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POTENTIAL ECOSYSTEM IMPACTS OF BIOSECURITY RISKS ASSOCIATED WITH FRESHWATER FISH FARMS

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EXECUTIVE SUMMARY

Freshwater aquaculture will always carry an element of biosecurity risk from potential negative impacts on the species being farmed, as well as surrounding river and lake ecosystems. Freshwater fish farms are not unique as regards the measures required to manage these risks to an acceptable level. However, there are many research gaps around the potential ecosystem impacts of biosecurity risks associated with New Zealand's freshwater farming. It is also the case that 'acceptable level of risk' is highly situation dependent and subject to interpretation within relevant regulatory frameworks. This means any risk analysis related to ecosystem impacts must be largely populated with common ecological risks previously identified for marine aquaculture in New Zealand and for international freshwater aquaculture. In addition, much of the global research on freshwater ecosystem impacts of fish farming has focused on commercially important salmonid aquaculture, with much less attention given to other freshwater finfish, mussels or crustaceans. This research 'gap' will need to be addressed if freshwater species not previously considered become candidates for farming in New Zealand. The legislative framework for possession and potential farming of freshwater fish species in New Zealand is complex and evolving and there are also recognisable gaps and anomalies here that may need addressing, if the freshwater aquaculture sector expands.

The associated level of biosecurity risk from the farm to the surrounding recipient ecosystem will also be greatly influenced by whether the system is closed, semi-closed or open. This is because the nature of the system and the consequent degree of control the farmer has of biosecurity pathways into, through and out of the farm influences the likelihood of escape / unintentional release of farmed stock, as well as any associated species, parasites and pathogens. The levels and types of biosecurity risk to farmed stock 'on-farm', will vary depending on the nature of the aquaculture system involved, be it a closed system such as a secure aquaculture facility, a semi-closed system such as an aquaculture pond or reservoir or a completely open system such as a river or lake.

Many of the risks for ecosystem biodiversity, function and structure are associated with escapees from fish farms. Escapees carry with them risks of ecosystem impact associated with increased competition with and predation of resident fauna, habitat alteration (in terms of fish such as koi carp), genetic hybridisation and introgression impacts on wild fish populations, as well as disease and parasite spread. Deliberate releases, whether for restocking or conservation purposes, carry many of the same risks for ecosystems as escapee incidents if they are not planned and well managed.

Species farmed with a goal of benefitting conservation and / or restocking purposes before deliberate release to the environment, can have negative ecosystem impacts. Careful consideration of alternative options should be considered first. If it is concluded that aquaculture-reared fish are required for conservation purposes, there is an opportunity to identify and address biosecurity risk management issues and potential ecological impacts on

recipient ecosystems with a much higher level of precision than accidental escape or using fish farmed for alternate purposes.

Ideally, each individual freshwater fish species (or crayfish or mussel), native or non-native, would have its own biosecurity risk analysis profile, whether for aquaculture or for processes linked to aquaculture. Such a profile would include risks to recipient ecosystems based on the ecological traits of each species. For instance, the relative trophic level of the farmed species is an important factor to consider in terms of potential for ecosystem disruption, should there be an escape. Many farmed finfish species are often at a higher trophic level than fish in local lakes and rivers and higher trophic level escapees can potentially disrupt ecosystem structure and function at multiple ecological levels. Such species profiles, backed by relevant research, would streamline the decision-making process for each potential aquaculture project, both for the proponent and regulator.

Prevention is always better than cure and a precautionary approach to fish farm location and species farmed is the one which will best protect recipient ecosystems. The location of any proposed freshwater fish farm should always ideally be judged in the context and knowledge of the recipient ecosystem, especially if the ecosystem contains species of conservation importance and / or culturally sensitive ones. The more detailed and comprehensive this assessment of the river and lake ecosystem (and connected freshwater systems), the better the cost-benefit analysis of any farm proposal can be judged by regulators and policy makers, at least in respect of environmental concerns.

Current typical fish farm license conditions are outlined, including the requirement for a biosecurity plan. License conditions and biosecurity plans in New Zealand mirror those in other countries such as Australia and the United Kingdom. They address issues of entry-level, internal and exit-level biosecurity pathways in terms of animals, water, effluent / waste, feed, equipment and people. Once hazards to farm biosecurity have been identified, focusing on conditions which address general pathways for diseases and parasites onto, through and out of the farm is the best way to manage current and future (i.e., parasites / diseases new to New Zealand) risks. Everything that contributes to minimising on-farm biosecurity risks will automatically contribute to reducing biosecurity risks to ecosystems. The aquaculture zoning management ‘ecosystem’ approach, in which multiple farms are located in the same hydrographic zone and act in a coordinated fashion to manage biosecurity risks, represents a practical way to enhance individual farm biosecurity plans, while diminishing the risk of wider geographic spread of pathogens and parasites.

A biosecurity risk analysis framework is presented, with specific risks to recipient ecosystems identified. Management of such risks in terms of risk mitigation and / or avoidance measures are provided. These could add context and inform the standards / conditions sought in application or conditions in resource consents. Farming of non-native species carries an inherently greater risk of negative impacts on recipient ecosystems than native species. Likewise, farming of native species which have never been present in the region or catchment, carries a greater risk than farming of natives, which are already present in resident assemblages. This report makes key recommendations to protect ecosystem health from biosecurity risks associated with freshwater fish farms.

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1. INTRODUCTION AND SCOPE

In New Zealand, the Ministry for Primary Industries (MPI) defines biosecurity as 'the exclusion, eradication or management of pests and diseases that pose a risk to the economy, environment, cultural and social values, including human health' (MPI 2016a). Cawthron was commissioned by the Department of Conservation (DOC) to produce a report identifying the potential biosecurity risks of freshwater fish farms. This specifically relates to section 26ZM 'Transfer or release of live aquatic life' of the Conservation Act 1987 (2019 amendment) and should inform DOC of the potential risks to freshwater ecosystems that should be considered while assessing resource consents or when providing comments back to external agencies such as MPI. The biosecurity issues that DOC have identified include (but are not limited to) pathogens, parasites and risk of escape. Consideration of the ecological and environmental impacts associated with these issues was also a requirement of this report. Another requirement is an investigation of how such biosecurity risks are currently being managed and what standards / conditions should be required in future licence or resource consent applications for prospective freshwater aquaculture operations.

Tasked with the above, this report describes the current legislative background that is relevant to freshwater fish farming in New Zealand and how this may influence biosecurity management.

The first part of this report identifies the main biosecurity risks and their potential ecological and environmental impacts on the receiving environment. The report outlines potential mitigation measures to either eliminate these risks or manage them to an acceptable level.

The second part of the report details what biosecurity risk management is currently taking place and what general conditions in licences are being sought at present. This could inform what standards / condition should be sought in the future, in context of minimising negative impacts to freshwater ecosystems.

A risk analysis framework is presented along with a brief methodology and the assumptions used in its construction. This follows the general design of a risk analysis framework for translocations in New Zealand (MacNeil 2021), as there are similar risks for recipient ecosystems. This report will restrict itself to consideration of biosecurity risk in terms of the farmed species, associated organisms, parasites and pathogens and will not address issues of physicochemical water quality, pollution or chemical release. This report will consider freshwater species currently farmed and also some which may be candidates for future farming.

This report presents an overview of the potential biosecurity risks and associated ecosystem impacts of freshwater fish farms. A follow-up companion report will include an inventory of current freshwater fish farms in New Zealand, their individual locations, their operating systems and the biosecurity measures being currently applied. This current report does refer to a specific fish farm licence issued to the Cawthron Institute on the basis that core licence conditions on current fish farm licences are very similar. The Cawthron licence referred to in this report is also very comprehensive as regards the extent and types of species it contains and therefore is a very useful template for considering licence conditions, biosecurity plans and biosecure methods in current and future freshwater fish farm licences.

2. CURRENT FRESHWATER FISH FARM BIOSECURITY – A LEGISLATIVE PERSPECTIVE

2.1. Biosecurity definitions and administration

There are many definitions of biosecurity available both in Australasia and globally (2016b). Certain European Union (EU) guidelines have defined biosecurity in very comprehensive scientific terms, as ‘ preventative measures to reduce the risk of spread of infectious diseases, pathogens, pests, invasive non-native species, and modified organisms, and can include toxins and pollutants’ (zu Ermgassen et al. 2020). However, such guidelines have less focus on the risks to cultural, social or economic values that are at the forefront of current New Zealand policy. It must be recognised that that the way the term ‘biosecurity’ is applied will be dependent on context and physical scale, with the latter ranging from local to national to transnational and even global scale (zu Ermgassen et al. 2020).

DOC has a pivotal role in safeguarding New Zealand’s plant and animal species and protecting the country’s unique biodiversity from pests and diseases (https://www.doc.govt.nz/nature/pests-and-threats/animal-pests/freshwater-pest-species/organisations-and-legislation/). Stopping the spread and impact of pests on freshwater ecosystems is a major goal (Freshwater pests: Pests and threats (doc.govt.nz)) and anyone who wishes to transfer or release plants or animals into fresh water (including freshwater fish farms) must obtain authorisation (https://www.doc.govt.nz/get-involved/apply-for-permits/interacting-with-freshwater-species/moving-freshwater-species/). To move a freshwater species to a location where they don’t already occur, DOC must be contacted and an Environmental Impact Assessment (EIA) may be required, to ensure the introduced species will not pose a risk to freshwater ecosystems via either direct or indirect negative impacts (Apply to move freshwater species: Moving freshwater species (doc.govt.nz)).

Potential biosecurity risks of freshwater fish farms to freshwater ecosystems are considered under section 26ZM ‘Transfer or release of live aquatic life’ of the Conservation Act 1987 (2019 amendment). When assessing resource consents associated with freshwater fish farms, DOC provides comments back to external agencies such as MPI and regional councils. It should be noted that nothing in this section applies to the transfer of any live aquatic life to an existing fish farm where the species is already present.

In New Zealand, MPI is tasked with a ‘whole system’ leadership role as regards biosecurity administration and orchestrating environmental, economic and social / cultural outcomes. The New Zealand biosecurity system is based on risk management processes taking place internationally, at the border and within New Zealand (MPI 2016a). The Biosecurity 2025 Direction Statement for New Zealand’s biosecurity system (MPI 2016a) provides guidance on how the 'within New Zealand component' can be further subdivided into 3 layers of biosecurity risk management:

1. Surveillance – general and targeted programmes for pest and disease detection.
2. Readiness and response – testing of the biosecurity system's capability and, once pests and diseases are detected, how the system responds.
3. Long-term management - nationally (eradication, containment and management across New Zealand), regionally (primarily regional council-led plans, including pest management plans) and locally (pests/ diseases with a specific place or site are managed to protect the values of that place or site)

2.2. Biosecurity, freshwater aquaculture and existing legislation

2.2.1. Freshwater ecosystems and biosecurity

Freshwaters represent the ecosystems most subject to biological invasion internationally and in New Zealand (Champion et al. 2002). An animal or plant that has been introduced to New Zealand becomes a pest if it has the potential to cause significant national negative economic, environmental, or cultural effects. Second only to habitat loss / degradation, invasive pest species constitute the major driver of biodiversity loss in freshwater systems globally (Simberloff et al. 2013). Although New Zealand is relatively free from freshwater pests and diseases compared to Europe and North America, invasive plant and animal pest species remain a significant threat to New Zealand's freshwater ecosystems (Gluckman 2017) and there are examples of harmful invasions such as didymo. New Zealand's freshwaters are home to over 50 native fish species (Dunn et al. 2018) and fish are near the top of the food chain in most freshwater systems. Many fish species are valued by Māori as mahinga kai (traditional food sources and practices for harvesting them). There are at least 23 introduced freshwater fish species in New Zealand and some pest fish species outcompete or prey upon natives (McDowall 1995). They can spread rapidly through a river or lake system or even entire catchments, after which attempts at eradication are extremely difficult or impossible and further range expansion to new regions becomes increasingly likely (McDowall 1995). Although commercially important salmonids are the current focus of New Zealand freshwater fish farming and / or production, the future aquaculture potential of non-salmonid finfish and other species in New Zealand fresh waters has been considered in the past (McDowall 1995) and continues to be considered, as acknowledged in the comprehensive technical guidance on aquaculture biosecurity management published by the MPI[1] (MPI 2016b).

[1] https://www.mpi.govt.nz/dmsdocument/13287/direct.

2.2.2. Freshwater aquaculture

Biosecurity, in relation to freshwater aquaculture in New Zealand, is regulated in the context of four principal pieces of legislation: the Freshwater Fish Farming Regulations 1983, the Conservation Act 1987, the Resource Management Act 1991 and the Biosecurity Act 1993. These acts often operate in parallel, are not fully integrated with one another and can partially duplicate one another in statutory requirements for the applicant fish farmer. There is a a biosecurity handbook for fish farmers[2] which intends to be a user-friendly guide for farmers to minimise on-farm biosecurity risk (MPI 2016c). There is also a published Government Industry Agreement on Biosecurity Readiness and Response Deed (June 2013)[3].

The sustainability of the freshwater aquaculture sector depends on minimising the environmental impact generated by freshwater farms (Mavraginis et al. 2017). Preventative biosecurity is the optimum approach to prevent ecosystem impact, with early detection and reporting the next 'best' approaches to minimise ecosystem impacts. These approaches are key to eradicating or at least managing pests and diseases and their respective impacts, once biosecurity issues are manifest outside the confines of the aquaculture facility. This is because at their best, early detection and reporting allow regulatory authorities to at least attempt rapid management / eradication responses to the presence of escapees, pests or diseases. Despite this, it should be acknowledged that freshwater eradication attempts have rarely been successfully globally so robust prevention remains as the critical safeguard against ecosystem impacts (MPI 2016b,c).This situation could change in the future if more effective response tools and strategies are developed, and doing that would provide additional lines of defence for more robust overall biosecurity systems.

