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# Application of the Relative Risk Model (RRM) to Investigate Multiple Risks to the Miranda Ramsar Site

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# Executive Summary

This report presents the application of the Relative Risk Model (RRM) to investigate multiple risks to the ecology of the Ramsar site in the southern Firth of Thames. The application of this model is part of the multi-agency collaborative 'Muddy Feet Phase II: the Firth of Thames Ramsar site' project, which is co-ordinated by Environment Waikato and Franklin, Hauraki and Thames Coromandel District Councils.

The primary objective of the application of the RRM to the Ramsar site is to assess the relative threat posed by different risk sources, and their stressors, to selected ecological values of the Ramsar site and surrounds.

The Relative Risk Model (RRM) is an analytical tool, which can be used to help decision-making. The process adopted by the Muddy Feet Phase II project was to use the RRM as a framework for a series of workshops discussing potential risks to the Firth of Thames Ramsar site. All known information was integrated into the RRM, which was used to predict the risks to the Ramsar site from various stressors and sources.

The RRM can utilise both precise information and estimates to rank the likely effects of different activities or stressors (*e.g.* nutrient runoff from agricultural land use) on various parts of the environments (*e.g.* intertidal or subtidal areas). Thus, all information available can be integrated into the model, and the model output provides an overview of the relative importance of different risks to the values (*e.g.* birds, fish and vegetation) identified by stakeholders. This makes the model a potentially valuable and cost-effective tool to facilitate the decision-making processes by management agencies. In particular, it provides an initial low effort overview of relative sources of stress on the environment which can be used to focus later efforts, through direct management actions and/or determining where more information is required.

Collaborators on the project include the four principal District Councils of the catchment draining into the southern Firth of Thames (Franklin, Hauraki, Matamata Piako and Thames Coromandel District Councils); Environment Waikato and Auckland Regional Council; the Department of Conservation and the Ministry of Fisheries. Representatives from these agencies participated in workshops where ecological values of the Ramsar site and surrounds were identified, as were stressors and sources of stressors that may threaten the site. A workshop was also held for members of the community, where values of the Ramsar site and perceived threats to these were recorded. Iwi values were incorporated through an analysis of submissions to Environment Waikato policy over the last six years, and feedback on these was sought in a hui.

These discussions were essential for the RRM-building process. Following the identification of agencies and community values and concerns, the RRM was constructed around those values and concerns.

The RRM structure consists of three components:

1. **Sources**: represent activities (*e.g.* sewage discharge, agriculture practices) that produce risks through one or many stressor(s) (*e.g.* chemical contaminants, sedimentation, habitat loss), referred to in this study as **Sources of Stressors**.
2. **Habitat**: represents the areas or sections within the region where the ecological values (*e.g.* species of birds and fish) live and which they use, referred to here as **Habitats**.
3. **Ecological Impact**: represents the impact on the management goals such as ecological, biological or other environmental values that we want to protect (*e.g.* the continued survival and well-being of various species of plants and animals, as well as water and air quality). These management goals are denoted **Assessment Endpoints** here.

The RRM provides a characterisation of the problem (indication of the relative importance of the risks identified), not specific answers (which may be, indirectly, in the form of recommendations for management responses which could reduce risks). However, the ranking of risks in terms of importance provides essential information which will help decision-making. Further, the use of the RRM as a framework provides a process which allows participants to communicate about, and agree on, management goals and threats to these, based on all available information. As more information becomes available, the RRM can be made more accurate and uncertainties reduced. This process can be documented and made available to interest groups, other agencies and the public.

Overall the RRM results indicated that the region is already under pressure from a number of existing sources of stressors, particularly agricultural land use. Where limited information was available, or uncertainty about impacts of some sources in an area was high (*e. g.* for urban and industrial land use, marine farms, mangrove expansion, and climate change), two different scenarios were modelled. These scenarios represent predicted risk based on best present day knowledge and worst case scenario, respectively. Predicted risk represents the likely predicted risk based on best knowledge available, and worst case risk represents worst case risks where some sources are given relatively high scores (due to the possibility that (a) they could increase and have major ecosystem impacts in the near future; or (b) the current risk may be underestimated due to limited knowledge).

The predictions of the RRM for the Ramsar site and its catchment found that:

- The greatest stressor on the biological endpoints appears to be from terrestrial drivers, including the generation and delivery of sediments, contaminants, habitat loss, invasive species and nutrients. Agricultural land use (dairy farming) contributed by far the largest risk to the Ramsar site. Climate change, Firth of Thames sediments, point sources, fishing, urban and industrial land use, and mangrove expansion posed lesser but important risks.
- In the worst case scenario, the risk posed by climate change was similar to that of agriculture land use, both by far exceeding risks posed by other sources.
- In both scenarios, the relative risks from all other sources were quite low.
- Sedimentation was found to be the biggest stressor, and the largest sources of sediments were agricultural land use and sediments already in the Firth of Thames.
- The greatest habitat risk was to the tidal flats of the Ramsar site.
- Lower, but relatively important risks existed for the water column, the sub-tidal seabed, and stilt ponds.
- Mangroves and open coastal areas were shown to be at relatively low risk, and the relative risk to the airspace used by birds was very low.
- At highest risk among the biological values were shellfish beds, some fish species and marine worms.
- The second highest risk was found to be to some shorebirds, the area important for creating the Chenier bank, saltmarsh, and other fish species.
- Whitebait (inanga and smelt) and water quality were at medium risk, and vegetation only marginally exposed to salt water influences (bachelor's button, sedges, Maori musk, burmedic short grassland, and ryegrass), and the coastal birds (shags, heron and banded rail) and mud crabs were at the lowest risk.

The high risk score predicted from agricultural land use is not surprising considering the extensive dairy farming that dominates the catchment. In particular, the terrestrial sediment loads and their accumulation in the coastal marine environments of the Firth of Thames contribute the major environmental risk to the Ramsar site. Whilst sediment supply rates from land are thought to be relatively low at present, the sediment reservoir in the Firth (built up from decades of high sedimentation rates from the catchment) is thought to be fuelling the recent dramatic expansion of the mangrove forests. These large-scale effects and changes demonstrate the potential for terrestrial inputs to significantly alter the coastal environment, and highlight the fact that even if sediment runoff from land is reduced, trends of increasing sedimentation could continue to occur for a while because of the storage of sediments in the Firth.

The highest loads of sediments, contaminants and nutrients are often associated with seasonal or periodic flood events. The frequency of these flood events may change with global climate change effects, which is why the worst case scenario predicted that climate change can also be a large contributor of risk to the region.

Overall the application of the RRM to the Ramsar site was useful. The work confirmed that the RRM is a rapid, powerful, flexible and cost effective tool that can provide an overview of the relative risks to a site from multiple sources, generating outputs that resource managers can likely use to aid decision-making. The overall scope of this study was to establish the RRM as a tool for the Ramsar site management. This tool can be used, and expanded upon, by management agencies and other stakeholders. The model used a number of stressors and environmental values that are likely to be representative of most stakeholder concerns, but these can be modified easily with new input. As such, the RRM results presented here are considered a starting point for discussion and a guide to prioritise management actions.

The largest uncertainty source found in this risk assessment was the lack of data or scientific knowledge and understanding. As future studies fill these data and information gaps, uncertainty will be reduced. Based on our review of the available information for the site as well as the Monte Carlo uncertainty analysis, we created a list of the most pressing information needs that we think would aid in the development of future studies to help reduce the uncertainty and above all aid in the sustainable management of the Ramsar site. They are:

- Data for climate change, particularly the combined effects of predicted sea level rise and subsidence in the Firth of Thames, and an assessment of the effects of sea level rise on the extent of the habitats considered in this report.
- Sediment budget for the Firth of Thames, quantifying annual sediment loads from the land, and the size of the sediment reservoir stored in the Firth basin.
- Estimate of the size of roosting and feeding habitat available to shorebirds; investigations determining whether mangrove expansion reduces the size of habitat available for shorebirds or whether the intertidal area seaward of the mangroves is building up at rates similar to the expansion of mangroves.
- Further investigations determining the sources and likely effects of the elevated mercury concentrations found in sediments at the mouth of the Piako River.
- Quantification of nutrient concentrations in water and sediments of the Ramsar site, a quantification of the major sources of nutrients, and assessment of any likely effects of nutrient enrichment on the components of the Ramsar site.
- Phytoplankton or algal growth limitation at the Ramsar site.
- Effects in the wider Firth from nutrient and sediment discharges.
- Quantification of the biosecurity risks to the Ramsar site from the marine farming at Wilson Bay.
- Quantification of the biosecurity and other risks to the Ramsar site from terrestrial invasive species, such as rodents, mustelids and cats.

Following on from the risk assessment described in this report, the Muddy Feet Phase II project proceeded to identify priority actions to reduce key risks to the Ramsar site. This was achieved through identifying what can be done to minimise each of the risks included in the model, and who should do it, and comparing this to what management agencies are currently doing or have plans to do in the near future. Actions not covered by existing work programmes were prioritised, as were any information needs identified, and recommendations provided to all agencies involved. The results from this part of the project are reported in Brownell (in press).

# 1 Introduction

This report presents details of the application of a Relative Risk Model (RRM) to investigate the multiple risks to the ecology of the Ramsar site in the southern Firth of Thames.

In 2005, the RRM was applied to the entire Firth of Thames in a pilot study funded by Environment Waikato, Auckland Regional Council and the Ministry for the Environment. The pilot study proved useful in identifying main risks to key species, but at the time it was recognised that the risk analysis would not be complete until the wider community and all agencies involved with the management of activities that might impact on the site were involved with the project. This report describes the application of the RRM to the Firth of Thames Ramsar site as carried out under the multi-agency collaborative 'Muddy Feet Phase II: the Firth of Thames Ramsar site' project.

## 1.1 The Muddy Feet Phase II Project

Prior to the start of the Muddy Feet Phase II project, published information and the results of some fieldwork were published in the Muddy Feet report (edited by Brownell 2004).

The Muddy Feet Phase II project is co-ordinated by Environment Waikato and Franklin, Hauraki and Thames Coromandel District Councils. The project objectives are to:

PART 1: Identify key risks to the Firth of Thames Ramsar site; and

PART 2: Prioritise action and provide recommendations aimed at ensuring the future sustainability of the site.

The risk analysis presented here was undertaken to meet the objective of Part 1 as listed above. The results of this risk analysis have been used in Part 2 of the project. The process and outcomes of Part 2 of the project are described in Brownell (in press).

The project is co-funded by Environment Waikato, Auckland Regional Council, the Department of Conservation, Franklin District Council, Hauraki District Council and Thames Coromandel District Council. Collaborators on the project include all the funding agencies plus the Ministry of Fisheries, Matamata-Piako District Council and the Miranda Shorebird Centre. The Cawthron Institute was engaged to carry out the risk modelling.

## 1.2 Objectives of the Current Study

The primary objective of the present study is to assess the relative threats posed by different risk sources, and their stressors, to selected ecological values of the Ramsar site and surrounds.

This was achieved by:

- Analysing cumulative impacts from multiple sources of chemical and non-chemical stressors to assess relative risk to defined biological endpoints; and
- Examining the confidence in the relative risk estimates using Monte Carlo analysis.

## 1.3 Structure of this report

This report summarises and describes the use of the RRM as an analytical tool, used to help decision-making, to predict the risks to the Ramsar site and as a framework for communication between different management agencies, community groups and science providers.

Background information to the study site is outlined in Section 2. The process and approach of the application of the RRM is detailed in Section 3, and a description of the

RRM can be found in Sections 3 and 4. The methodology and the model outputs obtained using published and unpublished information as well as inputs from management agencies to date are described in Sections 4 and 5. Section 6 concludes with a summary of the output and recommendations arising from the results, discussion of the limitation and usefulness of the model and the process, and an outline of expected follow-up work.

# 2 Background to study area

The southern part of the Firth of Thames (see Figures 1 and 4) is a semi-sheltered coastal embayment of mostly shallow water (<6 m deep). The area is characterised by the extensive intertidal mudflats that form one of the most comprehensive shorebird habitats in New Zealand (Medway 2000), and supports over 80 species of birds, including 49 species of migratory birds (Brownell 2004). Habitats of the area include expanding mangrove forests along much of the coastline, and Chenier banks off Miranda (Woodroffe *et al.* 1983; Brownell 2004). The significance of the southern Firth is highlighted by about 8,500 ha being designated a Ramsar wetland of international importance in January 1990.

The southern Firth is the primary receiving environment for the extensive Hauraki Plains agricultural catchment in the Waikato region. The Hauraki Plains Act (1908) led to the modification of about 32,422 ha of Piako swamp habitat to pasture land, making it one of the most productive and intensive dairy regions in New Zealand. The Hauraki Plains drain into the Firth of Thames via the major Waihou and Piako Rivers, which bring with them sediments, nutrients and fresh water into the Firth waters (EW 2004).

The Firth of Thames, including the Ramsar site, is home to a range of common inshore fish species (*e. g.* snapper, eels, jack mackerel, red gurnard, sand and yellowbelly flounders), many of which are of cultural, recreational and commercial value (EW 2004). The Firth of Thames is also an important juvenile fish nursery – in particular for snapper and spotted dogfish (rig), and a nationally important nursery area for smooth hammerhead shark (Morrison *et al*. 2002; Brownell 2004).

The Firth of Thames once supported extensive Greenshell™ mussel (*Perna canaliculus*) beds. However, a combination of commercial extraction, the loss of suitable habitats, few breeding stock, and an overall decrease in environmental quality has depleted populations and limited their development in the area, leaving only small, isolated patches of mussels (Reid 1969; HGF 2004; Morrison *et al.* 2002).

