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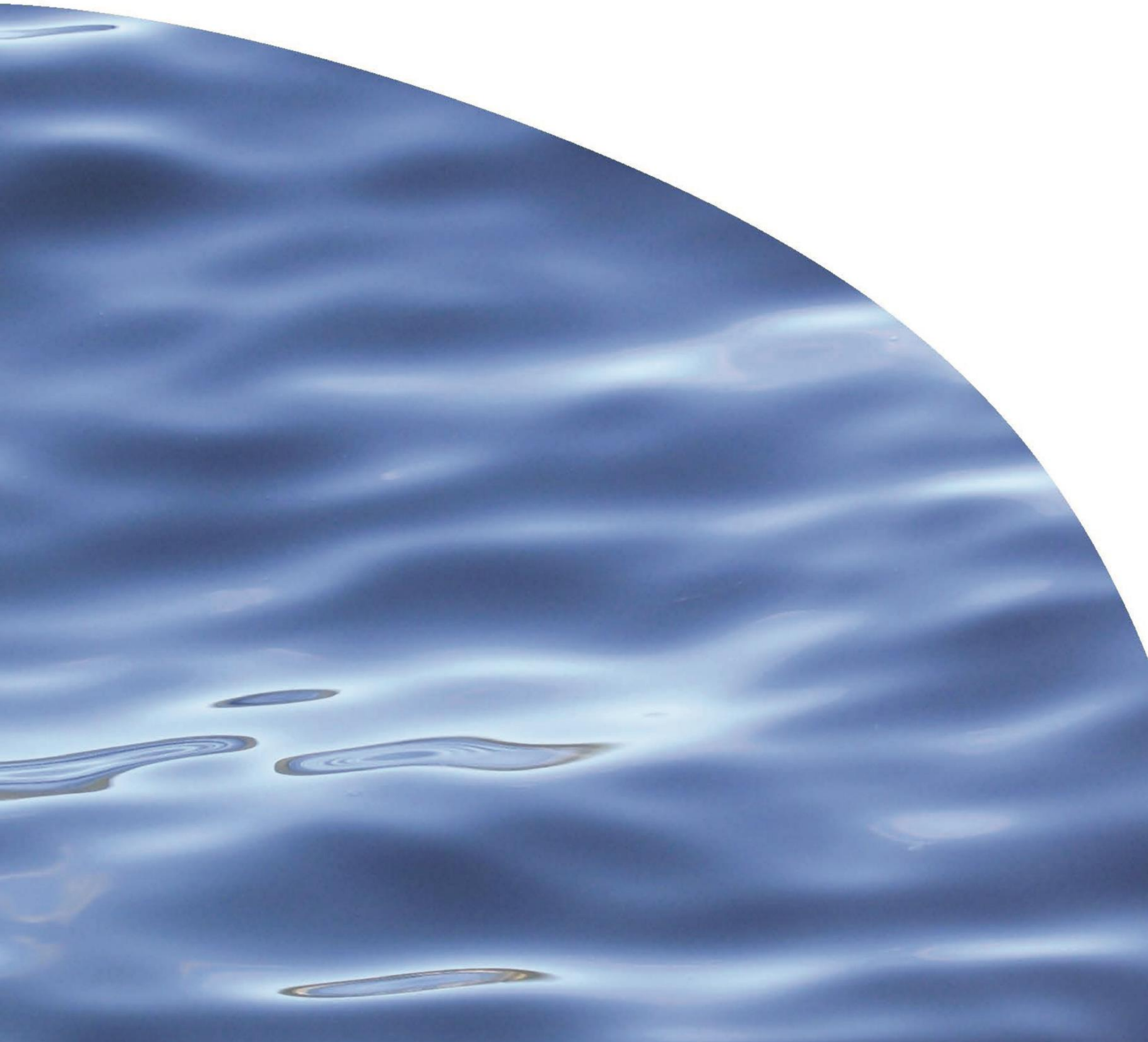
GROUPING AQUACULTURE SPECIES BY THEIR ECOLOGICAL EFFECTS



GROUPING AQUACULTURE SPECIES BY THEIR ECOLOGICAL EFFECTS

BARRIE FORREST, GRANT HOPKINS

Prepared for Ministry for Primary Industries

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
David Taylor

APPROVED FOR RELEASE BY:
Chris Cornelisen

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EXECUTIVE SUMMARY

Background

A 'National Direction for Aquaculture Reference Group' (Reference Group) has been established to provide expert advice and recommendations with respect to rules that will make it more straightforward for the aquaculture industry to innovate. Of particular interest is the scope to develop rules to enable aquaculture species to be more easily changed at existing marine farm sites (i.e. sites already consented for particular species) in situations where the conversion leads to effects that are of similar or lesser significance.

To assist with the development of such rules, the Ministry for Primary Industries (MPI) engaged Cawthron Institute to undertake an analysis and to recommend how aquaculture species might be grouped according to similarities in terms of their potential ecological impacts. For that purpose, this report is a high-level assessment that is expected to provide a platform for further discussion and stakeholder consultation. The report builds on a preliminary assessment conducted in 2016. In addition to the ecological assessment, the Reference Group asked Cawthron to provide a preliminary illustration of how the assessment method might be applied to the broader (i.e. non-ecological) environmental impacts associated with marine aquaculture (e.g. effects on fishing, recreation, navigation).

The focus of the assessment is the sea-based grow-out stage of aquaculture production, and the effects that arise from particular species, farming methods and related operations such as vessel movements. The assessment considered 13 actual or potential aquaculture species and identified five categories of farming method. As two of the candidate species each required assessment of two different methods, 15 different 'species-method' categories were assessed in total.

Species-method groups based on potential ecological effects

Based on existing reviews, we identified 27 main types of potential ecological impact from aquaculture. For each type, we qualitatively scored the relative scale of impact across the 15 different species-method categories. Where relevant, we also considered how effects might change in a relative sense if converting from one of the two main types of existing aquaculture (subtidal Greenshell™ mussels, GSM; intertidal Pacific oysters) to a different species-method. A matrix approach was used to visualise relative differences in ecological effects and to convey our level of confidence in the assessment. Multivariate analysis was used to identify species-method categories that were similar in terms of their effects scores. The overall findings of the assessment were that, except for variation in relation to certain mechanisms, impacts arising from feed-added finfish aquaculture were generally expected to be greater than for all other aquaculture types, whereas on-ground culture (i.e. directly on the seabed) was expected to have the lowest relative impacts.

From the 15 candidate species-methods, we recommend adopting seven 'groups' (i.e. four true groups and three discrete species-methods) as indicated in the Summary Table below.

Summary Table. Recommended groupings of aquaculture species-methods based on potential ecological effects. Indicated are within-group differences or uncertainties requiring specific consideration, and effects that may increase when converting from an existing Greenshell™ mussel (GSM) farm. In all instances, further investigation and assessment is recommended where effects are highly uncertain, where aquaculture methods differ to those on which this report was based, or where sites have special values for which a more in-depth analysis may be warranted.

Group	Candidate species	Within-group differences for specific consideration*	Effects that may be greater if converting from GSM
Caged finfish	All	• Biosecurity and genetic considerations • Escapee effects of salmonids	• Many - see Table 4 in the main report
Floating subtidal invertebrates	Mussels Pacific oysters Flat oysters Pāua Sponges	• Biosecurity and genetic considerations • Whether and to what extent plankton depletion occurs • Relevance and/or intensity of crop/shell accumulation • Escapee effects of Pacific oysters • Uncertainty of benthic effects of pāua culture and effects of additives (if artificial feed pellets used)	• Escapee effects of Pacific oysters • Benthic effects from pāua, and effects of additives (if artificial feed pellets used)
Floating subtidal macroalgae	All	• Biosecurity and genetic considerations • Escapee effects of *Undaria*	• Shading • Marine mammal entanglement • Escapee effects of *Undaria*
Elevated intertidal Pacific oysters	Pacific oysters	• Biosecurity and genetic considerations • Escapee effects	• Not applicable
Elevated subtidal shellfish	Toheroa Geoduck	• Biosecurity and genetic considerations	• Physical disturbance • Sediment accretion/erosion • Shading • Effects of additives (if treated timber used)
On-ground geoduck	Geoduck	• Biosecurity and genetic considerations	• Physical disturbance
On-ground sea cucumber	Sea cucumber	• Biosecurity and genetic considerations	• Physical disturbance • Benthic effects and additives (if method is feed-added)

* For all species-groups, genetic considerations are not regarded as relevant for non-indigenous species.

Where there are species-method differences within groups that need to be accounted for, they are indicated in the Summary Table, along with specific matters that should be considered if converting an existing GSM farm to a new subtidal species-method (i.e. on the basis that the capacity to have an impact could be greater). For most groups and species, this consideration is minor. However, for conversion to finfish, a range of impacts need to be considered.

The space occupied by existing intertidal Pacific oyster farms is unlikely to be suitable for most of the candidate species assessed in this report. The main exception is the possibility that seaward areas of existing oyster farms might overlap with habitat suitable for on-ground geoduck culture, and perhaps elevated subtidal shellfish. In all of these instances we judged intertidal Pacific oyster farms as having a similar or greater relative impact to these other species. However, as there was a high degree of uncertainty with some of the estimates for the emerging species, this general conclusion should be treated with caution.

Further considerations

The ecological assessment was high-level, and did not account for the many factors that influence the sensitivity and significance of impacts from a given type of aquaculture in a particular location. Additionally, the approach was based on a subjective assessment using a relatively crude scoring approach. Even when effects were scored as being the same, it is more the case that they are of a similar order; there will always be variation in actual or potential severity among different species or farming methods. It is also evident that there are many uncertainties regarding effects, especially in the case of new or emerging species for which aquaculture methods are still at an experimental stage. It is important that the various uncertainties are addressed as different species or methods move closer to commercial operations, and the report discusses some ways to achieve this. As the evaluation of broader impacts (i.e. non-ecological) was not the focus of the report, we provide this additional assessment as a separate appendix. Based on a preliminary analysis, we consider that the ecological assessment methodology provides a valid approach for considering these broader issues, provided the appropriate subject matter experts are involved with any assessment that is undertaken.

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1. INTRODUCTION

1.1. Background

The Natural Resource Sector Business Growth Agenda ministers have agreed to develop ‘national direction’ for aquaculture under the RMA. The overall objective is to improve national consistency in the resource management regime for aquaculture (particularly with regard to the management of existing aquaculture), which will ensure councils and industry manage aquaculture better and more consistently across the country, while supporting better environmental outcomes and community confidence in the industry. A ‘National Direction for Aquaculture Reference Group’ (with members from local government, the aquaculture industry, iwi and environmental non-government organisations) has been established to provide expert advice and recommendations.

One of the considerations is whether to include rules that will make it more straightforward for the industry to innovate. Of particular interest is the scope to develop rules to enable aquaculture species to be more easily changed at existing marine farm sites (i.e. sites already consented for particular species) in situations where the conversion leads to effects that are of similar or lesser significance. To assist with the development of these rules the Ministry for Primary Industries (MPI) engaged Cawthron Institute (Cawthron) to undertake an analysis and recommend groupings of species according to their potential impacts. This report builds on a preliminary assessment conducted in 2016 (Forrest & Hopkins 2016), and takes into account feedback on that initial work, which was provided by some of the Reference Group participants as well as an international expert.

1.2. Scope of this report

We describe a high-level assessment that is expected to provide a platform for further discussion and stakeholder consultation. In the main body of the report we describe an approach for grouping aquaculture species or methods according to broad similarities in their potential ecological effects. The focus of the assessment is the sea-based grow-out stage of aquaculture production, and the effects that arise from particular species, farming methods and related operations (e.g. vessel movements). Within this context we undertake the following:

- describe current and potential aquaculture species and farming methods
- undertake an analysis of groupings of species/methods that could be broadly considered ‘interchangeable’ according to their ecological effects
- provide recommendations for groupings that can be used as a basis for drafting rules and for consultation with stakeholders.

Our approach was to consider, in a relative sense, whether effects may increase or decrease when converting from one type of aquaculture to another at a given location. From this assessment, it is possible to identify particular ecological effects, if any, that should be specifically considered when changing aquaculture species. As such, this report ***does not provide an aquaculture risk assessment*** (i.e. a systematic evaluation of the likelihoods and consequences of specific adverse effects) nor make judgements about whether effects are likely to be acceptable. These matters are inherently situation-specific as, among other things, they need to consider the ecological values at risk for a given marine farm location.

In addition to the ecological assessment, the Reference Group asked us to provide a preliminary illustration of how the assessment methodology might be applied to the broader (i.e. non-ecological) environmental impacts associated with marine aquaculture (e.g. effects on fishing, recreation, navigation). For this purpose we have provided supplementary information in Appendix 1, but do not discuss these broader matters in the main body of the report.

1.3. Matters out of scope

By agreement with MPI, the following matters were deemed to be out of scope, but would be a consideration for any new aquaculture development:

Situation-specific assessment: We recognise that the impact of a given type of aquaculture is related to factors such as a site's values and sensitivities, farm attributes (e.g. spatial extent, stocking density/intensity) and biophysical factors (e.g. water depth, flushing characteristics). Our assumption is that, for a given location, these factors have been considered through the regulatory process, and the existing aquaculture operation deemed acceptable. Thus our approach is to consider how potential ecological effects may change (in a relative sense) with an associated change in aquaculture that involves conversion to a new species (which may also involve adoption of a different farming method).

Implications of a local or regional change in the aquaculture species 'mix': We make no assessment of the implications of farming a different mix of species in a given geographic location: for example, a location that may presently be dominated by one type of aquaculture (e.g. GSM). The prospect of having a range of culture species in a given location (e.g. farm, bay or region) gives rise to a range of new considerations relating to additive or synergistic effects (both negative and positive) as well as other interactions, which are beyond our present scope to consider.

Impact of supplying juveniles: For many species, the supply of juveniles used to stock grow-out farms comes from land-based hatcheries. The current exceptions are GSM and Pacific oyster culture where sea-based aquaculture structures may be put in place for 'spat-catching' (e.g. mussel spat ropes, oyster sticks) or for on-growing of seed-stock prior to the final crop production stage. Sea-based shellfish spat-catching or seed on-growing impacts are not explicitly considered, with the exception of certain issues that require situation-specific consideration (e.g. biosecurity and genetic issues arising from inter-regional spat/seed transfer). For other issues, it is assumed that effects will typically be of comparable or lesser magnitude to those arising from grow-out (MPI 2013). An exception recognised in a review by MPI (2013) was the potential for shellfish spat-catching lines to have a greater entanglement risk than grow-out lines, for certain marine mammal species[1].

Marine farm effects that occur away from the aquaculture site: The assessment does not consider issues from marine farm development that occur beyond the environs of the cultivation site (e.g. development of infrastructure such as jetties or rock walls along coastal margins, impacts from processing factory wastewater discharge).

