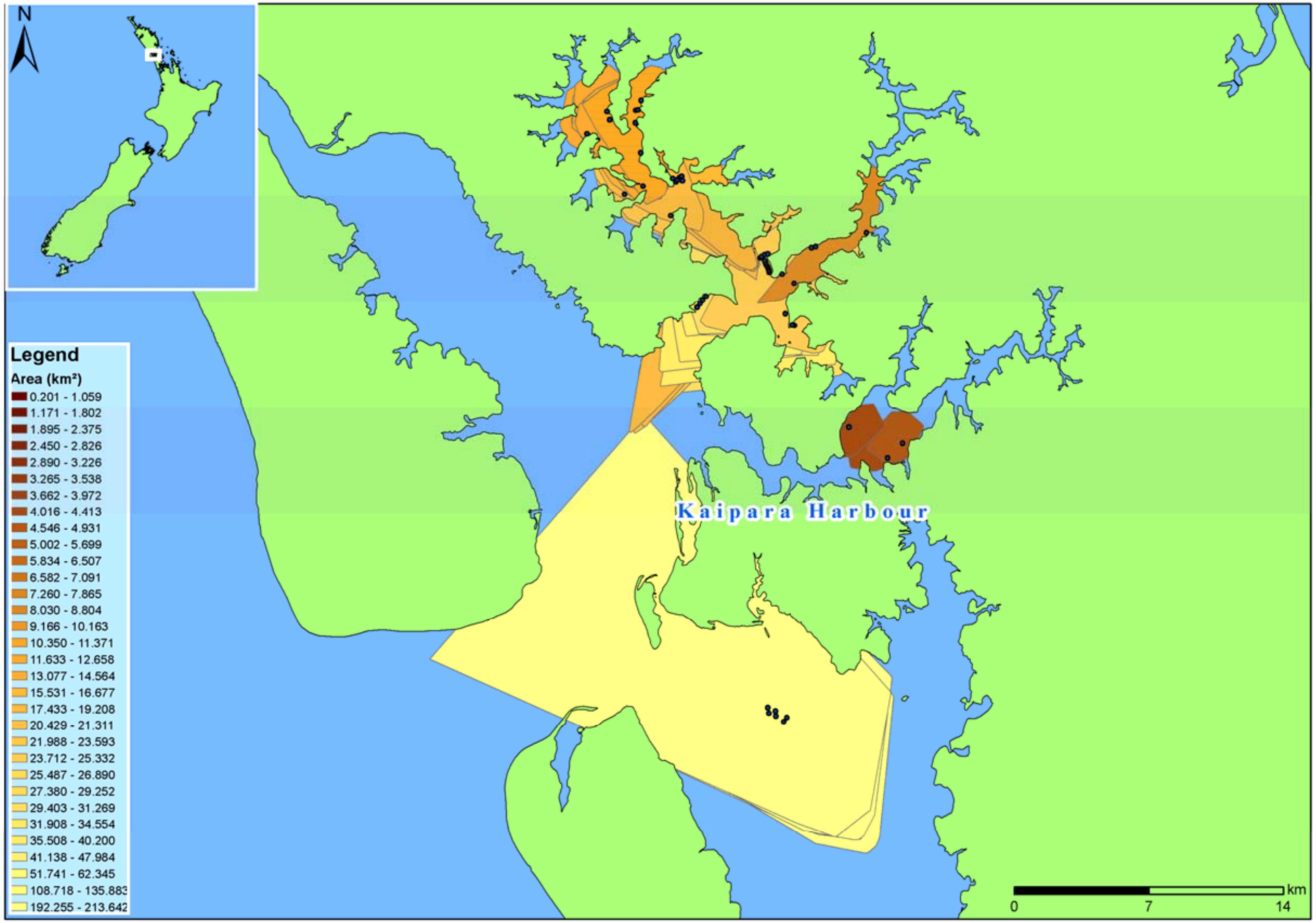

Figure 14 Overview of 24-hour pathogen dispersal from marine farms in the Kaipara Harbour.

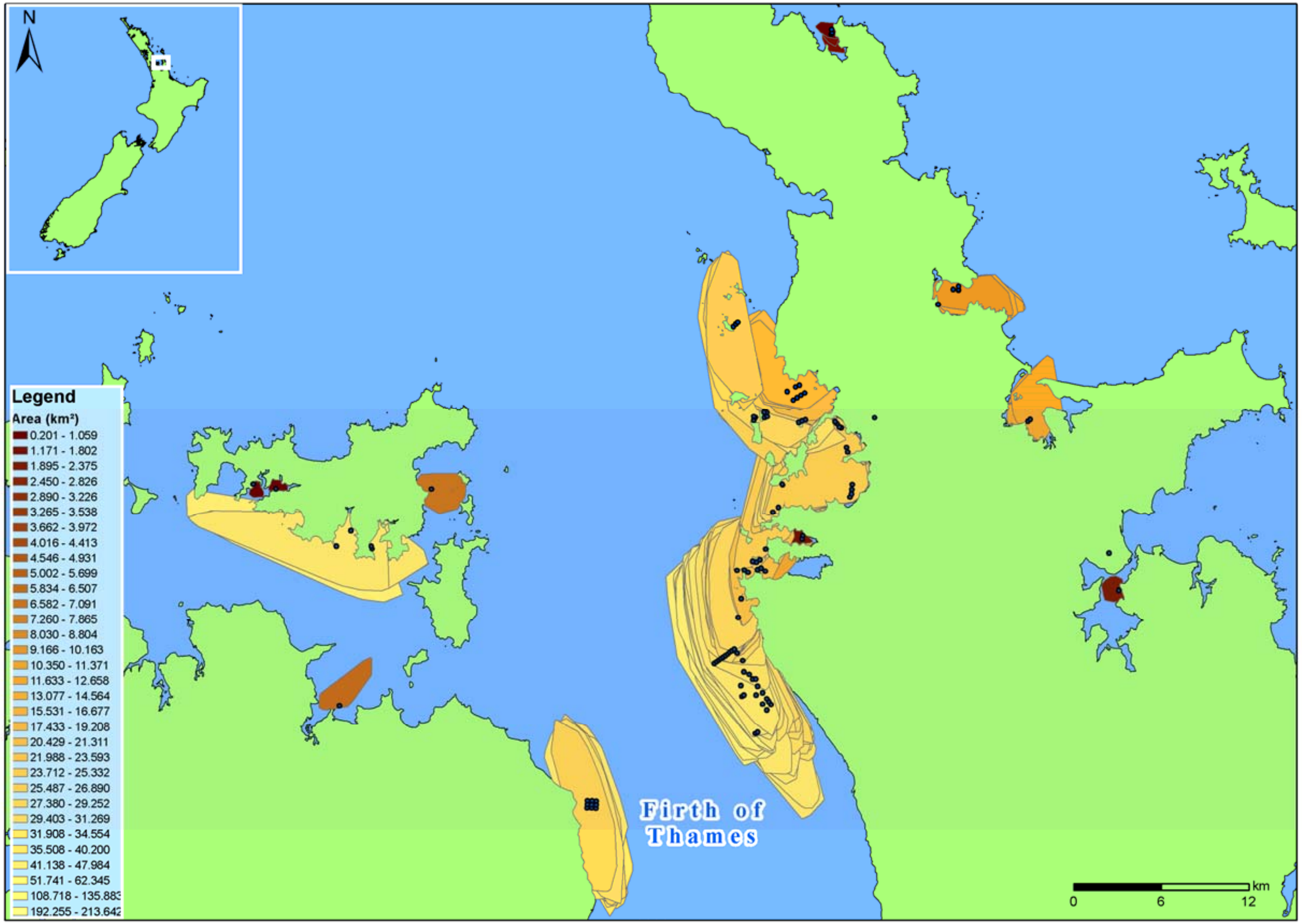

Figure 15 Overview of 24-hour pathogen dispersal from marine farms in the inner Hauraki Gulf.