The high pelagic primary productivity in the Firth of Thames has attracted aquaculture, particularly of the Greenshell™ mussel (*Perna canaliculus*). The main mussel farming in the area is within the Environment Waikato Wilson Bay Marine Farming Zone. Currently, Area A of the Wilson Bay Zone is consented for 470 ha of mussel longlines. Area B of the Zone, once developed, will comprise an additional 520 ha (Figure 1). In addition to this, a number of older smaller sized farms exist on both sides of the Firth (220 ha in Wilson Bay and 45 ha in the western Firth).

The intertidal habitat at the southern end of the Firth is recognised as the most important and perhaps sensitive habitat in the region, primarily due to its biodiversity and productivity, in particular its ability to support considerable numbers of both New Zealand and Arctic migratory shorebirds. Like many coastal areas around the world, the Ramsar site is vulnerable to pollution because of development and population growth and intensive agricultural land uses. Studies have indicated that the Firth of Thames is experiencing symptoms of sedimentation (*e.g.* elevated sedimentation rates, see Hume & Dahm 1992; muddiness, see Nodder *et al.* 2005; mangrove expansion, see Brownell 2004). The discharge of nutrients to the Firth of Thames is high (HGF 2004; Broekhuizen & Zeldis 2006), and studies have found elevated levels of some trace metals (Kim 2007). These issues have generally been attributed to historic and recent land-use changes in the catchment, ranging from the original clearfelling of indigenous forest (for Firth of Thames catchments the effects of clearfelling on sedimentation rates are noticeable from about 1850 (Hume & Dahm 1992)), to current population expansion and development occurring throughout the catchment. Lately, Firth waters have been supporting a growing commercial mussel-farming industry. As a result of the numerous potential threats to the Ramsar site, management agencies have come together in this project to assess and rank the possible effects of existing risks from different activities on the ability of the Ramsar habitats to support selected biological values.

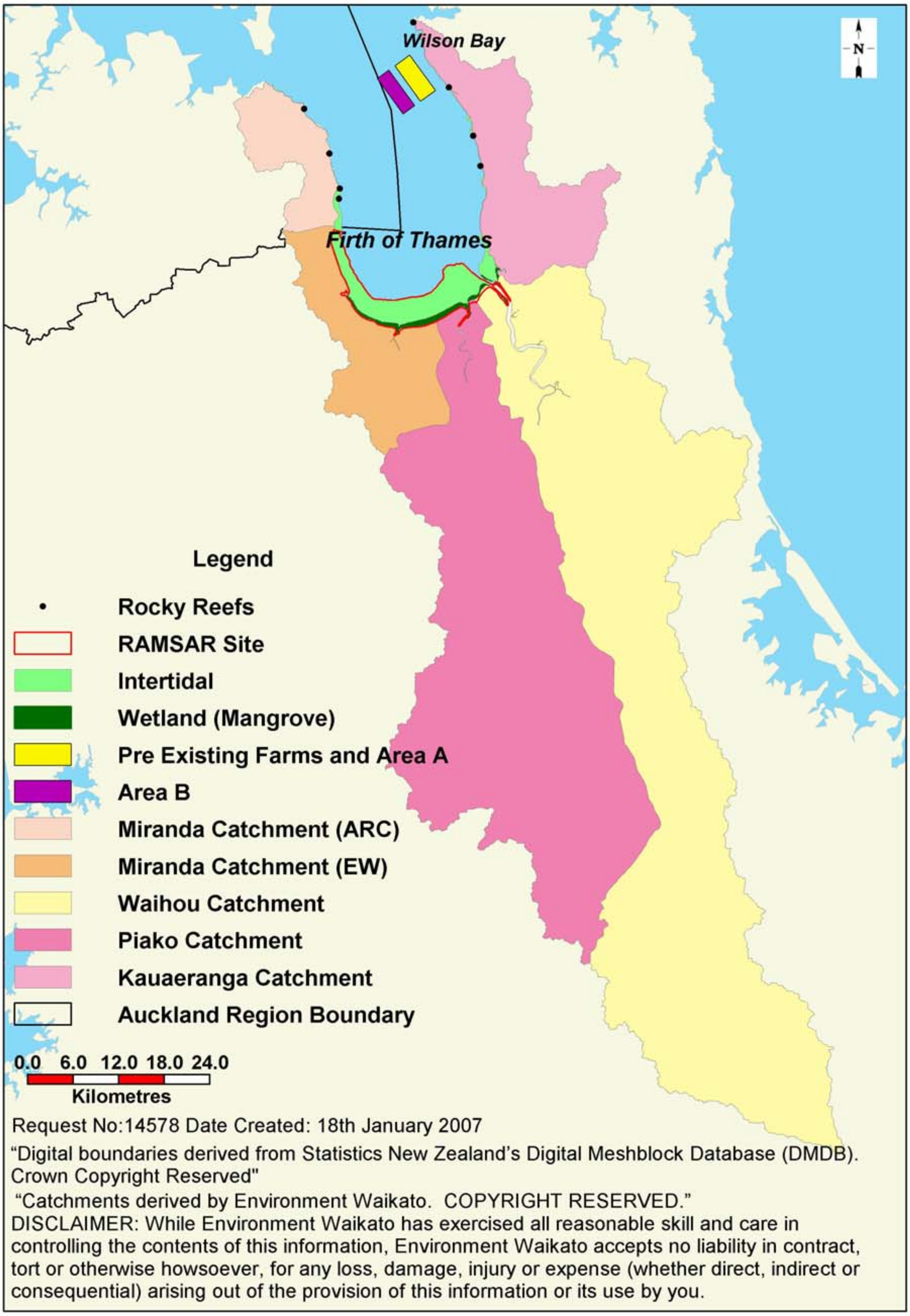

**Figure 1: Ramsar site study area and surrounding sub-catchments.**

# 3 The Relative Risk Model

## 3.1 Project Approach

The approach employed by the project has been to develop and apply a tool to aid decision making which works by characterising and predicting the risks of multiple stressors from many sources, which act via multiple risk pathways at a regional and ecosystem scale. Recently, a risk modelling tool, the Relative Risk Model (RRM), was developed in a pilot study for the Firth of Thames (see Elmetri *et al.* 2005). The RRM can utilise both precise information and estimates to rank the likely effects of different activities or stressors (*e.g.* nutrient runoff from agricultural land use) on various parts of the environments (*e.g.* intertidal or subtidal areas). Thus, all information available can be integrated into the model, and the model output provides an overview of the relative importance of different risks to the values identified by stakeholders. This makes the model a potentially cost-effective tool to facilitate decision-making processes. In particular, it provides an initial low effort overview of relative sources of stress on the environment which can be used to focus later efforts, through direct management actions or determining where more information is required.

The RRM pilot study used existing information and inputs from Environment Waikato and Auckland Regional Council. In the current project, additional management agencies with responsibilities relevant to the Ramsar site have been involved in defining sensitive or valuable habitats, identifying and ranking stressors on these habitats, and determining which ecological and/or biological values the model should consider.

## 3.2 Outline of the Relative Risk Model (RRM)

The RRM (Figure 2) developed by Landis and Wiegers (Landis & Wiegers 1997; Landis 2004) has been used to investigate ecological risks in a number of locations worldwide. While traditional ecological risk assessments often cover only a single stressor such as a chemical and one or few biological species at a limited spatial scale, the RRM approach can address multiple risk pathways by characterising and predicting the risks due to multiple impacts at regional landscape scales. The RRM combines spatial and site-specific technical information into the risk assessment process and provides an integrated picture of risk from multiple stressors. Relative risks and associated uncertainty of estimates are then assessed for specified scenarios, in this case the predicted response of selected ecological and biological endpoints within the Ramsar site and surrounds, to present and future catchment and water use activities.

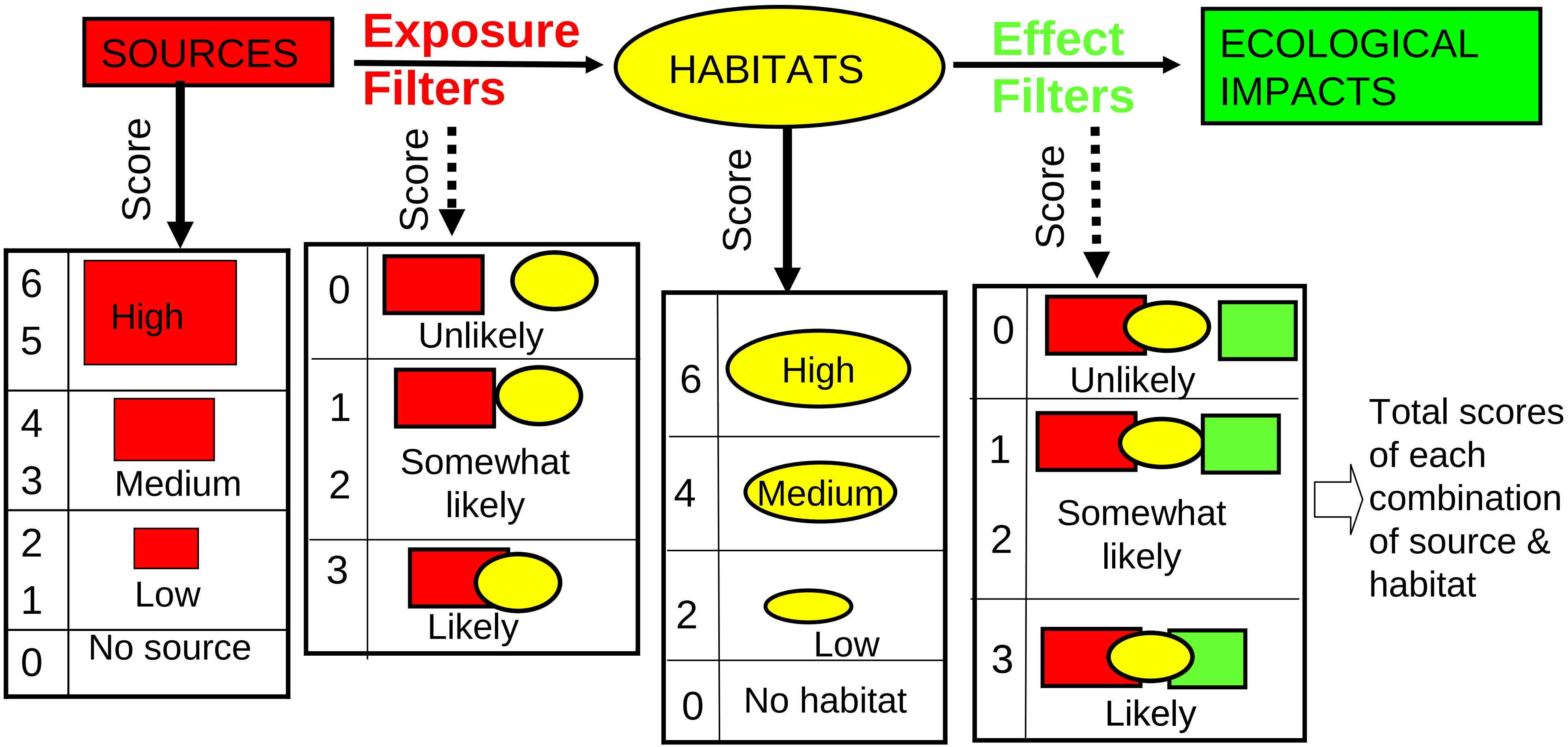


**Figure 2:** **Regional Risk Assessment components (based on Landis & Wiegers 1997)**

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The RRM structure consists of three components (Figure 2):
**Sources**: represent activities (*e. g.* sewage discharge, agriculture practices) that produce risks through one or many stressor(s) (*e.g.* chemical contaminants, sedimentation, habitat loss), referred to in this study as **Sources of Stressors**.
**Habitat**: represents the areas or sections within the region where the ecological values (*e.g.* species of birds and fish) live and which they use, referred to here as **Habitats**.
**Ecological Impact**: represents the impact on the management goals such as ecological, biological or other environmental values that we want to protect (*e.g.* the continued survival and well-being of various species of plants and animals, as well as water and air quality). These management goals are denoted **Assessment Endpoints** here.

In the RRM approach, sources of stressors and habitats are scored for the region under consideration. The contribution of risk from different sources, risks to habitats and risk to assessment endpoints can be calculated by quantitatively determining the interactions between sources, habitats and effects. The relative risks are calculated as follows:

$$RS_{(l;j;m)} = \sum (S_j \times H_l \times X_{jkl} \times E_{lm})$$

Where,
RS relative risk score calculated for region (Ramsar): habitats (*l*); sources (*j*); endpoints (*m*).
*j* source series (agricultural land use, marine farming *etc.* )
*k* stressor series (nutrients, sedimentation *etc.* )
*l* habitats series (intertidal flats, mangroves *etc.* )
*m* biological endpoint series (*e.g.* species of shorebirds, fish, polychaetes *etc.* )
$S_j$ source rank
$H_l$ habitats rank
$X_{jkl}$ exposure filter for each source-stressor-habitat combination
$E_{lm}$ effects filter for each habitat-endpoint combination

The RRM approach is flexible and can be driven at a number of levels, focusing on issues of particular interest and using information from a wide variety of sources. An overview of the process is provided in Section 4.

The RRM provides a characterisation of the problem (indication of the relative importance of the risks identified), not specific solutions (which may be, indirect, in the form of recommendations for management responses which could reduce risks). However, the ranking of risks in terms of importance provides essential information which will help decision-making. Further, the use of the RRM as a framework provides a process which allows participants to communicate about, and agree on, management goals and threats to these, based on all available information. As more information becomes available, the RRM can be made more accurate and uncertainties reduced. This process can be documented and made available to interest groups, other agencies and the public.