Cumulative effects: We take no account of carrying capacity issues or the potential for far-field effects or cumulative effects (i.e. of a specific marine farm with aquaculture and other activities).

Other matters: The Reference Group is considering whether there is a way to enable changing use of technology on existing farms (e.g. change to artificial lighting, structures), not just a change in species. Technology-driven changes are not considered here, except to the extent that for some of the emerging culture species the consideration of potential new farming methods is an intrinsic aspect.

[1] Spat lines may be under less tension than grow-out lines, hence present a greater entanglement risk (MPI 2013).

2. GENERAL APPROACH

2.1. Information sources

The project draws almost exclusively on existing reviews of the ecological impacts of aquaculture in New Zealand, in particular an overview by MPI (2013). The MPI overview was a synthesis of technical reviews of the ecological effects of aquaculture by subject matter experts (e.g. benthic effects, marine mammals) from Cawthron and the National Institute of Water and Atmospheric Research (NIWA). These reviews are available online[2], and themselves drew in part on earlier reviews conducted for particular species or groups (Forrest et al. 2007; Forrest et al. 2009; Keeley et al. 2009). For some emerging aquaculture species, or issues that are poorly understood, limited information was available, hence we have identified areas of uncertainty for which further investigation or assessment may be needed.

The MPI (2013) overview report and related literature reviews summarise the potential ecological effects of different types of aquaculture, discuss the magnitude and significance of those effects, consider management and mitigation options, and describe key knowledge gaps. As such, the present report does not delve into these matters in any depth. We consider the existing information only to the extent necessary to understand the ways in which the potential ecological effects of aquaculture may change at a given location as a result of a different species being farmed to those already grown (e.g. conversion of an existing GSM farm to a finfish farm). To our knowledge, no studies have previously undertaken this type of comparison. However, several Cawthron studies on the aquaculture of non-finfish species (or potential species) provide comparative information on potential effects that has informed our assessment, especially in relation to water column and benthic issues (Gibbs et al. 2006; Keeley et al. 2009; Taylor et al. 2010).

2.2. Species and farming methods considered

Bearing in mind the situation-specific factors that alter the nature and extent of effects (see Section 1.3), our approach considers how potential effects may change for a given farm location at a 'typical' stocking density for a given species. In this situation, the primary drivers that affect actual and potential impacts are the species cultivated and/or the farming method used. Accordingly, we assess a range of combinations of species (or groups) and farming methods, hereafter referred to using the term 'species-method(s)'. The candidate species initially considered are listed in Table 1, along with their Latin names, feeding type (e.g. filter-feeder, feed-added), geographic status (i.e. whether native or non-indigenous) and actual or potential farming methods.

[2] MPI literature review documents can be found at: www.fish.govt.nz/ennz/Commercial/Aquaculture/Marinebased+Aquaculture/Aquaculture+Ecological+Guidance.htm

Table 1. Species and groups at varying levels of aquaculture development in New Zealand. From this list, 13 species or groups were defined for further evaluation, along with five farming methods. GSM = Greenshell™ mussel, NIS = non-indigenous species. Farming methods were categorised as ‘actual’ (A) where the same or a very similar species is commercially farmed by that method in New Zealand or overseas, or ‘potential’ (P) where the actual method in a New Zealand context is still uncertain (and the method is not necessarily in use overseas). See text and Box 1 for details.

Species	Scientific name	General group	Feeding type	Geographic status	Actual (A) or potential (P) method(s)
Current species					
Chinook salmon	*Oncorhynchus tshawytscha*	Finfish	Feed-added	NIS	Floating subtidal cages (A)
GSM	*Perna canaliculus*	Bivalve	Filter-feeder	Native	Floating subtidal lines (A)
Pacific oysters	*CrassoStrea gigas*	Bivalve	Filter-feeder	NIS	Elevated intertidal racks or floating subtidal lines (A)
Flat oysters	*Ostrea chilensis*	Bivalve	Filter-feeder	Native	Floating subtidal lines (A)
Paua (abalone)	*Haliotis iris*	Gastropod	Feed-added	Native	Floating subtidal lines (A)
Species with short-term potential (< 5 years)					
Yellowtail kingfish	*Seriola lalandi*	Finfish	Feed-added	Native	Floating subtidal cages (A)
Hapuku	*Polyprion oxygeneios*	Finfish	Feed-added	Native	Floating subtidal cages (A)
Snapper	*Pagrus auratus*	Finfish	Feed-added	Native	Floating subtidal cages (A)
Sea cucumbers	*Australostichopus mollis*	Echinoderm	Deposit feeder[b]	Native	On-ground subtidal (P)
Asian kelp	*Undaria pinnatifida*	Macroalgae	Primary producer	NIS	Floating subtidal lines (A)
Geoduck	*Panopea zelandica*	Bivalve	Filter-feeder	Native	On-ground or elevated subtidal (P)
Species with longer-term potential (< 5 years)					
Other finfish[c]	Various species	Finfish	Feed-added	Native (except trout)	Floating subtidal cages (A)
Scallops	*Pecten novaezelandiae*	Bivalve	Filter-feeder	Native	Floating subtidal lines (A)
Toheroa	*Paphies ventricosa*	Bivalve	Filter-feeder	Native	Elevated subtidal (P)
Other macroalgae	Various species	Macroalgae	Primary producer	Unknown	Floating subtidal lines (A)
Sponges	Various species	Sponge	Filter-feeder	Unknown	Floating subtidal lines (P)

[a] Commercial operations for flat oysters and paua are small

[b] It is possible that sea cucumber culture could be feed-added, but for present purposes we assume that it is not

[c] Finfish species with longer-term potential include butterfish (*Odax* spp.), blue cod (*Parapercis colias*) and trout (*Salmo* spp.)

The selection of species was determined initially from those listed by MPI (2013) as being current aquaculture species or likely candidates with 'short-term' potential. Species with short-term potential were defined by MPI as being those species with potential for commercial-scale production within 5 years; we use this same definition. In addition to the MPI (2013) list we included some other species that are current (i.e. commercially farmed at small-scale presently) or that we considered to have short-term potential. We also included a few species that were considered to have longer-term potential. The latter were simply defined as those with the possibility of commercial-scale farming beyond 5 years, and their selection was based on conversations with aquaculture research scientists and input from MPI. A brief description of the species or groups from Table 1 is given in Box 1.

We initially considered including blue mussels (*Mytilus galloprovincialis*) as there is some interest in commercial cultivation on longlines. However, they were dropped from the formal assessment because, except for species-specific issues described in the main analysis, we considered that their effects would be the same as for GSM. Note that MPI initially asked us to consider three additional species/groups (horse mussels, *Atrina zelandica*; scampi *Metanephrops challengeri*; other crustaceans), but we discarded these on the basis that too little was known about the feasibility of sea-based aquaculture and the likely methods involved.

For the purposes of the assessment, some of the species were aggregated to higher groups, as follows:

- Finfish: In the analysis we distinguish between the non-indigenous salmonid finfish listed in Table 1 (i.e. salmon and trout) and 'other finfish' such as kingfish, hapuku and snapper. The basis for doing so was an initial screening that suggested most effects would be very similar given that culture methods all involve the addition of external feed sources to sea-cage systems. Nonetheless, in our assessment below we highlight where there are particular issues for which species-specific assessment is recommended.
- Macroalgae: Macroalgae, except the Asian kelp *Undaria*, are referred to as 'other macroalgae'. Too little is known about the most likely aquaculture species, and actual or potential effects, to enable a detailed species-based assessment. *Undaria*'s legal status as a non-indigenous 'unwanted organism' under the Biosecurity Act 1993 requires it to be separately considered.
- Sponges: Sponges are designated as a broad group, as the exact species likely to be farmed are unknown. Even if the species were known, too little is understood about actual or potential effects to justify a species-based assessment.

Following aggregation, the initial list from Table 1 and Box 1 was distilled to nine species and four higher groups for further assessment. For these candidate species or groups, we placed farming methods into one of five categories described below (see examples in Figure 1).

Box 1: Summary of current or potential aquaculture species

Current species

Chinook salmon: Salmon are second to GSM in terms of the total current economic value of the sector, although have a higher value on a per hectare basis. Salmon are grown in floating subtidal cages in Marlborough, Banks Peninsula and Stewart Island, and fed on pellets that are high in protein and lipids, and include trace supplements (e.g. vitamins and minerals).

Greenshell™ mussels (GSM): This is New Zealand's main aquaculture species. GSM are cultivated on floating subtidal lines, whereby culture 'longlines' are suspended beneath a floating double 'backbone' line that is anchored to the seabed at each end.

Pacific oysters: This is a non-indigenous species for which there is a long-established industry in northern New Zealand, mainly involving cultivation on elevated intertidal racks made from treated timber. A small-scale recent development involves culture in Marlborough using conventional floating subtidal lines similar to GSM, with the oysters grown in baskets or trays.

Flat oysters: Commercially grown at a small scale, with some holding of wild dredge oysters for fattening. Method uses floating subtidal lines as for GSM, with oysters grown in trays or lantern cages, or suspended from ropes. Marlborough industry is presently being affected by an exotic parasite *Bonamia ostreae*.

Pāua (abalone): Two small sea-based operations for pāua exist. Pāua are typically contained in barrels suspended from conventional floating subtidal lines. Pāua may be fed on macroalgae or feed pellets.

Species with short-term potential (< 5 years)

Yellowtail kingfish, hapuku & snapper: These are promising species for floating subtidal cage culture, for which hatchery methods to rear juveniles have been developed. Kingfish is already in commercial production overseas. Field trials for kingfish and snapper have been undertaken in New Zealand.

Sea cucumber: Not farmed commercially in New Zealand, but experimental trials have been undertaken. Sea cucumbers are deposit-feeders that ingest sediment and digest its organic components. They are likely to be grown on the seabed (on-ground subtidal), and in co-culture situations. There is a possibility of feed-added culture methods being used, as well as limited use of subsurface structures (e.g. cage enclosures).

Asian kelp, *Undaria*: *Undaria* is cultivated overseas, mainly for human consumption as 'Wakame'. In New Zealand it is non-indigenous with a legal status as an unwanted organism. MPI has identified a few locations where *Undaria* is well established and where permits for aquaculture can be applied for. Likely method would be floating subtidal lines.

Geoduck: High-value bivalve at field-trial stage. On-ground (in PVC pipes) and elevated (near-seabed) methods are being tested. On-ground methods would likely be shallow subtidal (wadeable depths), and may require predator exclusion cages/nets. Elevated methods would likely be used deeper in the subtidal zone.

Species with longer-term potential (> 5 years)

Other finfish: Blue cod, butterfish and trout are being considered. Presumably these species would be commercially grown in floating subtidal cages.

Scallops and toheroa: These species are both regarded as having aquaculture potential. While scallops will likely be grown in floating subtidal line systems, toheroa are more likely to be grown using elevated subtidal culture methods.

Other macroalgae: Exact species unknown, and will depend on technological developments and demand.

Sponges: There is interest in growing sponges for pharmaceuticals, with cultivation likely to involve floating subtidal line methods (with sponges grown in vertical or horizontal orientation, depending on species).

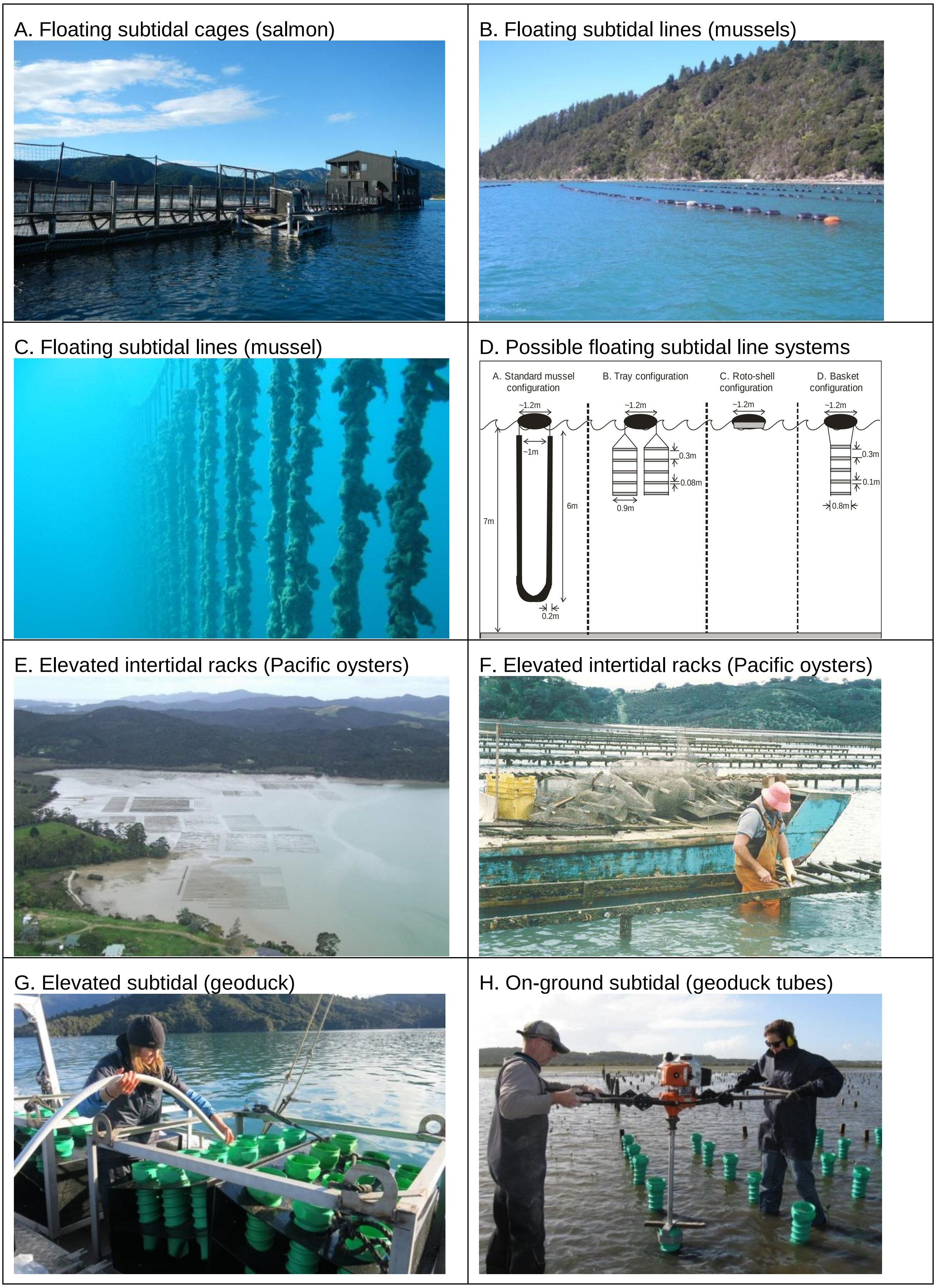

Figure 1. Examples of different types of actual (A-F) or experimental (G, H) aquaculture in New Zealand. The schematic shown in D (from Gibbs et al. 2006) may not accurately depict the current or future situation (see footnote on next page). The geoduck tubes shown in G are flush with the sediment surface when fully deployed.