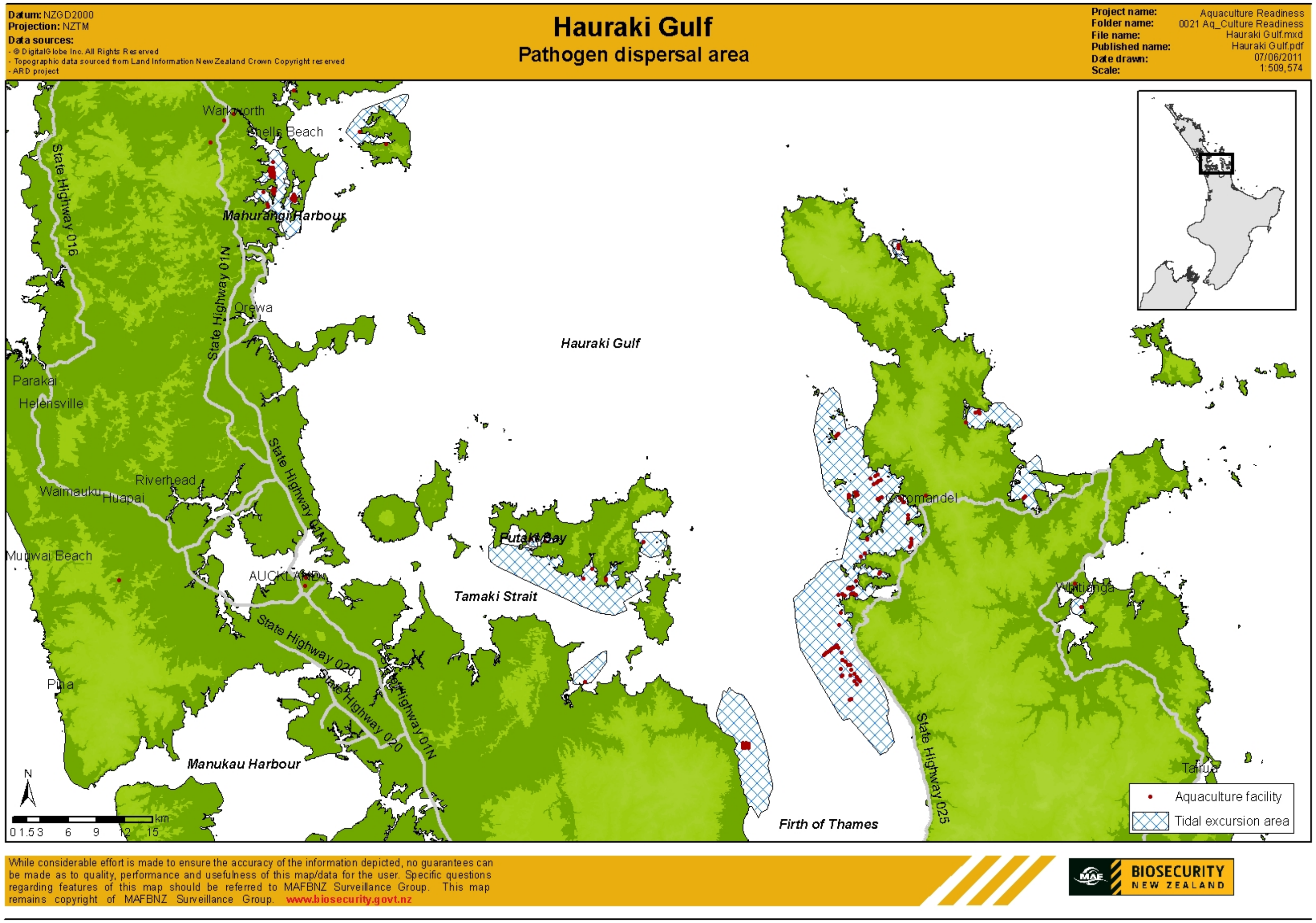

Figure 16 Proposed pathogen dispersal zones in the Hauraki Gulf, Firth of Thames and Coromandel.

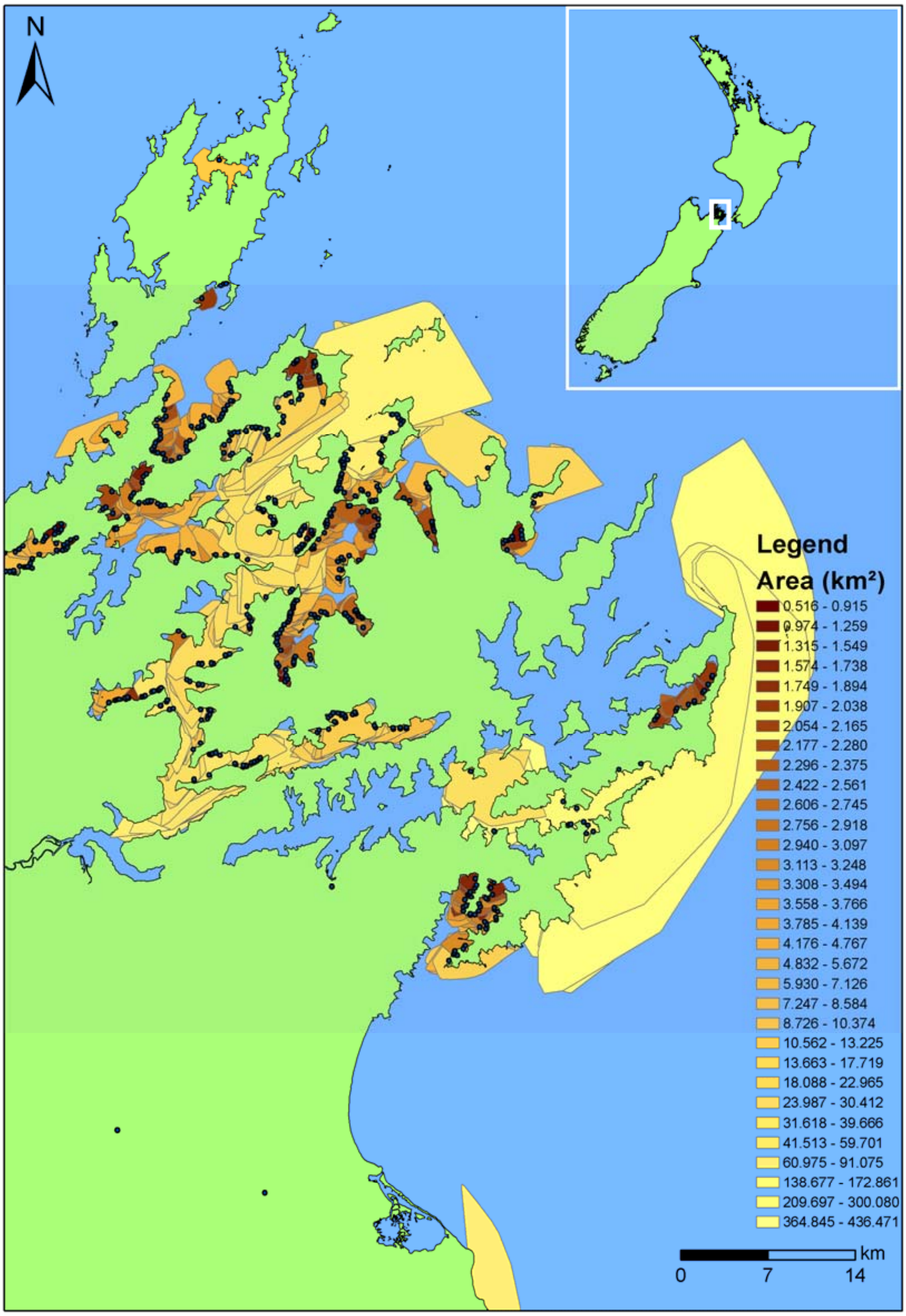

Figure 17 Overview of 24-hour pathogen dispersal from marine farms in the Marlborough Sounds. Polygons are shaded by area.