# 4 Relative Risk Model methodology

As highlighted in Section 1, the purpose of this regional risk assessment was to provide estimates of the relative contributions of risk from anthropogenic sources to selected management attributes (*i.e.* biological assessment endpoints) within the Ramsar site and surrounds, and to trial the applicability and usefulness of the RRM as a tool aiding management decision making. The specific objectives of the risk modelling component were outlined in Section 1.2.

In the current project, the RRM was used as a framework for discussions between agencies involved with the management of the southern Firth of Thames. Interest groups, wider community and Tangata Whenua inputs were also sought at different stages of the process.

The following sections outline the approach and process of the application of the RRM at a regional scale for the coastal marine area of the Firth of Thames Ramsar site.

## 4.1 Identification of model parameters

An overview of the relative risk modelling process is shown in Figure 3. Each of the steps involved is described in further detail below.

- The key initial phase was to determine the issues of concern to stakeholders and define the scope of parameters to be included. In a series of workshops in 2005 and 2006, stakeholders (community members and representatives from management agencies) defined the study area and the main management goals of interest, namely the protection of selected endpoints (*e.g.* species of birds, fish) or habitats (*e.g.* intertidal flats, water column).
    - At the community and interest group workshop, a wide range of issues and concerns were addressed[1]. These issues included social, economic and cultural values, as well as ecological values. Because the project was funded as an ecological study, focusing on protecting the ecological sustainability of the Ramsar site, the consideration of social and cultural values and how these are best protected was identified to be outside the scope of the project.
    - Tangata Whenua submissions to Environment Waikato were reviewed, and ecological values relevant to the Ramsar site mentioned in these were summarised. The identified values were presented to Tangata Whenua, and their feedback sought, in a hui in 2006. Once broad management goals were defined, potential stressors and habitats relevant to these management goals were identified.
    - In agency workshops, the participants were directly involved in the RRM development and configuration process, by identifying management goals, related habitats, and sources of stressors threatening these. Agencies agreed on preliminary scores denoting the relative extent/importance of habitats and the sources of stressors, and participated in the development of the conceptual models linking the different parameters of the RRM. Changes in these endpoints or habitats were then used in the risk modelling as the criteria against which environmental risk was analysed.

- The relationships between sources, stressors, habitats and endpoints were illustrated in conceptual models, and filters were assigned from available information to outline the relationships between model components. This acted as the foundation for the RRM configuration, and the analysis and risk characterisation assessment. The link between each combination of source of stressors and habitat was defined in an exposure filter (denoting the likelihood of impact), and the link between each combination of habitat and endpoint was defined in an effects filter (denoting the severity of impact).

- The different sources of stressors were scored, based on extent and significance of activity/land use. The habitats were also scored according to their spatial extent and ecological importance. Where limited information was available or uncertainty about future development in an area was high (*e.g.* for urban and industrial land use, marine farms, and climate change), two different scenarios were modelled. These scenarios represent present day risks as assessed by the team, as well as a worst case scenario for the different sources.

- The RRM was then run to predict the relative impact of the different stressors and sources on habitats and endpoints.

[1] See http://www.ew.govt.nz/enviroinfo/coasts/coastalecosystems/ coastallowlands.htm#Heading2

- Finally, Monte Carlo analysis techniques were used to perform uncertainty analysis, to examine the effects of the model and parameter uncertainty on the risk predictions.

As outlined above, the risk assessment process was applied in the context of the conceptual model assessment phases that led into analysis, risk characterisation and uncertainty analysis. The analysis and risk calculation methods used in this study were based on the risk characterisation assumptions of Landis & Wiegers (1997) and Landis (2004):

- The greater the size, frequency or strength of a source in the region, the greater the potential for exposure to stressors.
- The type and density of assessment endpoints is related (directly or indirectly) to the available habitats.
- The sensitivity of receptors to stressors varies between habitats.

The severity of effects in the Firth of Thames Ramsar site area depends on relative exposures and the characteristics of the organisms present.

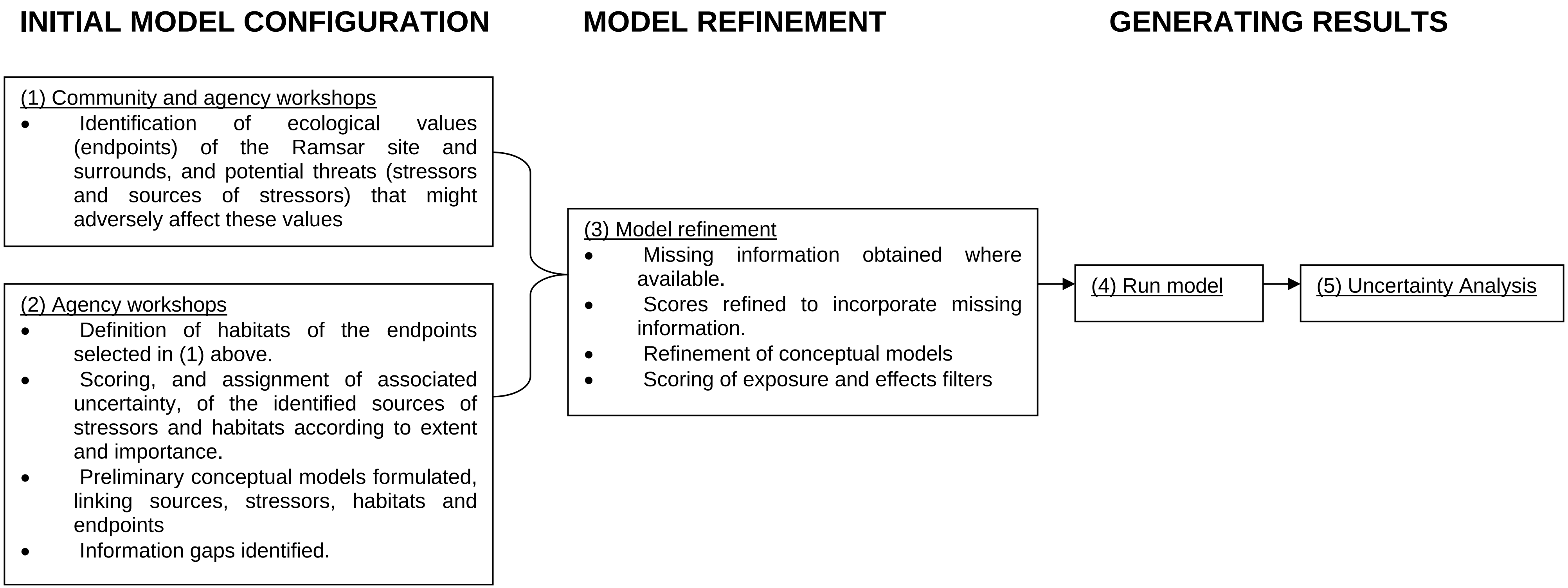


**Figure 3: Flowchart of the process involved with applying the Relative Risk Model.**

## 4.2 Study Area

The study area was selected according to the catchment boundaries draining to the Ramsar site and the wider Firth of Thames, and identified by the GIS layers supplied by EW (Figures 1 and 4). The Firth of Thames catchment encompasses the Kauaeranga, Waihou, Piako, and Miranda sub-catchments. The Miranda sub-catchment crosses the EW and ARC regional council boundary (Figure 1).

## 4.3 Assessment Endpoints

Management goals were identified in the workshops held with community members, management agencies and iwi. These focused on the protection of a series of groups of species of birds, fish, invertebrates and plants, as well as other components of the Ramsar site ecosystem. Seventeen endpoints were selected for the relative risk analysis (detailed in Table 1). These endpoints were selected because they are culturally, biologically and ecologically relevant, and because they are susceptible to site-specific stressors in the Ramsar region. The endpoints are known to utilise the habitats of the study area, have a probability of exposure to, and effects from, potential stressors in the area, and utilise different components of the region's ecosystem. They are also important to the stakeholders in the area, making them relevant to the overall management goals for the Firth of Thames Ramsar site.

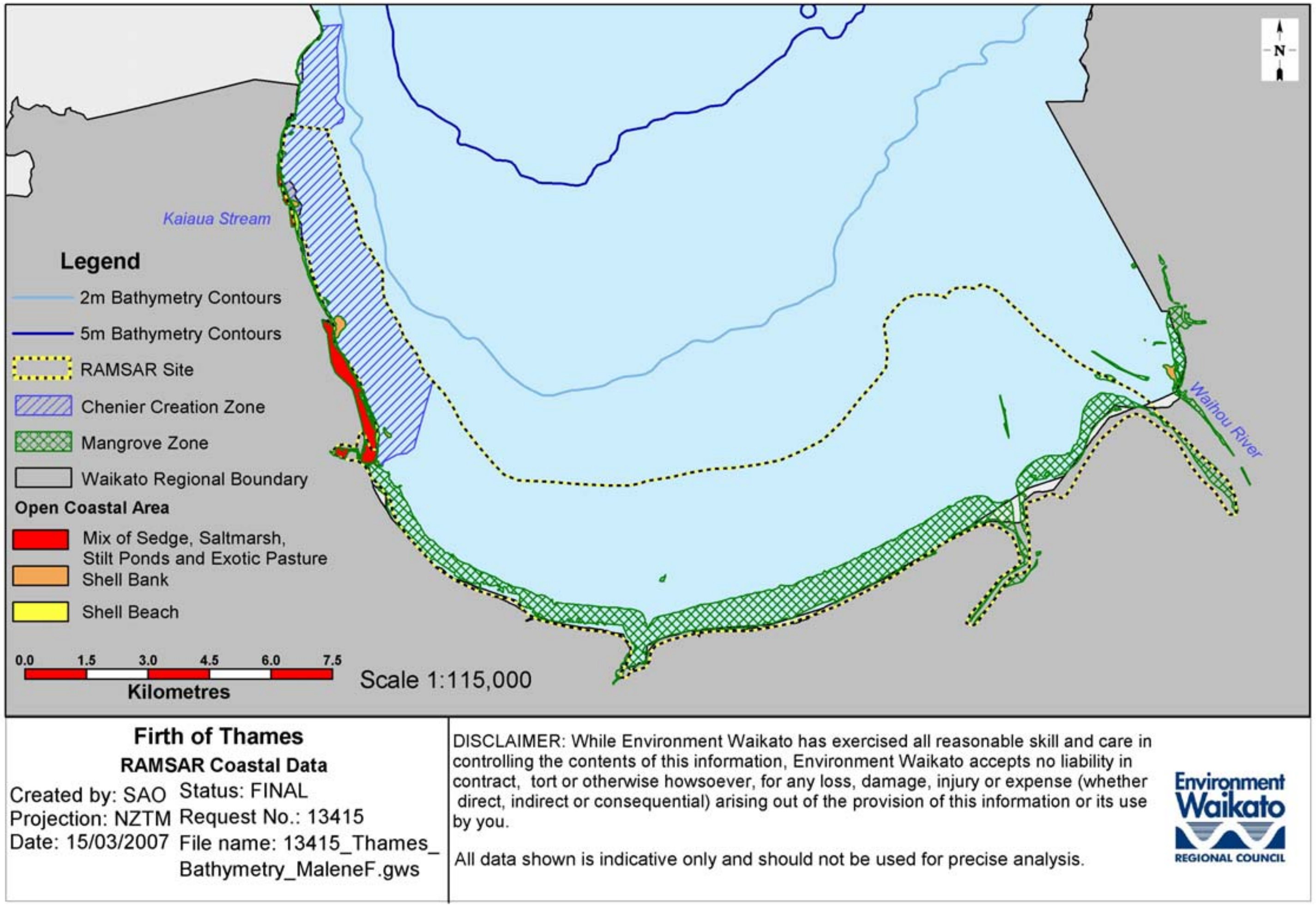


Figure 4. Ramsar site study area divided into habitats.

**Table 1: Endpoints representing the values that need protecting within Ramsar site.**

| Endpoint | Rationale |
|---|---|
| Chenier creation zone | Chenier banks are unique in New Zealand and the Chenier plain in the southern Firth of Thames is one of the world's finest examples of this rare coastal landform. Chenier banks provide protection from coastal erosion, and the Chenier plains provide important habitat for shorebirds. Functioning of the Chenier creation zone is vital for the continued survival of the Chenier system. |
| Bachelor's button, sedges, Maori musk, bur medic short grassland, ryegrass | Indigenous marginal coastal vegetation, grouped together because they tolerate minimal salt water exposure, and are therefore subject to similar stressors. Maori musk is a nationally threatened species (status: sparse). |
| Saltmarsh ribbonwood, mingimingi shrub, glasswort saltmarsh | Indigenous saltmarsh species, grouped together because they tolerate medium salt water exposure, and are therefore subject to similar stressors |
| Pied oystercatcher | Ramsar site is the second most important New Zealand site in winter for pied oystercatchers |
| Bar-tailed godwits, lesser knot, curlew sandpiper | Ramsar site holds 10% of the New Zealand population of lesser knots in winter, and the fifth highest abundance in summer nationally; bar-tailed godwits are migrants present in high numbers at site. Species grouped together because they are international migrants. |
| New Zealand dotterel, variable oystercatcher, black-billed gull, white-fronted tern, Caspian tern | NZ dotterel is endangered, black-billed gull is in serious decline, white fronted tern is in gradual decline, Caspian tern is nationally vulnerable. Ramsar site important for these birds. Species grouped because all are localised (New Zealand) migrants. |
| Wrybill | Site hosts 58% of New Zealand population in winter. |
| Shags, heron and banded rail | Banded rail is classified as sparse. Shag and heron numbers are increasing (Woodley & Brownell, pers. comm. ). Species grouped because they all use mangrove habitat. |
| Pied stilts | The Ramsar site has second highest abundance of pied stilts in winter nationally. |
| Snapper | Snapper juveniles use Ramsar site as habitat. Target species for customary, recreational and commercial fishermen. |
| Yellow belly flounder | Target species for customary, recreational and commercial fisheries. Concentrated within Ramsar site. |
| Small pelagics and kahawai | Mainly sprat, pilchard, yellow-eye mullet and juvenile kahawai. Important food source for seabirds. Target species for customary, recreational and commercial fisheries. |
| Eels | Target species for customary, recreational and commercial fisheries. |
| Whitebait (inanga and smelt) | Found in the Waihou River and to a lesser extent the Piako River. Target species for customary and recreational fisheries. Food source for seabirds and fishes. |
| Shellfish beds (*e.g.* cockles, *Macomona*, *Mactra*, oysters, *Nucula*) | Common bivalves, cultural and recreational importance as food source, important food source for birds and fishes. |
| Polychaetes | Important food source for birds and fishes. |
| Mud crabs | Important food source for birds and fishes. |
| Water quality | Water quality is vital to the functioning of, and impacts on, habitats and assessment endpoints. |

## 4.4 Habitats

The workshop identified seven habitats relevant to the chosen assessment endpoints. Habitat includes not only where an endpoint (*e.g.* biological value) lives or occurs, but also where it feeds and reproduces. The seven habitats selected, and the rationale behind their selection, are listed in Table 2.