The five farming methods were categorised as follows:

- **Floating subtidal cages:** refers to methods comparable to salmon farms, in which flexible mesh cages are suspended beneath square or circular floating pontoons. Associated with the cages is floating farm infrastructure such as accommodation and feed storage sheds. Farm cages may be surrounded above and below the waterline by marine predator and seabird exclusion nets (Figure 1A).
- **Floating subtidal lines:** refers to methods comparable to GSM farming (Figure 1B; Figure 2), in which floating double backbone lines are arranged in parallel rows with sufficient space between for vessels to operate. Various cultivation methods may be used, but all involve suspending the culture stock in some manner beneath the floating backbone lines; e.g. longlines (Figure 1C), tubs, trays, baskets and 'Rotoshells' (Figure 1D)[3].
- **Elevated intertidal racks:** refers to methods comparable to intertidal Pacific oyster farms in which fixed wooden racks are used to elevate the culture stock about 0.75 m above the substratum. Racks are arranged in parallel rows that allow vessel access between them. Racks are only visible at low tidal states (e.g. neap tide level or lower).
- **Elevated subtidal:** described in Table 1 as a potential method for toheroa and geoduck. The farming method may involve use of subtidal culture trays or bins supported/suspended just off the seabed. Depths may range from very shallow (wadeable) to c. 20 m subtidal.
- **On-ground subtidal:** this method could apply to both geoduck and sea cucumbers. For example, geoduck may be grown in PVC pipes embedded into the substratum in the very shallow subtidal (Heasman et al. 2016). For sea cucumbers, we assume for present purposes that there is no farm infrastructure on the seabed (but see Box 1).

For a given species or group, the above farming methods were categorised in Table 1 as 'actual' (A) where the same or a very similar species is commercially farmed by that method in New Zealand or overseas, or 'potential' (P) where the actual method in a New Zealand context is still uncertain (and the method is not necessarily in use overseas). Our overall analysis consisted of a comparison of potential effects from 15 species-method combinations, reflecting the assessment of 13 species/groups (9 species, 4 higher groups), for which we evaluated two farming methods for two of the species (Pacific oysters and geoduck).

[3] Note that the floating subtidal line schematics depicted in Figure 1D may not accurately represent actual or potential cultivation depths relative to GSM, for new or emerging species. For example, the industry expects that flat oysters could be cultured at depths comparable to GSM.

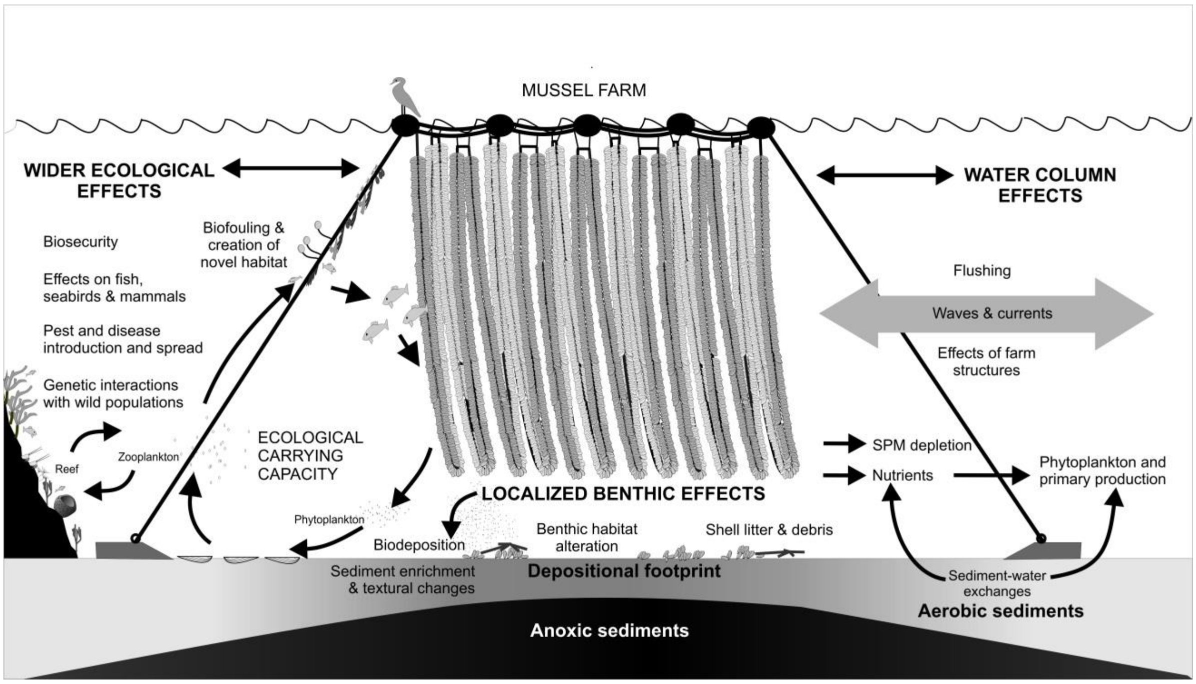

Figure 2. Schematic of a longline GSM farm configuration and associated environmental interactions (source: Keeley et al. 2009). A typical farm of 3-4 ha in size consists of ten floating double backbone lines, each c. 100 m long, which includes many more surface floats than depicted in this diagram (e.g. Figure 1B). SPM = suspended particulate matter.

3. SPECIES-METHOD GROUPINGS BY ECOLOGICAL IMPACTS

3.1. Categorising ecological impacts

The ecological effects considered in the assessment are summarised in Table 2, and indicate the extent to which the impact is ***primarily*** due to the culture species, the farming method, or both of these factors. The choice of main categories (benthic effects, marine mammal interactions, etc.) was based on those described by the MPI (2013) overview. The sub-categories reflect the primary mechanisms of actual or potential impact, which were also derived from the MPI report and its underpinning studies. These sub-categories capture the primary ecological effects that may arise from aquaculture, but do not necessarily reflect every impact conceivable.

Table 2. Ecological effects categories and mechanisms considered in the assessment.

Categories of ecological impact	Potential mechanisms of impact	Primary driver
Water column effects	Filtration, and plankton depletion or altered composition	Species
	Nutrient enrichment & harmful algal blooms	Species
	Dissolved oxygen depletion	Species
Benthic effects	Organic enrichment (biodeposits, waste feed, biofouling drop-off)	Species
	Crop loss or shell accumulation	Species & method
	Physical disturbance	Method
	Increased sedimentation, erosion or accretion	Method
	Shading	Method
Marine mammal interactions	Entanglement	Method
	Habitat exclusion or modification	Species & method
	Attraction (e.g. to fish, farm waste, structure)	Species & method
	Noise and lights	Method
Seabird interactions	Entanglement	Method
	Habitat exclusion or modification	Species & method
	Attraction (e.g. to fish, farm waste, structure)	Species & method
	Noise and lights	Method
Wild fish interactions	Habitat exclusion or modification	Method
	Attraction (e.g. to fish, farm waste, crop, structure)	Species & method
	Noise and lights	Method
Biosecurity	Introduction and spread of pests	Species
	Introduction and spread of disease (pathogens or parasites)	Species
	Status of species farmed (i.e. indigenous or not)	Species
Escapee and genetic effects	Ecological effects of escapees	Species
	Changes to genetic structure/fitness of wild populations	Species
Effects from additives	Use or release of chemicals & therapeutants, including trace metals	Species & method
Hydrodynamic alteration of flows	Impede or alter water currents or water column stratification	Method
	Wave dampening	Method

It should be recognised that the ecological categories in Table 2 are assigned for convenience, but there are interactions and overlaps among some of them (as well as potential for cumulative effects). For example, additives are flagged as a separate category for comparative purposes, to highlight the species for which additive use or release needs to be considered. However, any impact from additives is likely to occur in the water column or in benthic sediments; hence consideration of additive impacts needs to account for this broader picture.

3.2. Method of comparative analysis

3.2.1. Assessment method

We developed a matrix for comparative analysis consisting of 15 columns representing the species-method combinations, and 27 rows representing the ecological effect sub-categories. Hence, the matrix consisted of 390 cells that we populated, in order to enable a comparative analysis of the ***relative*** potential effects of each candidate species-method. The matrix cells were populated by the two report authors, with the underlying rationale provided in Appendix 2. Each cell in the matrix conveys two pieces of information using circles of three sizes and three colours, as described below.

Circle size

Sizes (small, medium, large) are used to express the relative potential impact (low, medium, high relative impact) of each species-method *within* a given row in the matrix (i.e. comparing different species-methods for a given ecological effect). For example, the largest circles represent the species-method scenarios considered to have the greatest relative potential impact. Circles of the same size indicate situations where effects are expected to be similar. In this way, for a given effect the circle sizes simply represent our assessment of the scaling of potential impacts of the species-methods relative to each other. In this respect, there are some important points that need to be recognised:

- In absolute terms circle size is unimportant: a large circle is not intended to imply an impact of a high actual magnitude (even though that may be the case for some effects in certain locations). For example, for a given effect mechanism Y, if species-method 1 has a medium circle and species-method 2 has a large circle, it simply means that species-method 2 has a ***capacity*** for a relatively greater impact on Y than species-method 1 does.
- It follows from the previous point that circle sizes have no comparability among the different effects in terms of the **scale** (e.g. absolute magnitude) of the impact. However, comparisons among effects can nonetheless be undertaken to examine species-methods that group according to similarities or differences in their relative scores.

To illustrate the last point, consider the relative scoring of different species-methods in terms of artificial lights (surface and submerged) in relation to wildlife interactions (i.e. interactions with marine mammals, seabirds, wild fish). Finfish culture is the only species-method for which artificial lighting is widely used. Lighting in other forms of aquaculture is minimal, and consists only of intermittently flashing surface beacons that mark the corners of structures. Accordingly, in our assessment we judged the ***relative*** effects of artificial lighting to be high for finfish culture, since the capacity for an impact is greater than for all other types of aquaculture (see Appendix 2).

This situation means that when changing to finfish culture from another type (e.g. from GSM) the effect of artificial lighting would be a matter for consideration. However, in absolute terms the effect of artificial lighting from a finfish farm may be relatively minor and straightforward to mitigate (Cornelisen & Quarterman 2010; MPI 2013). This situation contrasts with certain other effects from finfish farms that can be significant in absolute terms; e.g. pronounced benthic impacts beneath and adjacent to fish cages. However, irrespective of the scale of the impact in an absolute sense, our assessment approach would assign the same higher relative score for both lighting and benthic effects of finfish farms, on the basis that both matters would need to be addressed when converting to a finfish farm from any of the other types of aquaculture addressed in our assessment.

Circle colour

Colour was used to convey a sense of our confidence in our comparative assessment. The three colours used are interpretable as follows:

●	**Green:** Reflects reasonable confidence with the assessment of relative effects, often (but not always) because there were good descriptions of existing impacts for that same species-method, or for species-methods expected to be functionally similar.
●	**Orange:** Reflects situations where we made an assumption regarding relative effects, but generally lacked concrete information on the actual impacts of a given species or method.
●	**Red:** Reflects an educated guess for which we were highly uncertain, often indicating situations where the species of interest has not yet been cultivated (or not cultivated by the method indicated).

In addition to the circles, two more descriptors are used to code the matrix cells as follows:

- a black dot **(•)** indicates instances where a given effect is either insignificant or not generally relevant to the species-method being considered
- an asterisk **(*)** indicates instances where an impact is inherently situation-specific, hence needs to be assessed case-by-case.

3.2.2. Considerations for addressing 'negative' vs 'positive' effects

It is important to note that we do not distinguish negative impacts from those that could be interpreted as positive. Such an assessment would be complex, highly subjective and involve a high degree of uncertainty. This issue can be exemplified as follows:

- An aquaculture structure may provide habitat that leads to the attraction of wild fish. This could be interpreted as a positive effect. On the other hand, the effect may involve a change in the natural distribution of the fish population, or aggregation could make the fish more susceptible to fishing pressure; these could be considered negative effects.
- A second example is that of the benthic effects of sea cucumber on-ground culture. Being deposit feeders, sea cucumbers may be grown in co-culture situations (e.g. with bivalve and finfish farms) due to their potential to mitigate organic enrichment (Keeley et al. 2009). This is a positive outcome, which means that the enrichment impact of sea cucumber culture may be less than for some other species.

In both of these examples, what matters, and what our evaluation is based on, is the relative effect-size of a given aquaculture species-method; e.g. in the fish attraction example, the relative strength of the attraction, irrespective of whether it is perceived as 'good' or 'bad'.

3.2.3. Approach to determining groupings of species-method

The coded matrix described above provided a visual way to examine groupings of the 15 species-method combinations in terms of their relative ecological effect scores. In order to undertake a semi-quantitative analysis in this respect, we recoded the matrix as follows:

- circles of small, medium and large size were coded 1, 2 and 3, respectively
- dots were replaced with zeroes, on the basis that a dot can be interpreted as meaning no significant/relevant impact
- asterisks were replaced with a dummy value of 0.1 across all relevant species-method categories, in order that they were given equal weighting in the analysis.

The result was a semi-quantitative matrix of relative scores. Using the software Primer v7, a multivariate analysis was undertaken on the matrix to help visualise ways that species-method combinations grouped according to similarities in these scores. Pairwise similarities (i.e. in relative scores) among species-methods were first calculated using the Bray-Curtis similarity index[4]. From the triangular similarity matrix, a non-metric multi-dimensional scaling (MDS) ordination method was used to

[4] Although Bray-Curtis is more commonly used for ecological community data, it was preferred over alternatives in this instance as it provides an intuitive output; e.g. 100% Bray-Curtis similarity of two species-method scenarios means they have identical scores.

visualise the species-method groups in 2-dimensional space. The similarity percentages (SIMPER) procedure was applied to these groups, to determine their within-group similarity, and the ecological effects that distinguished them from other groups. Species-method categories were considered to form a clearly defined group when their within-group Bray-Curtis similarity was ≥ 90% (i.e. we judged a 90% similarity or greater to reflect a 'high' level of similarity).