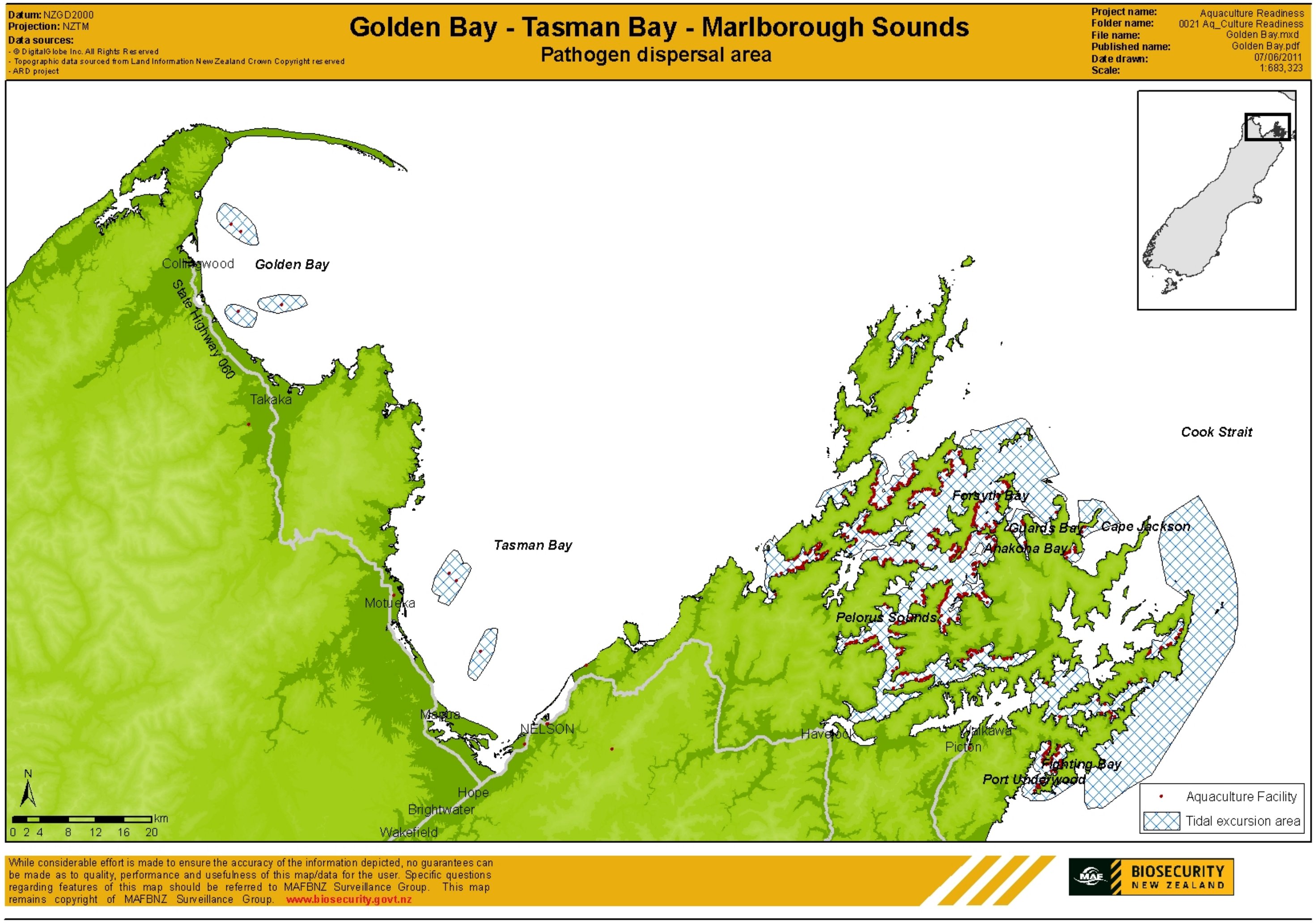

Figure 18 Proposed pathogen dispersal zones in the top of the South Island.

