Environment Waikato Technical Report 2008/50

Assessment of the Potential Impacts on Waders and Seabirds of Finfish Marine Farming in the Firth of Thames

www.ew.govt.nz
ISSN 1172-4005 (Print)
ISSN 1177-9284 (Online)

Prepared by:
Paul Sagar, NIWA

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

October 2008

Document #: 1388718

Approved for release by:
Peter Singleton Date Nov 2008

Disclaimer

Taihoro Nukurangi

Assessment of the potential impacts on waders and seabirds of finfish marine farming in the Firth of Thames

NIWA Client Report: CHC2008-094
October 2008

NIWA Project: EVW009501

Assessment of the potential impacts on waders and seabirds of finfish farming in the Firth of Thames

Paul Sagar

Prepared for

Environment Waikato

NIWA Client Report: CHC2008-094
October 2008
NIWA Project: EVW009501

National Institute of Water & Atmospheric Research Ltd
10 Kyle Street, Riccarton, Christchurch
P O Box 8602, Christchurch, New Zealand
Phone +64-3-348 8987, Fax +64-3-348 5548
www.niwa.co.nz

Contents

Reviewed by:	Approved for release by:
Niall Broekhuizen	John Zeldis

Executive Summary

Currently, Environment Waikato is scoping a possible plan change to allow for the diversification of aquaculture within existing aquaculture management areas in the region. This plan change would allow for the cultivation of species other than mussels, including finfish. This assessment is one of several studies commissioned as part of the information gathering and consultation phase of the aquaculture plan change. The primary objective of this study is to:

> Evaluate the impact of new types of aquaculture, such as kingfish farming, on waders and seabirds, and their habitat.

Key findings are:

(1) A total of 132 species of birds have been recorded from the Firth of Thames, primarily in the vicinity of Kaiaua/Miranda, at the north-western section of the Ramsar site. Of these, about 60 species are either abundant or common, the remainder being occasional or rare visitors.

(2) The Firth of Thames is of international importance for the numbers of Arctic-breeding bar-tailed godwits (*Limosa lapponica*) and red knot (*Calidris canutus*) and endemic pied oystercatchers (*Haematopus finschi*), pied stilts (*Himantopus leucocephalus*), black stilts (*Himantopus novaezelandiae*), NZ dotterels (*Charadrius obscurus aquilonius*) and wrybills (*Anarhynchus frontalis*) that it supports. All of these species forage on the intertidal mudflats. Of these, the species of conservation concern are black stilt (threat status B.1 Threatened - Nationally Critical); NZ dotterel and wrybill (B.3 Threatened - Nationally Vulnerable); pied stilt and pied oystercatcher (both D.1 At Risk – Declining).

(3) Of the species that forage in open water, some feed on small fish either taken near the surface of the sea by plunge diving (e.g., Australasian gannet *Morus serrator*, Caspian tern *Sterna caspia*, white-fronted tern *Sterna striata*) or from greater depths by swimming underwater (e.g., pied shag *Phalacrocorax varius*, spotted shag *Stictocarbo punctatus*). Other species dive to feed on a range of small fish, crustaceans, and cephalopods (e.g., flesh-footed shearwater *Puffinus carneipes*, blue penguin *Eudyptula minor*) and others take mainly crustaceans from the surface of the sea (e.g., red-billed gull *Larus noveahollandiae scopulinus*, black-billed gull *Larus bulleri*). Among these, the species of conservation concern are black-billed gull (B.2 Threatened – Nationally Endangered); caspian tern, red-billed gull and pied shag (B.3 Threatened – Nationally Vulnerable); white-fronted tern, flesh-footed shearwater and blue penguin (D.1 At Risk – Declining).

(4) Waders within the Ramsar site may be affected indirectly via changes to habitats and invertebrate prey species caused by nutrient release driving primary production. Such effects could be either positive or negative. Positive effects may occur if any increase in

phytoplankton production causes an increase in prey productivity. Negative effects could occur if an increase in nutrient levels led to either/or an increase in mangrove expansion, blooms of intertidal macroalgae, changes in the phytoplankton community that affected invertebrate prey species, severe eutrophication that affected the functioning of the intertidal ecosystem.

(5) However, these indirect effects are likely to be localised, and so not have any significant effects on the Ramsar site.

(6) Seabirds may be directly affected by entanglement, habitat exclusion, disturbance associated with farm activities, and increased prey availability with wild fish attracted to farms.

(7) Entanglement risk is well-managed in areas of New Zealand where marine salmon farming occurs, and so this is should be a minor risk that can be monitored effectively. Exclusion will be limited to the farm footprint. Limited anecdotal observations indicate that some seabirds become habituated to vessel movements and disturbance associated with finfish farming activities. Increased prey availability could become an additional food source of penguins, shags, gulls and terns. In addition, for some species, particularly shags, gulls and terns, marine farming structures are likely to provide roosts closer to the foraging areas of these birds resulting in them having to expend less energy commuting to the feeding areas. Overall, the potential consequences of these cumulative effects are likely to be minor.