3.2.4. Scaling of effects relative to Greenshell™ mussel and intertidal Pacific oyster culture

Greenshell™ mussels

On the basis that GSM are by far the dominant aquaculture species in New Zealand (by area farmed and number of farms), any change to a new culture species will most likely be from an existing GSM farm. However, we note that not all GSM farm space will necessarily be suitable for all other species (e.g. a GSM site that is shallow or low-flow may be unsuitable for finfish aquaculture). Bearing in mind these types of constraints, we present the species-method results in a matrix format in which each of the GSM effects is used as the baseline and the positive or negative deviance for other relevant species-method scenarios is scored. For example, if GSM scored 2 for a given effect and finfish score 3, in the GSM matrix the relative effect of finfish is scored as +1 (one rank greater); i.e. this indicates that the potential for a greater impact would need to be considered when converting from GSM to finfish. For illustrative purposes, we simplistically considered the relevant species-method scenarios to be all of those involving subtidal culture that could conceivably occupy water space currently consented for mussel farming. Accordingly, we considered all species-method scenarios except intertidal Pacific oyster culture.

Intertidal Pacific oysters

Theoretically, we could have made the same type of semi-quantitative assessment using intertidal Pacific oyster farms as the baseline, as this is the second most important type of shellfish aquaculture in New Zealand. However, the comparison would be of limited use at this stage in that none of the other species is expected to be farmed in the intertidal *per se*. Notwithstanding this comment, there is perhaps some potential for spatial overlap between the lower (seaward) limits of intertidal Pacific oyster culture and upper limits for elevated subtidal methods. At the seaward limits of intertidal Pacific oyster culture, while the crop is grown in the intertidal zone (i.e. on top of growing racks), the seabed beneath the racks may be in the very shallow subtidal (perhaps exposed for a short period during the largest spring tides). This type of habitat may overlap with suitable locations for species suited to the very shallow subtidal; i.e. in the wadeable depths of the shallow subtidal. The most likely candidate would be geoduck grown in plastic tubes (see Figure 1G), and perhaps (but less likely) geoduck or toheroa grown using elevated methods. As such, although we do not undertake the same matrix-based analysis as for GSM, we provide some general discussion of the relative effects of part-converting intertidal oyster farms to these other species-methods.

3.3. Species-method groupings based on ecological effects

Visually, some of the obvious differences among species-groups are evident in Table 3. The multivariate MDS ordination in Figure 3 helps to more objectively discriminate species-method groupings according to the level of their similarity in their relative scores.

From the initial 15 species-method categories considered in the analysis, the MDS discriminated four groups whose within-group Bray-Curtis similarity exceeded our subjectively defined 'high' similarity threshold of ≥ 90% (see Section 3.2.3). Three other species-methods remained discrete from the four groups and from each other. The low stress value of the MDS (0.03) indicates that a 2-dimensional biplot provides a reliable visual representation of the main groupings.

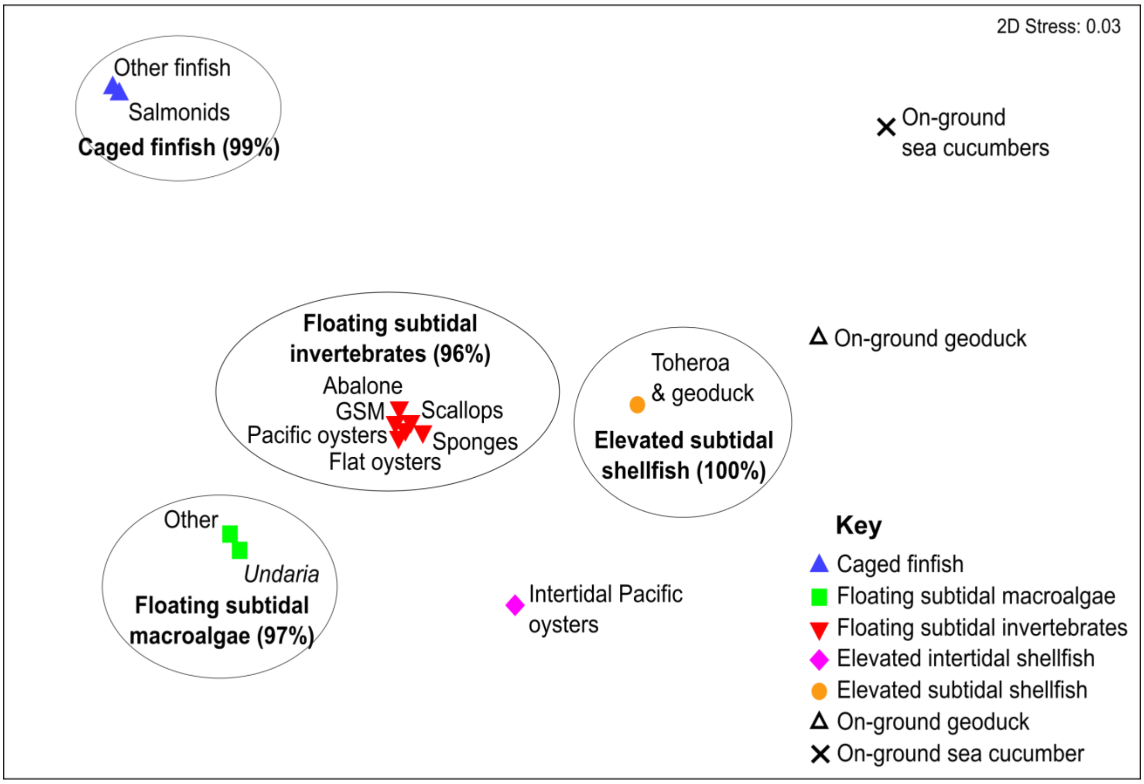

Figure 3. MDS ordination of the 15 aquaculture species-method categories based on levels of similarity in the relative scores derived from Table 3. The within-group Bray-Curtis similarity (%) is shown for each of four similar groups that were identified as exceeding a subjective 90% threshold of 'high' similarity. Three species-method categories were discrete from these groups. Note that the MDS should be interpreted in conjunction with Table 3, and account for uncertainty in the underlying scores, as well as other limitations described in the accompanying text.

Table 3. Comparison of relative scores for each effect category among the different aquaculture species-method combinations. See assessment method, Section 3.2.1 for details.

Category of ecological impact	Potential mechanism	Floating subtidal cages Salmonid finfish	Floating subtidal cages Other finfish	Floating subtidal lines GSM	Floating subtidal lines Pacific oyster	Floating subtidal lines Flat oyster	Floating subtidal lines Scallop	Floating subtidal lines Abalone	Floating subtidal lines Sponges	Floating subtidal lines Asian kelp	Floating subtidal lines Other macroalgae	Elevated intertidal Pacific oyster	Elevated subtidal Toheroa	Elevated subtidal Geoduck	On-ground subtidal Geoduck	On-ground subtidal Sea cucumber
Water column	Filtration and plankton depletion	•	•	large green	large orange	large orange	large orange	•	large red	•	•	medium orange	medium orange	medium orange	medium orange	•
	Nutrient enrichment & HABs	large green	large orange	medium green	medium orange	medium orange	medium orange	medium red	medium red	small orange	small orange	medium orange	medium orange	medium orange	medium orange	medium red
	Dissolved oxygen depletion	large green	large orange	small green	small green	small green	small green	small red	small orange	small orange	small orange	small orange	small orange	small orange	small orange	small red
Benthic	Organic enrichment (biodeposits, waste feed, biofouling drop-off)	large green	large orange	medium green	medium orange	medium orange	medium orange	medium red	medium red	small orange	small orange	medium green	medium orange	medium orange	medium orange	medium red
	Crop loss or shell (from crop) accumulation	•	•	large green	medium orange	medium orange	small orange	small red	small red	small orange	small orange	medium green	small orange	small orange	small orange	•
	Physical disturbance	small green	small green	small green	small green	small green	small green	small green	small green	small green	small green	large green	medium red	medium red	medium red	medium red
	Sedimentation, erosion or accretion	small orange	small orange	small orange	small orange	small orange	small orange	small orange	small orange	small orange	small orange	large green	medium red	medium red	small red	•
	Shading	large orange	large orange	small orange	small orange	small orange	small orange	small orange	small orange	large orange	large orange	medium orange	medium orange	medium orange	•	•
Marine mammals	Entanglement	large green	large green	small green	small green	small green	small orange	small orange	small red	medium red	medium red	small green	small red	small red	•	•
	Habitat exclusion or modification	large orange	large orange	small orange	small orange	small orange	small orange	small red	small red	small red	small red	small orange	small red	small red	•	•
	Attraction (e.g. to fish, farm waste, structure)	large orange	large orange	medium orange	medium orange	medium orange	medium orange	medium red	medium red	medium red	medium red	small orange	small red	small red	small red	small red
	Noise and lights	large green	large green	small green	small green	small green	small orange	small orange	small orange	small orange	small orange	small green	small orange	small orange	small orange	small red
Seabirds	Entanglement	large green	large green	small green	small orange	small orange	small orange	small orange	small red	small red	small red	small orange	small red	small red	•	•
	Habitat exclusion or modification	large orange	large orange	small orange	small orange	small orange	small orange	small red	small red	small red	small red	small orange	small red	small red	•	•
	Attraction (e.g. to fish, farm waste, structure)	large green	large green	large green	large green	large green	large orange	large red	large red	large red	large red	medium orange	small red	small red	small red	small red
	Noise and lights	large green	large green	small green	small green	small green	small orange	small orange	small orange	small orange	small orange	small green	small orange	small orange	small orange	small red
Wild fish	Habitat exclusion or modification	large green	large green	medium green	medium green	medium green	medium orange	medium red	medium red	small red	small red	medium green	medium orange	medium orange	medium orange	medium red
	Attraction (e.g. to fish, farm waste, crop, structure)	large green	large green	large green	medium orange	medium orange	medium orange	medium red	medium red	medium red	medium red	small orange	small red	small red	small red	small red
	Noise and lights	large green	large green	small green	small green	small green	small orange	small orange	small orange	small orange	small orange	small green	small orange	small orange	small orange	small red
Biosecurity	Introduction and spread of pests	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Introduction and spread of disease (pathogens or parasites)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Escapee & genetic	Ecological effects of escapees	large orange	medium orange	small orange	large green	small orange	small orange	small orange	small orange	large green	small orange	large green	small orange	small orange	small orange	small orange
	Changes to genetic structure/fitness of wild populations	•	*	*	•	*	*	*	*	•	*	•	*	*	*	*
Additives	Use or release of chemicals & therapeutants	large green	large green	small green	small green	small green	small green	small red	small orange	small orange	small orange	medium green	medium red	medium red	small orange	small red
Hydrodynamic	Impede or alter water currents or water column stratification	large orange	large orange	medium green	medium orange	medium orange	medium orange	medium orange	medium orange	medium orange	medium orange	medium orange	small orange	small orange	•	•
	Wave dampening	large orange	large orange	large green	large orange	large orange	large orange	large orange	large orange	medium orange	medium orange	medium orange	•	•	•	•

It should be kept in mind that the MDS represents an effort to take complex information on species-method similarities or differences (derived from Table 3, which itself is based on the text in Appendix 2) and represent it in simple summary format. However, in making this simplification some key information is lost or inadequately conveyed, including the following:

- The level of confidence in our assessment that is captured by the colour coding in Table 3 is not conveyed by the MDS, but is important when considering the MDS groupings.
- Biosecurity issues and genetic effects have situation-specific implications that need to be accounted for, and which may alter the perception or ranking of relative impacts. For example, although the Asian kelp *Undaria* groups closely with other macroalgae in Figure 3, the biosecurity implications of *Undaria* aquaculture require situation-specific consideration and set it apart from native algal species.
- When species-groups are assigned the same relative score for a given effect (i.e. for a given row in Table 3, they have the same circle size) it should not be interpreted that the potential effects are the same. It is more the case that these crude scores represent potential effects that can be regarded as being of a similar order relative to other species-groups with a different circle size.
- Following the previous point, the assessment method gives no weighting to the importance of the different types of effects, and therefore how much significance to place on what may appear to be small within-group differences. For example, one of the few discriminating effects in the 'floating subtidal invertebrates' group described in Figure 3 and Table 3 relates to crop/shell accumulation (see next section). Even though this single effect category does not strongly influence the MDS, the occurrence of shell accumulation in shellfish culture represents a significant way that the seabed may be altered, by comparison with sponge culture.

3.4. Consideration of differences within groups

Given that the general groups identified in the MDS could form the basis of aquaculture groupings for regulatory purposes (bearing in mind the limitations and caveats described in the preceding section), it is important to understand the level of within-group similarity and the reasons for differences within each group (or species) with respect to their scores. Such differences need to be taken into account when assessing specific ecological impacts, and form the basis for producing guidance on specific effects that need to be addressed when converting an existing marine farm to a different type of aquaculture.

The SIMPER analysis revealed that salmonid and other (i.e. non-salmonid) categories within the caged finfish group showed c. 99% similarity in their relative effects scores. The only difference related to the ecological effects of escapees, which were scored as more significant for a non-indigenous salmonid than for a native finfish (Appendix 2). In reality this may not be the case if species-specific issues are considered (e.g. predation or disease transmission to wild fish stocks may be a more significant issue for native finfish).

The 'floating subtidal invertebrates' group comprised five shellfish species (four bivalves[5], plus pāua) and sponges, having a within-group similarity of c. 96%. The within-group differences discussed in Appendix 2 reflected:

- Absence of plankton depletion in the case of pāua aquaculture, except what might arise due to filter-feeding by biofouling assemblages. Particular areas of uncertainty not reflected in the MDS include:
  - For sponges, there is high uncertainty regarding depletion and biodeposition effects. For example, sponges appear to have very high filtration rates compared with bivalves, but the level of associated water column effects and seabed biodeposition are unknown (Appendix 2).
  - For pāua, there is high uncertainty regarding benthic effects (Appendix 2). Additionally, the effects of additive may need to be considered in the event that artificial feed pellets are used.
- An expectation of relatively low crop loss and shell accumulation in the case of pāua and scallop culture, and an assumed low loss from sponge culture (with shell loss *per se* not applicable). On the other hand, crop loss and shell accumulation may be relatively high for mussel farms.
- Relatively high ecological significance scored for Pacific oyster escapees, given evidence that wild oysters become abundant in estuaries and harbours where they are farmed.

A very high within-group similarity (97%) was also evident for floating subtidal macroalgae. The only discriminating factor between native macroalgae and *Undaria* was the greater weighting given to *Undaria* escapees. However, note that present areas where *Undaria* aquaculture may be considered by MPI are restricted, and reflect locations where the species is already abundant. In such locations, escapee risk from *Undaria* aquaculture would not necessarily be significant.

In the case of elevated subtidal shellfish group, toheroa and geoduck effects were scored the same in all respects. The similarity of this group with elevated intertidal culture of Pacific oysters was 87%. The 13% dissimilarity reflects that the ecological effects of intertidal Pacific oyster culture were scored relatively high (see Appendix 2) due to:

- Significant crop loss and shell accumulation: this effect is more an issue for stick oyster culture than enclosed methods such as bags/baskets. Although there is

[5] Note that blue mussels can also be considered as part of this group, even though they were excluded from the formal assessment (see Section 2.2).

uncertainty regarding elevated subtidal toheroa and geoduck farming, it is assumed that such effects will be less.

