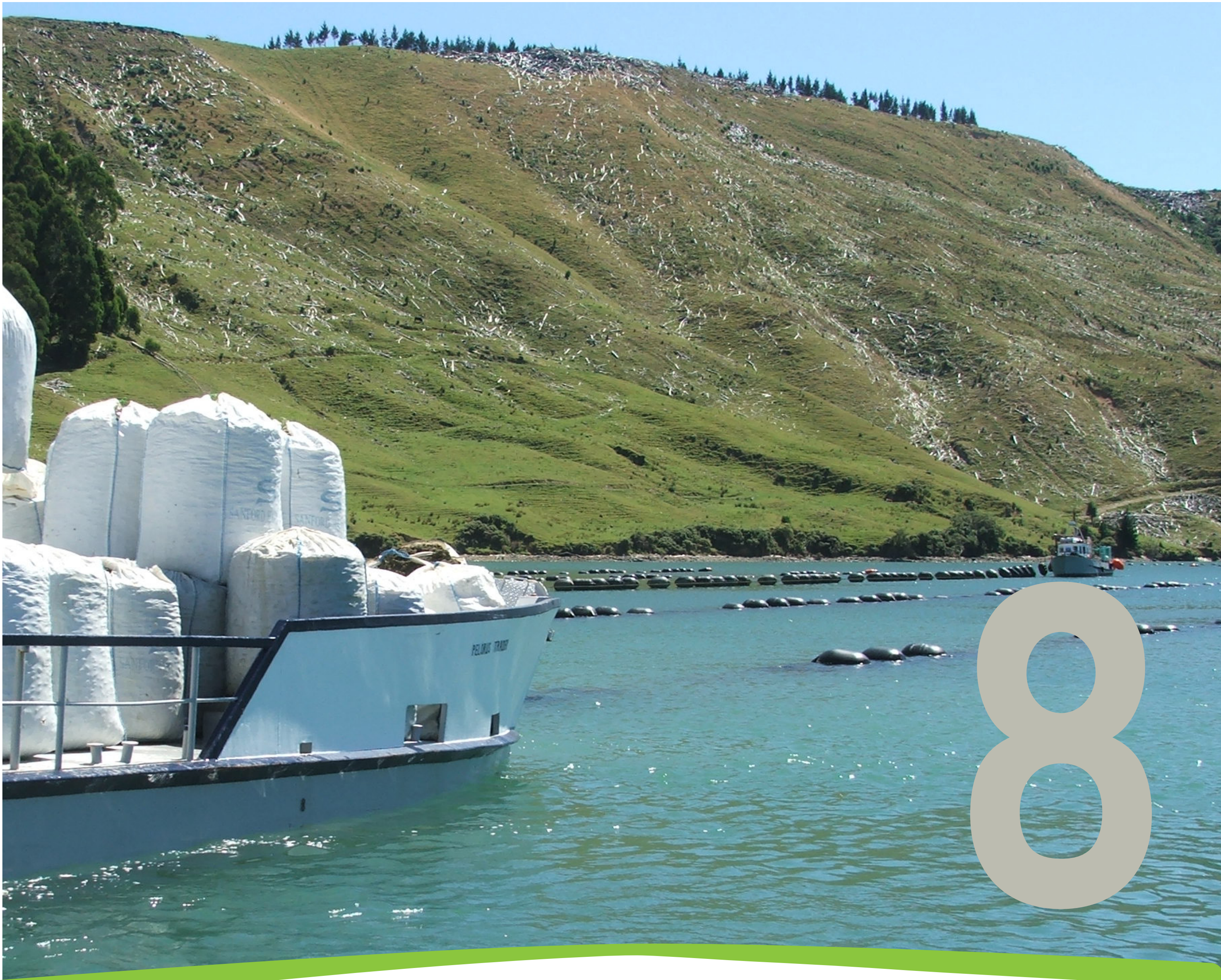
Ministry for Primary Industries
Manatū Ahu Matua

LITERATURE REVIEW OF ECOLOGICAL EFFECTS OF AQUACULTURE

Escapee Effects



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Escapee Effects

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8.1 Feed-added species (salmon, kingfish, hapuku)

8.1.1 Overview of escapee effects

The effects of escapees vary considerably in relation to the following factors (Forrest et al. 2007):

- the numbers involved in the escape episode;
- the location of the farm in relation to wild populations and its size, distribution and health;
- whether the species is native (hapuku, kingfish) or introduced (salmon);
- whether the brood stock is hatchery bred or wild sourced;
- the fish harvest size in relation to reproductive maturity and the ability of gametes to survive and develop in the wild;
- the ability of escapees to survive and reproduce in the wild, as determined by their ability to feed successfully and interbreed with wild stocks.