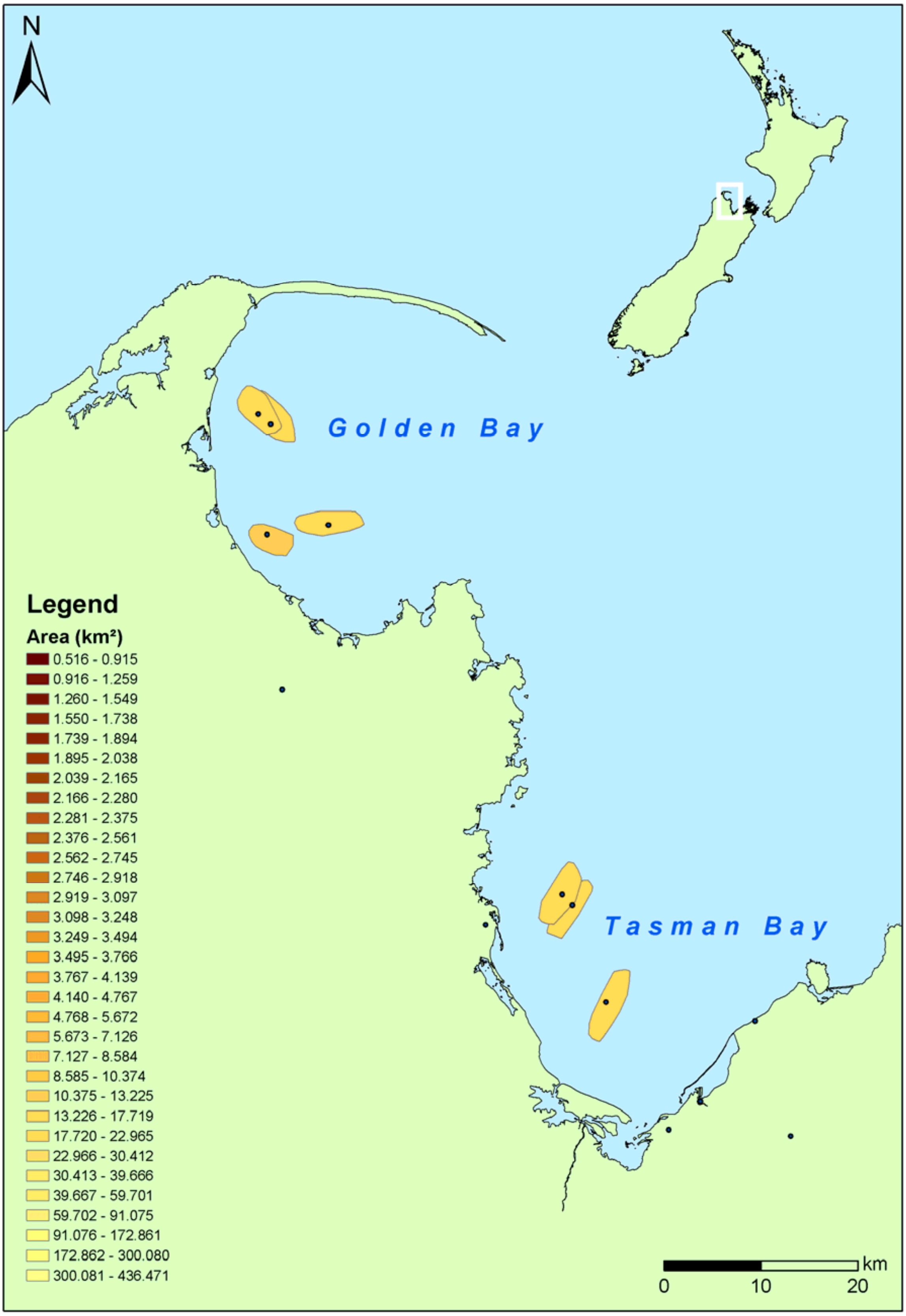

Figure 19 Overview of 24-hour pathogen dispersal from marine farms in Tasman and Golden Bays. Polygons are shaded by area.

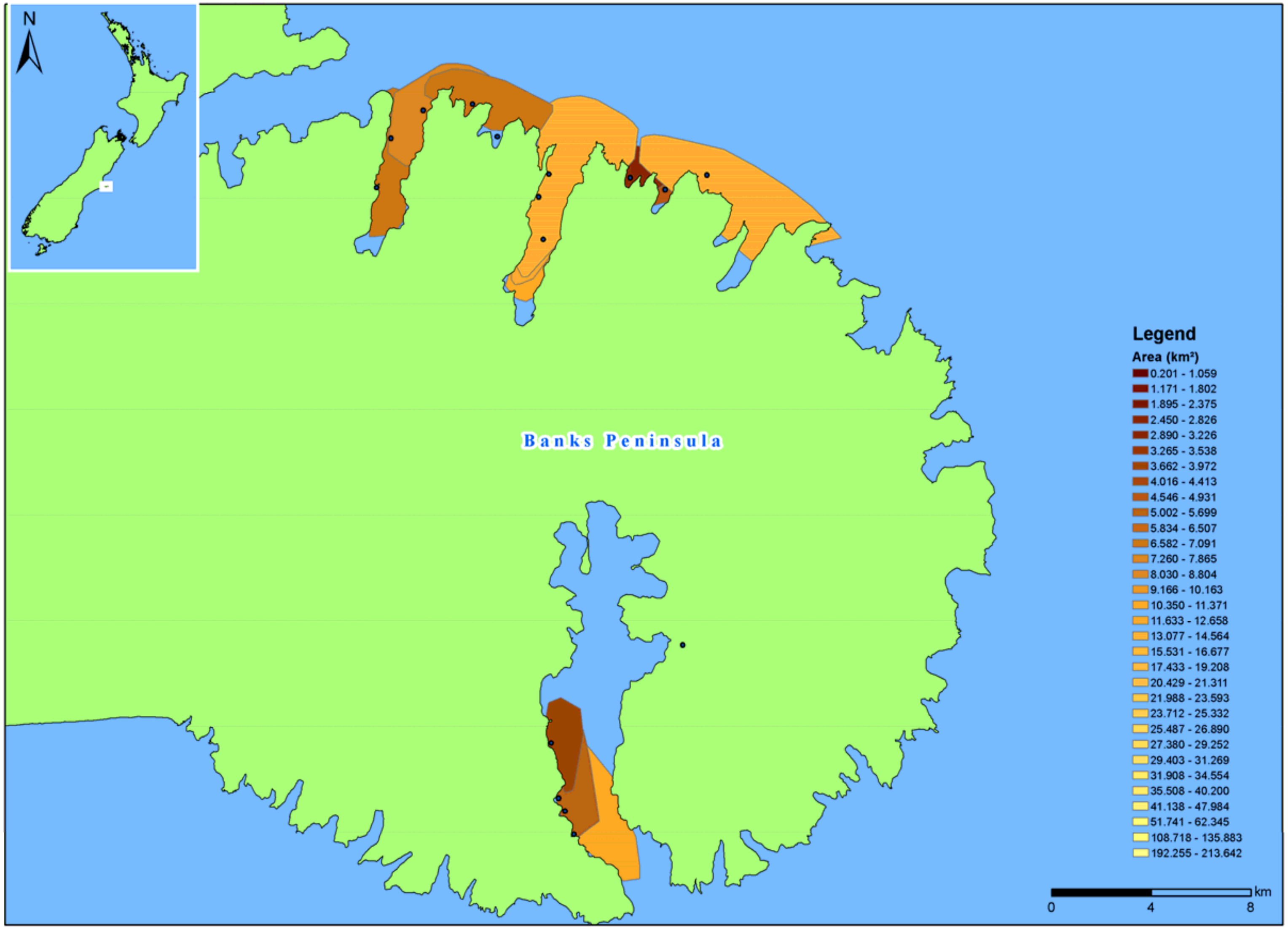

Figure 20 Overview of 24-hour pathogen dispersal from marine farms on Banks Peninsula. Polygons are shaded by area.