Where fish farms are in close proximity with one another, especially in the same catchments and sub-catchments, preventative biosecurity is best attempted as a collaborative process between farms and farmers, taking into account flows and relative location in the catchment (MPI 2016b). For instance, in Europe wild salmon and sea trout are at risk from larval sea lice associated with marine salmon farms and the level of risk is greatest in the long freshwater-saltwater fjords where they have to pass several farms during their migration to sea (Scottish Association for Marine Science and Napier University Scottish Executive Central Research Unit 2002).

2.2.3. Freshwater fish farming, aquaponics and existing legislation

Unless stated otherwise, when discussing biosecurity risks, this report uses the word 'fish' as specified in the Freshwater Fish Farming Regulations 1983, where legally 'fish' refers to 'such species of fish, aquatic life, or seaweed as may be specified….'

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[2] Aquaculture Biosecurity Handbook: Assisting New Zealand's commercial and non-commercial aquaculture to minimise on-farm biosecurity risk (mpi.govt.nz).

[3] Deed-Final-20131.pdf - Google Drive.

and includes 'the young, fry, ova, or spawn and any part of such fish, aquatic life, or seaweed'. This report also uses the MPI definition of aquaculture as 'the breeding, hatching, cultivating, rearing, or on growing of fish, aquatic life, or seaweed for harvest' (MPI 2016b). Aquaponics is a form of closed water system (see below) where fish and plants are cultivated together using the nutrients from one another and aquaponics can be for personal use or commercial purposes.

Aquaculture facilities can be a classified as open, semi-open, semi-closed or closed systems:

1. *Open systems* such as rivers and lakes have very limited or no control over the focal species or water environment.
4. *Closed systems* have strict and effective control over both the movements of the focal species and receiving water environment. Closed systems include recirculating aquaculture facilities and tank displays in the aquarium trade, research and education institutes. There is no contact with potential receiving waters
5. *Semi-closed systems* have effective control over the movement of the focal species and some control over the receiving water environment. These include aquaculture ponds, purpose-built lakes and reservoirs.

It should be noted at this point that there are currently non-native species that are not covered by existing legislation. Such species effectively have no legal status and include non-native species such as goldfish and aquarium / ornamental fish. Policy and legislation 'gaps' as regard such species in the context of the commercial aquarium / pet shop trade, have been identified and are gradually being addressed (Fisheries New Zealand 2021).

When considering freshwater fish in relation to aquaculture licensing in New Zealand, the Freshwater Fishing Farming Regulations 1983 are the core regulations. The regulations only apply to fish species listed in the Notice No. MPI 1134 Notice Specifying Fish Species Which May be Farmed (2020) (Notice Specifying Fish Species Which May Be Farmed). In the case of these listed species, it applies to all fish farming above the mean high-water mark and includes cage farming in freshwater canals and aquaria inside buildings. Farming on land using seawater or brackish water (either pumped in from the sea or circulated around the farm), is also subject to the same regulations (Fisheries New Zealand has created a guide to setting up a land-based aquaculture operation, see MPI (2021)). Approval of licences or exemptions of licences are granted under the Freshwater Fishing Farming Regulations 1983. Under section 5 of the 1983 regulations, the proponent is required to obtain any right required by the Water and Soil Conservaton Act 1967, in respect of any water required by or affected by the proposed fish farm. After making an application for this right the proponent must give notice to the Fish & Game Council. Under section 8, the Minister before granting or refusing a licence must take into account any submissions made by the Fish & Game Council in respect of section 5. Inland farms may require approval from DOC under the Conservation Act 1987 to stock freshwater species not already present in the area and / or release of freshwater farm stock to the wild. Consents under the Resource Management Act may also be needed to build structures associated with aquaculture developments and to abstract and / or discharge water.

Aquaponics is a form of closed water system where fish and plants are cultivated together using the nutrients from one another. If the system is for personal use and tanks have no inflows / outflows linked to freshwater systems then no approval to move freshwater species is necessary and no fish farm licence is required, although approval may be needed to possess some species (see Section 2.3). If the aquaponic system is linked to freshwaters, a licence is needed from DOC to move freshwater fish species, if the aquaponics is being undertaken for commercial purposes a fish farm licence from MPI is required and the species must be on the 'farmable' fish species list and if the aquaponic system is being stocked from an existing farm, then a licence is needed to apply to move the freshwater species (see https://www.doc.govt.nz/get-involved/apply-for-permits/interacting-with-freshwater-species/freshwater-fish-farming-and-aquaponics/).

While MPI manages freshwater aquaculture under the provisions of the Freshwater Fish Farming Regulations 1983, in conjunction with the Fisheries Act 1996, MPI are unable to fully consider a licence application until all necessary resource consents are granted, although they may give preliminary advice (Hollows 2016). Although licensed farms are required under licence conditions to maintain and implement a biosecurity plan to mitigate the risk of introducing, exacerbating and spreading pests and disease, it is not mandatory or a requirement to have biosecurity plans that are assessed and approved before farms are authorised (i.e., pre-licence approval) and then which are regularly audited against approved plans. In the future it is possible that plans may be mandatory (and have standards associated with them) in order to have authorisation to farm. MPI (2016b) defines a biosecurity plan as

> a plan that identifies significant potential pathways for the introduction and spread of pests and infectious diseases into an aquaculture facility, and describes the measures which are being, or will be, applied to mitigate the risks to introduce and spread pests and disease. The plan should also describe how these measures are audited, with respect to both their implementation and their targeting, to ensure that the risks are regularly re-assessed and the measures adjusted accordingly.

A biosecurity risk is defined as 'a likelihood of occurrence of an adverse event and magnitude of consequences to the facility, environment, human health or socio-cultural values'.

To develop the on-farm biosecurity management options, MPI attempted to gauge the current farming practices and on-farm biosecurity management, via commissioning Coast and Catchment Ltd to produce the MPI report ‘Managing Biosecurity Risk for Business Benefit’ (MPI 2016d). This revealed a high level of variation in biosecurity risk management and that the high level of concern expressed by the aquaculture industry as regards biosecurity threats was not always reflected by their own biosecurity practices. Research facilities were found to adopt the most stringent biosecurity measures, generally consistent with international best management practices. These facilities treated all intake water and used a wide variety of methods to reduce the risk of pests and diseases entering the aquaculture facility. In contrast, the report found that commercial salmonid farms (freshwater and marine) tended to have more moderate biosecurity measures. While these included regular disease testing, routine disinfection of equipment, use of footbaths, farms not sharing equipment and regular removal of fish mortalities, none of the freshwater hatcheries surveyed for the 2016 report treated their incoming water. Non-commercial salmonid farms used fewer biosecurity measures than commercial farms and while equipment was disinfected prior to transfer, sharing of equipment among farms was avoided or limited and fish mortalities regularly removed, they tended not treat their intake water, not use footbaths, and regularly brought wild brood stock on site.

These findings fed into the comprehensive MPI technical guidance on aquaculture biosecurity management[2] (MPI 2016b). This directed efforts from a biosecurity risk management approach that focused on named risks (in terms of individual specific pests or diseases) to a more holistic approach. This would involve managing the potential routes onto, within and from the farm and in so doing would address problems of unknown / future pests and disease as well as known / current pests and diseases. The scope of this document included aquaculture sectors involving Chinook salmon (*Oncorhynchus tshawytscha*, rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), among others. However, the 2016b report states that MPI envisaged repeating the project with other aquaculture species such as eels, koura, grass carp and whitebait. The Freshwater Fishing Farming Regulations 1983 does reference ‘fish farms used exclusively for eels or freshwater crayfish’. In respect of these two future potential aquaculture prospects, legislative changes allows only ‘experimental’ eel farming at present. It is currently illegal to possess eels weighing less than 220 g without a special permit and commercial access to glass eels for commercial purposes would require legislative change. There are aspects of the 1983 regulations that may need to be addressed from a biosecurity risk perspective. For instance, section 23 of the 1983 regulations requires that any animal material needs to be sterilised if it to be fed to fish on any fish farm but it does not apply to eels or freshwater crayfish unless they are fed with fish. Section 24 requires the licensee to keep records and make returns but states that no record of numbers of eels or freshwater crayfish need to be kept. Hollows (2016) provides a guide for carrying out freshwater crayfish aquaculture and this also references current fish farming regulations.

It should be noted that the MPI (2016b) report distinguishes trout production from finfish aquaculture. This is because although commercial farming of trout is prohibited, Fish & Game, DOC and volunteer hatcheries produce trout for re-stocking purposes. However, to ensure the associated risks of salmonid species that are farmed commercially or non-commercially, trout were included in the MPI report. The same approach has been taken with the current report as biosecurity risks and biosecurity management options are equally relevant to different types of operation.

All future applications involving freshwaters as a receiving environment, such as for a discharge point for effluent or abstraction source for influent, will involve the National Policy Statement for Freshwater Management 2020 (NPSFM 2020). The activity would have to prove itself to be a functional need, defined as *the need for a proposal or activity to traverse, locate or operate in a particular environment because the activity can occur only in that environment*. Once a functional need is proven, the effects of an activity such as fish farming would have to be managed by an effects management hierarchy. Although the NPSFM-2020 is principally concerned with water quality issues, biosecurity considerations are relevant as there is a focus on improvement to the health and well-being of water bodies and freshwater ecosystems.

2.3. Pests, unwanted organisms, aquaculture and existing legislation

This report is focused on the risk of pests / introduced species / pathogens escaping from the farms and their impacts on freshwater environments rather than risks to the farmed stock. In the context of aquaculture, this report uses the MPI definition of pests as 'aquatic organisms that may be problematic to aquaculture that are neither pathogens or parasites' (MPI 2016b). However, it must be noted that the definition of a 'pest' species is not legally bound by legislation or regulation (https://www.doc.govt.nz/nature/pests-and-threats/freshwater-pests/).

Fisheries New Zealand (2021) issued a consultation paper as regards the creation, issuing and granting of special permits to stakeholders so that they can manage and eradicate New Zealand aquatic pest species. In terms of the new special permit purpose, Fisheries New Zealand applied the following criteria for what constitutes a pest:

- an organism that is currently in a regional/national pest management plan (or is regarded as a pest species by the lead agency or council)
- an introduced or invasive organism, whether present in New Zealand or not, that has undesired effects on native flora and fauna, and their habitat
- an organism that is also an Unwanted Organism (Biosecurity Act 1993) or Noxious fish (Freshwater Fisheries Regulations 1983).

With reference to 'noxious fish' under the Freshwater Fishing Farming Regulations 1983, it is illegal to possess, control, rear, raise, hatch or consign species classified as noxious fish without legal authority. Tench, perch and rudd are termed 'pest fish' in most regional council pest management plans but are also defined as 'sports fish' in the Auckland/Waikato Fish & Game region under the Freshwater Fisheries Regulations 1983. Rudd are also classified as 'noxious' except within the Auckland/Waikato Fish & Game region. The koi carp is classified as both a noxious fish (Freshwater Fisheries Regulations 1983) and an unwanted organism (Biosecurity Act 1993).

For possessing of freshwater fish species as opposed to fish farming (holding to breed and sell), DOC's approval must be sought to possess koi carp (along with MPI's approval, in circumstances where it is classed as an Unwanted Organism), rudd (with the exception of the Fish & Game region listed above), any noxious species, grass carp and silver carp. Section 26ZQA (possessing certain kinds of fish without approval) of the Conservation Act 1987 specifies the unique status of grass and silver carp as 'Restricted Fish'. This permits both these species to be farmed and released into the environment, only as a controlled and tracked activity to ensure there is no negative environmental impact (http://legislation.govt.nz/act/public/1987/0065/latest/DLM106031.html). MPI's approval must be sought to possess catfish and pest freshwater plants, Fish & Game's approval must be sought for *Gambusia* mosquito fish (and MPI, in circumstances where it is classed as an Unwanted Organism), rudd (within the Auckland/Waikato Fish & Game region), trout, salmon, tench and perch. No approvals are needed for goldfish, orfe and ornamental aquarium species or for any legally obtained native freshwater animal or plant species.

Depending on circumstances, if 'unwanted organisms' (an unwanted organism being defined in very broad terms as any organism that's capable of causing harm to natural or physical resources (like forests and waterways or human health)) are involved or associated directly or indirectly with any aquaculture scheme, then potentially other existing legislation becomes more directly relevant such as the Conservation Act 1987, the Biosecurity Act 1993 and the Hazardous Substances and New Organisms Act 1996. The Biosecurity Act 1993 states it is illegal to release, spread, sell or breed 'unwanted organisms' (https://www.mpi.govt.nz/biosecurity/how-to-find-report-and-prevent-pests-and-diseases/handling-unwanted-organisms/). It should be noted that not all pest species are designated as Unwanted Organisms. Section 52 of the Biosecurity Act 1993 states 'No person shall knowingly communicate, cause to be communicated, release, or cause to be released, or otherwise spread any pest or unwanted organism' and section 53 states

> 'the owner or person in charge of an organism which that person knows or suspects constitutes, contains, or harbours a pest or unwanted organism must not (a) cause or permit that organism to be in a place where organisms are offered for sale or are exhibited; or

> (b) sell or offer that organism for sale; or (c) propagate, breed, or multiply the pest or unwanted organism or otherwise act in such a manner as is likely to encourage or cause the propagation, breeding, or multiplication of the pest or unwanted organism'.

Section 53 also includes organisms which may contain or harbour a pest or unwanted organism.

Both the terminology and application of existing legislation remains inconsistent. For example, under the Freshwater Fisheries Regulations 1983, having Noxious Fish 'under control, or rear, catch, hatch or consign' is illegal; whereas under the Biosecurity Act 1993, 'Unwanted Organisms' can have 'restricted sale, distribution and propagation' (Fisheries New Zealand 2021).