The main effects of escapees (Forrest et al. 2007) for feed-added species are in terms of:

- competition for resources with wild fish and related ecosystem effects from escapee fish (e.g., through predation);
- alteration of the genetic structure of wild fish populations by escapee fish and potential loss of genetic integrity in wild populations;
- transmission of pathogens from farmed stocks to wild fish populations.

The likelihood of escapee effects in New Zealand is low, given the current small size of the industry, limited overlap of wild and farmed populations (in terms of salmon) and broad home range (in terms of kingfish and hapuku) and the likelihood of high genetic diversity in these native species. If escapee effects are seen on wild populations they are, however, likely to be irreversible and could potentially be at a national scale. The main factor controlling the number of fish escaping, and their subsequent effects, is the integrity of the nets used to contain the fish and the amount of difference between wild fish and farmed fish in terms of their genetics, pests and diseases.

Management strategies to minimise escape are therefore usually based upon maintaining net integrity. In Norway, reporting of escapes, and estimation of numbers escaped, is mandatory and this information therefore provides a baseline to improve upon. In New Zealand, escapee events are not reported to any central authority. At this time, no information is available on the potential effect that escaped farmed kingfish or hapuku could have upon the wild populations.

This area is well covered by the reviews of Forrest et al. (2007) for New Zealand and Jensen et al. (2010) for Norway, and much of the content of this chapter has been taken as excerpts from these sources.

Finally, it is useful to recognise that the human-mediated transfer of marine organisms to New Zealand and around the coastline is an ongoing issue. Historically, this reflects deliberate transplants of marine organisms (including salmon), and more recently the inadvertent transfer of a range of native and non-indigenous marine species (including fish), especially via vessel movements and associated mechanisms such as ballast water, fouling and sea chests (e.g., Hayward 1997; Cranfield et al. 1998; Coutts et al. 2004). The alteration of marine ecosystems and the transfer of fish diseases via these unmanaged mechanisms is well recognised (Ruiz et al. 2000; Hilliard 2004), and hence any incremental risk from finfish culture should be considered within this broader context.

8.1.2: Descriptions of main effects and their significance

Table 8.1: Competition for resources and related ecosystem effects of escapees from feed-added aquaculture.

Description of effect(s)	Competition for resources with wild fish and related ecosystem effects from escapee fish (e.g., through predation).
Scale	Potentially up to *regional*.
Duration	*Long term* in duration.
Research gaps	The effect of escapees on native species.
Management options	Maintaining good net integrity, compliance with industry codes of practice, reporting of escapes, penalties for escapes, escapee identification for enforcement if penalties are imposed.

* Italicised text in this table is defined in chapter 1 – Introduction.

Effects from escapee salmon on the wild population will vary relative to the distribution of wild salmon. For most areas outside Canterbury and Otago where there are only small wild salmon populations, any escapes will have no long-term population survival or genetic impacts. This was demonstrated by the failure of ocean ranching techniques (Deans et al. 2004). In Otago and Canterbury, maturing escapee salmon are likely to enter rivers and mix and could potentially breed and compete with wild populations, but given the small scale of a likely escape compared to the size of the wild population and the introduced nature of the wild population this is as not likely to pose an ecological threat. For species such as kingfish, and other native candidate species that may be trialled in New Zealand, significant ecosystem effects, for example, causing localised extinctions, are unlikely, given that these fish are both native and a target of fishermen, therefore having a high likelihood of recapture. Fish escapes can also be minimised through adherence to appropriate management practices, for example, by using a robust, well-maintained containment system (e.g., Habicht et al. 1994).

In Norway, which is the world's largest aquaculture producer of salmon (FAO 2011), escapees are the most serious negative environmental consequence of aquaculture. These escapees are also seen to weaken the industry's reputation and thereby its competitiveness. The major consideration of the effects of escapees, in systems where escaped numbers are not small compared to the native population, is whether the escaped organism enters an environment that contains a native population. Competition for resources between escaping native species and wild populations is likely as they will consume much the same diet in oceanic waters (Hislop & Webb 1992; Jacobsen & Hansen 2001). Substantial competitive interactions in the ocean, however, appear unlikely to occur (Jonsson & Jonsson 2004), although limited information exists to assess if this is also the case for coastal waters (Jonsson & Jonsson 2006). Large-scale field experiments undertaken in Norway and Ireland showed highly reduced survival and lifetime success of farm and hybrid salmon (when released to the wild) compared with wild salmon (McGinnity et al. 1997, 2003; Fleming et al. 2000). Einum and Fleming (1997) found farm juveniles and hybrids are generally more aggressive and consume similar resources in freshwater habitats as wild fish. In addition, they grow faster than wild fish which may give them a competitive advantage during certain life stages (e.g., as juveniles or when breeding; Einum and Fleming 1997), thereby promoting suppression of wild traits.