1. Introduction

1.1. Background

In 1999, Environment Waikato amended the Regional Coastal Plan to establish the Wilson Bay Marine Farming Zone and set policy for the management of aquaculture. The rules included in this plan allowed for shellfish farming and research, but prevented farming and research on other species, such as finfish.

Marine farming may only occur within Aquaculture Management Areas (AMA) identified in a Regional Coastal Plan. There are now 1500 ha allocated to marine farming within the Waikato Region and nearly 900 ha of this has been developed already for mussel and oyster farming.

A number of new aquaculture species have been tested in New Zealand laboratories and some are ready for sea trials. This includes kingfish and, potentially, groper, snapper, seahorses, lobsters, seaweeds, and sponges. Environment Waikato is concerned that preventing aquaculture of new species could impede innovation and growth in the industry.

Consequently, in 2005 Environment Waikato established a work programme to consider developing policy which enables the trial and subsequent production of new species. If a plan change is adopted, it is envisaged that it will add rules to the Regional Coastal Plan which allow new types of aquaculture to be trialled in existing AMAs to determine their environmental sustainability and economic viability. Should trials prove successful and establish environmental sustainability of the activity, plan provisions will provide for full scale development.

This assessment is one of several studies commissioned as part of the information gathering and consultation phase of the aquaculture plan change.

The primary objective of this study is to:

> Evaluate the impact of new types of aquaculture, such as kingfish farming, on waders and seabirds, and their habitat.

The scope of the study is limited to a desktop assessment of the potential effects that a change from mussel/oyster farming to new types of aquaculture (in particular, fish farming) may have on waders and seabirds in the Waikato Region.

The assessment identifies:

1. The species of waders and seabirds most likely to be affected by changing from oyster/mussel culture to farming fish of other species;

2. The potential effects on each species of bird (e.g., attraction, leading to entanglement).

3. The likely risk of each effect occurring and a qualitative estimate of the severity/nature of its ecological consequences (taking into account the behaviour, life history characteristics, distribution, and rarity of each species).

Particular note is made of any potential impacts of new types of aquaculture on wader and seabird use of the Firth of Thames Ramsar site.

1.2. Brief overview of ecological effects of finfish farming

Typically, finfish are farmed in cages or pens suspended in the water column from the surface by buoys. The main impacts of finfish farming on the marine environment occur through the accumulation of waste products – usually as faeces or uneaten food – on the sediment in the vicinity of the cages (Giles 2007).

In a review of the considerable scientific literature on the seabed effects of salmon farming in New Zealand and overseas Forrest et al. (2007) concluded that the effects on the seabed are often highly localised and largely reversible in the medium to long term. Furthermore, they also concluded that while the ecological significance of impacts on the local seabed may be relatively high, in absolute terms the broader consequences can be mitigated by appropriate site selection.

Where large-scale new finfish farming developments were proposed, Forrest et al. (2007) noted that cumulative and threshold effects should also be considered and as an example cited the potential for nutrient enrichments to lead to algal bloom formation.

Finally, all the reviews of the potential ecological effects of finfish farming on the marine environment have emphasised the need for site-specific assessments (e.g., Pearson & Black 2001; Hargrave et al. 2005; Forrest et al. 2007). Consequently, in this review emphasis is placed on studies specific to the Firth of Thames, where these are available.

2. Methods

This assessment is a desk-top review of the potential ecological effects of finfish aquaculture on birds in the Firth of Thames, with particular reference to wading in the Miranda Ramsar site, and is based on the following information sources:

(a) Scientific papers, published texts, unpublished reports and university theses;

(b) Aquatic Sciences and Fisheries Abstracts for 1960- July 2008;

(c) *OSNZ news* and *Southern Bird* for 1977-2008;

(d) eBird NZ reporting system developed for the Ornithological Society of New Zealand (http://ebird.org/content/newzealand)

(e) Birding-NZ website (http://groups.yahoo.com/group/BIRDING-NZ/messages).

Given that any development of finfish aquaculture in the Firth of Thames would be based in areas currently approved for shellfish aquaculture, this assessment assumes that birds which use the marine ecosystem up to the extreme high water of the Firth may be affected by any potential ecological changes. Consequently, terrestrial species are not considered in this assessment.

3. Miranda Ramsar Site

3.1. Bird species

The Firth of Thames was designated a Ramsar site in 1990 on the basis of its importance to migratory waders. The Ramsar site comprises the intertidal area of the southern and western shores of the Firth of Thames between Kaiaua and the west bank of the Waihou River, near Thames (Battley & Brownell 2007). The boundary of the Ramsar site is defined by the extremes of mean low water spring tides (MLWS) and mean high water spring tides (MHWS), and covers 8500-9000 ha (Battley & Brownell 2007). This intertidal area comprises mudflats and mangrove (*Avicennia marina*) communities, the latter now covering much of the upper reaches of the intertidal zone.