[There are many freshwater plant species that fit the definition of a pest species and might possibly be associated with a freshwater fish farm. These species include didymo (*Didymosphenia geminate*), alligator weed (*Alternanthera philoxeroides*) and oxygen weed (*Lagarosiphon major*). These species and most other plant pest species are classified as unwanted organisms under the Biosecurity Act 1993 (Fisheries New Zealand 2021).]

In summary, not all pest fish have legal status but all are managed through either regional councils and regional pest management plans, the Department of Conservation (DOC), or Fish & Game New Zealand (Fisheries New Zealand 2021). Pest fish management varies due to the different legislation relevant to each fish and for some introduced species, there is inconsistency in legal status and therefore tension between different legislation, governing organisations, and management objectives (Fisheries New Zealand 2021). Fisheries New Zealand proposed to create a new special permit to enable all species that can be defined as pest fish, regardless of legislation, to be managed or eradicated under a single purpose. Before the consideration of any special permit that includes a pest species managed by another governing body (such as Fish & Game), thorough consultation will be undertaken.

It is acknowledged, that currently there are many non-native species that are not covered by either the Biosecurity Act 1993 or the Hazardous Substances and New Organisms Act 1996. Species not listed in Notice MPI 1134, and having a present role or potential for aquaculture, are currently not covered by the existing legislation. Such species effectively have no legal status in the context of current legislation. Such non-native species include goldfish and aquarium / ornamental fish, brown bullhead catfish and / or invertebrates. Although catfish and goldfish have no legal status, fishing regulations for recreational / commercial fishers require all captured catfish to be killed and eradication of goldfish may be covered under regional pest management plans such as in the Waikato Region. Policy and legislation 'gaps' as regard such species have been identified and are gradually being addressed (Fisheries New Zealand

2021). The freshwater ornamental aquarium trade is arguably the current greatest biosecurity threat to freshwater ecosystems in Australasia (Ebner et al. 2020).

2.4. Translocation in relation to freshwater aquaculture

A current Department of Conservation (DOC) definition of translocation is 'the managed movement of live indigenous plants or animals (taonga) from one location to another. Translocation covers the entire process, including planning, the transfers, release, monitoring and post-release management'. The most relevant New Zealand legislation for freshwater animal translocations is section 26ZM 'Transfer or release of live aquatic life' of the 1987 Conservation Act (2019 amendment), which deals with rules for moving freshwater species. A risk analysis framework for freshwater fish translocations in New Zealand, identifies many of the ecological risk associated with such translocations, including biosecurity risk associated with aquaculture (MacNeil 2021).

The current New Zealand government approval processes for freshwater translocations do not contain a formal risk assessment but follow a series of approval pathways, depending on species and location. There are two broad pathways:

1. Releasing species where they don't already occur, which includes stocking a freshwater species at a fish farm for the first time. DOC are the authority to apply to in this instance.
6. Releasing a freshwater species where they already occur. Fisheries New Zealand are the authority to apply to in this instance.

Approval pathway (1) is directly related to freshwater fish farming biosecurity and pathway (2) is directly related to biosecurity issues as a result of restocking / conservation release, which can occur as from a farm / hatchery facility. Both can have an impact on the receiving ecosystems. 26ZM is required for both pathways. In terms of freshwater fish farms, it includes transfer of a new species to an existing or a new fish farm. Section 26ZM does not apply where there is the transfer of any live aquatic life to an existing fish farm where the species is already present. The current DOC approval process and associated documents includes many of the core principles outlined in the 'Guidelines for reintroductions and other conservation translocations' of the International Union for Conservation of Nature (IUCN 2013).

3. ECOSYSTEM IMPACTS ASSOCIATED WITH FRESHWATER AQUACULTURE BIOSECURITY RISK

The general ecological risks associated with freshwater aquaculture can be classified into at least five general categories. These are risks associated with:

- ecological and genetic impacts involving escapee focal species (and associated species that may be inadvertently 'farmed' with it) and interactions with species assemblages present outside the aquaculture facility
- disease and parasite spread
- release of 'additive' such as chemicals from aquaculture facilities
- water quality impacts on the receiving environment
- water quantity issues with respect to the local environment.

Considering biosecurity risk only, this report uses the MPI (2016a) definition of biosecurity as the exclusion, eradication or management of pests and diseases that pose a risk to the environment. I will consider the risks and impacts associated with escapees from aquaculture facilities (focal species and any associated species) and the release of parasites and pathogens but will not consider the risk of the release of toxins, pollutants or chemicals from aquaculture facilities.

Details of how containment of farmed stock and treatment of effluents will be achieved to an appropriately level are a requirement in the current application form for a fish farm licence:

- Section E – How are farmed fish, aquatic life and seaweed prevented from escaping the farm?
- Section F – Give details of to where and how water will be discharge from the fish farm and give details of how water discharged from the fish farm will be treated, if any (https://www.mpi.govt.nz/fishing-aquaculture/aquaculture-fish-and-shellfish-farming/setting-up-a-land-based-fish-farm/#:~:text=To%20set%20up%20an%20aquaculture,relevant%20FishServe%20client%20registration%20form.&text=You%20can%20submit%20your%20application,for%20a%20fish%2Dfarm%20licence).

There have been numerous deliberate releases of trout and salmon from hatcheries and farms into New Zealand's rivers / lakes / reservoirs to support sport fisheries (Henrique 1987). Rearing native fish for conservation translocations should not be considered until all other options are explored and only after careful consideration has gone into the origins of the brood stock that are to be farmed and released (MacNeil 2021). It should also be noted that deliberate release of the farmed focal species for restocking and conservation purposes also carries with it many of the same inherent risks for the receiving ecosystem associated with accidental escapes (MacNeil 2021).

In terms of deliberate releases from fish farms, it is how such risks are managed and to what level of risk is considered acceptable in terms of potential ecosystem impacts that will determine if such releases are compatible with conservation and other goals (MacNeil 2021).

3.1. Core underlying biosecurity risks in relation to ecosystem impact

A review of risk frameworks from Australia, North America, Europe and the United Kingdom identifies similar suites of biosecurity risk associated with both marine and freshwater aquaculture and linked processes such as translocation. These can be classified into:

1. Ecological / genetic risks, involving the focal aquaculture species. These include:
    - Genetic diversity, loss of genetic integrity / viability due to inbreeding / genetic bottlenecks, genetic alteration and hybridisation of wild populations
    - Negative impacts on native freshwater species and/or habitat alteration
    - Negative impacts on rare or extinction threatened freshwater species
    - Establishment of 'feral' populations. Feral populations are populations that establish in an area because of the release or escape of a farmed species and may be a population of the focal species being translocated or a population of an associated (non-focal) species (e.g., other fish and eggs in the transport medium) and / or attached parasites. These latter species could be unintentionally translocated simultaneously with the focal species and/or escape with the focal species from an aquaculture facility (MacNeil 2021).
7. Disease and parasite spread. These include:
    - Parasites and diseases associated with escapees
    - Fish farm structures / equipment / effluents not sufficiently treated via disinfection and mechanical filtration to prevent on-farm pathogens and parasites being released in a viable state to the receiving environment. Depending on the specificity of pathogens / parasites this could have far-reaching consequences for wild populations of the focal species or naïve native fish species.

In relation to both of the above, the relative magnitude of differences between the farmed fish and conspecific wild fish in terms of genetic profile, disease and parasite presence will be the principal factor determining the impacts on wild populations and any consequent wider trophic / ecosystem impacts which result from this. The types of host specificity of diseases and parasites will determine if other fish species are impacted with consequent ecosystem impacts. The potential negative impacts will also vary in relation to the size and frequency of escape events, location in relation to wild conspecific populations, whether the farmed species is native or non-native and the vulnerability of the recipient ecosystem.

Escapes from open and semi-closed fish farm systems are probably inevitable (Atalah & Sanchez-Jerez 2020). Aside from theft and major system failure, escapes from closed systems should be very rare. The potential effects of escapes on wild populations represent a major issue of aquaculture, with detrimental effects on the environment (Sepúlveda et al. 2013; Cretu et al. 2016; Atalah & Sanchez-Jerez 2020). Escapes are likely greatly underestimated in many areas, as many are probably not detected and / or not reported (Sepúlveda et al. 2013). Causes of salmonid escape events are many and varied but severe weather conditions, theft and deficient handling are major technical issues associated with escape events (Sepúlveda et al. 2013). A global assessment of the ecological risks associated with marine farm escapes, including the impacts of releasing non-native species, genetic introgression of farmed stock into wild populations and the spread of parasites and pathogens, found almost a third of the world's marine ecoregions are at risk from the ecological impacts of fish escapes (Atalah & Sanchez-Jerez 2020).

In 2013 MPI produced an overview of ecological effects of aquaculture focusing on coastal and marine systems. Complementary to this was the literature review of ecological effects of coastal and marine aquaculture (2013) including a review of escapee effects (MPI 2013). The review of marine finfish species escapee effects considered the likelihood of escapee effects on New Zealand's ecosystems to be low, given the size of the industry and limited overlap of wild and farmed populations (MPI 2013). However, that could obviously change in the future if the sector, including freshwater fish farming, expands. The 2013 MPI review also does acknowledge that if escapee effects become manifest in wild populations, they will probably be irreversible and could expand to a national scale. Although focused on salmon, kingfish, hapuku, green-lipped mussel, Pacific oysters and seaweed, the review's overview of escapee effects on marine systems is relevant to New Zealand freshwaters (see also Forrest et al. 2007). The impacts of escapees on the receiving ecosystem will depend on:

- location of a fish farm relative to location of wild populations and the health and population dynamics of the wild populations
- number of fish farm escapees and frequency of escapes
- whether the farmed / hatchery species is native or introduced and whether the farmed / hatchery species is present in the receiving environment
- whether the brood stock is wild sourced or farm / hatchery bred
- population structure and reproductive maturity / reproductive potential of escapees and ability of gametes to survive / develop in wild
- ability of escapees to interbreed with wild stocks
- ability of escapees to tolerate environmental conditions and then survive / feed successfully.

The main ecosystem impacts of escapees outlined in this MPI literature review are the same as noted earlier. These include escapees competing with wild fish of the same species for resources (habitat and food), competing with and preying upon other freshwater species, including those native species important from a cultural and / or conservation perspective, loss of genetic integrity in wild populations and transmission of pathogens and parasites (MPI 2013; Sepúlveda et al. 2013). The overall long-term impacts of the establishment of a self-sustaining population derived from escapees remains unclear. In New Zealand, as elsewhere, more research is needed to identify and construct reliable indicators of the impacts of escapees at the ecosystem level for both freshwater and marine systems (Sepúlveda et al. 2013).

3.2. Ecosystem impacts – competition for resources, predation and related ecosystem effects

Atalah and Sanchez-Jerez (2020) considered ecological risks associated with marine farm escapes and recommended risk assessments for farming non-native species. Similarly, MacNeil (2021) highlighted the increased potential for negative ecosystem impacts involved in translocating fish species to catchments / regions of New Zealand where they had never occurred as opposed to catchments / regions where they were currently resident or had been resident in the past. Frequent escapee events of non-native species from aquaculture facilities result in high propagule pressure which is major driver of successful biological invasion into new regions (Simberloff 2009). In this respect, fish farms of non-native species, in regions where they don't already exist in local fish assemblages in rivers and lakes, can be viewed as potential bridgeheads for future invasions. The only thing preventing this are stringent preventative biosecurity measures and the adaptability / physicochemical tolerance of the escapee invader in the new environment (see Table 1 for examples of biosecurity measures; [Aquaculture Biosecurity Handbook: Assisting New Zealand's commercial and non-commercial aquaculture to minimise on-farm biosecurity risk (mpi.govt.nz)]).

In both marine and freshwater systems, non-native fish species can directly compete for resources with natives, can prey upon them and can alter habitats leading to declines in native populations (McDowell 1994; McIntosh et al. 2010; Sala et al. 2011). It has been argued fish species such Chinook salmon and rainbow trout may represent the greatest threat to ecosystems, as the high feeding plasticity of these species, with the ability to feed on a wide range of fauna, may mean they have the greatest potential to establish naturalised populations (Sepúlveda et al. 2013).

Escapees from finfish aquaculture may alter the trophic structure of the fish assemblages in the receiving ecosystem, as many farmed fish are high trophic level species. In New Zealand's freshwaters, salmonids and native fish can compete directly and indirectly for food and habitat, contributing to a reduction in populations and geographic range of some native species. There are also studies showing direct predation of native fish species such as galaxiids by brown trout (McIntosh et al. 2010). Salmonids invading rivers and lakes can alter ecosystem processes and functioning through trophic cascade effects (Carpenter et al. 1996). This may be especially pronounced if native species are replaced and / or the population of the non-native species increases. Lake ecosystems, where most of the freshwater phase of salmonid aquaculture occurs, are very sensitive to the impacts of salmonid escapees as these often represent the top predators in the system and can negatively impact on lake fish and invertebrate biodiversity (GarcÍa de Leaniz et al. 2010). There are various salmonid hatchery and aquaculture operations in hydro-electric canals in New Zealand, which connect power station networks with receiving lake / reservoir environments (Henriques 1987). Salmonids from such operations could represent a risk to normal lake ecosystem function.

Although often overlooked and regarded as secondary to impacts associated with genetic introgression (see Section 3.3), escapee farmed native species can directly compete for resources with the wild conspecific populations. Einum and Fleming (1997) found farmed Norwegian Atlantic salmon to be more aggressive than wild salmon while using the same freshwater habitat resources. They also grew faster than wild fish, gaining them a competitive advantage and ultimately diminishing wild traits (Einum & Fleming 1997).

3.3. Ecosystem impacts – alteration of the genetic profile of wild fish populations

When farmed escapees are non-native there can be genetic consequences for the receiving environment's wild fish assemblages. When escapees are also native or resident species in the receiving ecosystem, there is the risk of genetic introgression of farmed fish into wild populations, through interbreeding.