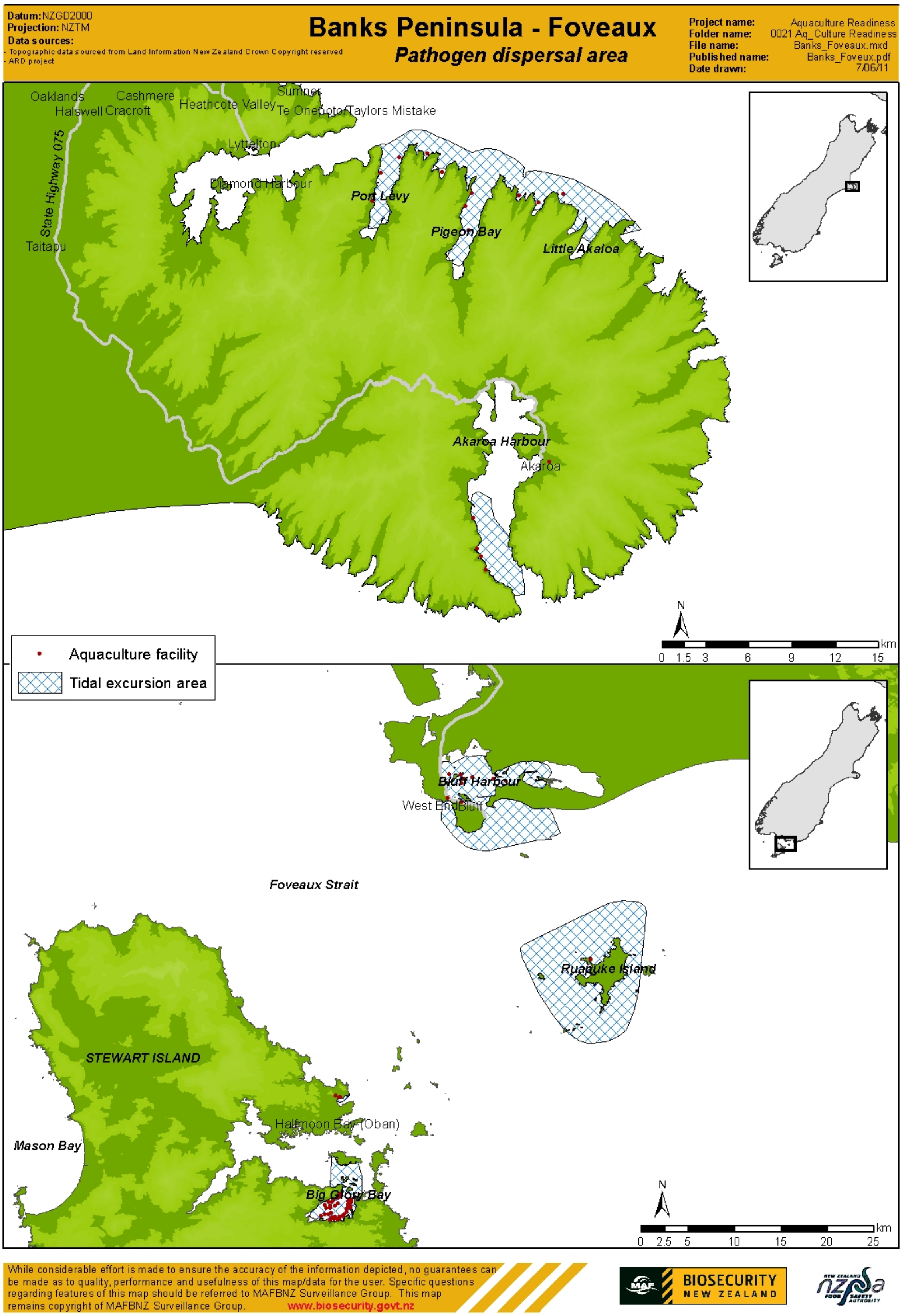

Figure 21 Proposed pathogen dispersal zones on Banks Peninsula and around Foveaux Strait.

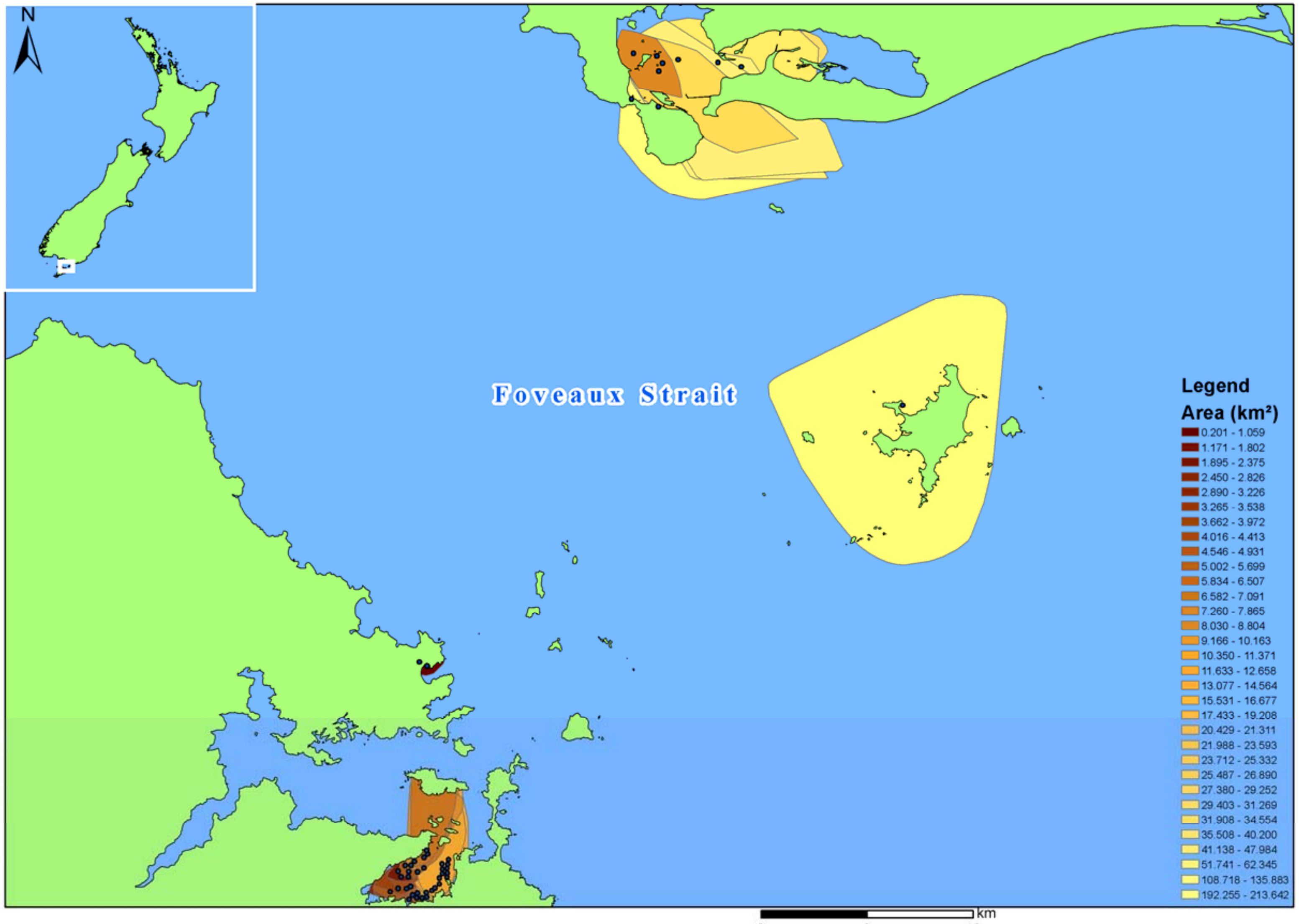

Figure 22 Overview of 24-hour pathogen dispersal from marine farms around Foveaux Strait. Polygons are shaded by area.

Appendix 3: Maps of 24-hr pathogen dispersal for freshwater and land-based facilities