Table 8.2: Alteration of the genetic structure of wild fish populations due to escapees from feed-added aquaculture.

Description of effect(s)	Alteration of the genetic structure of wild fish populations by escapee fish.
Scale	Potentially up to *national* scale effects.
Duration	*Long term* in duration.
Research gaps	The effect of escapees on native species.
Management options	Maintaining good net integrity, reporting of escapes, penalties for escapes, escapee identification for enforcement if penalties are imposed.

* Italicised text in this table is defined in chapter 1 – Introduction.

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 (McGinnity et al. 1997). In the northern hemisphere, there have been mass releases (hence considerable escape "pressure") in areas where the wild population has been over-fished (Forrest et al. 2007). Farmed fish are often bred from a small gene pool for selected traits (e.g., fast growth) that can result in genetic divergence from the wild stock (Fleming et al. 1996; Einum & Fleming 1997). In addition, escaped fish can have reproductive and survival deficiencies (Youngson et al. 2001) that may be passed on to wild fish through interbreeding (Cross 2000). Hybridisation of farmed with wild salmon has the potential to reduce local adaptation and negatively affect population viability and character (Ferguson et al. 2007). Hindar and Diserud (2007) recommended that intrusion rates of escaped farmed salmon in rivers during spawning should not exceed 5 percent to avoid substantial and definite genetic changes of wild populations.

Kingfish are an abundant pelagic species that can travel long distances, to the extent that there is some mixing of the Australian and New Zealand stocks (Gillanders et al. 2001; Nugroho et al. 2001). Such a wide geographic distribution is consistent with weak genetic structuring (or inter-population differences) and, therefore, a low susceptibility to genetic influences from farmed fish (Forrest et al. 2007).

Hapuku are found throughout New Zealand's waters and occur in shelf and slope waters from the Kermadec Islands to the Auckland Islands. Little is known about their migration patterns however, tagging studies reveal considerable mixing of hapuku between Otago, South Canterbury and Cook Strait (Paul 2002). This indicates that, similar to kingfish, there is a decreased risk of escapees negatively impacting on the genetic structure of wild populations due to the wide geographic distribution of this species. Hapuku can be harvested when they are five years old when farmed but reach maturity at 10 to 12 years, meaning that escapees would have to survive for at least another five years before having any genetic influence on the population. This would allow more time for escapees to disperse throughout the population and ease genetic influence in a particular geographic area. Genetic risks from other candidate species will need to be assessed on a case-by-case basis.

One management measure in the environmental code of practice for the New Zealand Salmon Association Inc is to carry out triploidy. This practice aims to produce sterile fish, which should enhance the speed and extent of growth. Triploidy theoretically limits the risk from escapees to the wild population, but, the practice, in New Zealand has been abandoned due to low viability of treated ova and poor growth of triploid fish (N. Boustead pers. comm). Other management measures to minimise the effect of escapees, that are relevant to all the effects of escapees are covered in Section 8.1.3.

Genetic effects are almost certainly species and location specific, as they will vary according to the abundance, distribution and behaviour of wild stocks. Effects from escapee salmon, for example, are likely to be minimal given the relatively small scale of the industry, and due to limited salmon numbers in the wild populations within existing grow-out regions. Furthermore, the wild populations are not indigenous; hence genetic effects from salmon are arguably of less importance than in the case of aquaculture of native finfish species. For species such as kingfish, and hapuku, significant ecosystem effects (including genetic effects) from escapees are unlikely due to the probably lack of strong genetic structuring of the wild population (Forrest et al. 2007), which means escapees are unlikely to differ genetically from wild populations. Issues regarding the genetic contributions from farms to wild population via gametes from farm fish will only apply if the farmed fish achieve reproductively mature size before reaching harvest size and if the gametes are viable in the wild (Dempster & Sanchez-Jerez 2008).

Table 8.3: Transmission of pathogens from escapees from feed-added aquaculture.