Hybridisation, introgression and the breakdown of species boundaries are significant threats to biodiversity and native fish species worldwide. Hybridisation has been defined as the crossing of two distinct species in which the offspring are not evolutionarily viable (sterile). Another definition could be the crossing of evolutionarily distinct populations which involves successful mating between individuals from two populations, which are distinct from each other on the basis of heritable characteristics. Introgression is the movement of genetic material between separate species / populations through hybridisation and backcrossing between fertile hybrids / parental lines. Introgression can only occur if hybrids are fertile and genetically compatible with either parental species/population. Apart the from the main genetic threats to resident fish fauna, there are related problems associated with small populations due to disease / parasite vulnerability. Hybridisation between non-native and native taxa has long-term consequences, for both species biology and management (Ayres & Clunie 2010).

Farmed fish such as salmon have undergone domestication for multiple generations and undergone selective breeding for favourable production traits, such as rapid growth rates and maturation. For example, they it has been shown that farmed salmon out-grow wild salmon under the same hatchery conditions (Heino et al. 2015). Thus, they can show considerable genetic differences to wild salmon for a number of fitness-related traits. Wild salmon populations are regarded as potentially adapted to their natal rivers and the survival of farmed salmon offspring in the wild is lower than for native salmon. Therefore, genetic interactions between farmed escapees with wild conspecifics represent a threat to the viability of native populations, with long-term loss of fitness and adaptability (Atalah & Sanchez-Jerez 2020). Escapees have been observed spawning with wild salmon In Norwegian rivers (Heino et al. 2015) and genetic changes have been observed in wild populations in Norway, Canada and Ireland indicating successful spawning of farmed fish (Heino et al. 2015).

A modelling approach using data on the observed relative frequency of escapee farmed salmon and average annual catch weights for Norwegian salmon rivers proved a better predictor for the cumulative introgression of farmed salmon into wild populations than simply the observed frequency of escapee farmed salmon alone. (Heino et al. 2015). Karlsson et al. (2016) observed wild genetic introgression was highest in those river systems in areas subject to the most intensive salmon farming. Karlsson et al. (2016) concluded the extensive genetic introgression documented posed not just a serious challenge to the management of farmed and wild salmon in Norway but probably to any other regions where farmed-salmon escapes occurred with regularity.

In Scotland, it has also been shown that fish farm escapees can interbreed with wild population causing a loss genetic variability, including the loss of naturally selected adaptations (Scottish Executive Central Research Unit 2002). This can ultimately lead to reduced fitness and performance in wild populations. This report noted that non-local genes had been introduced into wild populations for over a century in Scotland, as a result of salmonid restocking programmes intended to increase population sizes. However, the report concluded that the effect of these restocking programmes may be insignificant on the genetic make-up of wild populations compared with that caused by farm escapes, simply due to the large scale of escapes in comparison with the number and size of resident wild populations (Scottish Executive Central Research Unit 2002).

In contrast to the Scottish and Norwegian experiences, it has been stated

> In New Zealand, little impact of salmon farming upon wild populations has been reported and this contrasts with overseas salmon industry experience, where it is believed that interbreeding between escapees and wild salmon has adversely affected native populations, through long-term genetic changes (MPI 2013).

In the New Zealand context, it has been argued that for areas where only small wild salmon populations are found, any escapes of farmed salmon will have no genetic impacts and / or no or very minor long-term impacts on the survival and integrity of these populations (MPI 2013). Even in areas such as Otago and Canterbury, with larger wild salmon populations, it was assumed that the small scale of any escape relative to the size of the wild population (and its own genetic 'make-up' as an introduced species) would limit the impact on the population and the overall ecosystem (MPI 2013). However in 2020, Canterbury Fish & Game stopped raising and releasing salmon based on concerns about genetic fitness (https://www.scoop.co.nz/stories/AK2001/S00351/fish-game-closes-upper-rakaia-hatchery-operations.htm).

Genetic bottlenecks and low genetic variability in farmed aquaculture species are problems not confined to finfish. This problem has also been witnessed in Malaysian river prawns (*Macrobrachium rosenbergii*) in Huka Prawn Park, Taupo. Here, biosecurity measures such as the halting of on-site prawn fishing by the public, sourcing MPI-approved new broodstock and associated quarantine procedures, have had to be undertaken because of low survival rates and behavioral problems stemming from low genetic variability (https://hukaprawnpark.co.nz/latest-news/2022-prawn-fishing-update/). If such on-site problems are not addressed the genetic risks posed by escapees to wild populations or susceptible native species inevitably increase.

Ecosystem impacts from genetic effects are strongly influenced by demographics, because the genetic effects themselves are species- and location-specific and are dependent on the wild fish abundance and distribution (MPI 2013; Heino et al. 2015). Fish farm location is a crucial factor when considering genetic effects at the ecosystem level.

3.4. Ecosystem impacts – transmission of diseases and parasites

Aquaculture typically entails elevated stocking densities that can promote conditions which lead to disease development and subsequent spread into the environment, especially where there is direct contact with natural habitats (Diamant et al. 2007). Pathogen proliferation and spread is a major problem in aquaculture and is exacerbated by expansion and intensification of the industry (Costello 2009) and there is a concomitant increase in the risk of transmission into wild populations when wild fish and farmed fish of the same or related species are in the same vicinity (Arechavala-Lopez et al. 2013). Non-native fish species can introduce new pathogens and change disease patterns (i.e., usual prevalence and seasonality) in farms and via infected escapees, recipient ecosystems (García de Leaniz et al. 2010). If appropriate biosecurity measures are not applied to aquaculture operations such as effluent treatment, this is also a potential route to the outside environment. The types and host-specificity of diseases and parasites may determine the severity of ecosystem impact, if multiple fish species are affected.

3.4.1. Escapees and pathogen and parasite spread in the receiving environment

It has been argued that disease and parasites are not major issues within the New Zealand salmon industry because of geographic isolation of fish farms and relative lack of disease compared to many other parts of the world (MPI 2013). In contrast, epidemiological studies in Scotland, Ireland, Norway and Canada indicate the prevalence of diseases and parasites in both farmed and wild fish is directly related to increasing concentrations of farmed fish (Sepúlveda et al. 2013). In countries such as Scotland and Chile, infected escapees from salmon and trout farms are responsible for the spreading of diseases and other pathogens into wild fish populations (Scottish Executive Central Research Unit 2002; Sepúlveda et al. 2013; Atalah & Sanchez-Jerez 2020). The plumes of infected facilities also represent important pathogen vectors to the wild fish moving through them (Olivier 2002). The greater the movement of escapees, the greater the risk of pathogen spread into wild populations and any adjacent fish farms. These infected escapees also therefore alter the spatio-temporal occurrence of pathogens in the wild and in farms (Atalah & Sanchez-Jerez 2020). Any aggregations of wild fish around semi-closed or open aquaculture systems due to food availability and / shelter can also risk pathogen exchange (Dempster et al. 2009).

3.4.2. Preventing pathogen and parasites release to the environment – effluent treatment

Aside from being associated with escapees, pathogens and parasites can feature in effluent discharges direct to the environment or in biocontaminated aquaculture structures / equipment not appropriately treated. In terms of pest species, this is usually dealt with predominately by mechanical filtration and for disease, predominantly by disinfection. Fish farm effluents usually undergo a combination of filtration and disinfection. A combination of methods is usually beneficial, as they can be synergistic effectively combining to reduce risks to lowest practical levels (World Organisation for Animal Health (OIE) 2016).

The MPI Guidance document – *Options to strengthen on-farm biosecurity management aquaculture* (MPI 2016b) states:

> All water discharged from the facility should be treated (e.g., filtration, UV treatment, ozonation) to exclude or render identified pathogens and pests non-viable to an acceptable level.

Linked to this, recommendations are given to maintain the viability of the effluent treatment system. The following are examples:

- Regular monitoring should be in place to ensure treatment efficacy is maintained.
- To ensure continuous operation and complete containment:

  - Effluent treatment systems should be equipped with fail-safe backup mechanisms. This is particularly important for quarantine systems.
  - The discharges from land-based facilities should be double screened to prevent the entry of unwanted organisms and the loss of stock from the facility.
  - Screens should be inspected as often as possible and remedial action taken as required.
  - A back-up method should be in place in the event of failure of the disinfection system.
  - Pre and post treated water should be regularly monitored to ensure system efficacy.
  - Contingency plans should be put into place to ensure that all water entering and leaving a facility is treated in the event of system failure.

Settlement basins (also known as settlement ponds or lagoons) can be an important part of water filtration processes of an aquaculture operation and use sedimentation to remove unwanted solid matter from the water, reducing the water turbidity and, in turn, reducing possible solid contaminants from the water. In respect of settlement basins, MPI 2016b recommends:

- A site-specific analysis of settling within existing and planned settling basins for each facility should be conducted. This would consider pathogens of concern and their appropriate retention time and contingency plans regarding system failure
- Settlement basins should be of adequate size to hold necessary volumes of wastewater and ensure adequate retention of pathogens, nutrients and sediments.
- Settlement basins should be able to be drained and dried to remove all unwanted macro-organisms, desiccate pathogens, enable silt to be removed or the substrate to be tilled, scraped or limed, prevent excessive growths of aquatic plants.
- The outflow from tank and basin systems and discharges from the facility should be double screened to prevent the entry of unwanted species into and loss of stock from the facility.
- Disposal of settled effluent or unwanted macro-organisms should be disposed in an appropriate manner.
- Pre and post treated water should be regularly monitored to ensure system efficacy.

The fish farm licence application requires details from the applicant how effluent from the farm will be treated (see Section 3). It is a requirement of the biosecurity management plan to detail how these specific biosecurity issues are addressed. The biosecurity plan should contain the specific standard operating procedures (SOPs) that pertain to treatment of the effluent discharge and other biosecurity management measures. At the core of procedures should be:

- Regular monitoring to ensure treatment efficacy is maintained.

- To ensure continuous operation and complete containment, effluent treatment systems should be equipped with fail-safe backup mechanisms.
- The discharges from land-based facilities should be double screened to prevent the entry of unwanted organisms and the loss of stock from the facility.

Filtration

In terms of pests and parasites mechanical filtration via pumps, filtration devices and pore sizes are commonly employed. The maximum particle size in treatment system filtered effluent is a compromise between minimising the biosecurity risk from effluent discharged to the environment and what is practically achievable. Bacteria are typically 1 micron in size but can be as small as 0.2 microns, with viruses far smaller.

In terms of the culture species themselves and pests, filtering to a smaller size than their smallest relevant life stage is an intuitive approach. While mechanical filtration to 1 micron may essentially manage all risk, and although systems capable of filtering to 10 microns or smaller are technically possible in marine systems, their practical application has yet to be demonstrated (Morrisey et al. 2015). For grass and silver carp, DOC and Fisheries New Zealand (FNZ) have developed guide [32257-Standard-for-managing-exotic-hitchhiker-copepod-standard (mpi.govt.nz)](), which states water should be filtered to 50 microns to eliminate any aquatic 'hitchhikers' before releasing carp to a new site. In terms of marine pest species, a pore size of 60 microns was recommended by McClary and Nelligan (2001) to contain all mature organisms and the majority of propagules for 43 target marine pest species identified in their study. This standard has been adopted in MPI's guidance document for standards for facilities for the removal of biofouling from vessels that have arrived in New Zealand from overseas. In 2013, the Australian and New Zealand governments jointly released the Australian and New Zealand Anti-Fouling and In-Water Cleaning Guidelines (the Guidelines), which were subsequently updated in 2015. Currently the Guidelines state 50 microns as a pore size diameter to minimise the release of viable adult, juvenile and larval stages of macrofouling organisms. Although Morrisey *et al.* (2013) suggested a pore size as low as 2 microns to eliminate biosecurity risk from marine pests, 12.5 microns was later put forward as more realistic with current systems in treating biofouling effluent (Morrisey et al. 2015). Fraser et al. (2006) report that the effectiveness of disinfection procedures such as ozone and UV (discussed later in this section) is compromised if contaminated effluent with blood etc. is not removed prior to disinfection and refers to a filter capable of removing particles of 7 microns in size as being suitable for this purpose. However, Cripps and Bergheim (2000) reported difficulties with removal of solids smaller than 50 microns from human wastewater, due to poor sedimentation rates and low-flow capacities of screens with such small pore sizes.

In a freshwater aquaculture setting, to deal with pests, parasites and propagules (both of the focal species and pests), 50-60 microns may be a realistic 'best case' starting point to consider as appropriate level of filtration. However, such values will vary greatly on the characteristics of the effluent involved, the specific focal species involved, specific pathogens and parasites and other concurrent effluent treatments. The most suitable filtration system for any farm will also depend on the volumes to be filtered, reliability of the system and its feasibility in terms of operating costs and capital.

Disinfection

Although pathogens are known to adhere to inorganic and organic matter so that mechanical filtration and removal of suspended solids can significantly decrease the loading of pathogens in waters, disinfection is typically required to deal adequately with pathogens and reduce the potential for disease spread. The MPI (2016a) guidance document states:

> The aim…is to reduce potential pathogens to a concentration whereby the risk of acquiring an infectious dose is acceptable.

Chemical (e.g. chlorine and ozone) and physical (e.g. UV irradiation) disinfectants are typically used to disinfect treat fish farm effluent discharges. Suspended solids need to be removed prior to application of these disinfectants, either by bacteriological treatment plant or filtration, as organic matter inhibits oxidative disinfection and suspended solid inhibits UV transmittance (Fraser et al. 2006; OIE 2016). As stated earlier, a combination of disinfection methods is usually the most effective approach, as they often act synergistically. For instance, a Cawthron aquaculture facility currently treats its effluent with chlorine administered as sodium hypochlorite followed by UV sterilisation (see Section 5.2). Common effluent treatments are detailed below.