A total of 132 species of birds have been recorded from the Firth of Thames, primarily in the vicinity of Kaiaua/Miranda, at the north-western section of the Ramsar site (Battley & Brownell 2007). Of these, about 60 species are either abundant or common in the Firth of Thames, the remainder being occasional or rare visitors. Some 35,000 waders (including about 11,000 waders that breed in the Arctic from Siberia to Alaska) use the intertidal Ramsar site each year, with most occurring along the vicinity of Miranda and along the coast farther to the south and east (Battley & Brownell 2007). The Firth of Thames is of international importance for the numbers of Arctic-breeding bar-tailed godwits (*Limosa lapponica*) and red knot (*Calidris canutus*) and endemic pied oystercatchers (*Haematopus finschi*), pied stilts (*Himantopus leucocephalus*), black stilts (*Himantopus novaezelandiae*), NZ dotterels (*Charadrius obscurus aquilonius*) and wrybills (*Anarhynchus frontalis*) that it supports (Dowding & Moore 2006; Melville & Battley 2006). Of these, the species of conservation concern are black stilt (threat status B.1 Threatened - Nationally Critical); NZ dotterel and wrybill (B.3 Threatened - Nationally Vulnerable); pied stilt and pied oystercatcher (both D.1 At Risk – Declining) (Miskelly et al. in press).

The tidal flats exposed at low tide in the Firth of Thames provide important feeding grounds for the waders (Battley & Brownell 2007) with the shallow mud and silt of the tidal flats providing a habitat for polychaetes (worms), shellfish, crabs and shrimps, all of which are food items of the waders. The feeding ecology and diets of the main species of waders occupying the Miranda Ramsar Site are summarised in detail in Battley & Brownell (2007). However, these authors also note that specific information about the feeding ecology of waders in New Zealand is limited, with most of the information coming from studies completed in the Northern Hemisphere. In addition, Battley & Brownell (2007) noted that five studies, all with limited coverage, provide an overview of the benthic invertebrates present in the Miranda Ramsar Site, with some indications of distribution and abundance.

3.2. Current risks to the Miranda Ramsar Site

Stakeholder concerns over the possible effects of the proposed Western Firth shellfish aquaculture developments on the Miranda Ramsar Site led to the development of a hazard assessment and investigation of risk pathways through the use of a Bayesian network model and a complex systems model (Gibbs 2006). Although that study did not address finfish aquaculture, it’s results are summarised below to provide a background to subsequent material in this report.

- There were multiple pathways through which the proposed farm may interact with the wetland; including changes to primary productivity, detrital pathways and sediment dynamics.

- The ability of the habitat to support waders was shown to be non-linearly dependent upon habitat size and quality.

- Shellfish feed on planktonic organisms in the water column, therefore, there is a potential for the proposed farms to influence standing stock/production rates of plankton in the wader habitat. However, the network model suggested that habitat quality was not strongly dependent on primary production rates in the water-column. Therefore, along with the predicted low depletion of phytoplankton within the shellfish farm this result suggests that a reduction in phytoplankton would have a less than minor influence on the ability of the habitat to support waders.

- There is a risk that pest species may colonise the mussel farms and then disperse naturally to the Miranda Ramsar Site.

- Best estimates of the influence of the proposed mussel farms on sediment transport processes suggest that this interaction will be minor.

- Terrestrial factors such as the generation and delivery of sediments, organic material and nutrients appear to have the greatest influence on wader habitat.

Subsequently, Elmetri & Felsing (2007) used the Relative Risk Model (RRM) to investigate multiple risks to the ecology of the Miranda Ramsar site, with the primary objective to assess the relative threat posed by different risk sources. The findings of this study were similar to those reported by Gibbs (2006), who used a Bayesian Network Model and a Complex Systems Model to investigate risks of proposed aquaculture development on the carrying capacity of waders at the Miranda Ramsar site.

With respect to the waders in the Miranda Ramsar Site, the RRM found that (after Elmetri & Felsing 2007):

- The greatest stressor on the biological system as a whole (including the benthic invertebrates preyed upon by waders) appeared to be from terrestrial drivers, and included the generation of sediments, contaminants, habitat loss, invasive species, and nutrients.

- Agricultural land use (dairy farming) contributed by far the largest risk, with climate change posing a similar level of risk in the worst-case scenario.

- Sedimentation was the biggest stressor, with the largest sources being agricultural land use and sediments already in the Firth of Thames; the greatest risk of sedimentation was to the tidal flats at the Miranda Ramsar Site.

- Highest risks among biological values were to shellfish beds, some fish species, and polychaetes. Consequently, the second highest risk was found to be to some waders, through changes in the abundance of their main prey.