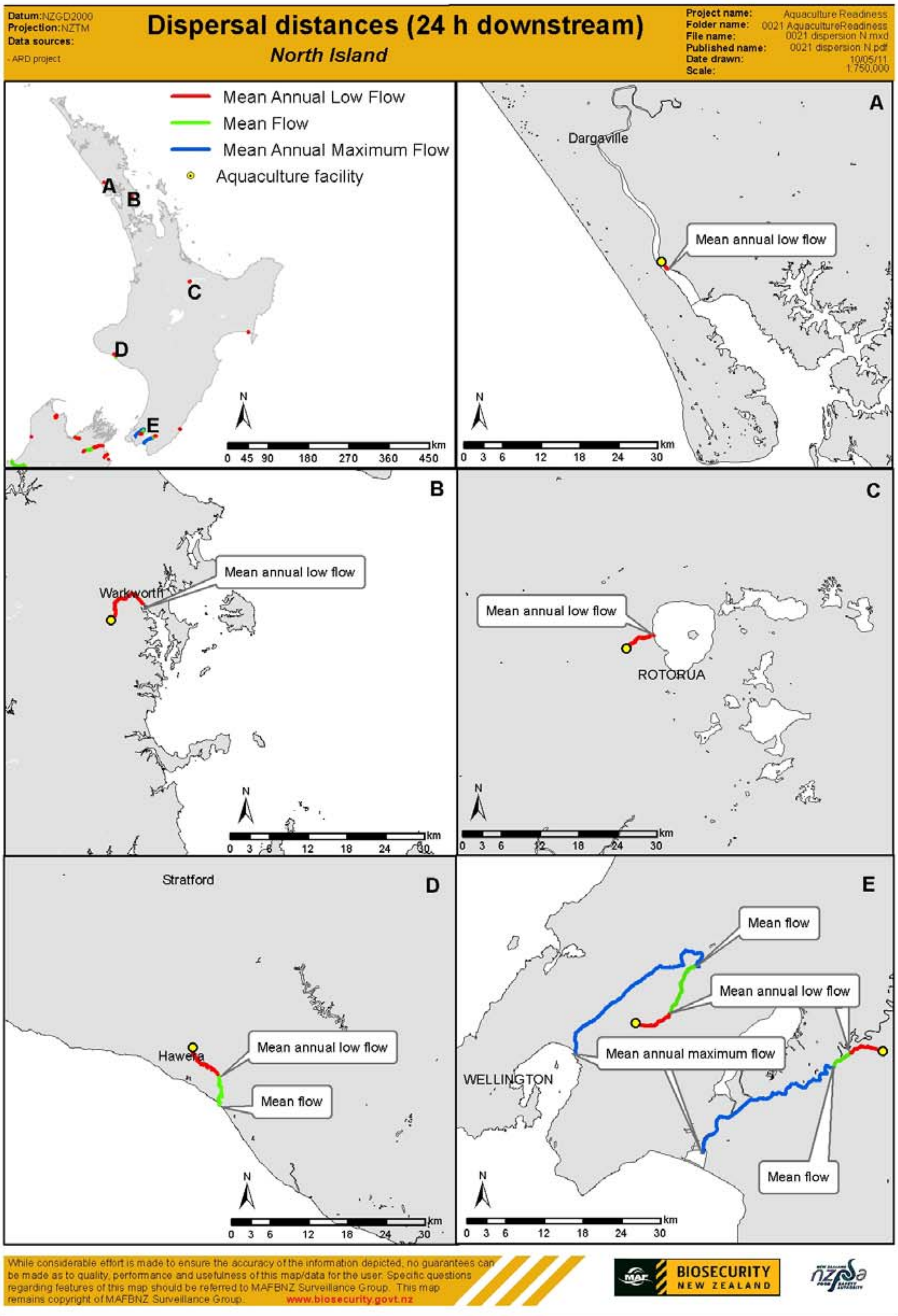

Figure 23 Estimated dispersal of pathogens from freshwater and land-based aquaculture facilities in the North Island over 24 hours under three different flow regimes.

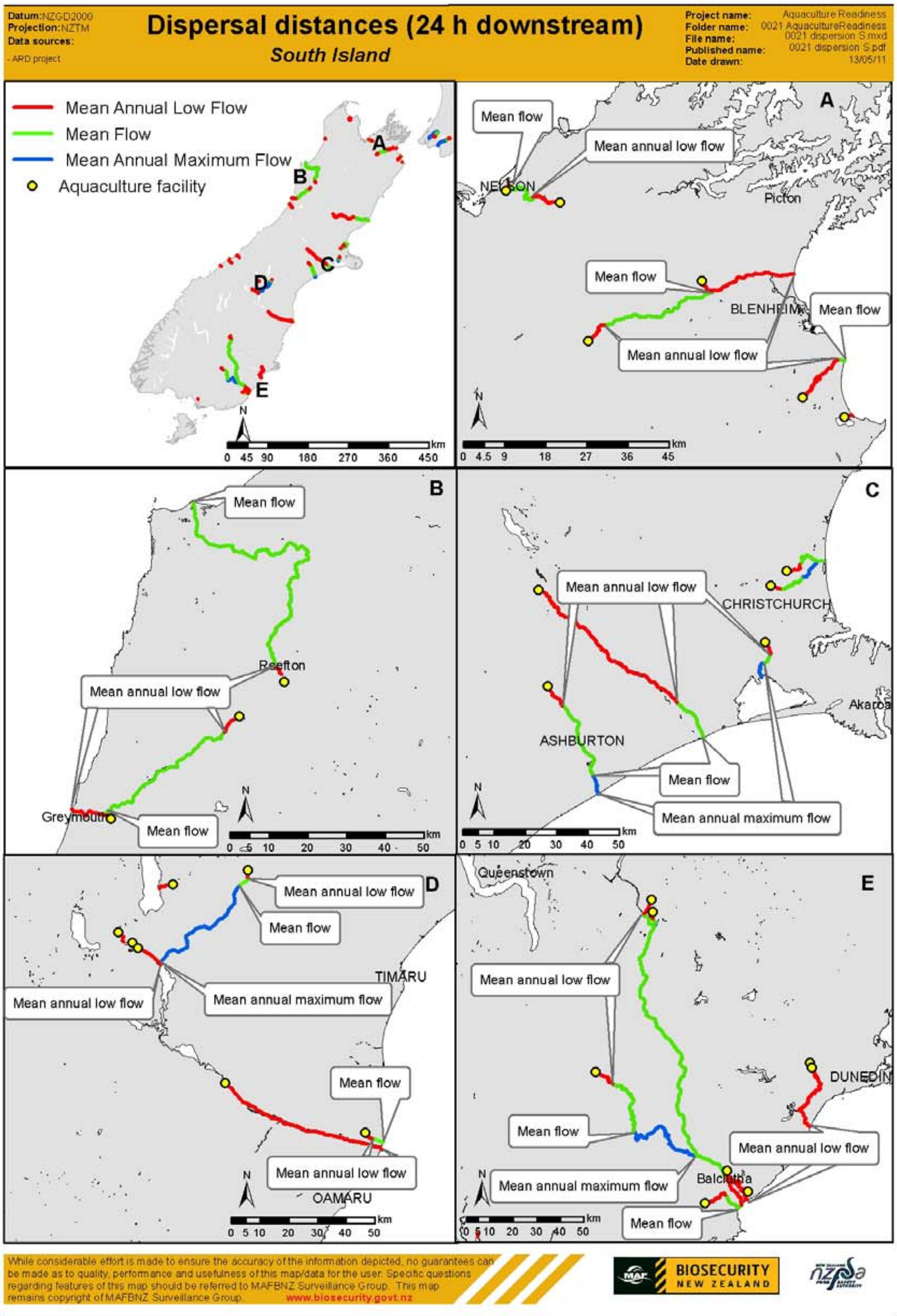

Figure 24 Estimated dispersal of pathogens from freshwater and land-based aquaculture facilities in the South Island over 24 hours under three different flow regimes.