- Relatively high physical disturbance of the seabed, and altered patterns of sediment accretion and erosion: however, note that physical disturbance may also be important for elevated systems in the very shallow subtidal, depending on actual farming methods used.
- Relatively high seabird attraction: for example, during low tide farm structures may be used for roosting, and wading birds may actively fish around racks.
- Escapee effects: high abundances of wild Pacific oysters have the potential for significant ecosystem impacts.
- Hydrodynamic effects: this was assumed to be a lesser issue for elevated subtidal toheroa and geoducks. The assumption was that, being deeper than Pacific oysters, elevated subtidal structures would impede wave action (and possibly water currents) to a reduced extent.

The final categories to consider from Figure 3 are the two species (geoduck and sea cucumbers) for which on-ground culture is likely. The Bray-Curtis similarity in the effects scores for these two was 87%. The only discriminating effects were the higher scores assigned to geoduck to reflect the following:

- Plankton depletion may need to be considered for geoduck culture, but is not relevant for sea cucumbers.
- Crop loss and/or shell accumulation, as well as the possibility of local sediment effects (e.g. erosion around tubes), were considered relevant to geoducks but not sea cucumbers. This may not be the case in the event that structures are used for sea cucumber aquaculture.

Initially we considered aggregating these on-ground species into a single group on the basis of these small differences. However, uncertainties in relation to the farming methods and actual effects, and the possibility that sea cucumber culture might be feed-added (our assessment assumed it was not), justifies keeping these species separate at this stage.

3.5. Comparisons between existing and new aquaculture species

3.5.1. Conversion from Greenshell™ mussel aquaculture

Comparisons of scores for each aquaculture species-method relative to existing GSM aquaculture are given in Table 4. The red highlighted cells indicate, for each given species-method category and type of effect, situations where the possibility of a greater potential impact should be considered when converting from an existing GSM farm.

Not surprisingly, conversion to finfish farms from GSM requires consideration of most of the potential effects, as well as species- or situation-specific considerations such as biosecurity. By contrast, conversion to other floating shellfish farms or macroalgal culture requires very few extra matters to be addressed except those flagged as species or situation-specific. Although not reflected in Table 4, there are also uncertainties regarding the benthic effects of pāua culture that need to be recognised. Similarly, for both pāua and sea cucumbers, Table 4 does not reflect that the effects of additives may need to be considered in the event that artificial diets (e.g. feed pellets) are used.

The development of new species or methods requires consideration of a few potential effects that may be greater than in GSM culture. For elevated subtidal bivalve culture and sea cucumber culture, an obvious difference to GSM culture is the potential for increased physical disturbance of the seafloor. Additionally, adverse effects from additives may need to be considered for elevated methods in the event that farms are constructed using treated timber (i.e. due to leaching of trace metals used in the timber treatment process). Similarly, for conversions from GSM to macroalgal culture, the potential for shading and marine mammal entanglement are specific issues that would need to be considered, as well as escapee effects if *Undaria* is being considered. Other examples can be seen in Table 4.

3.5.2. Conversion from intertidal Pacific oyster farms

As described in Section 3.2.4, it is worth considering the implications of part-conversion of existing Pacific oyster culture to new subtidal methods, especially for on-ground geoduck, given the potential for some degree of spatial overlap. Our assessment in Table 3 suggests that there will be no ecological effects for which a greater impact would be expected to arise from such a conversion. For all mechanisms considered, we judged intertidal Pacific oyster farms as having a similar or greater relative impact than geoduck or toheroa. Notwithstanding this comment, we reiterate the high degree of uncertainty with some of the estimates made for the emerging species, hence the need to treat this general conclusion with some caution.

Table 4. Comparison of relative scores for aquaculture species and/or methods (except intertidal oysters) derived from Table 3, with existing GSM aquaculture. Positive values (red) indicate an increase in potential ecological effects compared with GSM. * = situation-specific, dot = not relevant. This generic guide should be interpreted in conjunction with the uncertainty in underlying scores reflected in Table 3, and account for matters discussed in Section 3.4.

Category-mechanism of ecological impact	Salmonid finfish	Other finfish	Pacific oyster	Flat oyster	Scallop	Abalone	Sponges	Asian kelp	Other macroalgae	Toheroa	Geoduck	Geoduck	Sea cucumber
	Floating subtidal cages	Floating subtidal cages	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Elevated subtidal	Elevated subtidal	On-ground subtidal	On-ground subtidal
Filtration	-3	-3	0	0	0	-3	0	-3	-3	-1	-1	-1	-3
Nutrients & HABs	1	1	0	0	0	0	0	-1	-1	0	0	0	0
Dissolved oxygen	2	2	0	0	0	0	0	0	0	0	0	0	0
Benthic enrichment	1	1	0	0	0	0	0	-1	-1	0	0	0	0
Crop loss & shell drop	-3	-3	-1	-1	-2	-2	-2	-2	-2	-2	-2	-2	-3
Disturbance	0	0	0	0	0	0	0	0	0	1	1	1	1
Altered sediments	0	0	0	0	0	0	0	0	0	1	1	0	-1
Shading	2	2	0	0	0	0	0	2	2	1	1	-1	-1
Mammal-entanglement	2	2	0	0	0	0	0	1	1	0	0	-1	-1
Mammal-exclusion	2	2	0	0	0	0	0	0	0	0	0	-1	-1
Mammal-attraction	1	1	0	0	0	0	0	0	0	-1	-1	-1	-1
Mammal-noise/light	2	2	0	0	0	0	0	0	0	0	0	0	0
Bird-entanglement	2	2	0	0	0	0	0	0	0	0	0	-1	-1
Bird-exclusion	2	2	0	0	0	0	0	0	0	0	0	-1	-1
Bird-attraction	0	0	0	0	0	0	0	0	0	-2	-2	-2	-2
Bird-noise/light	2	2	0	0	0	0	0	0	0	0	0	0	0
Fish-exclusion	1	1	0	0	0	0	0	-1	-1	0	0	0	0
Fish-attraction	0	0	-1	-1	-1	-1	-1	-1	-1	-2	-2	-2	-2
Fish-noise/light	2	2	0	0	0	0	0	0	0	0	0	0	0
Biosecurity-pests	*	*	*	*	*	*	*	*	*	*	*	*	*
Biosecurity-disease	*	*	*	*	*	*	*	*	*	*	*	*	*
Escapee-ecological	2	1	2	0	0	0	0	2	0	0	0	0	0
Escapee-genetic	•	*	•	*	*	*	*	•	*	*	*	*	*
Additives	2	2	0	0	0	0	0	0	0	1	1	0	0
Hydro-current	1	1	0	0	0	0	0	0	0	-1	-1	-2	-2
Hydro-wave	0	0	0	0	0	0	0	-1	-1	-3	-3	-3	-3

4. RECOMMENDATIONS AND FURTHER CONSIDERATIONS

4.1. Recommendations for species groupings

The general findings of our assessment are consistent with the conclusions of Keeley et al. (2009) and others (including the MPI 2013 review), that except for variation in relation to certain mechanisms, impacts arising from feed-added finfish aquaculture are generally expected to be greater than for shellfish culture, with sea cucumbers and macroalgal culture being less again. However, the present report makes it clear that it is the culture method as much as the particular species that is often important when considering the relative scale of effects for a given location.

Bearing in mind the matters that were identified as being beyond the scope of this report (see Section 1.3), as well as the limitations and caveats described in Section 3.3, the MDS analysis (together with Table 3) provides a good basis for identifying coarse groupings of the 15 candidate species-methods. We suggest that the Reference Group considers the seven 'groups' (i.e. four groups and three discrete species-methods) identified by the MDS as a reasonable basis from which to develop rules for marine farm conversions. Thus, in Table 5 we describe these groups and the important within-group differences that need to be considered (where relevant), and identify effects that may be greater when converting from an existing GSM farm.

For readers interested in making comparisons among aquaculture species-groups in addition to GSM, Table 3 can be used as a guide (i.e. based on visual assessment of differences in circle size and colour). When applying these groupings to specific sites, it is important to consider fully the within-group differences identified in Table 5, and their importance in the context of any special values at that location. For example, the relevance and/or intensity of crop/shell accumulation is flagged as a specific issue among the 'floating subtidal invertebrates' group. As such, it is not just a matter of considering whether and to what extent crop/shell accumulation occurs, but what this effect means when a site's values are taken into account. For instance, does crop/shell accumulation alter seabed habitats in a way that negatively impacts food sources for wild fish or bottom-feeding seabirds? If so, what are the potential consequences, considering conservation status and implications for the seabird population?

We also reiterate that despite some reasonably clear groupings from the MDS, it is important to keep in mind that the approach is not perfect. As already noted, even when effects are scored as being the same, there will always be degrees of difference in actual or potential severity among difference species-methods. For example, benthic enrichment effects may differ slightly among bivalve species according to their filtration rates, biodeposit production and on-farm stocking density. Similarly, although we grouped sponges with bivalves, there are high uncertainties regarding water column and benthic effects arising due to sponge filtration and biodeposition.

Table 5. Recommended groupings of aquaculture species-methods based on potential ecological effects. Indicated are within-group differences requiring specific consideration and effects that may increase when converting from an existing GSM farm. In all instances, **further investigation and assessment is recommended where:** effects are highly uncertain (see Table 3), where aquaculture methods differ to those on which this report was based (see Section 2.2), or where sites have special values for which a more in-depth analysis may be warranted.

Group	Candidate species	Within-group differences for specific consideration*	Effects that may be greater if converting from GSM
Caged finfish	All	• Biosecurity and genetic considerations • Escapee effects of salmonids	• Many - see Table 4 in the main report
Floating subtidal invertebrates	Mussels Pacific oysters Flat oysters Pāua Sponges	• Biosecurity and genetic considerations • Whether and to what extent plankton depletion occurs • Relevance and/or intensity of crop/shell accumulation • Escapee effects of Pacific oysters • Uncertainty of benthic effects of pāua culture and effects of additives (if artificial feed pellets used)	• Escapee effects of Pacific oysters • Benthic effects from pāua, and effects of additives (if artificial feed pellets used)
Floating subtidal macroalgae	All	• Biosecurity and genetic considerations • Escapee effects of *Undaria*	• Shading • Marine mammal entanglement • Escapee effects of *Undaria*
Elevated intertidal Pacific oysters	Pacific oysters	• Biosecurity and genetic considerations • Escapee effects	• Not applicable
Elevated subtidal shellfish	Toheroa Geoduck	• Biosecurity and genetic considerations	• Physical disturbance • Sediment accretion/erosion • Shading • Effects of additives (if treated timber used)
On-ground geoduck	Geoduck	• Biosecurity and genetic considerations	• Physical disturbance
On-ground sea cucumber	Sea cucumber	• Biosecurity and genetic considerations	• Physical disturbance • Benthic effects and additives (if method is feed-added)

* For all species-groups, genetic considerations are not regarded as relevant for non-indigenous species.

While these within-group differences may lead to some variability in impacts at a given aquaculture site, it is worth considering that in many instances they may be no more significant that the differences in impact that can occur for the same species among different locations. In the Marlborough Sounds for example, benthic enrichment beneath mussel farms can range from causing moderate anoxia to being barely discernible. We would expect all species-methods in the ‘floating subtidal invertebrates’ group to fall somewhere in this range. For example, previous modelling studies for a range of bivalve species, including some not considered here (e.g. cockles), suggest that bivalves may be cultured at stocking densities equivalent to those used for mussels without posing additional risk to the marine environment (Gibbs et al. 2006).

4.2. Considerations for addressing uncertainties

Further investigation and assessment is recommended where effects are highly uncertain (see Table 3), where aquaculture methods differ to those on which this report was based (see Section 2.2), or where sites have special values for which a more in-depth analysis may be warranted. It is evident that much is known in New Zealand and internationally about the impacts of finfish culture (especially salmon), floating bivalve culture (especially mussels) and intertidal Pacific oyster culture. By comparison, there is little to nothing known about the methods and effects of culturing sponges, pāua, toheroa, geoduck and sea cucumbers.

For species like flat oysters and pāua that are currently farmed at a small scale, further investigations (e.g. field-based studies of effects), may produce information that would be of use for comparative assessment. However, for the other species with short-term and longer-term aquaculture potential it will be necessary to extrapolate from experimental trials to commercial systems, based on the commercial growing methods that are expected to be used. Even then there is an additional consideration as to whether the species are likely to be grown in isolation or in co-culture situations. For example, according to Keeley et al. (2009) macroalgae and sea cucumbers are typically grown in co-culture (e.g. with bivalve and finfish farms) due to their potential to mitigate impacts from water column and benthic enrichment, respectively.

In general, the easiest way to address uncertainty would be to ensure that monitoring or staged development plans are in place, as appropriate. Even when making changes within the groups described in Table 5 (e.g. GSM to sponges or vice versa), a targeted monitoring programme would be worthwhile where uncertainty has been identified. For species conversions where significant increases in impacts are expected, or where there is high uncertainty regarding effects, staged development may be appropriate; i.e. in which the spatial extent of farming is scaled-up only when monitoring has demonstrated that impacts are acceptable.

However, note that monitoring may be confounded in situations where conversion to a new species is proposed, given that a farm is already in existence; i.e. it may be difficult to disentangle the effects of the new species to impacts from past or ongoing aquaculture activities, at least for certain issues (e.g. benthic effects). Simultaneous with monitoring, it will be important to ensure that appropriate farm management practices are in place to minimise the potential for adverse effects (Forrest et al. 2015; Sim-Smith & Forsythe 2013). As part of this, management practices and growing innovations arising from aquaculture locally and overseas that lead to improved environmental outcomes should be adopted to the extent that is feasible and useful in a New Zealand context.

A complementary approach to address uncertainty would be to set effects-based standards that marine farms must meet. For example, the benthic effects of a marine farm at a given location could be limited to within a certain threshold, which is the basis of the 'Enrichment Stage' approach described for salmon farms in Marlborough (Keeley et al. 2014). Among other things, this approach would mean that the industry would need to consider whether or not it was economically viable to farm a given species at that location; e.g. based on whether an economically viable stocking density or feeding regime could be developed which did not result in a breach of the standard. Of course, there is considerable work involved in determining what standards are appropriate considering the sensitivity of the environment and the spatial extent of existing types of aquaculture. Some of these considerations have been investigated for Waikato Regional Council in relation to benthic and water column issues (Keeley et al. 2015).

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6. REFERENCES

Castinel A, Forrest B, Hopkins G 2014. Review of diseases of potential concern for New Zealand shellfish aquaculture: perspectives for risk management. Prepared for Ministry of Business, Innovation and Employment Contract CAW1315 (Enabling, Growing and Securing NZ's Shellfish Aquaculture Sector). Cawthron Report No. 2297. 31 p. plus appendices.