The large-scale effects and changes demonstrate the potential for terrestrial inputs to alter the coastal environment significantly. Increased sedimentation into the ecosystem causes a decrease in species diversity and reduces the overall ecological heterogeneity, resulting in displacement of benthic species, disruption of predator-prey cycles, decrease in food abundance, and shifts in community structure (Gibbs and Hewitt 2004). Benthic invertebrates adapt much more readily to smothering by sediment of similar grain size and organic content than to sediment where these characteristics are different (Cummings et al. 2003). In the Firth of Thames, it is the input of organically rich terrestrial sediments with a significantly greater proportion of fine grain size that have caused changes in the distribution and abundance of benthic invertebrates (Battley & Brownell 2007). Monitoring studies of Stage 1 shellfish aquaculture development at Wilson Bay (about 200 ha of a projected 1200 ha at a site across the Firth of Thames from the Miranda Ramsar Site) identified some near-farm effects on benthic communities and plankton depletion (Zeldis et al. 2005). However, these effects are unlikely to influence invertebrate populations targeted by waders in the Miranda Ramsar Site (Elmetri et al. 2005, Gibbs 2006, Zeldis et al. 2005, Elmetri and Felsing 2007). However, the potential for cumulative effects of marine farming in the Firth of Thames remains uncertain, particularly as the projected expansion progresses (Battley and Brownell 2007).

Application of the RRM also highlighted that the largest source of uncertainty in the risk assessment was the lack of data or scientific knowledge and understanding. With respect to waders, the main sources of uncertainty were (after Elmetri and Felsing 2007):

- Data for climate change, particularly the combined effects of predicted sea level rise and subsidence in the Firth of Thames and the effects of these on the extent of intertidal habitats.

- Sediment budget for the Firth of Thames, quantifying annual sediment loads from the land, and the size of the sediment reservoir in the Firth basin.

- An estimate of the size of roosting and feeding habitat available to waders, particularly with respect to mangrove expansion.

- The quantification of nutrient concentrations and their sources in water and sediments of the Miranda Ramsar Site.

- Benthic micro- and macro-algal growth limitation at the Ramsar site.

- Quantification of the biosecurity risks to the Miranda Ramsar Site from marine farming at Wilson Bay.

- Quantification of the biosecurity and other risks to waders at the Miranda Ramsar Site from terrestrial invasive species, such as rodents, mustelids and cats.

3.3. Potential effects of finfish farming on birds at the Miranda Ramsar site

Pelagic phytoplankton and benthic algae are the corner stones of the food web involving intertidal invertebrates and their wader predators (Battley and Brownell 2007). The feeding habits and diet of the most abundant species of waders in the Firth of Thames Ramsar Site are reviewed by Battley & Brownell (2007) and show that molluscs (bivalves) and polychaetes (worms) are the principal prey. Substrate composition and size of prey are important determinants of the utilization of these benthic invertebrates by wading birds. Therefore, will finfish farming affect substrate composition and invertebrate prey abundance within the intertidal zone of the Miranda Ramsar Site?

The information presented above indicates that in contrast to shellfish aquaculture, finfish farming in the Firth of Thames is likely to increase pelagic phytoplankton production, through an increase in nutrient inputs, and decrease benthic algal production through smothering effects of uneaten food and fish faeces. However, the latter will be a highly localised effect (Broekhuizen et al. 2002; Zeldis 2008). Therefore, the key concerns for the Miranda Ramsar Site associated with finfish farming are the extent of the effects on benthic production, and the extent of the effects of nutrient increase on pelagic phytoplankton production and the potential for phytoplankton blooms. The latter two could result in shading of benthic algae in the intertidal zone. In a discussion of the potential wider effects of shellfish aquaculture farms in the Firth of Thames Broekhuizen et al. (2002) identified the key issue as not being whether these effects occur in the immediate vicinity of the farms, but rather: how quickly (in time) and where (in space) they become dissipated.

3.3.1. Extent of effects on benthic production

In an exploration of the benthic carrying capacity of the Firth of Thames for finfish farming Giles (2007) concluded that ecologically significant benthic effects were unlikely to extend more than 100 m beyond the farm. Furthermore, Giles (2007) recommended that since the largest change of most parameters examined took place within about 50 m of the farm and the gap between farm blocks in Area A (of Wilson Bay) is 75 m, then a 50 m buffer zone between the outermost cages inside a farm block and the perimeter of the block was an adequate estimate of the buffer zone for initial applications.

3.3.2. Extent of effects of nitrogen discharges

Nutrient release from fish farms is likely to promote phytoplankton production and may affect macro- and micro-algal production. Zeldis (2008) compared nitrogen (N) discharges into the Firth of Thames originating from uneaten food and dissolved and faecal metabolic waste relative to Firth-wide loading from rivers and the ocean, biogeochemical processes (primary production and denitrification), and potential removal through mussel harvest. He concluded that depending on their size of operation, finfish farms could substantially increase nutrient inputs into the Firth of Thames. On a Firth-wide scale, the flow-on effects of these increases could range from insignificant to significant, with localised impacts being somewhat greater. However, Zeldis (2008) cautioned that it was difficult to draw definitive conclusions regarding how farm-derived nutrients might influence broader ecosystem processes.