Appendix 4: Maps of movements of aquaculture stock and gear

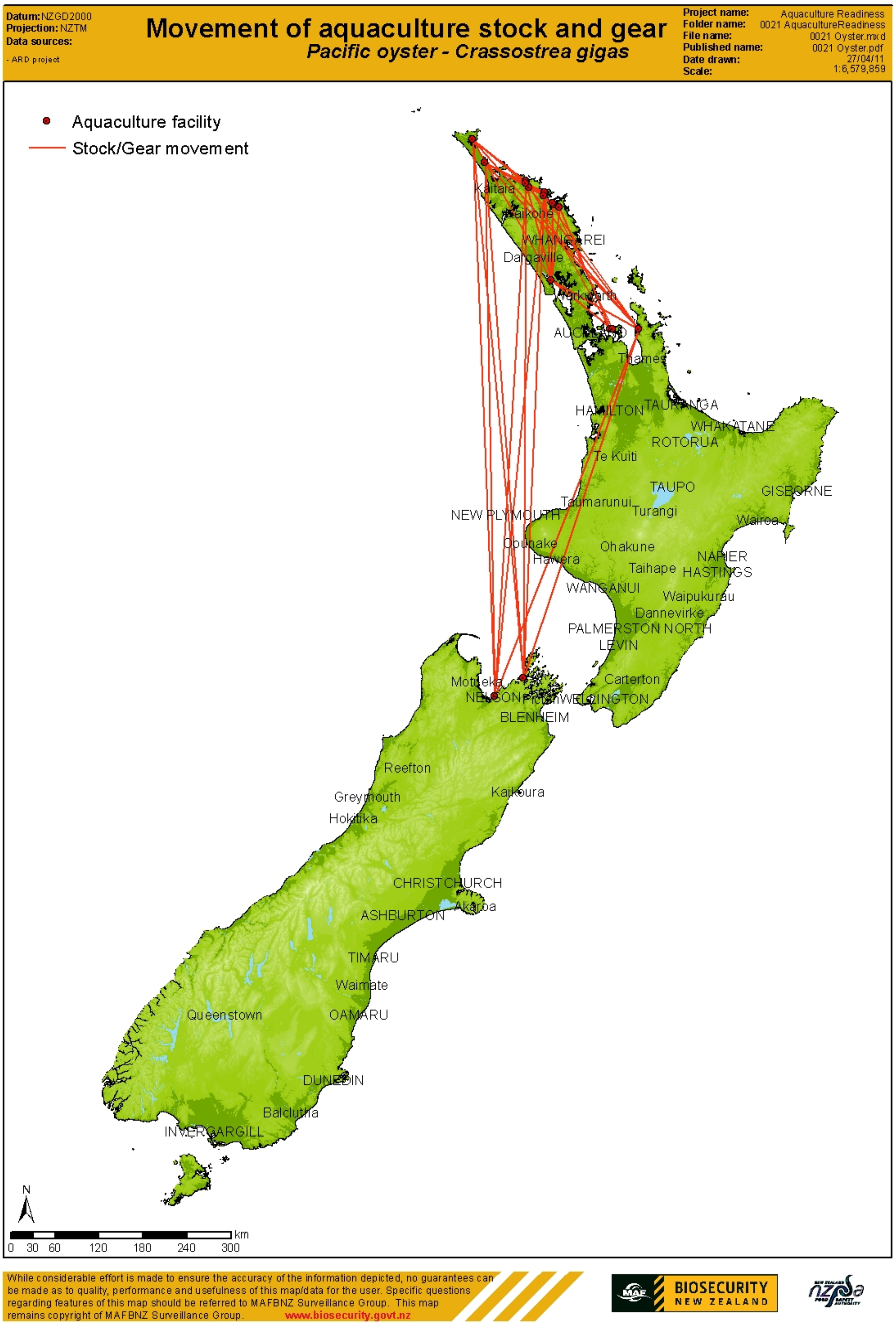

Figure 25 Movements of oyster farming stock and materials among aquaculture facilities, as identified during Phase I of the present study.

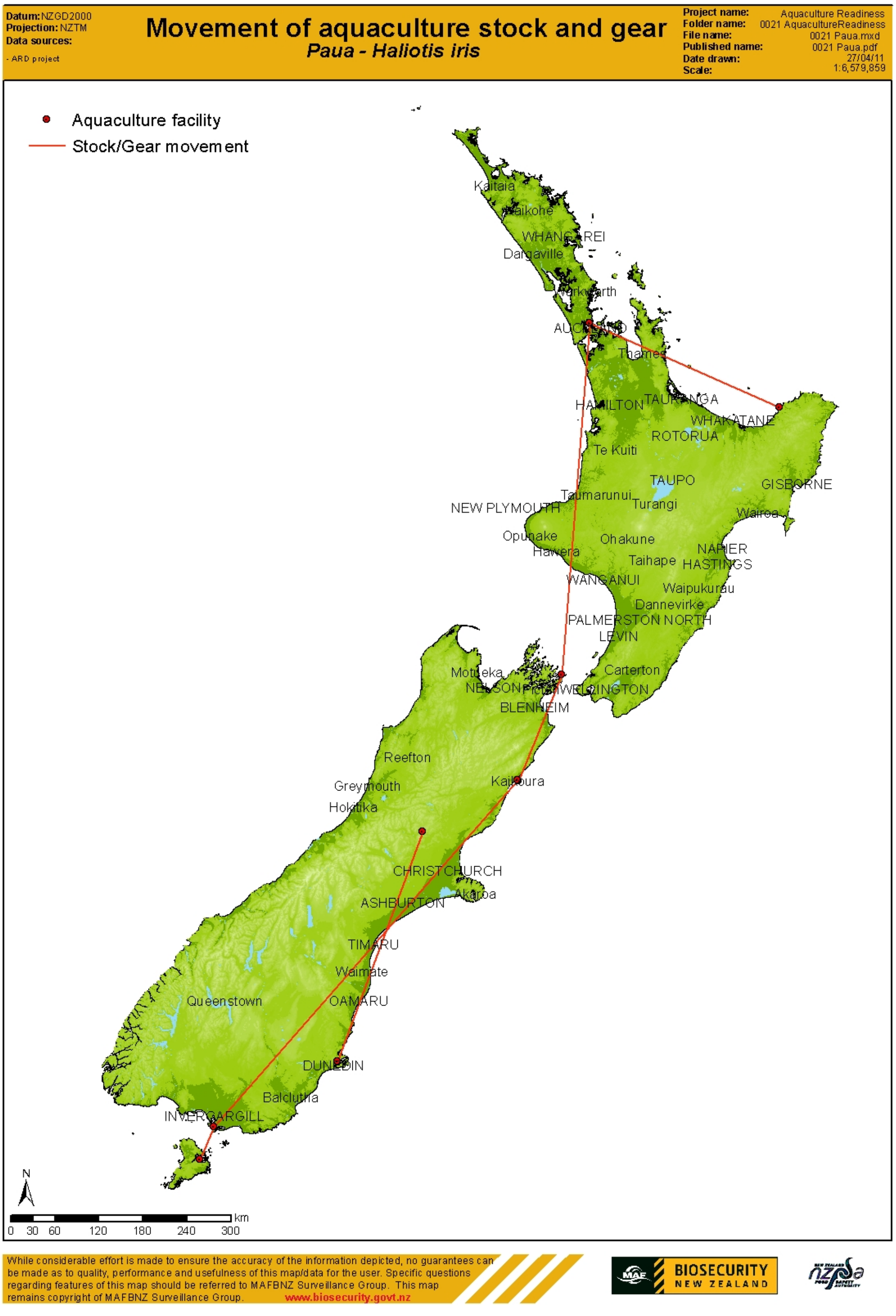

Figure 26 Movements of paua farming stock and materials among aquaculture facilities, as identified during Phase I of the present study.