Description of effect(s)	Transmission of pathogens from farmed stocks to wild fish populations.
Scale	Potentially up to *national* scale effects.
Duration	*Long term* in duration.
Research gaps	Parasites and diseases of indigenous new aquaculture species.
Management options	Maintaining good net integrity, reporting of escapes, penalties for escapes, escapee identification for enforcement if penalties are imposed. Having farmed fish with low levels of disease or parasitism. For transfers from land-based hatcheries to marine farms, compliance with the Ministry for Primary Industries "Guidelines for transferring and releasing aquatic organisms from land-based fish farms to the marine environment" regarding the limitation of transfer of pests and diseases in aquaculture. Establishment of buffer zones, regions or farm management areas to reduce the risk of horizontal disease transmission via movements of water and wild fishes (as described in the biosecurity chapter).

* Italicised text in this table is defined in chapter 1 – Introduction.

Escape incidents may also heighten the potential for the transfer of diseases and parasites, which are considered to be amplified in aquaculture settings (Heuch & Mo 2001; Bjørn & Finstad 2002; Skilbrei & Wennevik 2006; Krkošek et al. 2007). Disease is not a significant issue within the New Zealand salmon industry due to the geographic isolation of farms and the lack of any disease currently present. Despite there being several reported diseases in three species of New Zealand resident salmon, *Oncorhynchus* spp. (Diggles et al. 2002), salmon aquaculture in New Zealand has been largely free from problems with diseases or parasites. In relation to parasites, for example, risks arising from finfish aquaculture at any site could be assessed either practically or by literature review, referring to existing parasitological works such as Diggles et al. (2002); Hine et al. (2000), Haswell (1903), Hickmann (1978), Jones (1975), and Manter (1954) among others. For any significant risks, opportunities for management (e.g., application of therapeutants to reduce the incidence of disease) could then be considered.

Escapees from salmon aquaculture in Norway have been identified as reservoirs of sea lice in coastal waters (Heuch & Mo 2001) with the potential to increase infection of nearby wild fish (Costello 2009); although the sea lice species of most concern (*Lepeophthirius salmonis*) is not known in New Zealand. In addition, 60 000 salmon infected with infectious salmon anaemia, and 115 000 salmon infected with pancreas disease, escaped from farms in southern Norway in 2007, yet whether these precipitated infections in wild populations is unknown. The ability for escaped fish to transfer disease to wild fish depends on the extent of mixing between the two groups, which in turns varies with the life stage, timing and location of the escape (Thorstad et al. 2008). However, while escaped and wild fish mix, the evidence for disease transfer from escapees to wild salmon populations is variable. A relatively clear-cut example exists of *Furunculosis,* a bacterial disease that was accidentally introduced to Norway from Scotland in the 1990s with the transfer of stock and then believed to have been spread from farmed to wild populations by escapees (summarised by Naylor et al. 2005). A less clear example is of the viral disease infectious pancreatic necrosis (IPN). IPN was found in increased prevalence in wild fish close to a farm site and at lower prevalence further away, but this pattern was confounded by the presence of the virus at low levels in a variety of species (Wallace et al. 2008).

Diseases issues from escapes could arise with native finfish (kingfish or hapuku) in the future, although they are not currently farmed. This situation could lead to the use of therapeutants (i.e. pharmaceutical medicines) to manage disease risks. There are many known diseases and parasites associated with finfish (see Blaylock & Whelan 2004), and the spread of parasites, viruses and bacterial infections between caged and wild fish populations (from wild to farmed, or vice versa) is a significant concern for the fish farming industry worldwide (Pearson & Black 2001).

One management option is that transfer of organisms from land-based hatcheries to marine farms (excluding salmonids) could be required to comply with the Ministry for Primary Industries "Guidelines for transferring and releasing aquatic organisms from land-based fish farms to the marine environment"[1] regarding the transfer of pests and diseases for aquaculture.

[1] Contact Julie Hills, julie.hills@mpi.govt.nz; Steve Pullan steve.pullan@mpi.govt.nz or Christine Bowden christine.bowden@mpi.govt.nz for a copy.

In practice this involves documenting movements, hatchery protocols and evaluation of risk prior to stock movements. Other management measures to minimise the effect of escapees, that are relevant to all the effects of escapees are covered in Section 8.1.3.

8.1.3: Management of escapees

Effects from escapee fish should be assessed based on knowledge of ecological and fishery values at proposed farm locations (which is invariably gathered as part of the permitting process) in relation to the nature (e.g., finfish species) and scale of the proposed farm development. It is important to remember that the behaviour of fish may differ between species, which may influence management options.

The primary means of managing ecological risks from escapee fish is for the industry to adhere to best management practices, for example by having procedures in place (e.g., regular maintenance of nets and structures) to minimise the risk of fish escapees (complete prevention is virtually impossible).