Chlorine

The concentration of chlorine required to treat water will depend on the water source, organic loading, and types of pathogens targeted. Chlorine is commonly administered as sodium hypochlorite (Fraser et al. 2006). For complete microbial sterilisation, MPI Options to Strengthen On-farm Biosecurity Management Aquaculture 333 OIE (2012a) cited in MPI 2016b, recommended a concentration of 50 mg/L available chlorine for complete microbial sterilisation. Influent water has been successfully treated for viruses and bacteria at 1.2–1.6 mg/L available chlorine (contact time of at least 1 minute) and effluent water at 2 mg/L available chlorine (contact time of at least 5 minutes) (Meyers 2010). For treatment of effluent from fish processing facilities an available chlorine concentration of at least 5 mg/L has been recommended (contact time of more than 30 minutes) (the Scottish based Code of Good Practice Management Group (2011)). For these examples it is assumed that the water has undergone filtration prior to treatment. Treated water should be dechlorinated using sodium thiosulfate and tested for residual chlorine (Meyers 2010). That should be sufficient to allow discharge to freshwaters in respect of chlorine use. It should be a core condition of resource consent for discharges from fish farms that any ‘additives’ are removed before discharge to the receiving environment. No chemicals used for cleaning sterilisation, culture and rearing should be discharged in effluent at levels that cause a detectable adverse effect on the receiving environment.

Ultra-violet (UV) light

At wavelengths of approximately 254 nm can be an effective effluent treatment (Henze et al. 2008; MPI 2016a). However, the efficacy of UV treatment depends on factors such as UV lamp intensity (wattage), contact time, water clarity (e.g., suspended solid load, turbidity and cell ‘clumping’), and the size and biological characteristics of pathogens being targeted (Henze et al. 2008). MPI (2016a) states that many pathogens can be inactivated by UV treatments of 30 mW s/cm^2, with some exceptions requiring a much higher UV exposure. The Department of Agriculture, Fisheries and Forestry (DAFF) (2008) recommended treatments equivalent to > 25 mWs/cm^2 to inactivate viruses, bacteria and fungi and > 35 mWs/cm^2 to inactivate spores of myxosporidean species (common cyst forming parasites of salmonids) in aquaculture facility effluents. These doses assume pre-treatment of effluent with filtration or some form of chemical precipitation (DAFF 2008). Where conditions are not ideal and there are high flows and relatively high suspended solid loads, Meyers (2010) recommends a minimum 175 mW s/cm^2 after 7,500 hours of lamp operation to achieve a 99.9% reduction of some fish pathogens. In terms of the treatment of fish processing effluent the MPI (2016b) report cites the Scottish based Code of Good Practice Management Group (2011), which recommends that the dose exceed an equivalent of 120 mWs/cm^2. UV treatment is relatively inefficient at treating large volumes of water compared to other disinfection methods and both the capital and running costs tend to be higher. Although UV treatment has been employed on its own, it has often been used as an effective secondary treatment in combination with ozone (Fraser et al. 2006, Scottish based Code of Good Practice Management Group 2011).

Ozone

This has been used to control the microbial loading of effluent water from quarantine facilities and residual compounds formed between the interaction of ozone with seawater at levels of 0.08 to 1.0 mg/L, can significantly reduce viable microbes (particularly bacteria) (DAFF 2008, OIE 2016; Yanong & Erlacher-Reid 2012). DAFF (2008) recommend treatment at mg/L for > 1 minute for all pathogens. For treatment of fish processing effluent, the MPI (2016b) report cites the Scottish Code of Good Practice Management Group (2011) recommendation that ozone be applied at a minimum of 8 mg/L/min for 3 minutes. For complete sterilisation of seawater (e.g. for quarantine), UV treatment applied after ozone treatment may be required, (OIE 2016). This should also ensure sterilisation of fresh water.

Heat

Although not as commonly used as the previous treatments, heat has been used to treat wastewater and while it can be effective against most pathogens certain bacteria and viruses are resistant (Fraser et al. 2006, DAFF 2008, MPI 2016b). Doses of 60 °C for 10 minutes, 70 °C for 10 minutes, 80 °C for 10 minutes, 80 °C for 10 minutes have been recommended (DAFF 2008).

Desiccation and light

As applied to earthen tanks / ponds, this can deal with most pathogens and a recommended drying period is for > 3 months at an average temperature of >18°C (DAFF 2008). This drying period can be reduced if combined with chemical disinfection (see below).

Other treatments

Disinfection of settlement basins linked to existing aquaculture operations for the purposes of further effluent treatment by sedimentation has been discussed earlier. In terms of pond aquaculture systems where fish are reared, these typically use source water that has been disinfected to remove potential pathogens, pests, and disease-carrying agents via mechanical filtration, UV irradiation, and/or chemical disinfection and then detoxified before use in the pond hatchery or grow out ponds (OIE 2016). Following the routine harvest of a crop from a grow-out pond, chlorination is often used for routine treatment of ponds between crops to eradicate disease. After the pond has been treated with chlorine for the required minimum time and before any water is discharged to the environment, the chlorine is neutralised by exposure to sunlight for two to three days, or by the addition of sodium thiosulphate. Lime in the form of calcium oxide (quicklime) is also commonly applied to dried ponds beds for disinfection purposes.

In terms of disinfection onsite as regards fish farm equipment (i.e. cages, tanks, nets, diving gear, foot baths) and non-porous and plastic surfaces within the facility there are a range of disinfectant options (for detailed tables of individual disinfectants, their application and appropriate dosing levels see Fraser et al. (2006) and MPI (2016a) citing Department of Agriculture, Fisheries and Forestry (2008). Operational procedures manual - decontamination (Version 1.0)).

Additives in the form of chemical residues from the disinfection process need to be dealt with. Although not a biosecurity threat as such, in any effluent discharge these residuals are potentially deleterious to receiving water quality and toxic to freshwater life. For instance, residuals in the form of toxic bromide compounds can form between ozone and seawater, while chlorine is toxic to a range of organisms at relatively low concentrations. In the former case, the bromide compounds can be removed via charcoal filtration, while in the latter sodium thiosulfate can be used to dechlorinate treated effluent.

3.5. Ecosystem impacts – general considerations

In terms of ecosystem impacts, it must be emphasised that these impacts influence multiple ecosystem components and trophic levels simultaneously (Rowe et al. 2008; Ayres & Clunie 2010). This includes impacts at the community level (species diversity, species richness and community trophic structure), population level (abundance and growth dynamics), individual level (behaviour, growth, morphology, life history), genetics (hybridisation and introgression), ecosystem processes and even habitat (for instance, nutrient availability and vegetative habitat changes when frass and silver carp are present). Although most of the impacts are discussed in terms of escapees, similar impacts can be present in ill-judged deliberate releases (see MacNeil 2021).

The overall collective impact is difficult to predict as individual impacts all vary in scale and time and can act synergistically and / or cumulatively and even have cascading effects (McIntosh & Townsend 1996). The vulnerability of the recipient ecosystem is also an important determining factor, for instance if there are many fish species susceptible to predation from higher trophic level escapees. These ecosystem impacts can also translate into social impacts if the species and environments impacted feature in cultural heritage, beliefs, values and aspirations (Rowe et al. 2008).

Table 1 shows a simple risk assessment with the focus on ecosystem impacts from potential biosecurity risks associated with freshwater fish farms. It should be noted some of these risks duplicate those documented for freshwater translocations (MacNeil 2021), as recipient ecosystem processes may experience disturbance for a deliberate release as well as a mass escape from a local fish farm, even if the relative magnitude of such disturbances are different.

Table 1. Freshwater aquaculture biosecurity risk assessment from an ecosystem impact perspective.

	Potential effects	Explanation	Addressing effects: *recommendations for avoiding remedying or otherwise mitigating effects*
1	Escapees from fish farm facilities – *effects on fish, invertebrates, physical habitat and ecosystem structure and function*	*Negative impacts on native species, rare / threatened species and recipient ecosystems* • Escapees can prey upon resident fish species, outcompete resident fish species for habitat and shared prey species (fish and / or macroinvertebrate) and can even replace resident species if there is extensive niche overlap. • Escapees can negatively impact rare or threatened fish or macroinvertebrate species either by predation and / or increased competition for resources. • Escapees are often fish at higher trophic levels than resident species and this level of disparity will amplify competition and predation effects • Escapees such as various carp species, can be 'ecosystem engineers' disturbing physical habitat, disrupting ecosystem structure and function. • Escapees can establish feral populations, with all the attendant ecological impacts on the resident ecosystem described above. *Genetic effects* • Loss of genetic integrity and viability of focal species in receiving freshwaters - genetic introgression and hybridisation of wild populations, 'genetic bottlenecks' in feral populations due to founder effect / inbreeding. *Introduction of diseases and parasites* • Escapees can carry parasites and diseases which are passed onto focal species populations or other fish species / animal hosts in receiving waters, if host-specificity is not stringent. • Released novel pathogens and parasites can become prevalent in the recipient ecosystems, causing deleterious effects on naïve fish populations and have widespread community impacts. • Released novel pathogens and parasites can have widespread community impacts if infected host species is a 'keystone'	*For all applications* • Follow best practice MPI biosecurity management guidelines: - Aquaculture biosecurity handbook (Aquaculture Biosecurity Handbook: Assisting New Zealand's commercial and non-commercial aquaculture to minimise on-farm biosecurity risk (mpi.govt.nz)). - Strengthen on-farm biosecurity management technical paper (https://www.mpi.govt.nz/dmsdocument/13287/direct). - Technical guidance biosecurity management: finfish (https://mpi.govt.nz/dmsdocument/41979/direct). - Technical guidance biosecurity management: shellfish (https://www.mpi.govt.nz/dmsdocument/41982-Technical-Guidance-Document-High-Level-Biosecurity-Management-Plans-Shellfish-Land-based-and-Ocean-Facilities). *To address issues of stock containment* • A stock containment protocol should be constructed and available for assessment, based on a risk assessment for escapes that considers extreme weather events, equipment / power failure, theft and predator fencing. This risk assessment should identify where escapees can survive in the wild and if gametes can escape and survive. • If possible, fish farm sites should be located to avoid floodplains or any landscape feature that could accentuate the effects of extreme weather events on farm stock containment facilities. • Design and maintenance of aquaculture facilities should be capable of dealing with adverse weather and any environmental conditions that could be experienced on site, such as flooding. • Containment facilities should be inspected regularly to check these have not been compromised by predators and scavengers. *To address recipient ecosystem effects* • This requires detailed and reliable species data information on the aquaculture site and potential receiving waters. The conservation

	Potential effects	Explanation	Addressing effects: ***recommendations for avoiding remedying or otherwise mitigating effects***
		species capable of influencing other trophic levels in the ecosystem.	status of resident fish and / or macroinvertebrate species in both destination site and potential receiving waters needs to be considered. • Farm fish within only the natural range of the focal species or where the focal species has been stocked previously and preferably recently. • Any potential risk to ecologically valuable species in recipient ecosystems, must be judged against potential benefits of farming a species for conservation purposes and its own conservation status (https://www.doc.govt.nz/Documents/science-and-technical/nztcs24entire.pdf). • Limit number of species to be farmed. • Limit focal species to those for which biology, behaviour and ecology are comprehensively understood at all stages of life cycle. If research gaps exist, expert opinion may be required on proxy species. • Preferably farm fish species that are trophic specialists as opposed to generalists, as the latter are more risky as regards potential ecosystem impact. • If fish farms want to restock /release fish to environment, then these fish would need to be separate from their aquaculture stock and collected within same catchment for these purposes. This doesn't guarantee authorisation will be granted, as there are many other things that will be taken into consideration before any decision on release is made. • Farm fish where there is no unacceptable risk to native species whose conservation status is critical, endangered, vulnerable, or threatened. • Always avoid farming and / or stocking focal species outside its natural range. *To address genetic effects* • Source brood stock from aquaculture facilities following industry best practice • Source brood stock originating from the same river or at least catchment where possible, or in the case of diadromous species from the same region. • Source brood stock of known and well researched genetic history. • Source from sufficient numbers of brood stock to limit 'genetic bottlenecks' due to founder effect / inbreeding.