The flow-on effects for benthic macrofauna, including wader prey species, are therefore unknown. However, they could be neutral (if primary productivity in the RAMSAR site is not significantly affected), positive (by increasing the food supply for prey species and therefore prey productivity), or negative (e.g. if macroalgae blooms occurred or prey abundance decreased). Further information on the magnitude of nutrient inputs, and the likely pathways for nutrient and biological flows, is required before the effects on prey and bird species can be adequately determined.

4. Risk and ecological consequences of identified effects within the Ramsar site

This section considers the likely risk of the identified effects from section 3, and the ecological consequences to those species of most conservation concern. In determining possible ecological consequences, the conservation status, distribution and relevant ecological characteristics of each species are considered. A summary of potential effects, risks and likely consequences are listed in Table 1.

Table 1: Summary of potential impacts of finfish farming on wading birds in Ramsar site

Effect	Impact	Potential consequences	Context of impact
Changes in phytoplankton and benthic microalgae productivity affecting invertebrate prey	Increase or decrease in invertebrate prey	Unknown	Increased microalgae productivity may benefit birds by enhancing prey productivity, while changes in benthic community composition may be beneficial or detrimental.
Blooms of intertidal algae	Reduction in area for feeding waders	Significant	Additional nutrients from fish farms could increase the risk of macroalgae blooms, which negatively affect birds. However, the occurrence of macroalgae blooms is very unpredictable. Note that land derived nutrients dominate the system and are expected to increase substantially in the future.
Increase in mangrove expansion	Reduction in area available for benthic feeding waders	Significant	Mangrove expansion in the FoT does not appear to be related to nutrients, so it is assumed that fish farms will not affect birds through the promotion of mangrove growth.
Severe eutrophication affecting functionality of intertidal ecosystem	Reduction in invertebrate prey	Significant	Fish farms may cause localised enrichment, but widespread eutrophication extending to the RAMSAR site is unlikely. Note that land derived nutrients dominate the system and are expected to increase substantially in the future.

4.1. Changes to foraging areas and invertebrate prey through phytoplankton and macroalgal productivity

Waders forage primarily on intertidal mudflat invertebrate communities and obtain their food from the surface or by probing. Within the Firth of Thames, the review of the extent of the effects on benthic production (Giles 2007) indicates that direct benthic impacts are most likely to be limited to the marine farming site and a small distance beyond. Consequently, waders foraging in the Miranda Ramsar site and other intertidal areas of the Firth of Thames are unlikely to be directly affected by any reduction in benthic production as a result of waste deposition from finfish farms.

Currently, water quality of Firth of Thames is significantly enriched and its productivity is probably substantially higher than historically (Zeldis 2008). These conditions probably explain why mussel and zooplankton production are high (Zeldis and Francis 1998, Zeldis et al. 2005). Therefore, at lower farmed finfish production rates (1,000-3,000 t fish annum^{-1}), nitrogen enrichment resulting from aquaculture would be concentrated within the immediate farming zone and be relatively small relative to Firth-wide inputs from rivers and terrestrial sources (Zeldis 2008). However, at higher farmed finfish production rates (10,000 t fish annum^{-1}) nitrogen inputs would be relatively significant compared to Firth-wide inputs (Zeldis 2008), and so presumably have the potential to increase pelagic phytoplankton production and also affect benthic production (through a combination of nutrients promoting growth and reduced light levels inhibiting growth) in intertidal areas.

Limitations to pelagic phytoplankton and macroalgal (such as *Ulva* - as has occurred in Tauranga Harbour or *Gracillaria* – as has occurred in Kaipara Harbour) growth in intertidal areas at the Miranda Ramsar site were identified as one of the largest sources of uncertainty in the RRM (Elmetri and Felsing 2007). Consequently, the estimates of nitrogen input to the Firth of Thames resulting from various levels of finfish farming by Zeldis (2008) add further support for the recognition of the potential adverse effects of increased nutrient loading on waders reliant upon the intertidal invertebrate community.

The international importance of the Miranda Ramsar site is based upon the numbers of wading birds counted at high tide roosts, but relatively little is known about where these birds forage and the prey that they consume (Battley and Brownell 2007). Intertidal areas are relatively small and are utilised by a large number of wading birds and humans for food gathering. Some of the waders that roost within the Miranda Ramsar site may forage on mudflats outside the Ramsar site - perhaps in areas that are closer to designated marine farm zones. Although there are no extensive intertidal areas near the marine farming zone they may still provide important feeding areas for wading birds. These sites may be more affected by any increase in nitrogen availability and potential phytoplankton blooms. If so, such a situation increases the uncertainty about the potential effects of finfish farming on internationally recognised and populations of bar-tailed godwits, red knots, pied oystercatchers, pied stilts, black stilts, New Zealand dotterels, and wrybills.

4.2. Changes to foraging areas through expansion of mangroves

Mangrove expansion in the southern Firth of Thames since the 1930s has been attributed to the advance seawards of the mudflats in which they live (Morrisey et al. 2007). Elevated nutrient loadings (particularly nitrogen) enhance the growth rate of mangrove plants, but there is no conclusive evidence that nutrients are the main cause of the observed expansion. If the influence of nutrients on mangrove expansion in the Firth of Thames is assumed to be negligible, then it can also be assumed that fish farms are unlikely to affect wading birds in the RAMSAR site by promoting mangrove growth.