**Table 2. Ramsar site habitats selected for use in the Relative Risk Model.**

| Habitats | Rationale |
|---|---|
| Tidal flats within Ramsar site (including shellfish beds and saltmarsh areas, excluding mangrove areas) | Large area (9,236 ha (GIS; Turner & Carter 2004; Brownell *et al.* 2004)) of great importance to birds (Brownell *et al.* 2004). Bird breeding area (Brownell *et al.* 2004). Provide habitat necessary to maintain healthy benthic communities and fish |
| Mangroves within Ramsar site | Large area (approximately 1,084 ha, in March 2002 (Brownell *et al.* 2004)). Important for some endpoints (*e.g.* birds, especially the roosting and nesting of shags, roosting and feeding of herons, Brownell *et al.* 2004) |
| Open coastal areas (bird roosting and breeding areas within Ramsar site, excluding intertidal flats) | Small area (estimated at 180 ha) but vitally important to most of the bird species that frequent the Ramsar site. |
| Stilt ponds | Extremely important bird roosting area (Brownell *et al.* 2004) but small area (estimated total area 10 ha, Woodley & Brownell, pers. comm). |
| Airspace for birds | Small area (although migratory birds can fly at very high altitudes, it was thought that in the vicinity of the Ramsar site they would utilise airspace of up to 500 m of altitude). Airspace near the Ramsar site is important to birds. |
| Sub-tidal soft substrate <2 m: sub-tidal seabed with less than 2 m water depth | Important supply for recruitment of intertidal flat, but small area assumed to supply Ramsar site. The aerial extent of subtidal soft substrate of <2 m water depth shown in Figure 4 is 7,842 ha (GIS; EW 2006). |
| Water column: area of water of less than 2 m depth + pelagic influences on Ramsar site. | Large area (7,842 ha subtidal (Figure 4, GIS; EW 2006) and 9,236 ha intertidal (GIS; Turner & Carter 2004; Brownell *et al.* 2004)). Influences the whole Ramsar site, all endpoints: water provides large proportion of food for benthic communities and the ability for fish to frequent Ramsar site. |

## 4.5 Sources of Stressors

Land use in the Firth of Thames region is dominated by agriculture (dairy farming), and smaller amounts of land are forested, urban and industrial. The Ramsar site is the primary receiving environment for these adjoining land uses, predominantly via the Waihou and Piako Rivers. The Firth of Thames habitats are under increasing pressure from a variety of human activities, including different land use in the catchment, climate change, and the development of large-scale marine farms. For inclusion in the risk model, twelve anthropogenic sources of stressors were selected:

1. Agricultural land use
2. Forests
3. Urban and industrial land use
4. Shipping
5. Fishing
6. Marine farms
7. Point sources
8. Accidental spills
9. Human recreation
10. Climate change

11. Mangrove expansion
12. Firth of Thames sediment

The stressors that could potentially be released by the twelve potential sources listed above and their abbreviation are listed in Table 3*.* The description and rationale behind the selection of these sources of stressors are summarised in Table 4*.*

**Table 3 Stressors resulting from the risk sources.**

| **Stressor Abbreviations** | |
|---|---|
| C | Contaminants |
| N | Nutrients (effects include raised turbidity caused by phytoplankton blooms, toxic algal blooms, opportunistic green macroalgae, changes in phytoplankton community structure) |
| S | Sediments (effects include smothering, turbidity, substrate changes, but not mangrove expansion - this is covered as habitat loss) |
| F | Harvesting and exploitation (fishing) |
| H | Habitat loss (does not include habitat loss caused by sedimentation or nutrient enrichment, but includes *e.g.* habitat loss caused by sea level rise, mangrove expansion, drainage of wetlands *etc.*) |
| D | Disturbance |
| I | Invasive species |

**Table 4** **Sources of stressors for the study area. Stressors included are those acting directly on the Ramsar site, indirect stressors are not considered (e.g. habitat loss outside the area under consideration, causing a potential increase in use of, and need for, the Ramsar site habitats).**

| Source | Stressors associated with source | Source quantification (how much and where?) | Potential effects |
|---|---|---|---|
| Agriculture land use, particularly dairy farming | Sediment, contaminants, nutrient runoff. Spread of invasive weeds, habitat for invasive pest species (*e.g.* rodents, cats, goats). Habitat loss | Pastoral farming occupies 65% of catchment with over half a million dairy cows; giving rise to loadings based on un-attenuated estimates of 7,055 tonnes N, 326 tonnes P, and 40,705 tonnes suspended solids per year to the Firth of Thames, via Piako, Waitoa and Waihou rivers (Elmetri *et al.* 2005). Potential contaminants in agricultural runoff include cadmium (through the use of superphosphate fertiliser), zinc (mainly from that used for facial eczema treatment of livestock), other heavy metals, organic compounds and endocrine-disrupting chemicals such as oestrogen (Sarmah *et al.* 2005). Analysis of the shallow groundwater at Miranda showed high nutrient concentrations draining into adjacent saltmarsh and mangroves (Bryce 1998). Agricultural land use may be a source of terrestrial pests such as wild goats, and also provides suitable habitat for rodents, mustelids and cats. | Increased sediment runoff can lead to decreased primary productivity, and changes in sediment particle grain-size (changing habitat characteristics). There is some evidence that sedimentation has caused severe habitat loss for cockles, pipi and other shellfish at the Ramsar site. Increased nutrient load can lead to eutrophication which may lead to harmful algal blooms and other water quality problems. Contaminants can build up in organisms through the food chain and can cause increased mortality to exposed organisms. Lifestock grazing (*e.g.* in saltmarshes, mangroves) may destroy habitat, spread invasive weeds and cause localised nutrient enrichment. Terrestrial pest species like mustelids and cats have been found to prey on wrybills, variable oystercatcher, white-fronted tern and south Island pied oystercatcher at the Ramsar site (Battley & Moore 2004; Battley, pers. comm.). |
| Forests (indigenous and exotic) | Sediment, nutrient runoff. | Indigenous forests coverage in catchments: 22%; exotic forests: 7-5% (EW GIS 2005). Indigenous forests estimated to contribute 229 tonnes N and 4 tonnes P per year, exotic forests 78 tonnes N and 1 tonne P per year (Elmetri *et al.* 2005). | Even well managed pine plantations lead to increased erosion (associated with clear-felling events) resulting in sediment runoff (Phillips *et al*. 2005). Leakage from the wastewater spray-irrigation used in pine plantations can be a significant contributor to nutrient loads (Vant 2001), however no spray irrigation is currently undertaken in catchments draining into the Firth of Thames. |
| Urban and industrial land-use and development | Sediment runoff from earthworks. Diffuse nutrient and contaminant runoff. Disturbance. Habitat loss. | Does not include point source discharges. Past mining in Coromandel may continue to result in discharge of contaminated leachate (Kim 2007). Sedimentation arising from urban development and land use can be extensive (Hicks 1994). Potential habitat loss resulting from jetty, marina development *etc.* Urban land use is currently limited in extent (Thames is the only larger settlement near coast), but there are potential impacts through urban development further inland reaching site via rivers. At present levels probably not big threat to Ramsar site. Projected population growth is high, so potential for future increase in sedimentation and other runoff. Disturbance to airspace likely from Ardmore Airfield (aerobatics enthusiasts based here). | Increased sediment runoff can lead to decreased primary productivity, and changes in sediment particle size (modifying habitat characteristics). Increased nutrient loads can lead to eutrophication which may lead to harmful algal blooms and other water quality problems. Contaminants can build up in organisms through the food chain and can cause increased mortality of exposed organisms. Aerobatics can cause severe stress to birds in airspace and on mudflats. |

| **Source** | **Stressors associated with source** | **Source quantification (how much and where?)** | **Potential effects** |
|---|---|---|---|
| Shipping (ballast water and boat hulls) | Spread of invasive species, from *e.g.* ballast water and hulls *etc.* Contaminants from ballast water and antifouling | Shipping very small in extent, very few international craft frequent Firth waters, and there are not many large vessels that discharge ballast water into the southern Firth of Thames. However, introduced species can spread really quickly. | Ballast water can contain contaminants and introduce invasive species, which can also spread through attachment to boat hulls. Invasive species can cause physical and behavioural disturbances to native organisms, outcompeting them for food, space and other available resources. |
| Fishing (recreational and commercial) | Harvesting of fish and shellfish. Habitat loss. Spread of invasive species. | Principal target species for customary fishing are eels, inanga, smelt, yellow-eyed mullet, grey mullet, flounder, snapper, rig, bronze whaler shark and kahawai.<br>Favourite recreational fishing spots for snapper are the mussel farms, around shellbanks and near the Waihou river mouth.<br>Brownell (2004) reports 23 locally based small boats (<9 m) operated by full and half-time commercial fishermen. Of these, six fish snapper, one eels (southern Firth) and the rest flounder. Flounder constitutes 40% of catch in area north of the Ramsar site, a total of 14 commercial flounder fishermen operate in the inner Firth). Many fish short periods during the year for rig, pilchard, yellow-eyed mullet and grey mullet. A lot of recreational fishing activity occurs along the Kaiaua coast, and elsewhere around river mouths and shoals.<br>No specific information is available for shellfish gathering in and around the Ramsar site, though observations indicate very low use levels throughout the site (Brownell, pers. comm.).<br>Population increase expected to lead to increased fishing pressure, and as catch techniques improve pressure will increase too.<br>The commercial fishery is considered well regulated at present (Fanselow, pers. comm.). | Increased recreational catch through better fishing gear and increased numbers of recreational fishermen may lead to increased pressure on stocks of the most sought after species *e.g.* snapper, kahawai and flounder. Commercial fishing throughout the Hauraki Gulf, including in the Firth, led to a significant decline in snapper stocks some years ago. However there is now consensus among local fisherman that snapper stocks are recovering (Brownell 2004). Bycatch is mainly limited to occasional sharks and rays in flounder nets.<br>Populations of flounder fluctuate widely, and commercial catch limits may be higher than desirable in some years.<br>No control is applied to the number of commercial fishers in the Firth. This can potentially lead to local depletion.<br>Shellfish gathering can lead to a decline in shellfish species. Since 1998, a closure has been in place for taking pipi and cockle between Ngarimu and Wilson Bay, in response to local concern about the depletion of cockles and pipi along this coastline. Increase in harvesting pressure by amateur fishers was identified as one potential cause of this depletion. |

| **Source** | **Stressors associated with source** | **Source quantification (how much and where?)** | **Potential effects** |
|---|---|---|---|
| Marine farms (mussel longlines) | Phytoplankton depletion. Localised nutrient enrichment, benthic deposition and changes in current patterns. Invasive species | Currently 470 ha in Wilson Bay Area A are ~50% developed, plus 220 ha older farms on eastern side and 45 ha in western Firth. The Wilson Bay Marine Farming Zone will expand to 1,200 ha when it is fully developed. Potential for some marine farming development on the western side of the Firth, possibly as close as 12-15 km away from the Ramsar site. Phytoplankton depletion shown not to be a great risk (Broekhuizen *et al.* 2004; Zeldis 2005; Zeldis *et al.* 2006), and benthic effects are very unlikely to extend as far as Ramsar site. However, potential biosecurity issues could cause impacts in the future. | Seabed impacts through deposition of organic rich, fine grained sediment particles (mussel pseudofaeces and faeces) and the deposition and accumulation of live mussels, mussel shell litter and biota attached to the ropes, floats and mussels. Changes in predator-prey densities can occur near/under farms. Changes can occur in the amount of suspended organic material (including phytoplankton) and nutrients in the water column, as well as in current speeds and directions. Mussel longlines provide substrate for invasive species, and translocation of stock from one part of the country to another can bring about biosecurity risks. |
| Point sources (domestic and industrial outfalls) | Contaminants, nutrients | The largest point source from the Firth catchment is discharges from dairy farm ponds (HGF 2004) which discharge to both land and water. Other point sources include wastewater treatment plants and secondary treated municipal sewage. Estimated loads from dairy farm ponds is 621 tonnes of N, 164 tonnes of P and 6,935 tonnes of suspended solids per year (Elmetri *et al.* 2005). Industrial waste water (from dairy and meat works) contributes 85 tonnes of N, 32 tonnes of P and 189 tonnes of suspended solids per year; and secondary treated municipal sewage contributes 175 tonnes of N, 29 tonnes of P and 234 tonnes of suspended solids (Elmetri *et al.* 2005). | Increased nutrient load can lead to eutrophication which may lead to harmful algal blooms and other water quality problems. Contaminants can build up in organisms through the food chain and can cause increased mortality of exposed organisms. |
| Human recreation (visitors to birds from land) | Disturbance, habitat loss (trampling) | 12,000 visitors a year, mostly school children and bird watchers from around the world. Visitors can impact on bird areas through noise, trampling *etc.* The effects of this can be managed. | Noise can disturb the behaviour of birds. Damage to habitat in areas accessible to public can lead to habitat loss. Disturbance to roosting sites can have devastating effects. |