Castinel A, Fletcher L, Dhand N, Rubio A, Whittington RJ, Taylor M 2015. OsHV-1 mortalities in Pacific oysters in Australia and New Zealand: the farmer's story. Prepared for Ministry of Business, Innovation and Employment. Cawthron Report No. 2567. 48 p. plus appendices.

Cornelisen C, Quarterman A 2010. Effects of artificial lighting on the marine environment at the Clay Point and Te Pangu Bay salmon farms. Prepared for New Zealand King Salmon Company Limited. Cawthron Report 1851. 17 p.

Forrest B, Cornelisen C, Clement D, Keeley N, Taylor D 2015. Monitoring framework for the Waikato coastal marine area: Report 2 – Regional aquaculture monitoring priorities and guidance. Prepared for Waikato Regional Council. Waikato Regional Council Technical Report 15/39. Cawthron Report No. 2429. 67 p.

Forrest B, Hopkins G 2016. Grouping aquaculture species by environmental effects: preliminary assessment. Prepared for Ministry for Primary Industries. Cawthron Report No. 2914. 30 p. plus appendix.

Forrest B, Keeley N, Gillespie P, Hopkins G, Knight B, Govier D 2007. Review of the ecological effects of marine finfish aquaculture. Prepared for the Ministry of Fisheries. Cawthron Report No. 1285. 73 p. plus appendices.

Forrest BM, Keeley NB, Hopkins GA, Webb SC, Clement DM 2009. Bivalve aquaculture in estuaries: review and synthesis of oyster cultivation effects. Aquaculture 298 (1-2):1-15.

Gibbs M, Pilcher O, Keeley N, Heasman K, Webb S 2006. Aquaculture stocking density guidelines for alternative bivalve species. Prepared for Ministry of Fisheries. Cawthron Report No. 1192. 35 p.

Heasman KG, Taylor D, Mussely H 2016. Predicted environmental effects of geoduck aquaculture in New Zealand. Prepared for Ministry of Primary Industries. Cawthron Report No. 2753. 22 p.

Keeley N, Cornelisen C, Knight B, Forrest B, Taylor D 2015. Monitoring framework for the Waikato Coastal Marine Area: Report 3 – seabed and water column monitoring and standards. Waikato Regional Council Technical Report 15/40. 56 p. plus appendices.

Keeley N, Forrest B, Hopkins G, Gillespie P, Clement D, Webb S, Knight B, Gardner J 2009. Review of the ecological effects of farming shellfish and other non-finfish species in New Zealand. Cawthron Report No. 1476. 144 p. plus appendices.

Keeley N, Gillard M, Broekhuizen N, Ford R, Schuckard R, Urlich S 2014. Best Management Practice guidelines for salmon farms in the Marlborough Sounds: Benthic environmental quality standards and monitoring protocol. Prepared by the Benthic Standards Working Group, November 2014. Available at: http://www.marlborough.govt.nz/Environment/Coastal/Best-Practice-Guidelines-for-Salmon-Farming.aspx.

Morrisey DJ, Cole RG, Davey NK, Handley SJ, Bradley A, Brown SN, Madarasz AL 2006. Abundance and diversity of fish on mussel farms in New Zealand. Aquaculture 252(2–4): 277-288.

MPI 2013. Overview of ecological effects of aquaculture. Ministry for Primary Industries, Wellington, New Zealand. 79 p.

NZCPS 2010. New Zealand Coastal Policy Statement. Department of Conservation, Wellington. 28 p.

Ribes M, Coma R, Gili J-M 1999. Natural diet and grazing rate of the temperate sponge *Dysidea avara* (Demospongiae, Dendroceratida) throughout an annual cycle. Marine Ecology Progress Series 176: 179-190.

Sim-Smith C, Forsythe A 2013. Comparison of the international regulations and best management practices for marine finfish farming. NIWA Client Report No. AKL2013-013, prepared for the Ministry for Primary Industries, July 2013. 85 p.

Taylor D, Keeley N, Heasman K 2010. Farming alternative non-feed added species on an offshore mussel farm: assessment of ecological effects. Cawthron Report No. 1779. 38 p.

7. APPENDICES

Appendix 1. Illustration of approach to developing species-method groupings by broader impacts

A1.1 CATEGORISING BROADER IMPACTS

In addition to ecological effects, aquaculture has a range of non-ecological impacts that need to be considered when changing species or methods, which we have termed 'broader impacts'. Although the report authors are not experts in non-ecological effects, the Reference Group asked us to consider *examples* of the types of effects that might be considered, and to undertake a limited assessment using the same method (to the extent warranted) that was applied in the main report to assess ecological effects.

Table A1.1 lists the broader impacts and related mechanisms that we considered, ***by way of example***, and the extent to which each is primarily due to the culture species, the farming method, or both of these factors. For illustrative purposes, we defined five main effects and nine mechanisms of broader impact. There are no accepted or consistent approaches to defining or categorising these non-ecological impacts, and the nine mechanisms in Table A1.1 are clearly not exhaustive of the full range of matters that may be relevant to aquaculture. However, the ones chosen can be considered as useful examples for present purposes, in that they reflect a blend of the following:

- Relevant matters described in the Resource Management Act 1991 (RMA), which are matters that (in our experience) commonly arise via submission during marine farm consent applications. These include effects on natural character, recreation and navigation.
- Examples of non-ecological matters described in the New Zealand Coastal Policy Statement (NZCPS 2010); for example, Policy 13 regarding preservation of natural character and related effects of visual detraction, noise and artificial lighting[6]. As well as Policy 13, the NZCPS (2010) includes other policies that have an ecological basis (e.g. policy 11, indigenous biodiversity; policy 12, harmful aquatic organisms). However, we did not include these ecological aspects[7] given that our approach was illustrative rather than exhaustive.
- Matters relevant to MPI when assessing the effects of a proposed marine farm on fishing through the undue adverse effects test (UAE test)[8].

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[6] For present purposes, we considered only Policy 13 matters that relate to 'perceptual' factors, and did not extend the assessment to biophysical matters specified in that Policy (e.g. effects on natural elements, processes and patterns, natural movement of water and sediment).

[7] Note that the knowledge derived from the ecological assessment in the main text will assist in assessing some of the broader effects that have a biophysical basis.

[8] Undue adverse effects test: see https://mpi.govt.nz/growing-and-producing/fish-and-shellfish/aquaculture/setting-up-a-marine-farm/undue-adverse-effects-test/

We initially considered incorporating some of the categories of 'value' described in the RMA, but concluded that they were too broad to be useful as assessment criteria. For example, the RMA defines 'amenity values' as '*natural or physical qualities and characteristics of an area that contribute to people's appreciation of its pleasantness, aesthetic coherence, and cultural and recreational attributes*'. Similarly, the term 'intrinsic values' is defined in the RMA as '*those aspects of ecosystems and their constituent parts which have value in their own right, including….their biological and genetic diversity; and…. essential characteristics that determine an ecosystem's integrity, form, functioning, and resilience*'. In both cases, we felt that it was more useful to partition the very broad RMA terms into some of their constituent components, which are largely reflected in Table A1.1

Table A1.1. Broader impacts (i.e. non-ecological) and related mechanisms used as examples in the assessment. Broader impacts having a biophysical basis (in whole or part) were not considered for present purposes (see Section A1.1).

Categories of broader impact	Potential mechanisms of impact	Primary driver
Commercial fishing	Exclusion or interference with commercial fishing Impact on commercial fishery resources	Method Species
Recreational and customary fishing	Exclusion or interference with recreational or customary fishing Impact on recreational or customary fishery resources	Method Species
Non-fishing recreation	Exclusion or interference with non-fishing recreation	Method
Natural character	Visual detraction Noise disturbance Lighting disturbance	Method Method Method
Navigation and safety	Exclusion or interference with vessel movements	Method

A1.2 SPECIES-METHOD COMPARISON BASED ON BROADER IMPACTS

A1.2.1 Fishing

For fishing, three sub-categories of effects to fishing were considered. Of note, there was a big difference between our scores for commercial vs recreational/customary fishing activities, driven by the fact that we considered it unlikely that any form of commercial fishing activity could occur within the boundaries of a marine farm site. Effects to fisheries resources reflected our scoring for some of the ecological impact mechanisms in the main report.

Exclusion or interference with commercial fishing

The presence of marine farms has the potential to exclude or interfere with commercial fishing activities. We note the following in our assessment:

- We scored all species-method combinations the same (large green circle), as we considered it unlikely that commercial fishing could occur within a marine farm due to water column (longline, cage and intertidal rack methods) or seabed (ground and elevated culture) obstructions.
- Although we have scored this with reasonable confidence (green circle), we accept that in the future there may be occasions where commercial activities could take place (e.g. trolling over ground or elevated culture), but as yet we are unaware of any documented examples.

Exclusion or interference with recreational or customary fishing

The relative impact of aquaculture activities to recreational and customary fishing activities varies considerably with the culture method. Our assessment is as follows:

- The presence of finfish cages would have the greatest relative effect to recreational and customary fishing activities. We acknowledge that a fish farm could attract fish to the site; however, the presence of cages would result in the complete exclusion of fishers to the water column and seabed at the farm site.
- On-ground, elevated and intertidal rack methods are likely to interfere with bottom fishing methods, but other methods (e.g. trolling, floating lines) may be possible. For this reason, they were assigned a medium-sized circle. We are less confident with the level of impact associated with toheroa, geoduck and cucumber culture methods as they are yet to be trialled at a commercial scale in New Zealand.
- Recreational fishing commonly occurs at mussel farm sites throughout the country, as the presence of farm structures and crop often attracts fish (both demersal and pelagic). Fishers can SCUBA dive, free dive, line fish and even troll between longline structures. We have assumed similar access for other culture species using floating subtidal line methods (e.g. sponges, macroalgae). However, for macroalgae our high uncertainty reflected the possibility that macroalgae will be farmed in a way that maximises the use of shallow water space to the extent that easy access/navigation among lines is restricted (e.g. lines may be closer together than in a conventional GSM farm).

Impact on fishery resources

In our assessment we used MPI's definition of fisheries resources to mean *'any 1 or more stocks of species of fish, aquatic life, or seaweed'* (MPI 2013). Effects to fisheries resources will vary depending on the resources of significance. For example, benthic effects will be an important consideration for shellfish, whereas for finfish, wild fish interactions will be more relevant. As a generalisation, we considered that effects to fisheries resources were greater when benthic, water column and wild fish interactions were scored the highest. On this basis:

- Greatest relative impacts are expected in the case of finfish farms, given the higher level of benthic and water column impacts, and potential for wild fish interactions.
- On-ground culture methods (for geoduck and sea cucumber) and seaweed culture (longline methods) were considered to have the least impacts.
- The remaining species-method combinations were assigned intermediate scores.

A1.2.2 Recreation (other than fishing)

For recreational activities, our assessment focused solely on how the presence of marine farming infrastructure and associated vessels may affect access to and enjoyment of the marine environment at, and within the vicinity of, a marine farm site.

The presence of marine farm infrastructure such as floats, longlines, cages and intertidal racks will restrict (and in some cases prevent) access and utility of the marine environment for a broad range of recreational users. This mechanism of impact is not as well understood as many of the ecological (e.g. benthic and water column effects) and commercial/non-commercial impacts (e.g. fishing). Further, there is also uncertainty relating to the amount of infrastructure required for ground and elevated subtidal forms of aquaculture. The main findings of our assessment are as follows:

- Based on finfish culture methods used in New Zealand to date, the presence of cages will result in the complete exclusion of almost all recreational activities in the occupied water space. It is arguable that sightseeing may be possible within a consented area (i.e. people viewing farms from boats), however this would occur from a distance from the farm structures (direct access would not be permitted).
- The installation of longline and intertidal rack structures would result in a partial loss of access to a variety of recreational users (note: see below for navigational impacts). For example, easy or safe access for boating and certain water sports (e.g. water skiing, wind-surfing) will be impinged upon. However, certain other activities can readily occur around longline structures (e.g. kayaking).
- On-ground and elevated subtidal culture methods were considered to have a relatively low potential impact on recreational activities, nonetheless some potential exists. Additionally, our high uncertainty reflected a lack of information regarding the nature and extent of surface structures that will be used to identify these types of aquaculture operations.

A1.2.3 Natural character

In addition to the presence of aquaculture structures, natural character values may be affected by vessels operating in and around marine farms. We reiterate that our scope (see Section 1.3) did not include on-shore facilities and activities, hence the text below considers only effects in the environs of marine farm sites.

Visual detraction

As with many of the impact mechanisms, the scale of the farm activities plays an important role. The degree of visual detraction will also be strongly influenced by the vantage point (we have assumed sea level in our assessment) and the colour of structures. Our assessment is as follows:

- Finfish farms were scored the highest relative impact due to the presence of high-sided predator nets and building infrastructure. We note that salmon farms in the Marlborough Sounds have been painted in recessive colours so that they blend in with the natural surroundings. As such, it could be argued that they pose a lesser visual detraction for some people than say a large longline mussel farm with black and orange coloured floats.
- Floating subtidal longline methods were considered to have the next highest level of impact, due to the large number of floats often used.
- Intertidal rack culture was scored as low, given that structures are only visible during low tide. Clearly, however, from certain vantage points intertidal oyster farms can be quite conspicuous (e.g. Figure 1E of main report).
- For on-ground and elevated subtidal methods, we have assumed a low relative visual impact. This situation of course will need to be reassessed if the sites are marked with numerous floats.

Noise disturbance

Noise levels generated at marine farm sites can be continuous at finfish farms (e.g. the hum of a generator at a salmon farm) which are staffed and operated continually, but are expected to be intermittent for all other forms of aquaculture (e.g. vessel and machinery noises during crop checking, maintenance or harvesting). Devices such as generators can be designed and engineered to reduce noise levels, and harvesting activities can be timed to reduce the level of disturbance to people (e.g. during daylight hours). Bearing this in mind, the findings of our assessment are that:

- Finfish farms are likely to produce the highest relative noise impact due to on-going activities (feeding, net cleaning, power generation) and frequent vessel movements (feed delivery, staff shift changes), as well as less frequent activities (e.g. water-blasting of predator nets).
- All of the other species-method combinations were scored the same (medium), given that it is likely that there would be vessels travelling to the sites to undertake inspections, maintenance and harvesting activities.

Artificial lighting disturbance

All marine farms with surface structures are required to have lighting for navigational safety reasons; for example, lights that flash intermittently to mark the corners of farm structures[9]. At finfish farms, additional artificial lighting (surface and submerged) is

[9] Navigational lighting and safety requirements are described by Maritime New Zealand; see: www.maritimenz.govt.nz/commercial/ports-and-harbours/documents/Guideline-for-Aquaculture-Management-areas-and-Marine-Farms.pdf

used for staff operations during hours of darkness and, in relation to fish production, to reduce the risk of early maturation prior to harvest and assist in evenly distributing the fish in pens. Accordingly, in terms of the relative potential for effects:

- As with noise, finfish farms were considered to have the highest impact.
- All other forms of aquaculture were assessed as having a low relative impact.