Mandatory reporting of all escapee episodes in Norway provides the best dataset to examine the causes of escapes and the numbers of animals involved (Jensen et al. 2010). They found that the main causes of escapes were technical and operational failures of fish farming equipment. Since 2004 evidence shows that large-scale escape events of salmon, trout and cod (of over 10 000 individuals) represented only 19 percent of the escape incidents reported, but accounted for 91 percent of the number of escaped fish in Norway from 2006 to 2009. This indicates that a focus on preventing this small percentage of large scale incidents (generally resulting from structural failures) will have a great effect in diminishing the consequences of escapes. Net failure, and the subsequent formation of a hole, accounted for about two-thirds of reported escapes for cod from Norwegian aquaculture. Biting by predators or caged fish, abrasion, "collisions" with boats or flotsam, and cage handling procedures (e.g., lifting) are among the most common causes of holes in the nets.

In Norway the report by Jansen et al. (2010) recommended that to prevent escapes of juvenile and adult fish as sea-cage aquaculture industries develop, policy-makers should implement a five-component strategy (notably some of the measures were already in place and are referred to above):

- establish mandatory reporting of all escape incidents;
- establish a mechanism to analyse and learn from the mandatory reporting;
- conduct mandatory, rapid, technical assessments to determine the causes of escape incidents involving more than 10 000 fish;
- introduce a technical standard for sea-cage aquaculture equipment coupled with an independent mechanism to enforce the standard;
- conduct mandatory training of fish farm staff in escape-critical operations and techniques.

No industry-wide mandatory strategies of this nature exist in New Zealand presently, although they may be requirements of particular consents. In Norway the authorities have focused on developing govening tools and regulations, operational requirements and control schemes to limit the problem. As part of this, a new regulation focusing on consequences of escapes has been adopted. Among other things this entails intensifying the consquences of violations of the regulations that affect the environment, including escaped fish. A DNA standby method has been successfully used to identify escapees from different farms for three different species and may be applicable to identification of fish farm escapees for a wide range of aquaculture species in all regions of the world (Glover 2010).

Minimising escapees is recognised by the New Zealand Salmon Farmers Association Inc. in their code of practice to help achieve both environmental and economic goals. Practical advice for minimising escapes from salmon farms can be found in the Husbandry/Fish Resource chapter in the Finfish Aquaculture Environmental Code of Practice, a summary of the main points is included below:

- Marine sea-cages, nets and other structures holding salmon shall be designed and constructed so as to be capable of dealing with the weather and other environmental conditions.
- The mesh size and gauge shall be sufficient to contain the smallest fish in the cage's population.
- Nets in sea cages should be inspected regularly for holes or fouling, and records of this inspection held. Remedial action should be taken immediately to rectify any unsatisfactory situation.
- Fish procedures such as grading, transfers and harvesting, which can increase the risk of escape, should be: planned, supervised and follow company procedures.
- Any incidence or occurrence that did, or could have, led to an escape shall be recorded.
- There should be a site-specific plan that describes actions to be taken in the event of any mass escapes.
- The Company shall document and implement regular inspections of structures and equipment to ensure they are sound and operating correctly. Maintenance records shall be maintained.
- Specific checks required include; regular inspections of cages and nets and visual post-storm inspections.

8.2 Filter feeders (green-lipped mussels and Pacific oysters)

Table 8.4: Alteration of the genetic structure of wild fish populations by escapee fish.

Description of effect(s)	Alteration of the genetic structure of wild fish populations by escapee fish.
Scale	*Regional* but potentially *long-term* in duration.
Management options	Case-by-case assessment and response.

* Italicised text in this table is defined in chapter 1 – Introduction.

Oysters and mussels cannot "escape" as they are sedentary, but deposition of shellfish does occur to the benthos, and reproductive processes will release live material. Effects of these processes occur on the benthos and may pose some biosecurity risks (these are dealt with under those chapters), this section deals solely with the genetic implications of this release of live mussel material (oysters as a non-indigenous species are dealt with under the bisoecurity chapter).

The information in this section is extracted from Keeley et al. (2009) who reviews the ecological effects of non-finfish farming in New Zealand.

There is high connectivity among mussel populations, and the industry being is based on wild-sourced progeny. Furthermore there is already a high pre-existing level of inter-regional mussel seed-stock transfer. Therefore, the continued transfer of wild-sourced mussels within New Zealand is unlikely to adversely affect the fitness of wild stocks in the future.

Mussel selective breeding hatcheries are under development, if these change the genetic makeup of the spat relative to wild populations then this present low risk may need to be reassessed. Such an assessment should include factors such as dispersal range of gametes, reproductive state of farmed animals and distance from the farm to a viable habitat.