| Source | Stressors associated with source | Source quantification (how much and where?) | Potential effects |
|---|---|---|---|
| Accidental spills | Contaminants (from vessels carrying oil, oil tankers State Highway 25, oil or petrol accidentally/illegally poured down stormwater drains into waterways, or into the soil). | No specific information is available for the number of oil tankers using State Highway 25, the number of marine vessels carrying oil, or the extent of illegal dumping of paint *etc.* Only very large, industrial spills will result in measurable effects: spills from recreational boats are unlikely to leave measurable impacts. Even industrial spillages are most likely to adversely impact rivers. Worst threat would be petro-chemical spill. Three significant tanker spills have occurred in area in recent times, but these were into streams. Studies of marinas show that high rate of small spills pale in significance compared to runoff from land (Stewart 2003). Cumulative effects would be progressive degradation of marine environment, but this would only result from very large increase in boating traffic. Limited information available. | Exposure to contaminants can lead to mortality of organisms exposed and potential concentration of contaminants up the food chain. |
| Climate change | May lead to increased sediment, nutrient and contaminant runoff as a result of increased rainfall. Sea level rise causing habitat loss. Disturbance from increased flooding *etc.* Temperature changes may lead to favourable conditions for invasive species. | New Zealand North Island is likely to experience climate changes such as: higher temperatures; increasing sea levels (research has shown that sea levels globally are expected to rise between 9 and 88 cm by 2100 (Houghton *et al.* 2001)); more frequent extreme weather events such as droughts (especially in the east of New Zealand) and floods; a change in rainfall patterns - higher rainfall in the west and less in the east. Sea level rise in New Zealand was up to 16 cm in the last century (Hannah 2004). Not immediate threat to the Firth of Thames. Unsure of impacts on Ramsar site. Major threat is potential habitat loss and increased flooding events leading to disturbance and increased sediment input. | Habitat loss through sea level rise. Increased sediment runoff can lead to decreased primary productivity, and changes in sediment particle size (changing habitat characteristics). Eroded soils may contain contaminants from *e.g.* dairy farming. Climate change may lead to easier establishment of some invasive species. Forests and vegetation may grow faster, but native ecosystems could be invaded by invasive species. Drier conditions in some areas are likely to be coupled with the risk of more frequent extreme events such as floods, droughts and storms. Rising sea levels will increase the risk of erosion and saltwater intrusion, increasing the need for coastal protection. |
| Mangrove expansion | Habitat loss. | Mangrove expansion can cause habitat loss through mangroves growing into other intertidal areas and also through the trapping of sediments and slowing of water currents, causing habitat loss through increased muddiness seaward of mangroves (Battley & Brownell 2007). Mangrove habitat expanded from about 70 ha in the Firth of Thames in 1952, to in excess of 1,000 ha in 2002 (Environment Waikato GIS 2006). For stilt ponds, observations indicate mangroves are spreading and are causing infilling | Increased sedimentation can lead to changes in sediment particle size (changing habitat characteristics). Mangrove expansion into other intertidal areas is thought to have caused (feeding and roosting) habitat loss leading to a decline in a number of bird species associated with the Ramsar site (Battley & Brownell 2007). |

| Source | Stressors associated with source | Source quantification (how much and where?) | Potential effects |
|---|---|---|---|
| | | (Brownell & Woodley, pers. comm.). Mangroves can provide temporal habitat for rodents. | |
| Firth of Thames sediment | Sediments. | Sedimentation is known to be the most important contaminant in many New Zealand estuaries, adversely affecting intertidal flats and subtidal environments (Taylor *et al.* 1997; Lohrer *et al.* 2004). Recent NIWA work (Swales 2006) at the Firth of Thames Ramsar site has shown that most sediments being trapped in mangroves in the area have not come directly off the land, but rather have been in the Firth reservoir of sediments for a while. Thus, at the Ramsar site, the ultimate source of sediments is the land, but most sediments likely entered as a result of historic rather than current land uses. Present day sedimentation rates into the Firth of Thames from the catchments has been estimated at 56 tonnes per ha of catchment per year, which is quite low for New Zealand and the region (Mead & Moores 2004). However, because of the large catchment area, the total estimated input of sediments to the Firth is still high at 230,498 tonnes/year. | Increased sedimentation can lead to changes in sediment particle size (changing habitat characteristics). |

## 4.6 Conceptual models

Conceptual models were developed with workshop participants that depict the interconnections between sources, stressors, habitats and endpoints. The conceptual models provide a visual representation of answers to the following of questions:

- Does the source release or cause the stressor?
- Does the stressor occur and persist in the habitat?
- Does the endpoint use the habitat type?
- Does the stressor negatively affect the assessment endpoint?

For any given pathway, if the answer to all four of these questions is positive, the pathway is complete and the probability of effects occurring can be greater than zero.

The conceptual models are presented in Table 6.

## 4.7 Source and Habitat Scores

Sources and habitats were allocated scores from 0 to 6 (Table 5) by workshop participants, assigned according to area, size, importance, relative magnitude, and frequency of occurrence, based on data for the present time. All available information was used to assign scores. Tables 7 and 8 provide the scores for habitats and sources, and the rationale for the scores.

**Table 5. The categories of scores. Habitats scored on the basis of size and importance; sources of stressors on the basis of effect, relative magnitude and frequency of occurrence.**

| Risk Score Values | |
|---|---|
| 0 | None |
| 1 | Extremely low |
| 2 | Low |
| 3 | Low to medium |
| 4 | Medium |
| 5 | Medium to high |
| 6 | High |

Concurrent with the scoring, uncertainty estimates of high, medium or low were assigned. For each score, the uncertainty indicates the level of information that the score is based on – if the score is based on a great deal of site-specific information, the uncertainty was documented as being low, if based on very little information, a high uncertainty was assigned.

**Table 6** **Conceptual models depicting potential sources, stressors, habitats and endpoint interactions.**

**Source-Stressor-Habitat Exposure Interactions**

**Stressor Abbreviations**

| | |
|---|---|
| **C** | Contaminants |
| **N** | Nutrients (effects include raised turbidity caused by phytoplankton blooms, toxic algal blooms, opportunistic green macroalgae, changes in phytoplankton community structure) |
| **S** | Sediments (effects include smothering, turbidity, substrate changes, but not mangrove expansion - this is covered as habitat loss) |
| **F** | Harvesting & exploitation (fishing) |
| **H** | Habitat loss (does not include habitat loss caused by sedimentation or nutrient enrichment, but includes *e.g.* habitat loss caused by sea level rise, mangrove expansion, drainage of wetlands, etc). |
| **D** | Disturbance |
| **I** | Invasive species |

| | **Habitats** | | | | | | |
|---|---|---|---|---|---|---|---|
| **Source** | **Tidal flats within Ramsar site (including shellfish beds, excluding mangrove areas)** | **Mangroves within Ramsar site** | **Open coastal areas (bird roosting and breeding areas within Ramsar site, excluding intertidal flats)** | **Stilt ponds** | **Airspace for birds** | **Sub-tidal soft substrate < 2 m: sub-tidal seabed with less than 2 m water depth** | **Water column: area of water of less than 2 m depth + pelagic influences on Ramsar site** |
| **Agriculture land use, particularly dairy farming** | C, N, S | C, N, S, H | H, I | C, N, S, I | | C, N, S | C, N, S |
| **Forests (indigenous and exotic)** | N, S | N, S | | N, S | | N, S | N, S |
| **Urban and industrial land-use and development** | C, N, S, H | C, N, S | H | C, N, S | D | C, N, S | C, N, S |
| **Shipping (ballast water, boat hulls)** | C, I | C, I | | C, I | | C, I | C, I |
| **Fishing (recreational and commercial)** | F, H, I | I | | I | | F, H, I | F, I |
| **Marine farms** | N, S, H, I | N, S, H, I | | N, S, I | | N, S, H, I | N, S, I |
| **Point sources (domestic and industrial outfalls)** | C, N | C, N | | C, N | | C, N | C, N |
| **Accidental spills** | C | C | | C | | C | C |
| **Human recreation (visitors to birds from land)** | D | D | D | D | | | |
| **Climate change** | C, N, S, H, D, I | C, N, S, H, D, I | H, D, I | C, N, S, H, D, I | | C, N, S, H, D, I | C, N, S, I |
| **Mangrove expansion** | H | | H | H | | H | |
| **Firth of Thames sediment** | S | S | | S | | S | S |

*(Continued on next page)*

*Table 6. (continued)*

| | Habitat-Endpoint Exposure & Effects Interactions | | | | | | |
|---|---|---|---|---|---|---|---|
| | Habitats | | | | | | |
| **Endpoint** | **Tidal flats within Ramsar site (including shellfish beds)** | **Mangroves within Ramsar site** | **Open coastal areas (bird roosting and breeding areas within Ramsar site, excluding intertidal flats)** | **Stilt ponds** | **Airspace for birds** | **Sub-tidal soft substrate < 2 m: sub-tidal seabed with less than 2 m water depth** | **Water column: area of water of less than 2 m depth + pelagic influences on Ramsar site** |
| Chenier creation zone | Area of occurrence S, H | | Area of occurrence H, I | | | Source of material S, H | |
| Bachelor's button, sedges, Maori musk, bur medic short grassland, ryegrass | | | Habitat H, I | | | | |
| Saltmarsh ribbonwood, mingimingi shrub, glasswort saltmarsh | Habitat C, N, S, H, D, I | | Habitat H, I | | | | Provision of nutrients C, N, S, I |
| Pied oystercatcher | Roosting, feeding C, S, H, I, D | | Roosting, feeding H, D | Rare, roosting, feeding C, S, H, I, D | Air Traffic D | | |
| Bar-tailed godwits, lesser knot, sharp-tailed sandpiper | Roosting, feeding C, S, H, I, D | | Roosting, feeding H, D | Roosting, feeding C, S, H, I, D | Air Traffic D | | |
| New Zealand dotterel, variable oystercatcher, black-billed gull, white-fronted tern, Caspian tern | Roosting, feeding C, S, H, I, D | | Roosting, feeding H, D | Dotterel occasionally C, S, H, I, D | Air Traffic D | | |
| **Wrybill** | Roosting, feeding C, S, H, I, D | | Roosting, feeding H, D | Roosting, feeding C, S, H, I, D | Air Traffic D | | |
| **Shags, heron and banded rail** | Feeding, roosting C, S, H, I, D | Feeding, nursery C, S, H, I, D | Herons: feeding, roosting H, D | Feeding (banded rail) C, S, H, I, D | Air Traffic D | | |
| **Pied stilts** | Feeding C, S, H, I, D | | Roosting, feeding, breeding H, D | Roosting, feeding, | Air Traffic D | | |

| Endpoint | Tidal flats within Ramsar site (including shellfish beds) | Mangroves within Ramsar site | Open coastal areas (bird roosting and breeding areas within Ramsar site, excluding intertidal flats) | Stilt ponds | Airspace for birds | Sub-tidal soft substrate < 2 m: sub-tidal seabed with less than 2 m water depth | Water column: area of water of less than 2 m depth + pelagic influences on Ramsar site |
|---|---|---|---|---|---|---|---|
| | | | | breeding C, S, H, I, D | | | |
| **Snapper** | Feeding, nursery C, S, H, I, D | Feeding, nursery C, S, H, I, D | | | | Feeding, nursery C, S, H, I, D | Feeding, nursery, habitat C, S, F, D |
| **Yellow belly flounder** | Feeding C, S, H, I, D | Feeding, nursery C, S, H, I, D | | | | Feeding, nursery C, S, H, I, D, F | Feeding, nursery, habitat C, S, F, D |
| **Small pelagics and kahawai** | Feeding, nursery C, S, H, I, D | Feeding, nursery C, S, H, I, D | | | | Feeding, nursery C, S, H, I, D, F | Feeding, nursery, habitat C, S, D, F |
| **Eels** | Feeding C, S, H, I, D | Feeding C, S, H, I, D | | | | Feeding C, S, H, I, D | Feeding, habitat C, S, F, D |
| **Whitebait (inanga and smelt)** | | | | | | Feeding C, S, H, I, D | Feeding, C, S, F, D |
| **Shellfish beds (*e.g.* cockles, *Macomona*, *Mactra*, oysters, *Nucula*)** | Feeding, nursery C, S, H, I, D | | | | | Feeding, nursery C, S, H, I, D | Feeding, larvae, C, S |
| **Polychaetes** | Feeding, nursery C, S, H, I, D | Feeding, nursery C, S, H, I, D | | Feeding, nursery C, S, H, I, D | | Feeding, nursery, C, S, H, I, D | Feeding, larvae C, S |
| **Mud crabs (three species)** | Feeding, nursery C, H, I, D | Feeding, nursery C, H, I, D | | Feeding, nursery C, H, I, D | | Feeding, nursery, C, H, I, D | Larvae C |
| **Water quality** | Food chain C, N, S | Food chain C, N, S | | Food chain C, N, S | | Food chain C, N, S | Food chain C, N, S |