	Potential effects	Explanation	Addressing effects: *recommendations for avoiding remedying or otherwise mitigating effects*
			• Genetic risks are numerous and complex, so an expert technical panel may be required and a separate genetic risk analysis pathway. • Source brood stock from aquaculture facilities following industry best practice. *To address effects of parasites and diseases associated with escapees* • Fish must come from aquaculture facilities following industry best practice and / or from adequately researched wild source populations known to be free of disease and parasites (or where these are judged to be at an acceptably low level). • Fish are transported in a medium and containers confirmed free from diseases, and parasites. • Fish are fed sterilised food where appropriate. If aquatic organisms are used to feed stock, these should be irradiated, pasteurised or similarly processed to render it microbiologically safe. • Stock from different year classes should be maintained in separate culture systems or sites throughout the production cycle to avoid pest and pathogen transfer between different year classes. • All incoming stock should be received by designated quarantine facilities before entering production areas. • Identification of parasites and diseases associated with focal species (at all stages of life cycle in terms of parasite and host) and the relative specificity of any diseases and hosts. • Identify if other potential hosts are present at the destination site or potential receiving waters. • There is less risk if no fish species are present, including resident populations of focal species, although this could obviously change if fish species are found in this area at later date. • If the escapee focal species is farmed outside its natural range, the risks and impact of the above is increased.
2	Potential release of viable pathogens and parasites from farm effluent, dead / dying stock,	*Introduction of diseases and parasites* • Parasites and diseases can infect focal species populations or other fish species / animal hosts in receiving waters, if host-specificity is not stringent.	*As 1. for relevant parts in minimising risks from parasite and disease presence for farm stock and facilities generally.* *To address presence of parasites and diseases associated with effluent*

	Potential effects	Explanation	Addressing effects: ***recommendations for avoiding remedying or otherwise mitigating effects***
	infrastructure and equipment – *effects on fish, invertebrates, ecosystem structure and function*	• Released novel pathogens and parasites can become prevalent in the recipient ecosystems causing deleterious effects on naïve fish populations and have widespread community impacts. • Released novel pathogens and parasites can have widespread community impacts if infected host species is a 'keystone' species capable of influencing other trophic levels in the ecosystem	• Effluent water should be treated (e.g. filtration, UV treatment, chlorination, ozonation) to exclude identified pathogens and pests or render them non-viable. Protocols and doses as detailed in this report and in MPI guidance documents (https://www.mpi.govt.nz/dmsdocument/13287/direct). • Infrastructure for decontamination of effluent (e.g. UV lamps) should be monitored and maintained to remain effective. • Infrastructure such as settlement basins should be monitored and maintained to ensure remains effective. • For in-land systems, influents and effluents should be located to avoid cross-contamination. • For pond-type systems, chlorination or liming of dried ponds can be used for disinfection purposes, between harvesting of stock. *To address presence of parasites and diseases associated with farm infrastructure, equipment and on-farm operations.* • Procedures should be in place to clean and disinfect equipment, vehicles and vessels brought onto the site. All staff and visitors should follow biosecurity disinfection protocols. This and other protocols should follow best practice in biosecurity management. • Should be regular removal of dead and dying animals and these should be disposed of in a biosecure manner, so no contamination of the aquatic environment is possible.
3	Unintentional release of associated (non-focal) species from aquaculture facilities - *effects on fish, invertebrates, physical habitat and ecosystem structure and function*	As 1.	As 1. *To address effects of parasites and diseases associated with escapees, equipment, effluents* • Fish transported in a medium and containers confirmed free from associated species, see best practice guides at head of this table and https://www.mpi.govt.nz/dmsdocument/32257/direct for DOC standard for managing exotic copepods that can be associated with grass and silver carp.

4. BIOSECURITY RISK ANALYSIS FOR FRESHWATER FISH FARMS

4.1. Biosecurity and risk—some general considerations

In reality, there will always be a degree of uncertainty, but the fundamental question is how stringent management decision and activities should be, to keep risk to an acceptable level. Any freshwater aquaculture proposal needs to comprehensively evaluate the risks and benefits and realistic ways to manage risk. There are many ways to define a risk assessment (MacNeil 2021) but generally a risk assessment refers to the overall process or method which allows:

1. identification of hazards and risk factors that have the potential to cause harm (hazard and risk identification)
8. analysis and evaluation of the risk associated with that hazard (risk analysis, and risk evaluation)
9. formulation of efficient ways to eliminate the hazard or control the risk to a tolerable level when elimination is not possible (risk control).

A biosecurity risk assessment framework for freshwater fish farms, as it relates to potential ecosystem impacts, will need to take into account all significant factors relating to identifiable risks to ecosystems and balance them against the benefits to New Zealand of each specific fish farm proposal. How such identified risks are then managed needs to be reflected in standards and / or conditions sought in applications and / or as conditions in resource consents and biosecurity plans associated with farm licence conditions (Dahlstrom et al. 2011).

Many of the biosecurity risks and potential ecosystem impacts for freshwater fish farming in closed, semi-closed and open systems are either similar or the same as those already identified within the same type of systems for freshwater fish translocations in New Zealand (MacNeil 2021). Many of the core risks associated with freshwater fish farms and the framework to manage them, can be recognised in a translocation risk management framework presented in an earlier Cawthron report (MacNeil 2021) and many well established marine biosecurity risk assessment frameworks (Dahlstrom et al. 2011).

4.2. Risk evaluation

Risk evaluation is the examination of what the identified risks actually mean in practice. It deals with the trade-off between the perceived risks of a freshwater fish farm operation and the economic / conservation benefits. Based on the acceptable level of risk, eventual choices of action are determined that will achieve the desired level of risk. If risk is deemed to exceed a prescribed acceptance level, actions should be taken to reduce the risk. If a risk cannot be managed to an acceptable level, the activity should not occur.

The three major approaches to evaluate risks are:

1. Professional judgement: technical experts evaluate risks based on 'best judgement', which may include estimating the probability of a biosecurity problem occurring and consequence of that biosecurity issue manifesting in the farm and outside ecosystem.
10. Formal analysis: such as a cost-benefit analysis, comparing the benefits (e.g. commercial benefit or conservation benefit of rearing a local population of native fish) with costs of a risk management option either not being suitably stringent or not being adhered to. These costs could include the potential impact on genetics, and the ecological disruption of fish assemblages in receiving environment by effects of disease, parasites, pests and increased competition / predation from farmed escapees or ill-thought-out deliberate releases.
11. Bootstrapping: biosecurity policies which have evolved over time and appear to work on existing freshwater fish farms (and marine fish farms in terms of general principles) in New Zealand and overseas are adopted. These can identify the safety levels achievable and 'lessons learned' with old risks. This may provide the best guide as to how to manage potential new risks to New Zealand's freshwater ecosystems.

4.3. Uncertainty

An application for a freshwater fish farm licence may not be a viable option if there is significant uncertainty in the level of risk at any stage of that specific aquaculture activity and / or a high level of risk that unacceptable harm may occur. In terms of potential ecosystem impacts on the receiving environment, this may include lack of knowledge of the species assemblages in the receiving environment, especially conservation sensitive / rare indigenous species.

If significant information is lacking, options include:

- Wait for data gaps to be rectified (although these gaps can very large and take a long time to address in respect of potential impacts on resident fauna and ecosystems).
- Undertake or commission research to fill this data gap (for instance composition of fish species assemblages in receiving environment).
- Obtain proxy information from freshwater fish farms involving the same or a closely related species in similar freshwater systems or in the same region.
- A staged approach to project management, by allowing an aspect of the activity to occur with strict controls and require the applicant to generate more data in order

to proceed in staging. This can be pragmatic because some risks cannot be quantified unless the activity is occurring. There would usually be 'adaptive management triggers' stipulated (i.e. if something goes wrong, things are halted).

A degree of uncertainty is inherent to all risk assessments. However, it is crucial to realistically assess the magnitude of this uncertainty to determine the 'relevance' of the quantified risk.

4.4. Underlying principles for setting up a risk management framework – ecosystem impacts

The Department of Conservation (DOC) and other stakeholders should ideally adopt a defined risk-based assessment based on the Australian/New Zealand risk management standard, AS/NZS ISO 31000:2009, Risk Management – principles and guidelines.[4] In this standard, the term 'risk management' refers to the principles, framework and process for effectively managing risks. Although in Australia AS/NZS ISO 31000:2009 has been revised and replaced by AS ISO 31000:2018, in New Zealand AS/NZS ISO 31000:2009 remains current until further notice. The risk assessment process outlined in any new freshwater aquaculture biosecurity risk evaluation in relation to ecosystem impacts should conform to and be consistent with AS/NZS ISO 31000:2009. ISO standards are regarded as 'best practice' and can help regulators and policy makers ensure they meet legal requirements. Like biosecurity management plans, risk assessments focused on risk of ecosystem impacts and the standards these assessments are based on, are 'living' documents. They need to be periodically reviewed and amended where necessary, to remain current and effective.

Figure 1 shows the AS/NZS ISO 31000:2009 general relationships between risk management principles, framework and process, as could be applied to freshwater fish farms. Note this is aimed at managing on-farm risk which will inevitably reduce off-farm risk, by reducing the risks of farmed escapees, parasites and diseases reaching the environment outside the farmed system. This will in turn reduce the potential magnitude of any consequent ecosystem impacts. Such impacts will be dependent on factors such as number of escapees involved, farm location in relation to location of wild populations, parasite and disease loads of escapees and the species being farmed (introduced or native, already present in the region or not).

The biosecurity management plan and its SOPs, the fish farm licence and its application requirements and the associated resource consents and their inherent conditions, all form part of this overall risk management process, despite being sometimes administered / regulated by different stakeholders, of which DOC is one.

[4] https://policy.deakin.edu.au/download.php?id=214&version=4&associated.

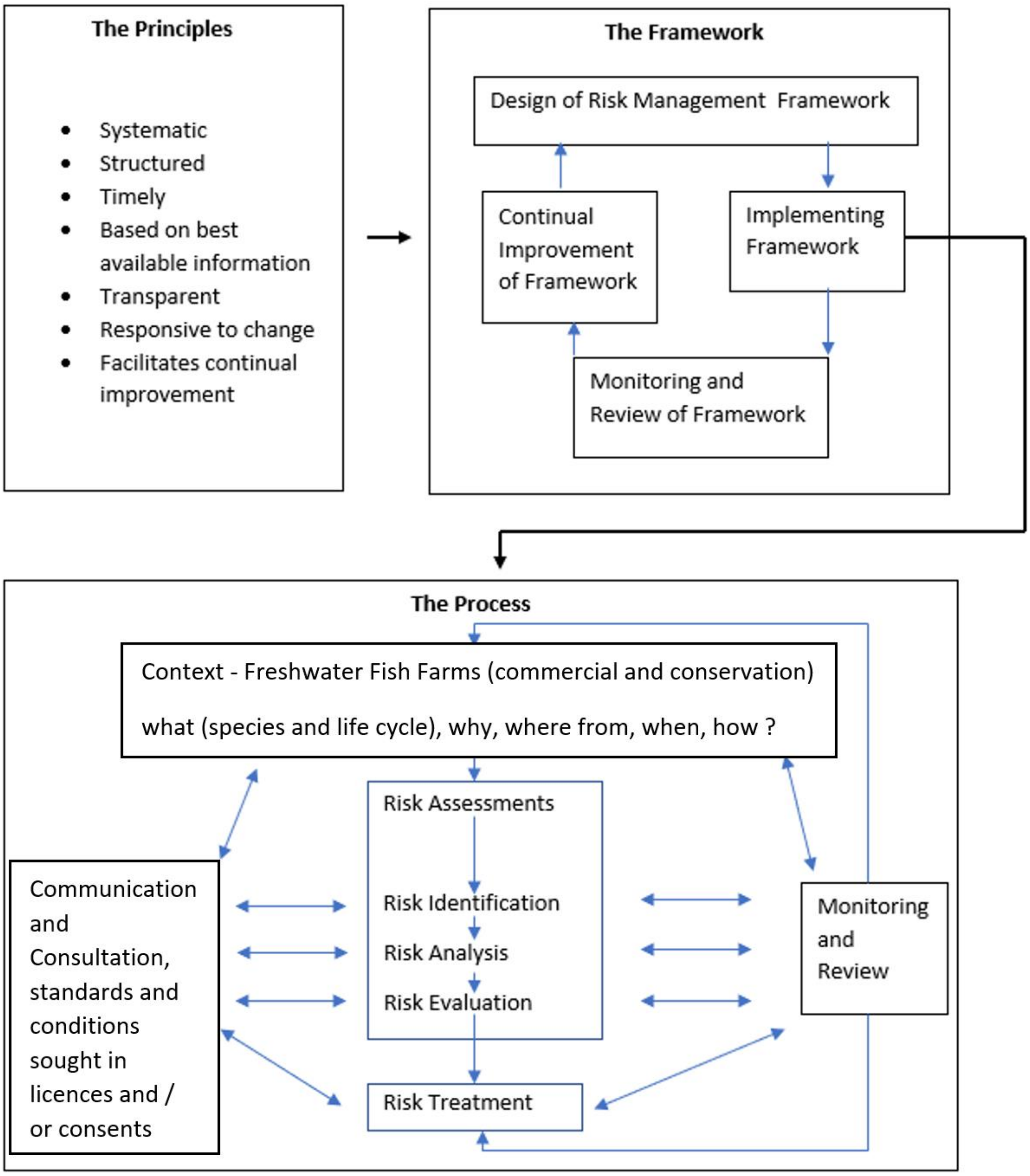

Figure 1. Example of the relationships between risk management principles (examples provided), framework and process, as adapted for freshwater fish farm biosecurity (adapted from AS/NZS ISO 31000:2009, Risk Management – principles and guidelines https://policy.deakin.edu.au/download.php?id=214&version=4&associated).

The AS/NZS ISO 31000:2009 Standard is intended to meet the needs of a wide range of stakeholders including: those accountable for ensuring that risk is effectively managed, those responsible for developing risk management policy, those who need to evaluate an organisation's effectiveness in managing risk and developers of standards and codes of practice. There are a number of stakeholders involved in native ecosystem protection in New Zealand, of which DOC is a principal player.

5. MANAGING BIOSECURITY RISKS IN FRESHWATER FISH FARMS

5.1. Current biosecurity requirements in New Zealand fish farms

Although licensed freshwater fish farms are required under licence conditions to maintain and implement a biosecurity management plan to mitigate the risk of introducing, exacerbating, and spreading pests and diseases, it is not mandatory or a requirement to have biosecurity management plans assessed and approved before farms are authorised (i.e., pre-licence approval). As part of the current fish farm licence application process, resource consents for discharges of effluents, in terms of factors such as location, volume and treatment must already be in place before the application can be progressed (https://www.mpi.govt.nz/dmsdocument/15910-Application-for-a-fish-farm-licence-new-or-transfer). Resource consent conditions are often general and granted for significant periods of time (i.e. 10–30 years). This generality could allow for flexibility to accommodate new knowledge, information and technology and changes in resource consents can be a legislatively onerous undertaking. Once licensed to stock the farm with fish, under section 26ZM(3)(a) of the Conservation Act 1987, the farmer must obtain an approval from DOC to release a new freshwater species into a new or existing fish farm. From a safeguarding biosecurity standpoint, biosecurity could be considered at all stages of the approval process where DOC is involved, during both RMA affected party approval and 26ZM.