8.3 Lower trophic level species

Table 8.5: Competition for resources due to escapees from lower trophic level aquaculture.

Description of effect(s)	Competition for resources with wild fish and related ecosystem effects from escapee fish, alteration of the genetic structure of wild fish populations by escapee fish.
Scale	Site specific but potentially *long-term* in duration.
Management options	In the case of *Undaria*, limiting farming areas.

* Italicised text in this table is defined in chapter 1 – Introduction.

The effects of lower trophic level species as broadcast spawners and transmission of diseases to wild populations is considered in the under biosecurity chapter as these effects are not related to organisms escaping.

Undaria pinnatifida (*Undaria*) is an introduced seaweed. It has been classified as an unwanted organism under the Biosecurity Act 1995. However, farmers are now able to apply for permits to culture *Undaria* in areas where it is already established. This seaweed remains attached to the substrate throughout its adult life and is not motile. Escapee effects are therefore absent. There are, however still concerns over the spread of spores of this species which reproduces via broadcast spawning. These concerns limit where *Undaria* is allowed to be cultured in relation to its perceived current infestation level.

Genetic risks from other candidate species will need to be assessed on a case-by-case basis.

References

Bjørn, P.A.; Finstad, B. (2002). Salmon lice, *Lepeophtheirus salmonis* (Krøyer), infestation in sympatric populations of Arctic char, *Salvelinus alpinus* (L.), and sea trout, *Salmo trutta* (L.), in areas near and distant from salmon farms. *ICES Journal of Marine Science 59*: 131–139.

Blaylock, R.B.; Whelan, D.S. (2004). Fish health management for offshore aquaculture in the Gulf of Mexico. In: *Efforts to develop a responsible offshore aquaculture industry in the Gulf of Mexico: A compendium of offshore aquaculture consortium research,* pp. 129–161. Bridger, C.J. (ed.). Mississippi–Alabama Sea Grant Consortium, Ocean Springs, Mississippi, United States of America.

Costello, M.J. (2009). How sea lice from salmon farms may cause wild salmonid declines in Europe and North America and be a threat to fishes elsewhere. *Proceedings of the Royal Society B: Biological Sciences 276*: 3385–3394.

Coutts, A.D.M.; Taylor, M.D. (2004). A preliminary investigation of biosecurity risks associated with biofouling of merchant vessels in New Zealand. *New Zealand Journal of Marine and Freshwater Research 38:* 215–229.

Cranfield, H.J.; Gordon, D.P.; Willan, R.C.; Marshall, B.A.; Battershill, C.N.; Francis, M.P.; Nelson, W.A.; Glasby, C.J.; Read, G.B. (1998). *Adventive marine species in New Zealand.* NIWA Technical Report 34.

Cross, T.F. (2000). Genetic implications of translocation and stocking of fish species, with particular reference to Western Australia. *Aquaculture Research 31*: 83–94.

Davey, N.K.; James, P.J.; Moss, G.A.; Woods, C.M.C.; Stenton-Dozey, J. (2011a). Evaluation of tagging techniques for the sea cucumber *Australostichopus mollis* for short term laboratory and field studies. Draft internal NIWA report. (Unpublished report held by NIWA).

Davey, N.K.; Woods, C.M.C.; Stenton-Dozey, J.; Unwin, M. (2011b). Movement and residency of transplanted sea cucumbers, *Australostichopus mollis* under Greenshell (*Perna canaliculus*) mussel farms. Draft internal NIWA report. (Unpublished report held by NIWA).

Deans, N.; Unwin, M.; Rodway, M. (2004). Sports fishery management. In: *Freshwaters of New Zealand*, chapter 41. Harding, J.; Mosley, P.; Pearson, C.; Sorrell, B. (eds.). New Zealand Hydrological Society, Wellington, New Zealand.

Dempster, T.; Sanchez-Jerez, P. (2008). Aquaculture and coastal space management in Europe: An ecological perspective. In: *Aquaculture in the ecosystem,* pp. 87–116. Homer, M.; Black, K.; Duarte, C.M;. Marba, N.; Karakassis, I. (eds.). Springer Science

Diggles, B.K.; Hine, P.M.; Handley, S.; Boustead, N.C. (2002). *A handbook of diseases of importance to aquaculture in New Zealand*. NIWA Science and Technology Series 49.

Einum, S.; Fleming, I.A. (1997). Genetic divergence and interactions in the wild among native, farmed and hybrid Atlantic salmon. *Journal of Fish Biology 50*: 634–651.