**Table 7 Scores assigned for habitats, criteria used, and rationale for scores**

| Habitats | RRM score | Criteria | Uncertainty | Notes |
|---|---|---|---|---|
| Tidal flats Ramsar site | 6 | Size (9236 ha) and importance | Low | Large area, which is very important for birds |
| Mangroves | 2 | Size (~1084 ha in 2002) | Medium | Large area |
| Open coastal area | 6 | Importance | Low | Small area (180 ha), but very important for most bird species. |
| Stilt ponds | 4 | Importance | Low | Small area (~10 ha), but very important for pied stilts, wrybill |
| Airspace | 2 | Size and importance | Medium | Although the airspace used by birds near the Ramsar site is relatively small (thought to be up to 500 m of altitude), this lower stratum is very important for birds |
| Sub-tidal <2m | 4 | Size (7842 ha) and importance | Medium | No data available on how large an area supply the Ramsar site (*e.g.* recruitment), unsure of importance |
| Water column <2m | 6 | Size (17,078 ha) and importance | Low | Very important for all species in intertidal and subtidal areas |

**Table 8. Source scores and criteria used for predicted risks (scenario 1). For rationale, selection and scores of these sources, see Table 4.**

| Source | RRM Rank | Criteria | Present Extent | Uncertainty |
|---|---|---|---|---|
| Agricultural land use | 6 | % Land use | 65% of catchment | Medium |
| Forests | 2 | % Land use | 29% of catchment | Medium |
| Urban & industrial land use | 2 | % Land use | ~1% of catchment | Medium |
| Shipping | 2 | Significance | (low/~~med~~/~~high~~) | Low |
| Fishing | 3 | Catch per year / significance | (~~low~~/med/~~high~~) | High |
| Marine farms | 2 | Size (ha) | 470 ha | Low |
| Point sources | 4 | Loads / significance | (~~low~~/med/~~high~~) | High |
| Accidental spills | 2 | # Spills per year / significance | (low/~~med~~/~~high~~) | Medium |
| Human recreation | 4 | # of users / significance | (low/~~med~~/~~high~~) | Low |
| Climate change | 2 | Significance | (low/~~med~~/~~high~~) | Medium |
| Mangrove expansion | 2 | Size / significance | (low/~~med~~/~~high~~) | High |
| Firth of Thames sediment | 6 | Loads / significance | (~~low~~/~~med~~/high) | High |

For some of the sources, workshop participants felt that there was considerable uncertainty about potential extent in the future. To account for this, it was therefore decided to allocate a second score for these sources, which represents a 'worst case' scenario for the next fifty years or so. These sources, their 'second scenario' scores, associated uncertainty and the rationale for needing a second scenario are presented in Table 9.

**Table 9 Scenario 2 (worst case) scores, associated uncertainties, and rationale.**

| Source | Second RRM score | Uncertainty | Rationale |
|---|---|---|---|
| Urban & industrial land use | 4 | Medium | Presently urban and industrial land use does not cover much of catchment. However, predictions are that this land use will increase along rivers and adjacent to Firth. |
| Marine farms | 4 | High | Potential for marine farms to host invasive species warrants a 'worst case' scenario. Wilson Bay is thought to have low connectivity to Ramsar site, and invasive species found on mussel farms normally like hard structures (of which there are few at the Ramsar site) but there is potential that in the future marine farms will increase the connectivity of invasive species to the Ramsar site. |
| Climate change | 4 | High | Currently, not many effects have been categorically attributed to climate change, but changes over the next 50-100 years predicted to occur (*e.g.* sea level rise, temperature rise, increased incidence of flooding). |
| Mangrove expansion | 4 | High | Mangroves have expanded rapidly over the last 50 years. Current levels of mangrove expansion are known to have adversely impacted on bird populations (Battley & Brownell 2007), but the extent of this has not been established. Predicted increase in mangrove area in the future may result in further adverse effects. |

## 4.8 Exposure and Effects Filters

To reflect either no, low, medium or high probability of exposure or effects for each source to an endpoint combination, exposure and effects filters of 0, 1, 2 or 3 were assigned within the RRM. These filters were based primarily on linkages described in the conceptual models outlined in Table 6. The criteria for assigning the different filter values are outlined in Tables 10 and 11. The assigned Exposure and Effect Filters values and the reasons behind their selection are documented in Appendices A and B.

**Table 10 Criteria for assigning exposure filter values.**

| Exposure filter value | Criteria for assigning |
|---|---|
| **0** | Improbable - no link in conceptual model OR no risk to habitat |
| **1** | Possible, low linkage AND / OR data shows low / no persistence OR low risk to habitat |
| **2** | Possible, high linkage, doubt about persistence OR data shows intermediate persistence |
| **3** | Definite high linkage and persistence |

**Table 11 Criteria for assigning effects filter values.**

| Effects filter value | Criteria for assigning |
|---|---|
| **0** | Improbable - no link in conceptual model |
| **1** | Endpoint uses habitat, but stressors will not have particularly adverse effects on endpoint |
| **2** | Endpoint uses habitat. Stressors likely to have intermediate effect on endpoint |
| **3** | Endpoint uses habitat. Stressors likely to have significant effect on endpoint |

The assigned filter values were based primarily on the stressor pathways described in the conceptual models, knowledge contributed by project participants, published literature, and other site-specific available information at the time of the model configuration. The inclusion of additional site-specific information or any future stakeholder input could potentially modify the filter values in the future.

Once the conceptual models were developed, habitat and source score completed, and exposure and effects filters assigned, risk estimates were determined by multiplying and summing together ranks and filters for each risk component as outlined in Equation 1 and shown diagrammatically in Figure 2. The relative risks in the region were determined by summing the product of the source rank, habitat rank, and exposure and effects filters. The risk estimates in the study area were calculated for sources, habitats and biological endpoints to reveal:

- The sources and stressors contributing the most risk,
- The habitats where most risk occur, and
- The selected endpoints most at risk at the Firth of Thames Ramsar site and surrounds.

The results from the risk modelling are presented in Section 5.

## 4.9 Monte Carlo Uncertainty Analysis

A major advantage of the RRM technique is that the uncertainty of relative risk estimates can be quantified. The uncertainty in the risk assessment arises from a number of factors including paucity of site-specific and species-specific data within the study area, poor data quality, and little information on the fate and transport of stressors in the Firth of Thames environment. The risk predictions produced in the RRM are point estimates based on scores and filters derived from imperfect data, as often there is a lack of detailed or long-term information. In order to communicate the uncertainty associated with these point estimates, and quantify the effects of parameter uncertainty on the risk predictions, Monte Carlo analysis was applied to the RRM results to generate distributions of probable risk predictions for each risk component.

Most real problems involving elements of uncertainty are too complex to solve analytically. There are simply too many combinations of input values to calculate every possible result. Monte Carlo simulation is an efficient technique that uses random numbers to measure the effects of uncertainty in a data model. Monte Carlo simulation randomly generates values for uncertain variables over and over to simulate a model. The values for each assumption’s probability distribution are random and are totally independent. In other words, the random value selected for one trial has no effect on the next random value generated. Crystal Ball® 7 Software, which implements Monte Carlo simulation, was used to analyse parameter uncertainty in the risk predictions. In risk assessment situations, Monte Carlo uncertainty analysis combines assigned probability distributions of input variables to estimate a probability distribution for output variables (Burmaster & Anderson 1994). In this case, the input variables are the ranks and filters with medium or high uncertainty and the output variables are the risk estimates.

In this analysis, we assigned Monte Carlo assumptions of low, medium or high uncertainty to each source and habitat, and exposure and effects filter, based on data availability and quality (see Appendices A and B). For medium and high uncertainty, we assigned discreet probability distributions to ranks and filters according to the criteria in Tables 12 and 13. For the low uncertainty ranks and filters, the original estimates were used.

The selection of exposure and effects filter values as well as the Monte Carlo uncertainty level was based on available information, project participant input and assumptions as described in the foot notes in Appendices A and B.

**Table 12. Monte Carlo input distributions for ranks with medium and high uncertainty.**

| Assigned Rank Value | Uncertainty | Assigned Probability (%) for Ranks | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 0 | High | 60 | 30 | 10 | 0 | 0 | 0 | 0 |
| 0 | Medium | 80 | 10 | 10 | 0 | 0 | 0 | 0 |
| 1 | High | 20 | 60 | 20 | 0 | 0 | 0 | 0 |
| 1 | Medium | 10 | 80 | 10 | 0 | 0 | 0 | 0 |
| 2 | High | 0 | 20 | 60 | 20 | 0 | 0 | 0 |
| 2 | Medium | 0 | 10 | 80 | 10 | 0 | 0 | 0 |
| 3 | High | 0 | 0 | 20 | 60 | 20 | 0 | 0 |
| 3 | Medium | 0 | 0 | 10 | 80 | 10 | 0 | 0 |
| 4 | High | 0 | 0 | 0 | 20 | 60 | 20 | 0 |
| 4 | Medium | 0 | 0 | 0 | 10 | 80 | 10 | 0 |
| 5 | High | 0 | 0 | 0 | 0 | 20 | 60 | 20 |
| 5 | Medium | 0 | 0 | 0 | 0 | 10 | 80 | 10 |
| 6 | High | 0 | 0 | 0 | 0 | 10 | 30 | 60 |
| 6 | Medium | 0 | 0 | 0 | 0 | 10 | 10 | 80 |

**Table 13. Monte Carlo input distributions for filters with medium and high uncertainty.**

| Assigned Filter Value | Uncertainty | Assigned Probability (%) for Filters | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| 0 | High | 60 | 20 | 10 | 10 |
| 0 | Medium | 80 | 20 | 0 | 0 |
| 1 | High | 0 | 60 | 30 | 10 |
| 1 | Medium | 0 | 80 | 20 | 0 |
| 2 | High | 0 | 20 | 60 | 20 |
| 2 | Medium | 0 | 10 | 80 | 10 |
| 3 | High | 0 | 10 | 30 | 60 |
| 3 | Medium | 0 | 0 | 20 | 80 |

Using these ranks and filters of uncertainty we ran Monte Carlo analyses for different iterations and derived output distributions for each source, habitats and endpoint risk prediction. After running preliminary simulations of up to 100,000 iterations, we found 1,000 iterations to be sufficient and provide similar results. The purpose of these distributions is to examine a range of likely risk predictions associated with each point estimate.

# 5 RRM Results

## 5.1 Risk Characterisation

To investigate the risk and sensitivity of two possible scenarios for the sources (*i.e.* the scores of sources in the present situation and in the worst case future; see Table 9), two RRM simulation runs were conducted. The general exposure and effects filters were left unchanged (see Appendices A and B).

Overall the RRM results indicated that the Ramsar site is under pressure from a number of existing sources, particularly agricultural land use. The model predicted that agricultural land use (dairy farming) contributes much of the risk in the study region, followed by climate change, Firth of Thames sediments and urban and industrial land use (Figure 5). In the worst case scenario, climate change became the second highest risk and contributed similar risk as agriculture land use. The predicted relative risks from forests, shipping, accidental spills and human recreation were relatively low.

Risks from stressors are shown in Figure 6. The highest contributing stressors to the area for both scenarios were sediments and contaminants followed by invasive species, habitat loss and nutrients. The worst case scenario mainly caused increases in the relative risks posed by invasive species, habitat loss, and sedimentation, reflecting the uncertainty about increases in invasive species associated with expansion of mussel farming and with climate change, the potential habitat loss associated with sea level rise, and the potential for higher sedimentation rates with increased frequency of high intensity rainfall that might come about with climate change (see Table 9).

Figure 7 shows the relative contribution of risk by source for each stressor. The results show that agricultural land use and the Firth of Thames itself were thought to be the biggest contributors of sediment (which was the highest risk of all stressors in Figure 6) to the Ramsar site. Agricultural land use is regarded as a significant source of contaminants to the site, a reflection of the extent of agriculture in the catchment, as well as the potential runoff of mercury from the drained wetlands in the Piako River catchment. It is likely that smaller amounts of zinc and cadmium enter the Firth from agricultural land use. The biggest contributor of invasive species was found to be the worst case prediction for climate change, and climate change was also the biggest contributor to habitat loss. Other important factors for habitat loss include mangrove expansion.

In terms of habitats, the highest risk was found to be to the tidal flats of the Ramsar site (Figure 8). Risks were relatively lower but important for the water column, the sub-tidal area and stilt ponds. Open coastal areas and mangroves showed lower risks again, and the lowest risk was to airspace.

The scenarios did not significantly alter the relative risks to endpoints, but all endpoints were found to be at higher risk in the worst case scenario (Figure 9). Shellfish beds, polychaetes, yellow belly flounder, and small pelagics and kahawai were at comparatively similar high risk. The second highest risk was found to be to snapper and eels, most of the shorebird species, saltmarsh, the area important for creating the Chenier bank, and water quality (Figure 9). Whitebait were found to be exposed to medium risk, and the coastal vegetation least exposed to tidal influences (bachelor's button *etc.* ), mudcrabs and the bird species that utilise mangroves (shags, heron and banded rails), were shown to be at the lowest risk.