5. Outside the Miranda Ramsar site

5.1. Bird species

There is no comprehensive report about the species and occurrence of birds in the Firth of Thames away from the Miranda Ramsar site. However, Bull et al. (1986) and Robertson et al. (2007) provide information about the species of birds that occur in the Firth of Thames, and the Hauraki Gulf State of the Environment Report 2008 Update provides a list of seabirds that occur in the wider Hauraki Gulf. Of the species reported, some feed on small fish either taken near the surface of the sea by plunge diving (e.g., Australasian gannet *Morus serrator*, Caspian tern *Sterna caspia*, white-fronted tern *Sterna striata*) or from greater depths by swimming underwater (e.g., pied shag *Phalacrocorax varius*, spotted shag *Stictocarbo punctatus*). Other species dive to feed on a range of small fish, crustaceans, and cephalopods (e.g., flesh-footed shearwater *Puffinus carneipes*, blue penguin *Eudyptula minor*) and others take mainly crustaceans from the surface of the sea (e.g., red-billed gull *Larus noveahollandiae scopulinus*, black-billed gull *Larus bulleri*). Among these, the species of conservation concern are black-billed gull (B.2 Threatened – Nationally Endangered); caspian tern, red-billed gull and pied shag (B.3 Threatened – Nationally Vulnerable); white-fronted tern, flesh-footed shearwater and blue penguin (D.1 At Risk – Declining) (Miskelly et al. in press).

5.2. Potential effects of finfish farming on seabirds

In New Zealand, reviews of the potential effects of finfish farming on seabirds have focussed on Chinook salmon (*Oncorhynchus tshawytscha*) in the Marlborough Sounds, Akaroa Harbour and Stewart Island. Additional information comes from several studies of the potential impacts of mussel farms. A summary of potential effects, risks and likely consequences are listed in Table 2.

Table 2: Summary of potential impacts of finfish farming on seabirds

Effect	Impact	Potential consequences	Context of impact
Entanglement	None reporded in NZ; cormorants drowned in sea cages overseas.	Unknown	Entanglement risk minimised by current management practices
Exclusion	Surface feeders such as gulls, terns and shearwaters excluded.	Insignificant	Unlikely to have an impact because of large foraging range of these species.
Changed prey abundance	Aggregations of small fish may benefit shags, penguins and terns.	Unknown	In conjunction with on-site roosts could have significant beneficial effect for shags and terns.
Provision of roosts	Floating structures recognised as providing safe roosting sites close to foraging areas	Unknown	In conjunction with access to aggregations of small fish could have significant beneficial effect for shags and terns.

5.2.1. Entanglement, habitat exclusion and disturbance

There are very few studies and only a handful of reports on the direct impact of finfish sea cage structures on wildlife. The generally perceived negative effects of both shellfish and finfish sea-cage aquaculture on seabirds have centred on entanglement (resulting in birds drowning), habitat exclusion, and displacement from feeding grounds. For example, in a study of the possible effects of a large mussel farm on king shags (*L.eucocarbo carunculatus*) in the Marlborough Sounds Lalas (2001) concluded that the most commonly anticipated negative effects (entanglement and avoidance of feeding grounds due to increased boat traffic) were largely unfounded. Instead, he concluded that king shags may actually benefit from a new and additional food source as the birds took advantage of small pelagic fish attracted to the marine farm. Butler (2003) was also concerned about the potential loss of feeding habitat for king shags in areas where large marine farms were developed, particularly with respect to the loss of habitat for flounders, one of the main prey species of king shags. However, there was insufficient information to determine whether this was a significant risk, and whether factors such as the attraction of other fish species to feed on detrital food from the farm, mitigate adverse effects by providing an alternative food source.

Lloyd (2003) reviewed the potential effects of mussel farming on New Zealand's seabirds and marine mammals. He identified possible effects (detrimental or beneficial) as entanglement, ingestion of foreign objects, changed foraging success, exclusion spread of pathogens or pest species, and creation of roosting places. However, there are no reports of seabird death as a result of entanglement in fixed lines used in mussel farms and spat catching areas. In addition, although marine litter, particularly plastics is ingested by many seabirds and can cause death by dehydration, gut blockage or toxins released in the intestines, its availability to seabirds can be mitigated by management practices of marine farming operations.

Despite the absence of reported deaths due to entanglement in New Zealand finfish farming operations, drowning of birds (most commonly cormorants) after entering sea cages has occurred overseas (Iwama et al. 1997). However, the deployment of top nets over sea cages to exclude birds appears to be an effective management procedure.

5.2.2. Aggregation of prey and provision of roosting sites

Of the possible effects, changes in foraging success of species that feed in open water on schooling fish (e.g. white-fronted tern) is most likely to be correlated to the area physically occupied by any marine farming operation. Likewise, marine aquaculture provides new roosting sites (usually on buoys supporting sea cages) and increased fish activity (not only the fish inside the sea cages, but also those attracted to the detrital fish food) in the immediate vicinity attracts, and possibly benefits, some bird species (Lalas 2001), with shags, gulls and terns the species most likely to benefit from additional roosting sites.