FAO (2011). *The State of World Fisheries and Aquaculture 2010.* Fisheries and Aquaculture Department, Food and Agriculture Organization, Rome, Italy.

Ferguson, A.; Fleming, I.; Hindar, K.; Skaala, Ø.; McGinnity, P.; Cross, T.F.; Prodöhl, P. (2007). Farm escapes. In: *The Atlantic salmon: Genetics, conservation and management*, pp 357–398. Verspoor, E.; Stradmeyer, L.; Nielsen, J.L. (eds.). Blackwell Publishing, Oxford, United Kingdom.

Fleming, I.A.; Jonsson, B.; Gross, M.R.; Lamberg, A. (1996). An experimental study of the reproductive behaviour and success of farmed and wild Atlantic salmon (*Salmo salar*). *Journal of Applied Ecology 33*: 893–905.

Fleming, I.A.; Hindar, K.; Mjølnerød, I.B.; Jonsson, B.; Balstad, T.; Lamberg, A. (2000). Lifetime success and interactions of farm salmon invading a native population. *Proceedings: Biological Sciences 267*: 1517–1523.

Forrest, B.M.; Keeley, N.; Gillespie, P.; Hopkins, G.; Knight, B.; Govier, D. (2007). *Review of the ecological effects of marine finfish aquaculture: Final report*. Prepared for Ministry of Fisheries. Cawthron Report 1285. Cawthron Institute, Nelson, New Zealand.

Gillanders, B.M.; Ferrell, D.J.; Andrew, N.L. (2001). Estimates of movement and life-history parameters of yellowtail kingfish (*Seriola lalandi*): How useful are data from a cooperative tagging programme. *Marine and Freshwater Research 52*: 179–192.

Glover, K.A. (2010). Forensic identification of fish farm escapees: The Norwegian experience *Aquaculture Environment Interactions 1(1)*: 1–10.

Habicht, C.; Seeb, J.E.; Gates, R.B.; Brock, I.R.; Olito, C.A. (1994). Triploid coho salmon outperform diploid and triploid hybrids between coho Salmon and Chinook salmon during their first year. *Canadian Journal of Fisheries and Aquatic Sciences 51*: 31–37.

Haswell, W.A. (1903). On two remarkable sporocysts occurring in *Mytilus latus*, on the coast of New Zealand. *Proceedings of the Linnean Society of New South Wales 27*: 497–515.

Hayward, B. (1997). Introduced marine organisms in New Zealand and their impact in the Waitemata Harbour, Auckland. *Tane 36*: 197–223.

Heuch, P.A.; Mo, T.A. (2001). A model of salmon louse production in Norway: Effects of increasing salmon production and public management measures. *Diseases in Aquatic Organisms 45*: 145–152.

Hickmann, R.W. (1978). Incidence of a pea crab and a trematode in cultivated and natural greenlipped mussels. *New Zealand Journal of Marine and Freshwater Research 12*: 211–215.

Hilliard, R. (2004). *Best practice for the management of introduced marine pests: A review.* Global Invasive Species Programme, GISP Secretariat, Cape Town, South Africa.

Hindar, K.; Diserud, O. (2007). Vulnerability analysis of wild salmon populations towards escaped farm salmon. *Norwegian Institute of Natural Resources Report 244*: 1–45 (in Norwegian with English summary).

Hine, P.M.; Jones, J.B.; Diggles, B.K. (2000). *A checklist of parasites of New Zealand fishes, including previously unpublished records.* NIWA Technical Report 75.

Hislop, J.R.G.; Webb, J.H. (1992). Escaped farmed Atlantic salmon (*Salmo salar*) feeding in Scottish coastal waters. *Aquaculture and Fisheries Management 23*: 721–723.

Jacobsen, J.A.; Hansen, L.P. (2001). Feeding habits of wild and escaped farmed Atlantic salmon, *Salmo salar* L., in the Northeast Atlantic. *ICES Journal of Marine Science 58*: 916–933.

Jensen, Ø.; Dempster, T.; Thorstad, E.; Uglem, I.; Fredheim, A. (2010). Escapes of fish from Norwegian sea-cage aquaculture: Causes, consequences and methods to prevent escape. *Aquaculture and Environmental Interactions 1*: 71–83.

Jones, J.B. (1975). Studies on animals closely associated with some New Zealand marine shellfish. PhD thesis, Victoria University of Wellington, Wellington, New Zealand.

Jonsson, B.; Jonsson, N. (2004). Factors affecting marine production of Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Science 61*: 2369–2383.