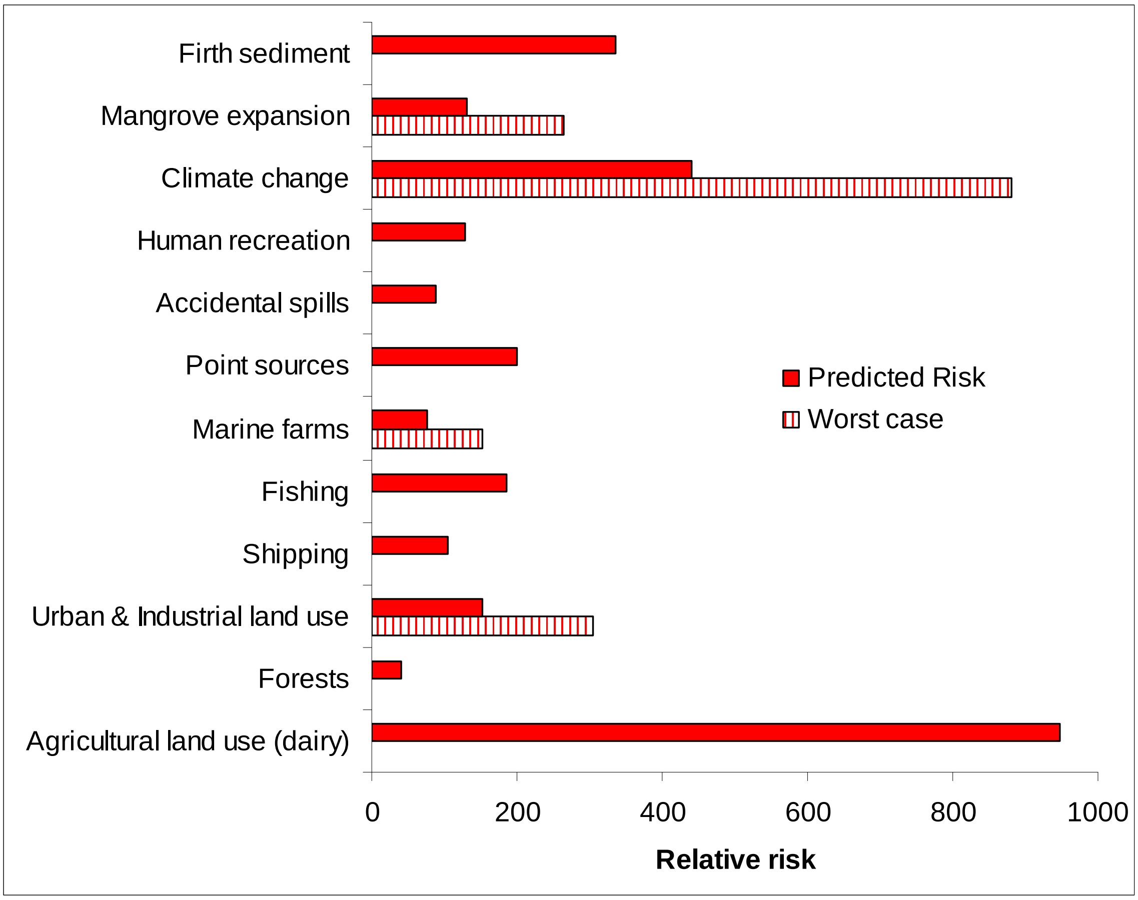


**Figure 5. Relative contribution to risk from sources in the Ramsar site. The two scenarios are based on different scores for the sources climate change, marine farms, mangrove expansion and urban and industrial land use. 'Predicted risk' is an estimate of current and likely future risk, and 'worst case' is an indication of worst case risk within the next 50 years.**

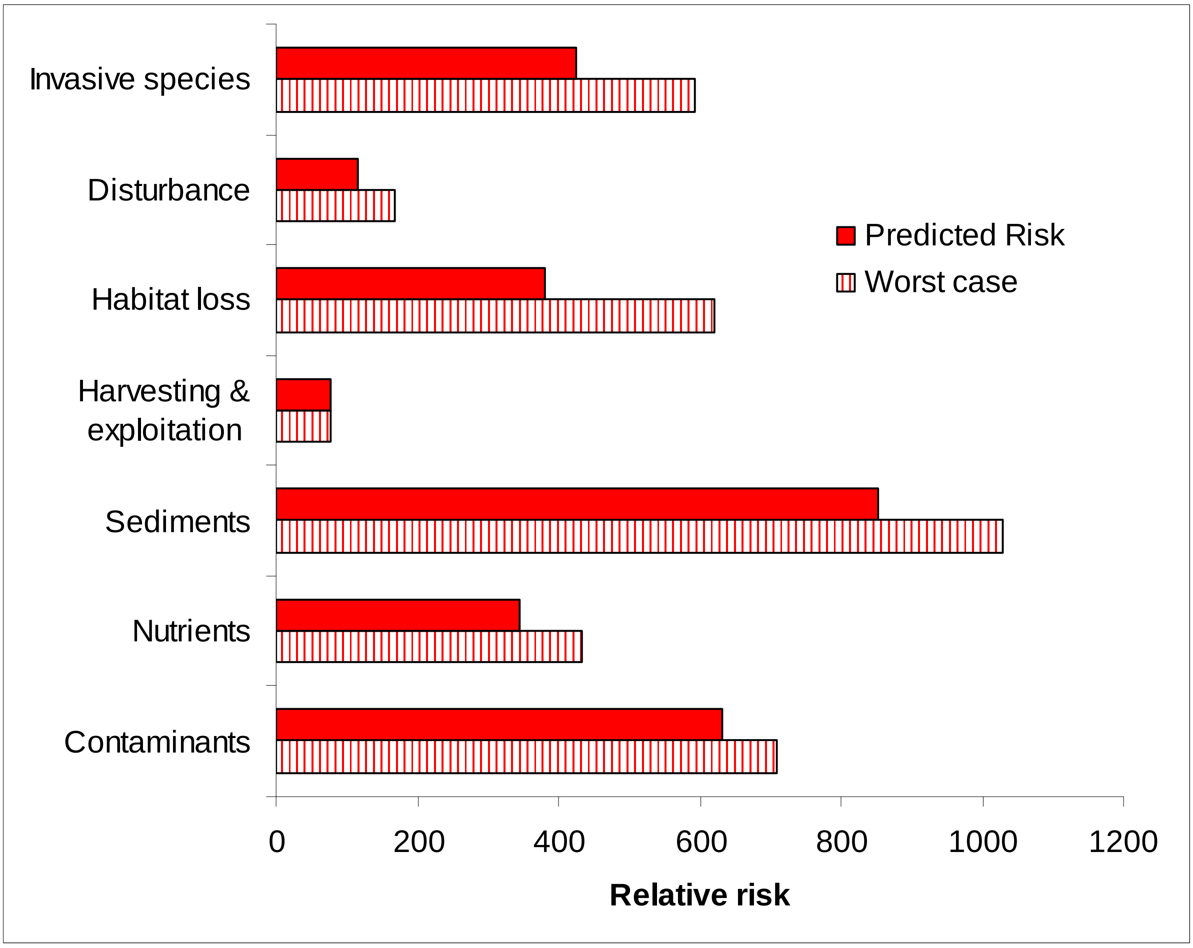


**Figure 6. Stressor contribution of risk to the Ramsar region. The two scenarios are based on different scores for the sources climate change, marine farms, mangrove expansion and urban and industrial land use. 'Predicted risk' is an estimate of current and likely future risk, and 'worst case' is an indication of worst case risk within the next 50 years.**

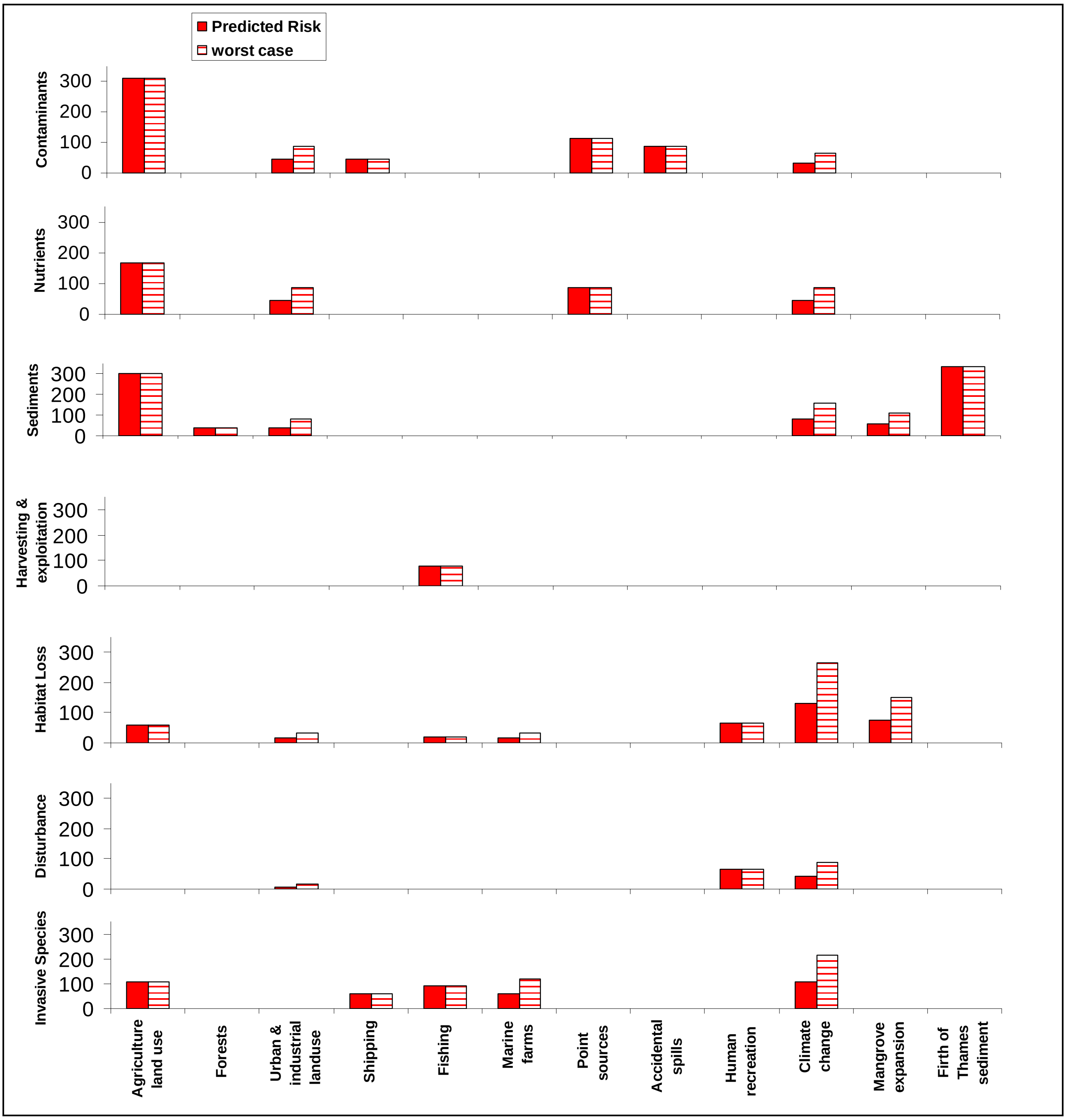


**Figure 7.** **Contribution of risk from the different sources for each stressor. The two scenarios are based on different scores for the sources climate change, marine farms, mangrove expansion and urban and industrial land use. 'Predicted risk' is an estimate of current and likely future risk, and 'worst case' is an indication of worst case risk within the next 50 years.**

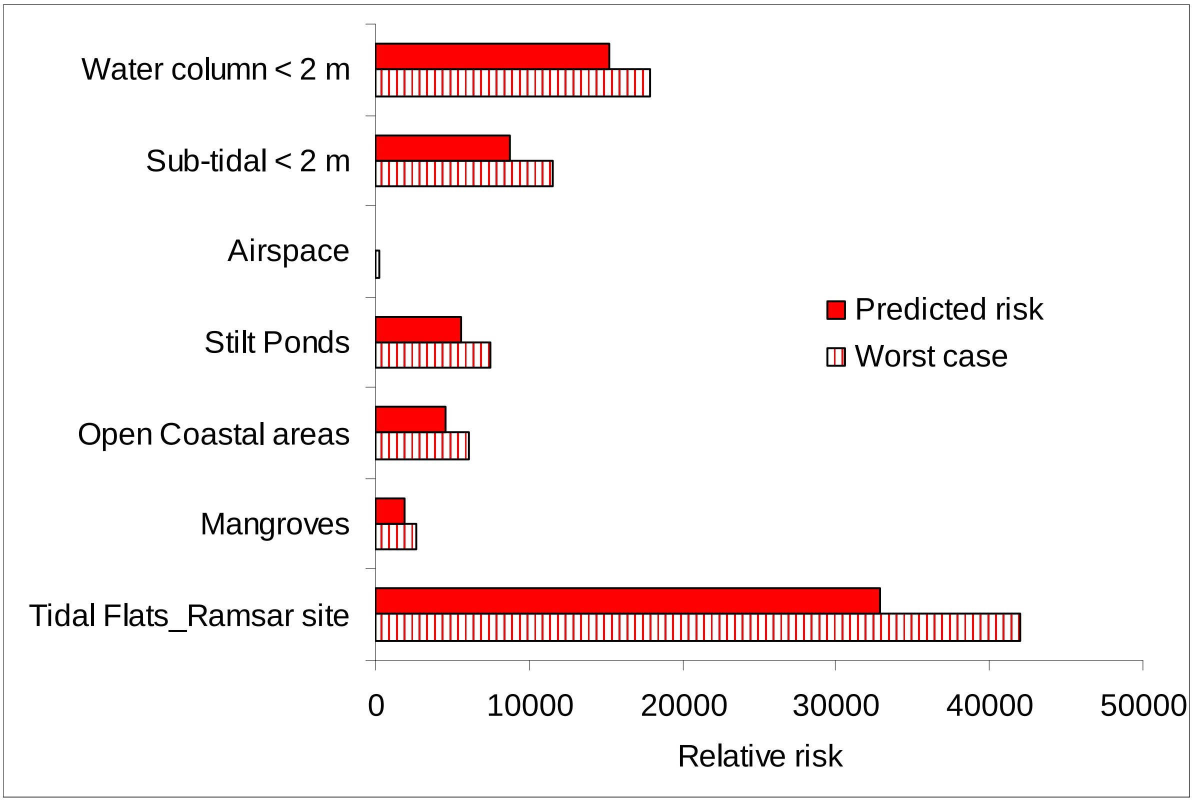


**Figure 8. Risk scores for habitats. The two scenarios are based on different scores for the sources climate change, marine farms, mangrove expansion and urban and industrial land use. 'Predicted risk' is an estimate of current and likely future risk, and 'worst case' is an indication of worst case risk within the next 50 years.**