A1.2.4 Navigation and safety

Navigation and safety effects are likely to vary with farm size, orientation with the coastline, time of day and the type of vessels operating in the region. For example, small recreational craft will be able to safely navigate through a subtidal longline farm structures during the day, but larger vessels (including commercial vessels) will likely be completely excluded. Our assessment is as follows:

- Finfish farms were scored as having the highest relative impact, as they result in the complete exclusion of all vessel types (large and small).
- Subtidal longline and intertidal rack methods were considered to have less of an impact than finfish culture, as some vessel types (small recreational and commercial vessels) would be able to travel between farm blocks and in some cases between backbones. We note that there will be occasions where boat access to and from jetties may be impeded (e.g. if a farm is positioned directly in front of a jetty and backbones are orientated parallel to the shore).
- There is considerable uncertainty regarding on-ground and elevated subtidal culture, but we assume that there will be fewer surface floats than for subtidal longline culture methods. Maritime New Zealand rules describe the nature and extent of surface buoys required to mark subtidal structures (see link in previous footnote).

A1.3 METHOD OF COMPARATIVE ANALYSIS

The same method used to assess ecological effects in the main report (see Section 3.2) was applied to the comparison of broader impacts from Section A1.2 above. That is, a matrix was developed using circles and colours to convey relative effect size and uncertainty, respectively. As the authors do not have expertise in the broader issues, the matrix cells were populated solely on author judgement. As the purpose was to illustrate the efficacy of the approach, no quantitative analyses were undertaken. We also made no formal comparison with GSM aquaculture such as undertaken for ecological effects (i.e. Table 4 of the main report). Nonetheless, we make some comment below on species-method similarities based on comparisons from the matrix.

A1.4 ILLUSTRATION OF SPECIES-METHOD GROUPINGS BASED ON BROADER IMPACTS

The broader impacts that we considered in A1.2 show some overall patterns (see Table A1.2), with respect to aquaculture type, that largely mirror the ecological effects groups described in Section 3.3 of the main report and in Appendix 2. However, the effects considered are attributable solely to the farming method and associated operations. A more comprehensive evaluation that considered broader matters that may have an ecological basis (e.g. ecological/biophysical aspects of natural character, NZCPS policies regarding biodiversity and harmful aquatic organisms) may need to account for species as well as farming method.

Given the preliminary nature of the broader assessment, it is premature to define any specific groupings; however, some of the overall findings are of interest. In general, the relative effects of finfish culture are estimated to be greater than floating shellfish or sponge culture systems, which in turn are greater than elevated or on-ground culture. There are nonetheless a few exceptions evident from the discussion in Section A1.3. For example, we expect that all types of aquaculture will exclude commercial fishing equally, hence there is nothing to discriminate among farming methods.

We considered that recreational and customary fishing were least affected by floating bivalve culture systems, as these can be accessed for fishing at all states of the tide. However, elevated subtidal and on-ground culture systems have the potential to have an impact on recreational and customary fishing by restricting or precluding access for bottom-fishing methods such as dredging and line fishing (i.e. due to the underwater hazard).

We were unsure of the extent of visual impact for elevated subtidal and on-ground culture systems. For all cases, an impact is expected due to farm operations (e.g. vessel activities). However, the nature of the visual impact otherwise depends on the extent of surface infrastructure (e.g. poles, floats) that is required to support or identify submerged farm areas.

Overall, our impression is that the assessment approach used here provides a reasonably simple and useful means of visualising the effects that are important to consider when converting to a new aquaculture species-method at a given site. The MDS ordination analysis that was used for the ecological assessment could equally be applied to scores derived for broader effects based on the matrix in Table A1.2. However, first it will be necessary to involve appropriate subject matter experts to ensure that the ‘results’ such as depicted for the illustrative case in Table 3 reflect the best available information.

Table A1.2. Illustrative comparison of relative scores for each broader (non-ecological) effect category among the different aquaculture species-method combinations. The categories and related mechanisms we have used reflect a blend of the non-ecological effects typically addressed for coastal aquaculture under the RMA 1991 and the MPI UAE test. The mechanisms assessed are also relevant to some of the high-level matters required to be considered by NZCPS (2010). See text for details.

Broad environmental impact	Potential mechanism	Floating subtidal cages	Floating subtidal cages	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Floating subtidal lines	Elevated intertidal	Elevated subtidal	Elevated subtidal	On-ground subtidal	On-ground subtidal
		Salmonid finfish	Other finfish	GSM	Pacific oyster	Flat oyster	Scallop	Abalone	Sponges	Asian kelp	Other macroalgae	Pacific oyster	Toheroa	Geoduck	Geoduck	Sea cucumber
Fishery	Exclusion or interference with commercial fishing	Large green	Large green	Large green	Large green	Large green	Large green	Large green	Large green	Large green	Large green	Large green	Large green	Large green	Large green	Large green
	Exclusion or interference with recreational or customary fishing	Large green	Large green	Small green	Small green	Small green	Small orange	Small orange	Small orange	Small red	Small red	Large orange	Large red	Large red	Large red	Large red
	Impact on fishery resources	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large red	Large red	Small orange	Small orange	Large orange	Large orange	Large orange	Small orange	Small orange
Recreation	Exclusion or interference with recreation (except fishing)	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large red	Large red	Large orange	Small red	Small red	Small red	Small red
Landscape & Natural character	Visual detraction	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Small orange	Small red	Small red	Small red	Small red
	Noise disturbance	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange
	Lighting disturbance	Large orange	Large orange	Small orange	Small orange	Small orange	Small orange	Small orange	Small orange	Small orange	Small orange	Small orange	Small orange	Small orange	Small orange	Small orange
Navigation and safety	Exclusion or interference with vessel movements	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Large orange	Small red	Small red	Small red	Small red

Appendix 2. Comparison of relative ecological effects across different aquaculture species-method combinations for each of the effects in Table 2 of the main report.

The assessment below is based on information contained in reviews conducted by MPI and others (see Section 2.1 of the main report).

A2.1 WATER COLUMN

Three sub-categories of water column effects were considered, with the relative scale of impacts roughly relating to the feeding type of the candidate species.

A2.1.1 Filtration and plankton depletion

This subcategory describes the process whereby filter-feeding animals extract plankton (potentially both phytoplankton and zooplankton) and other suspended particulate matter from the water column. This process can alter the amount and composition of the plankton community. Studies of phytoplankton indicators around mussel farms have shown this type of depletion effect. Actual differences among species depend on factors such as their filtration capacity and farm stocking densities. In terms of relative scale among the candidate species-methods, this effect was considered to be important only for filter-feeding bivalves and sponges, noting the following:

- We judged it of greatest overall importance for floating bivalve and sponge (with less certainty) aquaculture, on the basis that the culture is 3-dimensional in that it usually extends down into the water column (e.g. a typical GSM longline extends to c. 15 m depth).
- By comparison, elevated bivalve culture systems tend to have a 2-dimensional configuration, meaning a relatively lower stocking density per hectare.
- Filtration and plankton depletion were scored as insignificant for non-bivalve systems (except sponges). However, note that while the aquaculture crop in such systems will not exert this effect, the assemblages of biofouling organisms that colonise farm structures are likely to be dominated by filter-feeders, hence exert some level of depletion.

A2.1.2 Nutrient enrichment and algal blooms

This subcategory describes the process in which farm wastes lead to nutrient enrichment in the water column. Nutrient enrichment has the potential to cause or exacerbate algal blooms. Of particular interest is the potential for blooms of harmful microalgae (i.e. HABs), as such blooms can produce biotoxins that make shellfish unsafe to eat. Aquaculture in New Zealand has not been linked to such effects, but we judged the relative potential as follows:

- Finfish aquaculture has the greatest relative potential by virtue of the relatively high dissolved nutrient output from fish excretion and remineralised biodeposits (see Section A2.2.1).
- Bivalves and other invertebrates like sponges, pāua and sea cucumbers produce nutrients in similar ways but of lesser magnitude than finfish; bivalves also remove particulate nutrients by filtration. Although we scored bivalves and other invertebrates equally, our reduced confidence (red circles in Table 3 of the main report) for pāua and sea cucumbers reflects the possibility that effects could be more significant in the event that a proportion of any added feed was lost to the environment.
- By comparison with animals, the cultivation of macroalgae, which are primary producers that uptake dissolved nutrients, was presumed to have minimal potential for adverse enrichment-related effects. In fact there is interest in the use of macroalgae in integrated culture systems to 'mop up' excess nutrients discharged from finfish farms. MPI (2013) suggest that nutrient extraction by macroalgae could lead to reduced nutrient availability for natural phytoplankton populations.

A2.1.3 Dissolved oxygen depletion

The combination of animal respiration and microbial decay of farm wastes (water column and seabed) has the potential to lead to dissolved oxygen depletion in the water column and bottom waters. In terms of relative effects:

- The most significant effects are expected to arise in finfish culture due especially to fish respiration, and to some extent benthic oxygen demand from organic matter decomposition. However, oxygen depletion is likely to be more of an issue for the cultured fish than the wider environment. Species such as salmon are highly sensitive to low DO, hence an indicator of any significant depletion in the culture environment.
- We judged the potential for DO depletion to be comparatively very low for non-finfish aquaculture; however, our lack of confidence in the assessment for pāua and sea cucumbers is in consideration of a possible depletion effect from the decay of waste feed, in the event that artificial feeds are used.

A2.2 BENTHIC

Five sub-categories of benthic impact were identified, and the relative important of effects differs among culture species-method mainly according to feeding type and farming method.

A2.2.1 Organic enrichment of the seabed

Organic enrichment arises from the accumulation of biodeposits (e.g. fish faeces, shellfish faeces and pseudofaeces), waste feed (in the case of feed-added aquaculture), and biofouling (e.g. via drop-off, biodeposition). Our assessment of relative effects is as follows:

- Benthic impacts are invariably greatest in finfish aquaculture, attributed to fish faeces and uneaten feed pellets. In addition to the local-scale 'footprint', the potential for 'far-field' impacts has been recognised, although is poorly understood.
- Intermediate and localised benthic impacts can be expected in the culture of bivalves and other invertebrates, although the degrees of impact among this group will be linked to factors such as filtration rates (among the bivalves and sponges) and stocking densities. We were uncertain about the following:
    - For sponges, the potential nature and extent of biodeposition is unknown. Sponges appear to have very high filtration rates compared with bivalves (Keeley et al. 2009), but the capacity for associated seabed effects is uncertain, with limited relevant studies (e.g. Ribes et al. 1999). For example, there is a lack of information on the type of biodeposits produced; e.g. organic content, production rate, buoyancy and sedimentation rate.
    - For pāua, we were unsure of the extent of faecal deposition and food loss from culture systems used. Keeley et al. (2009) suggested that a pāua farm could produce waste products at a rate comparable to a salmon farm, and perhaps have comparable benthic impacts. However, even where feed pellets are used (rather than macroalgae), we assume that loss would be low compared with 'open water' feeding of finfish. Discussions with existing operators may clarify this situation to some extent, but further investigation (e.g. field studies) will likely be necessary.
    - Our assessment assumed that sea cucumber culture would not be feed-added. MPI (2013) suggested that sea cucumber effects would likely be relatively minor, which is reasonable assertion on the basis that sea cucumbers will remove sediment organic matter. However, if feed-added culture is undertaken, benthic impacts may be increased in magnitude. Further investigation is needed to clarify this issue.
- Benthic impacts arising from farming macroalgae are expected to be relatively low on the basis that significant biodeposits are not produced. Organic matter may be produced from erosion of seaweed fronds (e.g. apical erosion), but the near-neutral buoyancy of such particulates would probably lead to their wide dispersion.

A2.2.2 Crop loss or shell accumulation

Crop losses in some forms of aquaculture, especially shellfish, can occur due to natural drop-off, and can exacerbated by biofouling or operational activities such as size grading, line defouling/maintenance and crop harvest. Crop loss is likely to be a significant consideration only in shellfish aquaculture. Shellfish crop drop-off to the seabed can lead to the aggregation of predators (e.g. sea stars) and accumulated shell can alter seafloor habitats. We judged the relative significance of this effect to be greatest in mussel culture, as mussel seed and crops are attached to rope and are relatively easily dislodged. Shell accumulation can also occur with some flat oyster culture methods, and would also be expected to occur with some floating Pacific oyster methods. However, the relatively high value of oysters provides a strong economic incentive to minimise losses, and some culture methods (e.g. baskets) will lead to minimal loss.

On the assumption that other bivalves would be cultured in contained systems (e.g. baskets, trays), we expect crop loss would be relatively low. Like oysters, other emerging or potential species are relatively high value, hence there will be an economic incentive to minimise losses. However, the actual magnitude of this issue for these emerging species should be further considered once commercial farming methods have been developed. We scored a low relative impact for sponges and macroalgae (including *Undaria*); however we were uncertain regarding the extent to which crop losses from these forms of aquaculture would occur (e.g. during harvest) or result in a negative impact on the environment.

A2.2.3 Physical disturbance

The likely relative significance of physical disturbance was judged as follows:

- Greatest relative impacts are expected in the case of intertidal Pacific oyster culture where farm workers walk between or beside culture racks, and boats (e.g. propeller wash) are likely to disturb sediments between racks.
- Intermediate levels of disturbance are possible in the case of other elevated (geoduck, toheroa) or on-ground (geoduck, sea cucumber) culture methods. However, we were uncertain as to the nature and magnitude of potential effects. For example, sea cucumbers themselves will disturb the seabed by bioturbation, and disturbance is likely to result from harvest, depending on harvest methods. Similarly, the nature of the ongoing disturbance regime for on-ground geoduck culture will depend on harvest methods (Heasman et al. 2016).
- We assumed that disturbance from all forms of floating culture system (bivalves, sponges, finfish cages) would be relatively minor (e.g. limited to minimal disturbance during placement of anchors).

A2.2.4 Altered patterns of sedimentation, erosion or accretion

One of the benthic effects of elevated culture methods, such as intertidal Pacific oyster culture in New Zealand, is alteration to patterns of sediment accretion and erosion. This situation will also arise in the case of elevated seabed culture, however we assumed in our assessment that this would be less pronounced. For all other forms of aquaculture, we assumed that sedimentation *per se* is relatively low (biodeposition being the primary source of fine sediment deposition), with altered patterns of erosion and accretion only occurring adjacent to farm anchors/blocks. One possible exception might be local scouring around on-ground geoduck tubes. The same may be true if structures are used in sea cucumber culture.