In a review of the ecological effects of marine finfish aquaculture in New Zealand Forrest et al. (2007) concluded that none of these potential effects is well understood. In addition, they noted that if any adverse effects on habitat exclusion or modification do occur, then their significance will depend on the spatial scale of the finfish farming operation in relation to the distribution and abundance of prey species.

In summary, changes in foraging success may be positive, or negative, depending upon the species. Some species (e.g., flesh-footed shearwaters and gannets) may not be prepared to forage close to farms and will be forced to forage elsewhere. Fortunately, individuals of all these species naturally forage over very large areas. Unless Wilson Bay region is of unusually high foraging value (there is no evidence either way on this), exclusion from that small part of their natural range is unlikely to change their overall foraging success markedly. On the other hand, the foraging success of species that are prepared to forage close to farms (e.g., white-fronted terns, shags) may actually rise.

5.3. Significance of effects on seabirds outside the Ramsar site

In the absence of reports of entanglement of seabirds in finfish farming gear elsewhere in New Zealand this is unlikely to occur in the Firth of Thames, and so the consequence are likely to be insignificant.

The main possible detrimental effects of finfish aquaculture appear to be changed prey availability through exclusion by farm structures and changed prey abundance through ecosystem disruption. Some seabirds, particularly shearwaters, prefer open water and are likely to avoid areas with aquaculture farm structures. However, such seabird species exhibit extreme energy efficiency and cover large areas of open sea when foraging. For example, a tracking study of flesh-footed shearwaters breeding on Lady Alice Island, off Whangarei, showed that these birds covered much of the Hauraki Gulf as well as outer Firth of Thames when searching for food (primarily small fish) to feed their chicks (NIWA, unpublished data). Consequently, marine farm zones within the Firth represent a small proportion of their overall foraging range, and so it is likely that the risk to such seabirds would be insignificant.

Species that forage closer to the coastline (such as shags, gulls and terns) are known to feed around structures, including mussel farms (P.M. Sagar, pers. obs). Increases in the abundance and diversity of some prey species around mussel farms have been documented (Grange 2002), and shoals of small fish are likely to be attracted to finfish farm structures for shelter and to feed on detrital food. Consequently, this may increase the abundance of prey species of penguins, shags, gulls and terns, and so be beneficial to these species, although the consequences are unknown.

6. Research recommendations

For many of the identified impacts discussed here a comprehensive risk assessment is hampered by a lack of information about the distribution and use made of the Firth of Thames by birds. Of particular concern is the need to know where (both within the Miranda Ramsar site and elsewhere within the Firth of Thames) the waders of most conservation concern (black stilt, NZ dotterel, wrybill, pied oystercatcher, pied stilt) forage, and the prey which they consume. Likewise, little is known of the food and feeding of seabirds of most conservation concern outside the Ramsar site (black-billed gull, Caspian tern, pied shag, white-fronted, flesh-footed shearwater, blue penguin, red-billed gull).

Therefore, it is strongly recommended that systematic surveys of the Firth be undertaken to determine:

1. Habitat use by wading birds and seabirds of conservation concern;

2. The species composition and size range of prey they consume;

3. The distribution and size range of prey species that are available to the birds.

7. Conclusions

This desk-top review has identified that the main uncertainty concerning the potential effects of finfish farming on wading and seabirds in the Firth of Thames is associated with the spatial scale and significance of increased nitrogen inputs. Because increased nitrogen has the potential to decrease benthic algal growth on intertidal areas that are used by foraging species of conservation concern it is important to determine if and where any such effects may occur.

The other risks identified include entanglement, habitat exclusion, and disturbance. In general, such risks are likely to be minor or insignificant. However, although the general issues of the potential effects of finfish farming are recognised and well understood, site-specific effects are likely to be determined by spatial scale and site location. Although a high rate of finfish production could add significant inputs of nutrients to the Firth of Thames ecosystem, the potential effects of this situation on prey availability for seabirds are likely to be small and can be minimised by management. However, finfish farming is known to attract shoals of small, wild fish, and so these could become an additional food source of penguins, shags, gulls and terns. Thus this form of marine aquaculture could benefit these seabirds. In addition, for some species, particularly shags, gulls and terns, marine farming structures are likely to provide roosts closer to the foraging areas of these birds resulting in them having to expend less energy commuting to the feeding areas.

8. Acknowledgements

I thank Chris Gaskin for providing a provisional list of seabirds in the Hauraki Gulf. This report benefitted from my discussions with John Zeldis, and by comments from Niall Broekhuizen on a draft of this report that substantially improved the final product.

9. References

Battley, P.F.; Brownell, B. (2007). Population biology and foraging ecology of waders in the Firth of Thames – update 2007. Auckland Regional Council Technical Publication No. 347. November 2007.