Jonsson, B.; Jonsson, N. (2006). Cultured Atlantic salmon in nature: A review of their ecology and interaction with wild fish. *ICES Journal of Marine Science 63*: 1162–1181.

Keeley, N.; Forrest, B.; Hopkins, G.; Gillespie, P.; Knight, B.; Webb, S.; Clement, D.; Gardener, J. (2009). *Sustainable aquaculture in New Zealand: Review of the ecological effects of farming shellfish and other non-finfish species*. Prepared for Ministry of Fisheries. Cawthron Report 1476. Cawthron Institute, Nelson, New Zealand.

Krkošek, M.; Ford, J.S.; Morton, A.; Lele, S.; Myers, R.A.; Lewis, M.A. (2007). Declining wild salmon populations in relation to parasites from farm salmon. *Science 318*: 1772–1775.

Manter, R.H.W. (1954). Some digenetic trematodes from the fishes of New Zealand. *Transactions of the Royal Society of New Zealand 82*: 475–568.

McGinnity, P.; Prodohl, P.; Ferguson, K.; Hynes, R.; Maoiléidigh, N.O.; Baker, N.; Cotter, D.; O'Hea, B.; Cooke, D.; Rogan, G.; Taggart, J.; Cross, T. (2003). Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings: Biological sciences 270*: 2443–2450.

McGinnity, P.; Stone, C.; Taggart, J.B.; Cooke, D.; Cotter, D.; Hynes, R.; McCamley, C.; Cross, T.; Ferguson, A. (1997). Genetic impact of escaped farmed Atlantic salmon (*Salmo salar* L.) on native populations: Use of DNA profiling to assess freshwater performance of wild, farmed, and hybrid progeny in a natural river environment. *ICES Journal of Marine Science 54*: 998–1008.

Naylor, R.; Hindar, K.; Fleming, I.A.; Goldburg, R.; Williams, S.; Volpe, J.; Whoriskey, F.; Eagle, J.; Kelso, D.; Mangel, M. (2005). Fugitive salmon: Assessing the risks of escaped fish from net-pen aquaculture. *Bioscience 55*: 427–437.

Nugroho, E.; Ferrell, D.J.; Smith, P.; Taniguchi, N. (2001). Genetic divergence of kingfish from Japan, Australia and New Zealand inferred by microsatellite DNA and mitochondrial DNA control region markers. *Fisheries Science 67*: 843–850.

Paul, L. (2002). Can existing data describe the stock structure of the two New Zealand groper species, hapuku *(Poliprion oxygeneios)* and bass *(P. americanus)*? New Zealand Fisheries Assessment Report 2002/14. Ministry of Fisheries, Wellington, New Zealand.

Pearson, T.H.; Black, K.D. (2001). The environmental impact of marine fish cage culture. In: *Environmental impacts of* *aquaculture,* pp. 1–31. Black, K.D. (ed.). Academic Press, Sheffield, United Kingdom.

Ruiz, G.M.; Rawlings, T.K.; Dobbs, F.C.; Drake, L.A.; Mullady, T.; Huq, A.; Colwell, R.R. (2000). Global spread of microorganisms by ships. *Nature 408*: 49–50.

Skilbrei, O.; Wennevik, V. (2006). Survival and growth of sea-ranched Atlantic salmon, *Salmo salar* L., treated against sea lice before release. *ICES Journal of Marine Science 63*: 1317–1325.

Slater, M.J.; Carton, A.G. (2007). Survivorship and growth of the sea cucumber *Australostichopus* (*Stichopus*) *mollis* (Hutton 1872) in polyculture trials with green-lipped mussel farms. *Aquaculture 272*: 389–398.

Thorstad, E.B.; Fleming, I.A.; McGinnity, P.; Soto, D.; Wennevik, V.; Whoriskey, F. (2008). Incidence and impacts of escaped farmed Atlantic salmon *Salmo salar* in nature. *Norwegian Institute of Natural Resources Special Report 36*: 1–110.

Wallace, I.S.; Gregory, A.; Murray, A.G.; Munro, E.S.; Raynard, R.S. (2008). Distribution of infectious pancreatic necrosis virus (IPNV) in wild marine fish from Scottish waters with respect to clinically infected aquaculture sites producing Atlantic salmon, *Salmo salar* L. *Journal of Fish Diseases 31*: 177–86.

Youngson, A.F.; Dosdat, A.; Saroglia, M.; Jordan, W.C. (2001). Genetic interactions between marine finfish species in European aquaculture and wild conspecifics. *Journal of Applied Ichthyology 17*: 153–162.