A2.2.5 Shading

Local-scale shading effects on the seabed are only a consideration for marine farms located in waters where benthic primary producers are present; i.e. macroalgae, benthic microalgae, eelgrass. In terms of current forms of aquaculture in New Zealand, shading is probably a very minor issue, except perhaps in situations where oyster racks have historically been placed over intertidal and shallow subtidal macroalgae or eelgrass beds.

Conceivably, site selection may steer aquaculture away from locations where such values are important, and in many instances the effect of shading is likely to be minimal by comparison with other benthic effects (see above). However, there may be exceptions; for example, a shallow-water seaweed farm may have a minimal deposition effect but have a significant effect on the attenuation of light to the seabed. Our assessment with respect to the importance of shading reflects a degree of uncertainty, and is based on the relative capacity of different culture methods or species to reduce light penetration. Key points are as follows:

- The greatest attenuation of light can be expected where the aquaculture structure covers the entire water surface (i.e. finfish cages), or where the species is grown at high density or has a growth morphology that cover the water surface (i.e. macroalgae). For example, *Undaria* can grow 2-3 m long and form a dense and extensive canopy; however, shading effects would be limited to seasonal windows of *Undaria* cultivation or peak biomass.
- Intermediate levels of shading are assumed to arise in the case of elevated aquaculture where the culture structures are close to the seabed. The actual effect would depend on the spatial configuration of farm structures.
- We expect that most floating line culture systems for invertebrates would have relatively less potential for shading, due to the fact that the space occupied by lines (in plan view) is considerably less than the space between them.
- Shading is not considered relevant for on-ground culture, except perhaps if extensive netting is used to exclude predators from geoducks.

A2.3 MARINE MAMMAL INTERACTIONS

Four sub-categories of impact were identified relating to interactions between marine mammals and aquaculture. There are clearly species- and situation-specific elements that dictate the potential effects of aquaculture, which include the conservation status of the species and the degree of population interaction with marine farms and related operations. Our assessment considers only generically the relative potential of different types of aquaculture to have adverse effects in the event that interactions do occur. The interactions are primarily attributed to the farming method, reflecting both farm structures and operational practices.

A2.3.1 Entanglement

Marine mammal mortality through entanglement in aquaculture structures is one of the high profile issues with aquaculture development, but is a generally a well-managed and rare occurrence. The relative importance of the different scenarios was assessed as follows:

- The potential is the greatest in a relative sense for caged fish culture, but can be mitigated by following guidance on appropriate net mesh sizes. The placement of predator exclusion nets around cages may also increase entanglement potential.
- Entanglement risk is likely to be least (in a relative sense) in invertebrate culture as culture structures are either rigid (e.g. oyster racks) or involve lines under high tension (e.g. GSM farms). A primarily cause of entanglement is loose rope, or rope under low tension, which does not occur with these culture methods with the possible exception of spat-catching (see Section 1.3 footnote in the main report).
- Although we were uncertain in our assessment, we considered that entanglement potential may be an issue of some importance for macroalgal culture. The buoyancy of seaweeds compared to invertebrates means that culture lines may be under less tension, thereby increasing risk. However, this is a matter that needs to be further considered once farming methods are known.
- Entanglement was not considered relevant for on-ground culture.

A2.3.2 Habitat exclusion or modification

This subcategory describes the potential for aquaculture to exclude the use of a marine habitat or modify it in such a way that it is of less (or altered) value to marine mammals (e.g. through negative impacts on a food source or negative food web impacts). The issue is not well understood, but generally the relative scale of impacts can be expected to be related to: (i) the relative magnitude of water column and benthic effects; and (ii) the extent to which farming methods physically exclude the use of space (i.e. when comparing conversion at a given farm of a specific size). On the basis of these criteria, our general assessment is that relative impacts are likely to be greatest for finfish aquaculture (e.g. fish farms completely exclude water column habitat use, and greatly modify benthic habitat). At the other end of the spectrum we would expect impacts to be non-existent or negligible for on-ground culture. All other forms of aquaculture were rated as having potential for low relative effects. Of course, where methods are unknown (especially the spatial configuration of elevated structures), there is associated uncertainty.

A2.3.3 Attraction (e.g. to wild or farmed fish, farm waste, structure)

The attraction of wildlife in general to marine farms can arise for a variety of reasons. For example, farms may attract small fish (e.g. for waste feed, habitat), which itself attracts other wildlife. For marine mammals specifically, attraction is most likely to arise for prey fish that aggregate around farms, especially the 'reef' structure provided by 3-dimensional floating culture systems. However, actual effects will be specific to the different mammal species and the way they interact with aquaculture. For example, mussel farms are actively used by certain dolphin species for hunting prey fish, and seals use finfish farm structures for haul out, except where predator nets exclude them. Where seals can gain access, they will prey on farmed fish stock. On the other hand, the attractant effect for many whale species is more likely to be neutral. Lights and noise may also have attractant (or deterrent) effects, but these issues are considered separately (see below).

On the basis of such interactions, we expect the relative importance of attraction effects to be as follows:

- Greatest for cage finfish culture due to presence of wild or farmed prey fish. Seals may also have a haul-out opportunity.
- All forms of subtidal floating line culture are likely to attract wild prey fish to some extent (Morrisey et al. 2006), and therefore, certain mammal species, although we were less certain about the scale of such effects for sponge aquaculture. We were also unclear whether the effects of floating line systems would be comparable to seaweed farms; on one hand the seaweed could provide a complex habitat (e.g. for fish recruitment), but on the other the culture zone would be shallower (due to light requirements for photosynthesis) than many floating invertebrate culture systems (i.e. less of an artificial 'reef' effect).
- We assume that attractant effects of marine mammals in relation to elevated and on-ground culture will be low, reflecting a weak 'reef' effect. However, this is a consideration for further assessment.

A2.3.4 Noise and artificial light

As indicated in Appendix 1, noise levels generated at marine farm sites can be continuous at finfish farms (e.g. the hum of a generator at a salmon farm) which are staffed and operated continuously, but are expected to be intermittent for all other forms of aquaculture (e.g. vessel and machinery noises during crop checking, maintenance or harvesting). Surface and submerged artificial lighting is used at finfish farms for personnel operations, and to reduce the risk of early maturation prior to harvest and assist in evenly distributing the fish in pens. All other forms of aquaculture have only intermittently flashing lights, which are used to aid night-time navigation and safety.

The nature and significance of artificial noise and light effects are not well understood for marine mammals, with both attraction (direct and indirect) and deterrence possible, depending on species. Attributes such as sound volume, sound frequency, light intensity and direction, and duration of exposure are possibly all important considerations. As such, the scores in Table 3 of the main report simply reflect the potential relative effect of noise and light among aquaculture types, considering the amount of noise or light produced by each. On this basis:

- Cage finfish culture has by far the greatest potential effect, due to the fact that fish farms are continuous operations with permanent staff, with noise generated from multiple sources (e.g. feed distribution tubes, vessels, harvest equipment).
- For all other types of aquaculture, the potential for noise and light effects is relatively low-to-negligible. Noise is intermittent during vessel visits, and lighting is needed only to identify farms for navigational safety purposes (e.g. a mussel farm usually has an intermittently flashing light on each corner).

A2.4 SEABIRD INTERACTIONS

The general considerations for seabird interactions, including recognition of the bird-specific nature of the interactions, are the same as for marine mammals, and the same subcategories are relevant. The main findings of our assessment are:

- Entanglement is of greatest relevance to cage finfish cultures where birds can occasionally be entangled in exclusion netting. It is a minor consideration for all other types of aquaculture.
- The potential for habitat exclusion or modification mirrors that for marine mammals; i.e. it is greatest for caged finfish aquaculture and far less for other types.
- In terms of the seabird attraction effect:
    - We did not discriminate between finfish and other floating culture methods. All types have surface structures that provide roosting habitat for seabirds (e.g. shags, terns), and both attract potential prey fish.
    - Intertidal oyster culture was given an intermediate score. Oyster racks provide bird habitat in various ways; for example roosting and foraging during low tide.
    - We assume that elevated subtidal and on-ground culture methods would have only a limited seabird attractant effect (e.g. perhaps attraction to aggregations of prey fish).
- Artificial noise and light effects were rated the same as for marine mammals (i.e. greatest effect due to caged finfish culture) for the same reasons given above.

A2.5 WILD FISH INTERACTIONS

The subcategories of effect relevant to wild fish interactions are the same as for marine mammals and birds, with the exception of entanglement which is not a significant consideration. Again, the nature of the interactions depends on the particular fish species and the way they interact or are influenced by aquaculture. Key findings from our assessment are as follows:

- The potential for habitat exclusion or modification is expected to be relatively high for caged finfish aquaculture; for example, because of pronounced impacts on benthic habitats. We also expect a moderate relative effect from floating, elevated and on-ground shellfish aquaculture systems, due primarily to benthic habitat change.
- The attraction of wild fish is assumed to be stronger in all cases of floating aquaculture, but strongest for finfish cages because of fish attraction to waste feed or wild and cultured fish (e.g. shark attraction to certain salmon farms in Marlborough). Attraction may also be relatively strong for mussel farms. This assessment reflects that snapper predation on cultured mussels in the Hauraki Gulf is believed to be significant. However, all floating culture systems develop considerable biofouling, which provides habitat (e.g. food, shelter) for a range of wild finfish species.
- We assume that elevated and on-ground culture methods would have a limited fish attractant effect by comparison with floating systems, due to the lesser 'reef' effect they create. However, the types of species attracted may differ among different systems; for example, pelagic fish for floating systems vs bottom-feeding fish for elevated on-ground systems (e.g. rays are known to prey on geoduck).

Additional considerations for aquaculture and wild fish interactions relate to the spread of disease and the effects of escapees; however, these are considered separately below.

A2.6 BIOSECURITY

Aquaculture activities can result in biosecurity risk in a number of ways, in particular:

- The movement of vessels, or the transfer of juveniles and equipment (e.g. among facilities or growing regions), can lead to the accidental spread of pests and diseases to marine farms.
- The farm operation can provide an environment where certain pests and diseases can flourish, which in turn may be a reservoir for spread to the wider environment.

Table 3 of the main report does not provide relative scores for biosecurity risk across the different species-method scenarios. The reason is that the nature and extent of risk in all cases is specific to the operational activities of the industry and, in the case of disease, the particular aquaculture species and the farm environment. Moreover, the risk profile can dramatically change; for example, according to operational changes or the emergence of new disease threats. Accordingly, risk needs to be assessed case-by-case in light of the most up-to-date information available.

In New Zealand at present, aquaculture species have different risk profiles with respect to disease. For example, both the Pacific and flat oyster sectors are currently having to contend with disease agents that have significantly impacted these industries, whereas GSM aquaculture has not yet experienced significant disease issues (Castinel et al. 2014; Castinel et al. 2015). The potential for disease to be a significant issue with some of the emerging species is poorly understood, although disease issues are reported for sea cucumber aquaculture overseas (MPI 2013). Even less well understood are the implications for the wider ecosystem resulting from the emergence of disease in sea-based aquaculture.

A2.7 ESCAPEE AND GENETIC EFFECTS

Our assessment considered the potential for ecological effects from escapees, and changes to the genetic structure/fitness of wild populations. These are complex issues as discussed by MPI (2013). In the case of genetic effects, species and situation-specific assessment is required, and would need to consider the population range of the farmed species, the genetic distinctiveness of sub-populations, and the operational practices that could lead to effects (e.g. long distance stock movements, hatchery breeding programmes). Our assessment of the potential for ecological effects from escapees considered both the adult farmed organism and the release of planktonic reproductive life-stages (i.e. life-stages that enable spread to the wider environment). Our findings are as follows:

- We considered the potential ecological effects to be most significant in a relative sense for non-indigenous species. For example, Pacific oysters typically become abundant in natural habitats in estuaries where they are farmed, and can dramatically alter natural estuarine environments.
- We gave the lowest scores to all other species except non-salmonid native finfish, which we gave an intermediate rating. The rationale for the latter was that predatory species such as yellowtail kingfish perhaps have the potential to exert adverse ecological effects if they escape in high numbers.
- Disease transmission is an additional escapee issue that needs to be considered, but requires case-by-case assessment as part of the biosecurity theme.

A2.8 EFFECTS FROM ADDITIVES

The main actual or potential sources of contamination from sea-based aquaculture stem from the following:

- additives included in feed, such as dietary zinc in salmon aquaculture, which can accumulate in seabed sediments
- leaching of chemicals (trace metals) from farm structures, which is relevant for oyster racks constructed from treated timber, and finfish farm cages/pontoons that are coated in antifouling chemicals
- effects from therapeutant compounds or treatment chemicals used to prevent or manage disease, or respond to biosecurity incursions

- contaminants may be introduced by vessels, with perhaps minor other sources such as greywater discharge (e.g. from accommodation facilities in continuously-operating finfish aquaculture operations).

Our scoring reflected the greater potential for contamination in finfish culture due to zinc or other trace elements in feed, the possibility that antifouling paints will be used on structures, and the likely use of various compounds to manage disease risk (e.g. for treating fish stock or sterilising equipment). We gave intermediate scores to intertidal oyster culture on the basis that treated timber racks are used, although any effect may be quite small.

We gave the same intermediate scores to some of the emerging species, but were highly uncertain about these; e.g. unclear as to the materials used in elevated culture methods for geoduck and toheroa. MPI (2013) note that the intensive cultivation of sea cucumbers may induce outbreaks of diseases, requiring the use of therapeutants (mainly antibiotics). In the event that artificial feed was used for pāua (i.e. rather than macroalgae) and sea cucumber culture, the issue of additives should also be considered.

A2.9 HYDRODYNAMIC ALTERATION OF FLOWS

Farming structures may lead to changes in the surrounding environment through the alteration of water flows (e.g. altered direction, reduced current speeds) and dampening of wave action. Our simplifying assumptions were as follows:

- Effects are likely to be relatively greater for caged finfish culture given that the nature of the cage structures and their greater potential to impede or alter water movement.
- We would expect floating longline and intertidal rack culture to have intermediate effects on water currents, given that there is spacing between lines/racks for water flow. However, orientation of subtidal floating lines perpendicular to waves could lead to an increased dampening effect.
- Subtidal and on-ground culture methods presumably have minimal potential for significant hydrodynamic effects, although local scale scouring may occur around intertidal or near-seabed structures (MPI 2013).

For some of the emerging bivalve species that are farmed in floating culture systems, some possible farm configurations were considered by Gibbs et al. (2006). That assessment suggested that present mussel farms occupy a greater cross-sectional area than is expected to be the case for other emerging methods but, as noted in the main report, may not accurately depict all future farming methods. Nonetheless, for certain methods (e.g. surface ‘Rotoshell’ methods; Figure 1D of main report) it is clear that the cross-sectional area is relatively small. Accordingly, farming of new bivalve species may be expected to have comparable or lesser effects on hydrodynamics.