Once licensed as a fish farm, the farmer is also required to meet licence conditions, regulations and related parts of the Fisheries Act (MPI 2016c). These requirements can include:

- maintaining and implementing a biosecurity plan to protect the farm, other farms and farmers and the surrounding ecosystem
- keeping records of all movements of stock / product on to the farm and all movements off the farm
- only sourcing stock and bringing stock onto farm as per 192A *Restriction on acquisition of fish, aquatic life, and seaweed by fish farmers*, which include that the stock must come from another licensed fish farmer or licensed fish receiver or lawfully bred or cultivated by the fish farmer
- mortality records of farmed stock must be kept
- farmed stock must not be fed to other farmed stock
- any aquatic life fed to farmed stock must be sterilised
- movements of stock onto and from the farm must be reported to Fisheries New Zealand each month, even if none occur
- approval from Fisheries New Zealand must be granted before bringing in or removing freshwater species, where the transfer involves moving between islands

- approval from DOC and Fisheries New Zealand may be necessary before any freshwater species are released from the farm to the wild and other locations.

With respect to the last item, MacNeil (2021) provides a detailed risk analysis of potential ecosystem impacts associated with such releases. Detailed background knowledge of resident freshwater species present in the recipient environment, including parasites and diseases, overlap with conservation areas and habitats of threatened species, should ideally be established before proposals are progressed.

5.2. Example of biosecurity requirements addressed in current fish farm licence conditions, including maintenance of a biosecurity plan

The current biosecurity conditions on land-based / freshwater fish farms are those found in the Freshwater Fish Farming Regulations 1983 and fish-farm licence granted under those regulations. Licence conditions are consistent across all licences with the exception of the individual freshwater species listed and that some fish-farms either allow or sell rights to the public, for on-site recreational fishing. Licence conditions tend to be very general and not prescriptive as this may futureproof them as new information, issues and protocols emerge. The current generality of licence conditions also has compliance considerations associated with it (i.e. having a general condition allows for farmers/licensees greater provision to meet the condition through various ways, rather than one set way which might be difficult for some to achieve and lead to compliance difficulties and risks, both for the regulator and the regulated).

The Cawthron Institute Trust Board holds several fish farm licences. One of these licences (hereafter called Licence A) runs from 8 May 2020 to 1 May 2028. Schedule A of this licence provides a list of species permitted to be farmed. In the case of the Cawthron Institute, this is an extensive list of finfish, shellfish, algae or seaweeds, plants, sponges or porifera, cnidarians, bacteria and rotifers. The majority of licensed farms have a far more limited range of species than Cawthron and the majority will only list the species actually farmed or intended to be farmed. The Cawthron Institute's species list is extensive to enable the transfer from research to commercial use of species held at Cawthron.

Licence A has 52 conditions, 15 general conditions, 10 fish, aquatic life and seaweed health management conditions, 9 authorisation to bring stock onto fish farm conditions, 15 authorisation to remove stock from fish farm conditions and 3 disposal conditions. Within the fish, aquatic life and seaweed health management conditions is one condition that refers directly to a biosecurity plan, which states:

> The licensee must maintain and implement a biosecurity plan for the farm. The plan must set out protocols, preventative measures,

treatments and contingencies. The plan must be reviewed at least annually and updated accordingly.

There are many other conditions related to biosecurity risk but only one which directly refers to the biosecurity plan itself. The contents of the plan itself are only referred to in very general terms in the licence itself. With respect to specific biosecurity, the biosecurity management plan will contain the specific standard operating procedures (SOPs) that pertain to treatment of the effluent discharge and other biosecurity management measures.

In respect of fish farm licence conditions that work to protect the off-farm environment and thereby mitigate against potential ecosystem impacts, examples include:

- Discharge of any effluents from the farm in a manner and location approved for that purpose pursuant to the Resource Management Act 1991 (RMA).It should be noted the resource consent conditions in respect of treatment of the effluent does not contain biosecurity requirements but addresses more general water quality issues, including prevention of ‘additive’ release, such as chemicals from the aquaculture facility.
- Water cannot be discharged without being treated in a manner and location pursuant to the RMA.
- Appropriate measures to prevent unauthorised access to the fish farm area.
- Where possible separate or manage species and batches in a way to minimise the risk of pathogen transfer.
- Notification of the MPI Aquatic Incursion Investigator of any unusual / unexplained stock mortalities and / or sickness.
- Diseased / sick stock must be kept from coming into contact with other fish, aquatic life or seaweed.
- Damaged / dead animals and parts of diseased / sick stock must be kept in an area separated from other stock.
- Before releasing newly sourced and approved stock into the fish farm, any dead and sick fish must be removed and not released, with any dead fish and contaminated transport water being disposed of in a biosecure manner.
- All necessary steps are taken to ensure naturally occurring fish and aquatic life are prevented from entering the licensed farm area.
- In the event of naturally occurring fish and aquatic life accessing aquaculture facilities, such species must not be harvested and where necessary be removed and destroyed in a biosecure manner. Such organism cannot be returned to the natural environment unless approval is granted by the Licensor.
- Freshwater stock must not be transferred from or to any other island of New Zealand without prior permission of the Licensor.

- No fish, including eggs / larvae are to be released into the aquatic environment not being part of a licensed or registered fish farm without prior authorisation of the Licensor.
- No person shall knowingly transfer diseased fish from any farm to any other farm, or release into any waters any diseased fish kept on any fish farm.
- Appropriate measures must be taken to prevent any unauthorised removal and escapes of fish and aquatic life from the fish farm area.
- Any fish and aquatic life removals, losses and / or escapees must be reported to the licensor as soon as possible and no later than 24 hours after discovery.
- Any unwanted/ dead fish or aquatic life or any parts considered waste, must be contained in leak and scavenger proof containers before being disposed of to an approved landfill or other biosecure location in a biosecure manner approved for that purpose pursuant to the RMA.
- Any unwanted/ dead fish or aquatic life or any parts must not be disposed of as bait unless authorised by the Licensor.

The above list is not exhaustive and is only a small selection of the 52 licence conditions. The individual conditions themselves are also far more detailed in the licence and the above represent highly simplified versions of these. The licence conditions, biosecurity measures and derived biosecurity plans applied to New Zealand aquaculture are all very similar to those in other countries such as Australia and the United Kingdom (Commonwealth of Australia 2016; Centre for Environment Fisheries & Aquaculture Science 2019).

5.3. Recommendations already identified to improve biosecurity best practice

5.3.1. The Aquaculture Biosecurity Handbook (MPI 2016c)

The Aquaculture Biosecurity Handbook (MPI 2016c) is principally concerned with advising farmers how to minimise on-farm biosecurity risk. However, anything which minimises biosecurity risks on-farm, such as disease and parasite spread of farmed stock, also significantly reduces the potential for these issues to become damaging in any receiving ecosystem, should escapes or accidental discharges of contaminated waste effluents occur. A biosecurity plan template accompanies the MPI Biosecurity Handbook (MPI 2016c) and outlines guidelines that should be followed to minimise on-farm biosecurity risks and gives examples of management policies that can be used to achieve this. Some these directly address minimising biosecurity risks on-farm to stop them becoming manifest off-farm. For instance:

- Outbreaks of pest and / or diseases on farm should result in an immediate halt to movement onto, within or off the farm.

- Holding units on the farm should be designed and maintained to minimise the potential for escapes.
- Pen systems should ideally adopt epidemiological separation of populations (year class separation and fallowing).
- The farm should have a clear biosecurity zone, such as clearly defined secure perimeter fencing.
- All farm waste material should be assessed for biosecurity risk to the environment.
- Control, exclude or prevent aggregations of predators, wildlife and any aquatic life from land-based and open systems.

5.3.2. The Managing Biosecurity Risk for Business Benefit Report (MPI 2016d)

The Managing Biosecurity Risk for Business Benefit report prepared by Coast & Catchment Ltd, environmental consultants for the Ministry of Primary Industries (MPI 2016d) details a number of recommendations to improve biosecurity best practice in New Zealand. Some of its recommendations are directly applicable to freshwater farms and are reflected in other biosecurity strategies adopted overseas. These include:

- Biosecurity should be managed in geographic zones such as Aquaculture Bay Management Areas which have been used to ensure sustainable aquaculture activities in seawater farming, in areas such as Newfoundland and Labrador. Their implementation requires a good understanding of the water connectivity in the region in order to estimate zones of hydrographic influence around each individual farm. In terms of effectively managing biosecurity risk as regards pest and disease transmission, this collective farm – aquaculture zoning management 'ecosystem approach' is one favoured in many countries (see Aguilar-Manjarrez et al. 2017). In freshwaters, zones could be catchments, sub-catchments, rivers depending on knowledge of water connectivity and farm location.
- Pathogens and parasites can spread between farms by local processes (i.e. water movement) and by long distance processes (i.e. live fish movements). In relation to the hydrographic zone management recommendation, single-year class production of the farmed fish and adoption of a fallowing period (a management measure where production is paused for a few months) could be adopted by all the farms in the zone, to minimise pest and disease transmission. Network modelling of Scottish salmon farms has shown synchronised fallowing of interacting farms can be effective at eradicating epidemics when transmission rates are low (Werkman et al. 2010).
- Stock can harbour pests and diseases and methods should be adopted to reduce the risk of pest and disease transmission with stock transfers. These can include:
    a. Establishment of a national pest and disease testing / surveillance system that facilitates routine testing of stock.

b. Biosecurity certification of hatcheries to ensure hatchery stock are pest and disease free.
c. Related to the above point, implement routine disease and pest testing of stock prior to stock transfers among managed geographic zones if these exist in freshwater systems.
d. Implement routine disease testing and quarantining for wild brood stock.
e. Implement routine egg disinfection.
f. Prevent stock transfers and / or deliberate releases from locations where pest and diseases are present to receiving environments where they are absent.

For points a–f, accurate recordkeeping will significantly improve the ability to identify the sources / donor populations of pests and diseases and prevent further spread of the same pests and diseases. The final point (f) is a key biosecurity strategy and preventative measure, which if strictly adhered to will negate any potential negative ecosystem impacts emanating from pest and disease spread.

5.3.3. The Salmon Biosecurity Standards (Aquaculture New Zealand 2019)

The industry body Aquaculture New Zealand produced the Salmon Biosecurity Standards (Aquaculture New Zealand 2019). Under this scheme, salmon farmers would self-report against previously agreed standards developed by current farming members of the New Zealand Salmon Farmers Association (NZSFA). Chinook (king) salmon are farmed in seawater and fresh water, with freshwater ‘grow out’ farms located in hydroelectric canals in the MacKenzie Basin and brood stock farms and hatcheries located across New Zealand, including Otago and Golden Bay. The aquaculture zoning management ‘ecosystem’ approach described earlier in the Managing Biosecurity Risk for Business Benefit (MPI 2016d) is acknowledged in the Aquaculture New Zealand 2019 document. Specific separable freshwater zones have been agreed to be established, including a freshwater grow out zone in the MacKenzie Basin and 8 separate freshwater nursery zones (brood stock sites, hatchery sites and smolt production). The 8 nursery zones are in fact individual sites at present and these are:

- Takaka brood stock site
- the Ruataniwha Canal at Twizel
- Waiau hatchery
- Waitaki hatchery
- Kaitangata hatchery
- Tentburn hatchery
- McLeans Island hatchery in Christchurch
- Silverstream and Winchmore hatcheries.

The 2019 report then sets out zone standards that specify restrictions and biosecurity requirements for movement of stock between zones. If movements are necessary which do not meet these standards, a risk assessment must be carried out, peer reviewed by all affected parties and agreement reached with all affected parties. The report details facility standards including staff biosecurity training, monitoring fish health and biosecurity status, and investigations into biosecurity challenges. The latter can involve unexplained elevated mortality rates in farmed stock. For instance, where mortality rates exceed 0.05% per day over an increasing 4 day trend and/or 0.5% per week, a 'potential biosecurity event' is considered to have occurred, with the facility veterinarian and any external expertise as required being used to identify the cause. When such a 'biosecurity event' occurs all other salmon farms in the same zone are then notified within 24 hours and contingency plans to halt movement between zones are put in place.

It should be acknowledged these Aquaculture New Zealand Standards (2019) are industry-led and the report does state all salmonid farming operations have to participate in any fish health or fish biosecurity programmes as required by the Ministry for Primary industries as regulatory requirements.

5.3.4. High Level Biosecurity Management Plans for finfish and shellfish in land-based and ocean facilities (MPI 2020a, 2020b)

The Biosecurity New Zealand arm of the Ministry of Primary Industries in 2020 produced two technical guidance documents on high level biosecurity management plans for finfish and shellfish in land-based and ocean facilities (https://mpi.govt.nz/dmsdocument/41979/direct and https://www.mpi.govt.nz/dmsdocument/41982-Technical-Guidance-Document-High-Level-Biosecurity-Management-Plans-Shellfish-Land-based-and-Ocean-Facilities, MPI 2020a and MPI 2020b, respectively). These documents complement the earlier, very detailed technical document on aquaculture (MPI 2016b). These management plans allow adoption of on-farm biosecurity procedures for each farm based on site-specific conditions, where individual farm design, location, prevailing environmental regimes are at the core of the biosecurity management plan.

The majority of the guidance points outlined in these documents and the accompanying management tasks are directly applicable to freshwater fish farming biosecurity plans and lend themselves to an ecosystem protection approach. For instance, there is the guidance point on farming of *New and Unfamiliar Species*, where the objective is *To manage the risk of pest and pathogen transfer onto, within and from the facility from the production of new species* (point 16 - MPI 2020b). One of the tasks linked to achieving this objective is that …*Facilities should demonstrate a knowledge of biology, pest and disease susceptibility prior to production of new species. Transfer to commercial practice should not take place until these have been* *assured* (MPI 2020b). It is assumed the appropriate regulator assesses this as part of the licencing process and assessment of the farm's biosecurity plan.