Broekhuizen, N.; Zeldis, J.; Stephens, S.A.; Oldman, J.W.; Ross, A.H.; Ren, J.; James, M.R. (2002). Factors related to the sustainability of shellfish aquaculture operations in the Firth of Thames: a preliminary analysis. *NIWA Client Report EVW02243*.

Bull, P.C.; Gaze, P.D.; Robertson, C.J.R. (1986). The atlas of bird distribution in New Zealand. Ornithological Society of New Zealand, Wellington.

Butler, D.J. (2003). Possible impacts of marine farming of mussels (*Perna canaliculus*) on king shags (*Leucocarbo carunculatus*). DOC Internal Series 111, Department of Conservation, Wellington.

Cummings, V.; Thrush, S.; Hewitt, J.; Norkko, A.; Pickmere, S. (2003). Terrestrial deposits on intertidal sandflats: sediment characteristics as indicators of habitat suitability for recolonising macrofauna. *Marine Ecology Progress Series 353*: 39-54.

Dowding, J.E.; Moore, S.J. (2006). Habitat networks of indigenous shorebirds in New Zealand. Science for Conservation 261, Department of Conservation, Wellington.

Elmetri, I.; Felsing, M. (2007). Application of the Relative Risk Model (RRM) to investigate multiple risks to the Miranda Ramsar Site. Environment Waikato Technical Report 2007/22.

Elmetri, I.; Gibbs, M.; Landis, W. (2005). Application of the Relative Risk Model (RRM) to investigate risks of a proposed aquaculture development in the Firth of Thames. Cawthron Report No. 1058.

Forrest, B.; Keeley, N.; Gillespie, P.; Hopkins, G.; Knight, B.; Govier, D. (2007). Review of the ecological effects of marine finfish aquaculture: Final report. Prepared for the Ministry of Fisheries. Cawthron Report No. 1285.

Gibbs, M. (2006). Application of Bayesian network model and a complex systems model to investigate risks of a proposed aquaculture development on the carrying capacity of shorebirds at the Miranda Ramsar wetland. Environment Waikato Technical Series 2007/04.

Gibbs, M.; Hewitt, J. (2004). Effects of sedimentation on macrofaunal communities: a synthesis of research studies for ARC. *NIWA Client Report HAM 2004-060*.

Giles, H. (2007). Baysian network analysis exploring the benthic carrying capacity for finfish farming within the Firth of Thames. *NIWA Client Report HAM2007-172*. December 2007.

Grange, K. (2002). The effects of mussel farms on benthic habitats and fisheries resources within and outside marine farms, Pelorus Sound. *NIWA Client Report NEL2002-03*. March 2002.

Hargrave, B.T.; Silvert, W.; Keizer, P.D. (2005). Assessing and managing environmental risks associated with marine finfish aquaculture. *Handbook of Environmental Chemistry* Vol. 5, Part M: 433-461.

Iwama, G. K.; Nichol,L.; Ford, J. (1997). B.C. Salmon Aquaculture Review Interim Draft Report. Key Issue D: Aquatic Mammals and Other Species. B.C: Environmental Assessment Office.

Lalas, C. (2001). Evidence presented for Kuku Mara Partnership, Forsyth Bay. Environment Court Hearing, Blenheim, Statements of Evidence Volume 1. October 2001.

Lloyd, B.D. (2003). Potential effects of mussel farming on New Zealand's marine mammals and seabirds: a discussion paper. Department of Conservation, Wellington.

Melville, D.S.; Battley, P.F. (2006). Shorebirds in New Zealand. *Stilt 50*: 295-303.

Miskelly, C.M.; Dowding, J.E.; Elliott, G.P.; Hitchmough, R.; Powlesland, R.G.; Robertson, H.A.; Sagar, P.M.; Scofield, R.P.; Taylor, G.A. (in press). Conservation status of New Zealand birds. *Notornis*.

Morrisey, D.; Beard, C.; Morrison, M.; Craggs, R.; Lowe, M. (2007). The New Zealand mangrove: review of the current state of knowledge. Auckland Regional Council Technical Report 325.

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

Robertson, C.J.R.; Hyvönen, P.; Fraser, M.J.; Pickard, C.R. (2007). Atlas of Bird Distribution in New Zealand 1999-2004. Ornithological Society of New Zealand, Wellington.

Zeldis, J. (2008). Exploring the carrying capacity of the Firth of Thames for finfish farming: a nitrogen mass-balance approach. *NIWA Client Report: CHC2008-02* June 2008.

Zeldis, J.; Francis, R.I.C.C. (1998). A daily egg production method estimate of snapper biomass in the Hauraki Gulf, New Zealand. *ICES Journal of Marine Science 55*: 522-534.

Zeldis, J.; Oldman, J.; Ballara, S.; Richards, L. (2005). Physical fluxes, pelagic ecosystem structure, and larval fish survival in Hauraki Gulf, New Zealand. *Canadian Journal of Fisheries and Aquatic Sciences 62*: 593-610.