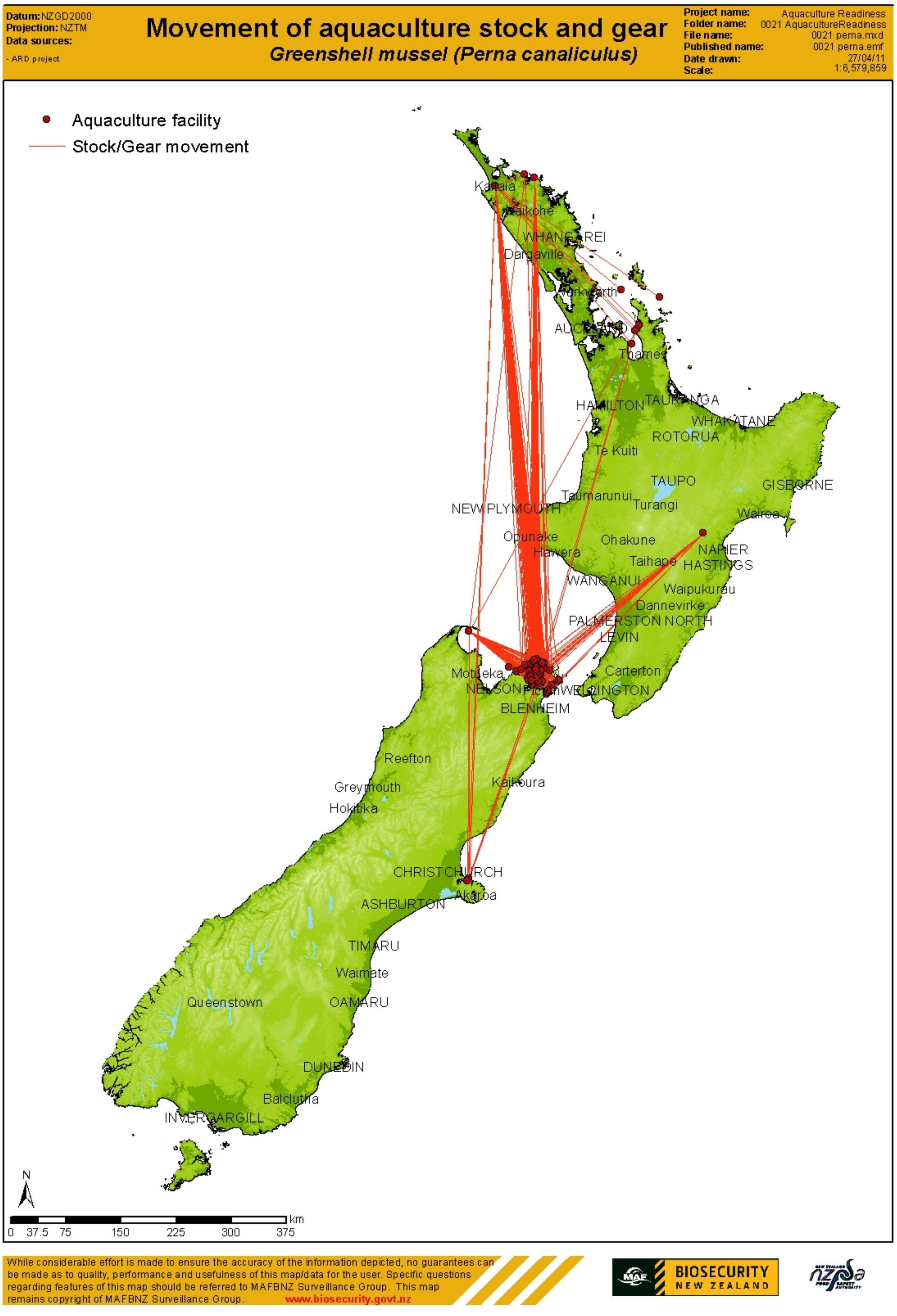

Figure 27 Movements of mussel farming stock and materials among aquaculture facilities, as identified during Phase I of the present study.

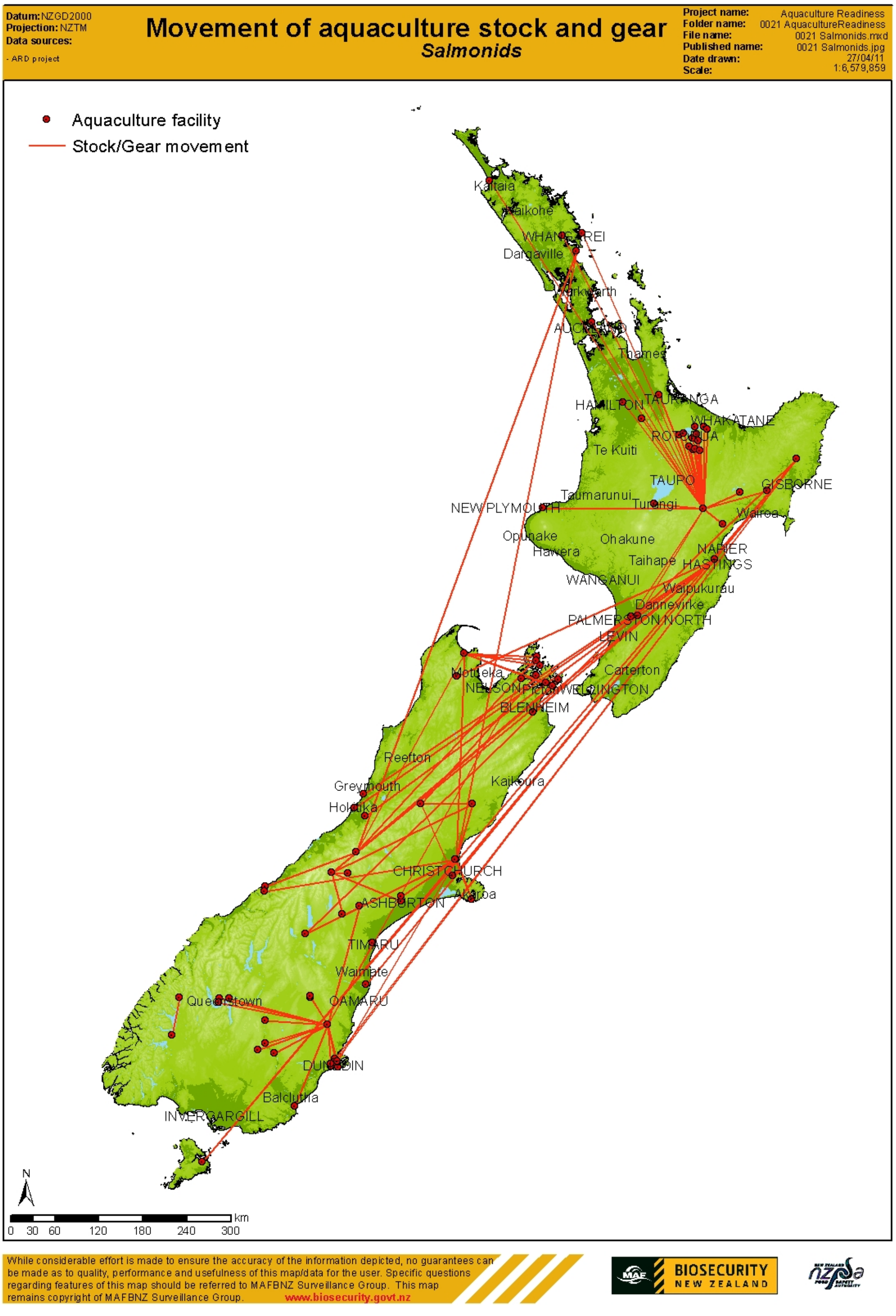

Figure 28 Movements of salmonid farming stock and materials among aquaculture facilities, as identified during Phase I of the present study.