Another related guidance point concerns *Stock containment*, with the objective '*To manage the risk of pest and pathogen transfer onto, within and from the facility* (point 24 – MPI 2020b). One of the tasks linked to achieving these objective states … *A documented facility containment protocol should be developed. This should be based on a risk assessment for escapes which should consider extreme weather events, predator fencing, theft, equipment failure and fouling. The assessment should also identify the risk of escape, for example, whether the stock will survive in the wild and whether gametes will escape and survive*. Other related tasks for this objective include informing MPI of the number of stock involved in an escape event and keeping a record of escapes to help identify critical control points in the facility for effective escape risk monitoring and escape risk reduction (MPI 2020b).

There is also a *Wildlife Management* point, with the objective *To manage the risks of wildlife, scavengers and vermin transferring pest and disease onto, within or from the facility* (point 29 – MPI 2020b). The tasks related to achieving this objective include controlling / excluding wildlife and scavenger populations from production facilities, production units having features to prevent stock escapes and all measures to exclude wildlife being approved by DOC.

These guidance documents, with points to strengthen and populate farm biosecurity plans, are similar to those produced in countries such as Australia and the United Kingdom emphasise the biosecurity plan as a 'living' document in the biosecurity response is ongoing and evolving. Maintaining fit-for-purpose aquaculture facilities with excellent containment systems where appropriate, treating intake and effluent waters (via UV treatment / filtration / ozonation) to render identifiable risks (i.e. pathogens and pests) non-viable, reporting of escapees, compliance with industry codes of practices and area based management zones to reduce the risk of horizontal pathogen transmission are all assumed in guidance given to farmers by government agencies in New Zealand, Australia and the United Kingdom. If things still go wrong, enforcement is a deterrent, with the regulator imposing penalties for escapees and escapee identification for enforcement if penalties are imposed.

5.4. Core research gaps - ecosystem perspective

It is important to note there are many research gaps. Some of these have already been acknowledged in the context of marine aquaculture (MPI 2013) and the extent of these gaps is arguably even larger in terms of freshwater aquaculture. These gaps could invariably be summarised as 'effects of escapees and / or introduced farmed stock on native species and ecosystems'. Background knowledge of the receiving environment for the location of any proposed fish farm is crucial but often sparse.

Ideally the diversity and relative abundance of aquatic species present, including species of high conservation status or cultural significance, the presence of naturally occurring disease and parasites and whether the proposed farm species has ever naturally occurred in the system should all be well understood before a proposed fish farm in that area is considered. Coupled with this is the proposed farm's demonstratable *knowledge of biology, pest and disease susceptibility prior to production* if a new or unfamiliar species is intended to be farmed (MPI 2020b).

Lack of comprehensive background knowledge of both the farmed species and the recipient ecosystem will make managing risks to acceptable level almost impossible if the ecosystem is to be protected. It is already acknowledged that impacts from farm escapees that have already manifested in ecosystems, such as increased competition and predation, alteration of genetic structure and transmission of pathogens will all be long term (if not permanent) and the scale of impacts will be regional up to national (MPI 2013). If there are persistent research gaps but economic / social drivers promote expansion of the freshwater aquaculture sector, the application of stringent biosecurity preventative measures (i.e. not permitting farming of a species in a region where it has never occurred, detailed knowledge of the genetic origins of any brood stock), while such research gaps are addressed, is vital.

6. A RISK ASSESSMENT FRAMEWORK – ECOSYSTEM IMPACTS

6.1. Endpoints and type of receiving environment / destination site

Ecological risk assessments are often based on a series of simple and measurable assessment endpoints, each of which is 'an explicit expression of the environmental value to be protected, operationally defined as an ecological entity and its attributes' (US Environmental Protection Agency 2016). Setting appropriate assessment endpoints is a vital part in ensuring a risk assessment will be of practical use to regulators in making informed and scientifically defensible decisions, in respect of both the aquaculture system, the focal species being farmed and the receiving freshwater environment. Endpoints in relation to the farming of freshwater fish will be related to the three basic types of aquaculture system (see also MacNeil 2021):

1. *Open systems* such as rivers and lakes have little or no control over the focal species or water environment.

12. *Closed systems* have strict and effective control over both the movements of the focal species and receiving water environment. Closed systems include recirculating aquaculture facilities and tank displays in the aquarium trade, research and education institutes. Contact with potential receiving waters can be prevented.

13. *Semi-closed systems* have effective control over the movement of the focal species and some control over the receiving water environment. These include aquaculture ponds, purpose-built lakes and reservoirs.

Hayes (1997) in a review of ecological risk assessments methodologies, suggests simple endpoints to be used in assessing ecological risk. These can be adapted to assess risks generated from freshwater aquaculture of the likelihood (and ecosystem consequences of):

- escape and/or release of farmed fish, associated organisms, parasites and pathogens into receiving environment
- survival of farmed fish, associated organisms, parasites and pathogens in receiving environment
- establishment of feral populations of fish and associated organisms. Parasites and pathogens become established in feral population of focal species and / or potential other host species in the receiving environment.

Risks of ecosystem impact associated with aquaculture can be assessed in the context of such endpoints and assessed through a series of questions or consideration points in the context of whether the aquaculture operation is an open, closed or semi-enclosed system. The endpoint related to establishment is the most crucial 'point' in considering significant ecosystem impacts, because if for instance an escapee or pathogen does not survive and persist in the receiving environment, its scope for causing long term ecosystem impacts is moot.

6.2. Adaptive and ongoing management – deliberate releases

Adaptive management, which means undertaking progress reviews at all stages of an aquaculture operation, including restocking / deliberate release, allows any negative impacts to be recognised early in the process and an exit strategy deployed. Adaptive management also lends itself to monitoring the progress of a deliberate conservation release / translocation in a cyclical way. This approach lends itself to detecting potential negative ecosystem impact associated with the presence of the focal species in its new environment. Parker et al. (2020) detailed the steps required in a conservation translocation decision making process in New Zealand and this includes adaptive management in the form of 'double loop learning' whereby monitoring could lead to a revision of alternatives (Figure 2). For instance, ongoing management may be required at various points, such as disease control and parasite treatment, before the population can be left unattended. In a worst-case scenario if there are unintended or negative ecosystem impacts management alternatives such as eradication programmes may be necessary, although these are seldom successful.

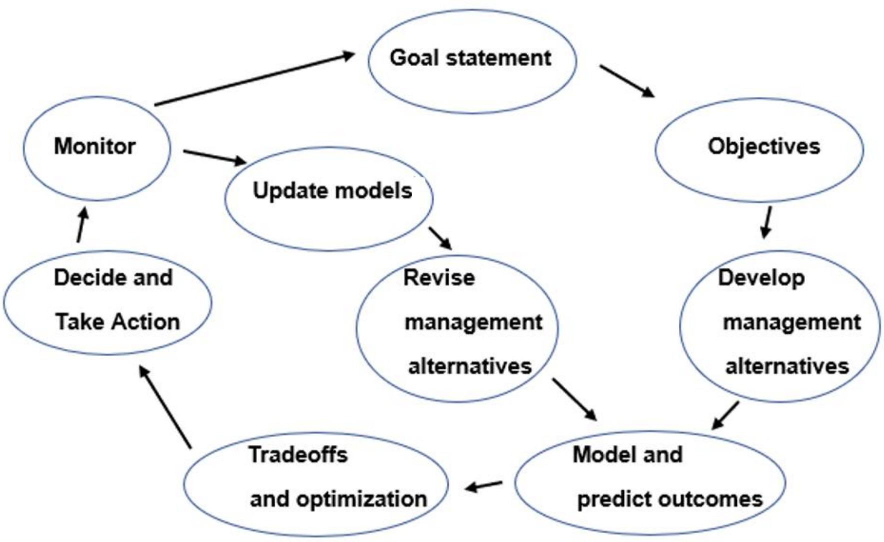

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Figure 2. Steps in the deliberate release for restocking / conservation translocation structured decision-making process (Parker et al. 2020, adapted from Gregory et al. 2012).

Double loop learning as above promotes adaptive management whereby monitoring can lead to a revision of management alternatives. In an ecosystem approach, not just the translocated fish population is monitored but any impacts on the receiving environment.

6.3. Value judgements and risk – escapees and deliberate release, pathogens and parasites

Risk analysis frameworks often have a points system allied to each individual risk factor and each type of risk (Climate Technology Centre and Network 2019). The individual weighting of any scoring system will be determined by the policy being pursued and what is considered to be an acceptable level of risk in the context of a cost-benefit analysis (whether the benefit is a conservation benefit or an economic benefit, or a combination of both). While considering the potential ecosystem impacts of freshwater fish farming and the inherent risks associated with escapees or even deliberate releases, at some level these must be balanced against potential economic and social / cultural 'costs and benefits'. A high degree of technical expertise may be required, as well as practical knowledge of the species and recipient ecosystems involved. As stated earlier (see Section 5.4), there may well be large gaps on potential impacts of released farmed fish on freshwater ecosystems and its resident fauna (MPI 2013).

7. SUMMARY

Ecosystem impacts need to be assessed against ecological values at proposed locations for aquaculture facilities including the scale and type (i.e. range of species involved, native or non-native) of farm (MPI 2013). A guiding principle of freshwater fish farming in relation to native ecosystems should be to 'do no harm' (George et al. 2009). This can be achieved to a great degree by strict adherence to farm licence conditions and biosecurity plans, especially as regards effluent treatment and minimizing the risk of escapees. However, there will always be the element of risk that can never be totally discounted (Sepúlveda et al. 2013). Developing effective incursion response strategies and tools is an important next step for aquatic biosecurity to provide additional lines of defence, as part of overall biosecurity systems.There are also many research gaps when considering the impacts of farmed fish, their associated organisms, parasites and diseases on recipient ecosystems. This means parts of any risk analysis framework are populated with assumptions associated with common core risks identified for marine fish farms and freshwater farms (and associated processes such as translocations) globally. Ideally every single New Zealand freshwater fish, crayfish or mussel species that is a candidate for aquaculture would have its own risk analysis profile. This could inform the decision-making process for each potential aquaculture operation proposal, where that species may unfortunately end up as an escapee or feature in a conservation translocation or restocking.

Management options for most invasive species / aquatic pests and diseases are limited, hence prevention remains the best line of approach for aquaculture and preventing negative ecosystem impacts (MPI 2016). The costs of implementing good preventative biosecurity practices will always be lower than the costs of managing pests and disease once they occur, although eradication methods need to improve. Preventative biosecurity is especially important for multiple farms in close proximity and ideally farmers should address biosecurity collaboratively by taking into account water movements and catchment zones.

Although there is relatively little New Zealand-based research regarding the biosecurity risks associated with freshwater aquaculture, there exists a significant body of literature relating to the negative ecological impacts of introduced species such as brown trout in New Zealand water bodies. Globally, biosecurity aquaculture effects on freshwater ecosystems primarily relates to salmonids, with their impacts on fitness reduction in wild populations, transmission of diseases, parasites and pathogens and genetic effects, being recorded in rivers in countries such as Norway, Canada, Ireland, Chile and Iceland. This focus on salmonid aquaculture indicates there will be significant knowledge gaps for the range of species that may be considered for freshwater fish farming in the future in New Zealand. MPI is currently undertaking a comprehensive Aquaculture Biosecurity Work Programme. Part of this at least, will consider a range of 'new' species such as ornamental goldfish in regard to legislation and aquaculture. While legislative and policy changes may be relatively fast, research gaps in terms of potential ecosystem impacts in New Zealand's freshwaters will take much longer to address.

7.1. Key recommendations

- Introduce a dedicated biosecurity management framework specifically for freshwater fish farming, as much of the current guidelines and templates are geared towards marine fish farming.
- The legislative and policy landscape involving freshwater fish species in New Zealand is complex and evolving. There are a number of areas of duplication anomalies and gaps that have been identified. Some of these will require addressing if certain species become candidates for commercial freshwater aquaculture. For instance, legislation and policy as regards ornamental fish such as goldfish is still deficient.
- Linked to the above, comprehensive and demonstrable knowledge of the biology, behaviour, pest and disease susceptibility of the species proposed for farming needs to be established. This is especially important for 'new or unfamiliar' species. Advice from expert technical panels may be an option as regards this latter case.
- Standardised guidance for risk management approaches for freshwater fish farms need to be developed and regulated. For example, agreed / prescribed treatment thresholds for fish farm effluent are needed, and providing regulated standards could be the most robust option. Ideally a range of options should be researched and defined to account for different farming scenarios.
- Background knowledge of the receiving environment for the location of any proposed fish farm, including the species present and whether the proposed farm species has ever naturally occurred in the system, must be well understood as part of the process for considering an application. Farming of non-native species adds an additional element of risk, when considering native ecosystems.
- Linked to the above, the relative magnitude of differences between the farmed species and conspecific wild fish in terms of genetic profile, disease and parasite presence will be the principal factor determining the impacts on wild populations and any consequent wider trophic / ecosystem impacts which result from this. The types and host specificity of diseases and parasites will determine if other fish species are impacted with consequent ecosystem impacts. Potential negative impacts will depend on the size and frequency of escape events and location in relation to wild conspecific populations in the area. The factors detailed above will all inform the overall level of risk, as regards recipient ecosystem impacts, for any potential freshwater fish farm application.
- Assessment of each application and potential ecosystem impacts linked to biosecurity risks, must be dealt with on a 'case by case' basis. In terms of specific

fish farm proposals, the MPI biosecurity management plans (2020a,b), although principally geared towards marine fish, shellfish and salmonids, represent extremely good templates on which conditions should be sought and addressed in biosecurity plans for freshwater fish farms generally.

- All future applications involving freshwaters as a receiving environment, such as for a discharge point for effluent or abstraction source for influent, will involve the National Policy Statement for Freshwater Management 2020 (NPSFM 2020). Although the NPSFM-2020 is principally concerned with water quality issues biosecurity considerations are relevant, as there is a focus on improvement to the health and well-being of water bodies and freshwater ecosystems.

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