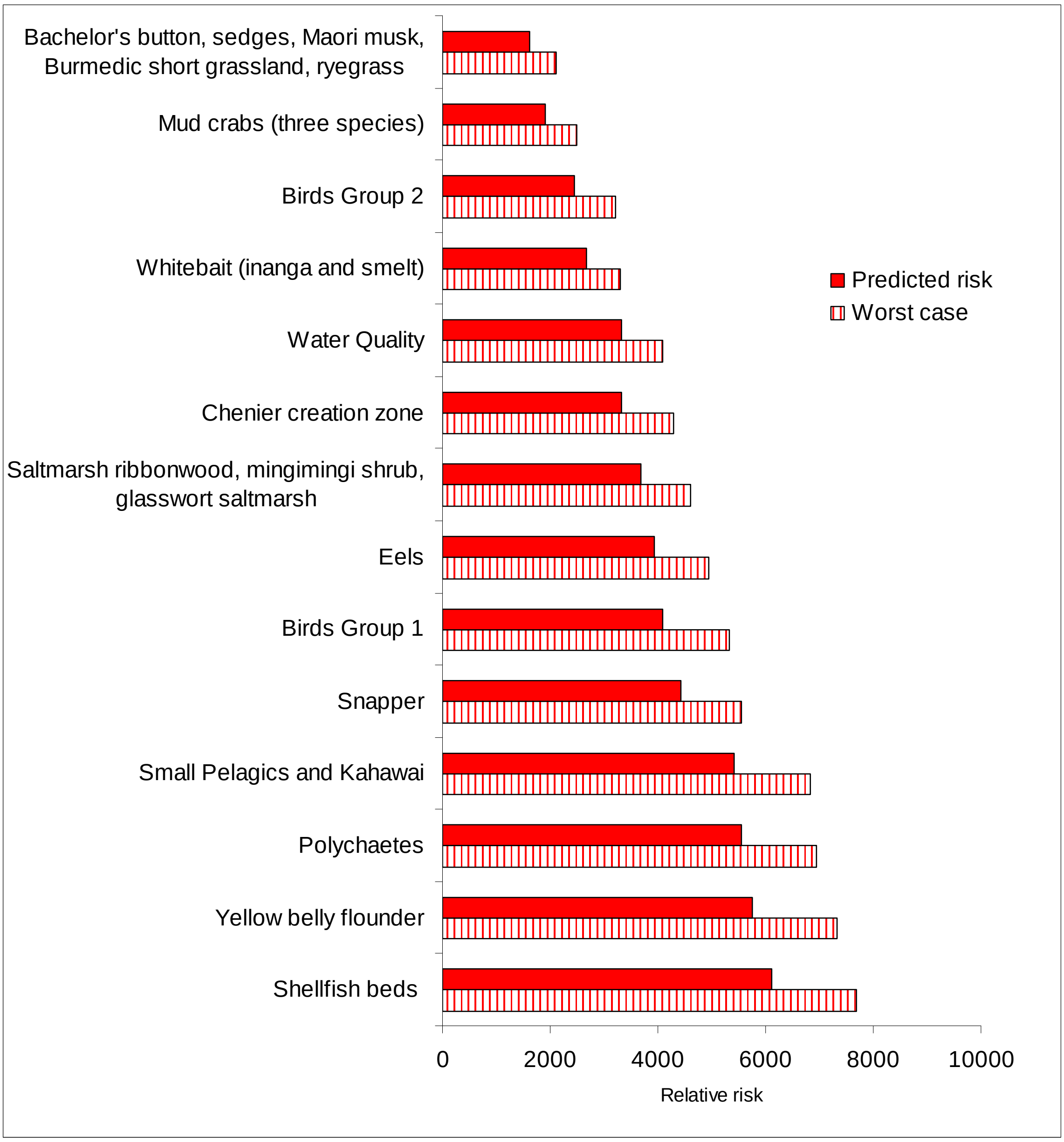


**Figure 9. Relative risk to biological assessment endpoints. The two scenarios are based on different scores for the sources climate change, marine farms, mangrove expansion and urban and industrial land use. 'Predicted risk' is an estimate of current and likely future risk, and 'worst case' is an indication of worst case risk within the next 50 years. Birds Group 1 represents pied oystercatcher, pied stilts, wrybill, and bar-tailed godwits, lesser knot, curlew sandpiper. Birds group 2 represents the group of shags, heron and banded rail, and New Zealand dotterel, variable oystercatcher, black-billed gull, white fronted tern, Caspian tern. Shellfish beds include cockles, *Macomona*, *Mactra*, oysters, and *Nucula*.**

## 5.2 Monte Carlo Uncertainty Analysis

The model developed for this risk assessment was based on a combination of available regional data and general site knowledge about interconnections between risk components. Uncertainty in the assessment arose from both the quality and availability of input data, and imperfections in the model. To quantify the effects of parameter uncertainty on the risk predictions, Monte Carlo uncertainty analysis was applied to the RRM to derive probability distributions of possible risk estimates. The Monte Carlo uncertainty analysis, which was conducted on present predicted risk scenario only, resulted in probability output distributions for each source, stressor, habitat, and assessment endpoint (Figures 10; 11; 12; 13).

Figure 10 shows the overlay charts distributions of possible risk scores from all sources. The results show that most of the sources maintained their order of risk grouping as predicted in the general RRM results. Some risk sources (*e.g.* Firth of Thames sediment and fishing; mangrove expansion, point sources and urban and industrial land use) show overlap between groups indicating similarity in the risk contribution (Figure 10). The risk sources agricultural land use, climate change, point sources, mangrove expansion and fishing showed wider distributions with some being skewed and having lower probability distributions, indicating high uncertainty compared with other risk sources that displayed very narrow output distributions and higher probability of risk occurrence.

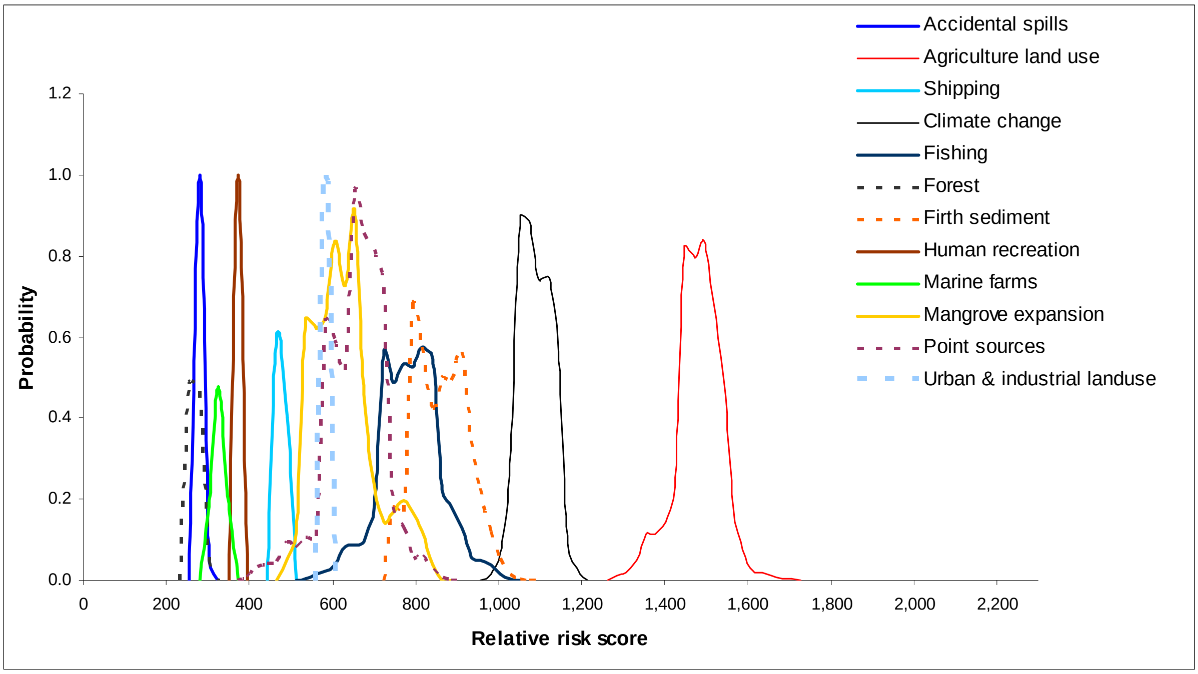


**Figure 10. Monte Carlo Results of the RRM predictions for Sources using the predicted risk scenario. Lines do not depict continuous distribution but are outlines of discreet distribution.**

As with most of the sources, the output probabilities charts of the high risk stressors showed wide and skewed probability distributions indicating high uncertainties in the risk predictions (Figure 11). In agreement with the results from the general risk model (shown in Figure 6), the stressors maintained their order of risk grouping, although some high risk distributions (sediment and contaminants; invasive species, nutrients, and habitat loss) showed some overlap between the stressors indicating similar risk predictions (Figure 11). The stressors nutrient and habitat loss showed similar risk and had the lowest probability peaks. The wide and skewed distribution observed for nutrients indicates that the risk from this stressor is uncertain in the model estimation. The remaining stressors such as harvesting and exploitation and disturbance showed lower risk than other stressors, and their narrow probability distributions suggest a relatively high certainty of the risk predictions (Figure 11).

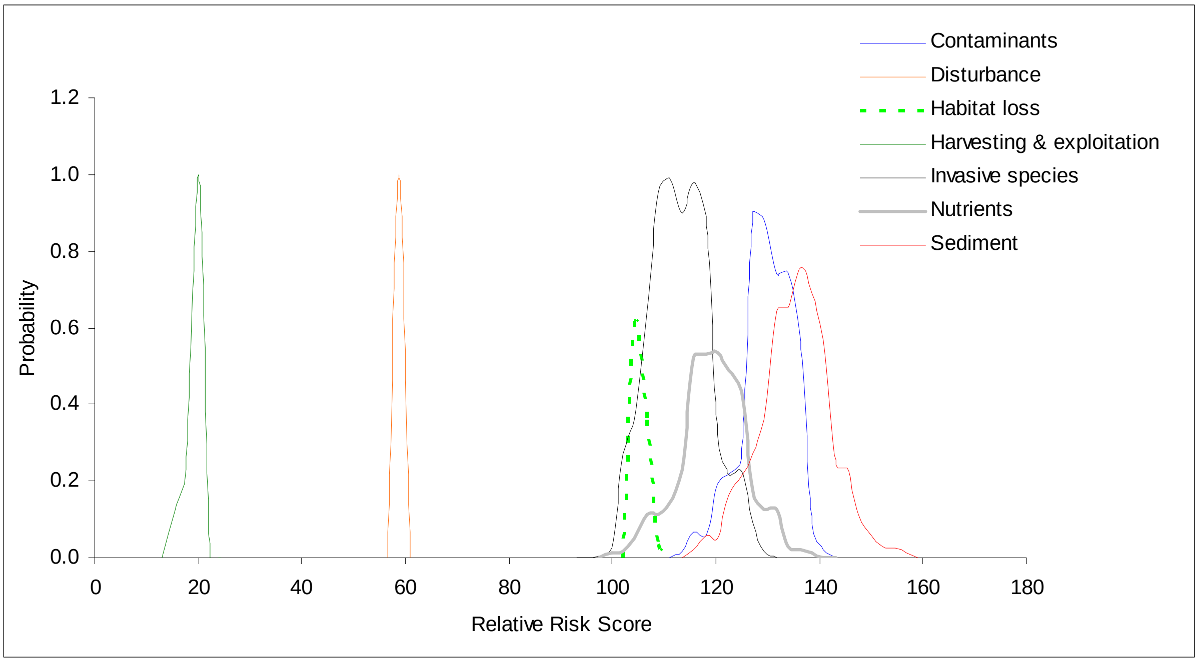


**Figure 11. Monte Carlo Results of the RRM predictions for Stressors using the predicted risk scenario. Lines do not depict continuous distribution but are outlines of discreet distribution.**

The habitat probabilities were normal with narrow distributions indicating high certainty in risk predictions (Figure 12). Consistent with the general results (Figure 8), the probability distributions showed the Ramsar tidal flats and water column were at the highest risk, while the mangroves and airspace were at low risk.

The endpoint uncertainty analyses produced normal and narrow probability distributions for most endpoints (Figure 13). The only wide and skewed distributions were for water quality and mud crabs. The distribution probabilities for these were both right skewed, suggesting that risk may have been underestimated for these endpoints. The results also showed distribution overlap for some endpoints reflecting similarities in their risk prediction *e.g.* Chenier creation zone, saltmarsh ribbonwood, bar tailed godwits group, pied stilts and oystercatchers, and wrybills, are all shown to be at similar medium risk, and mudcrabs and the group of vegetation including bachelor button are shown to be at similar but lower risk.

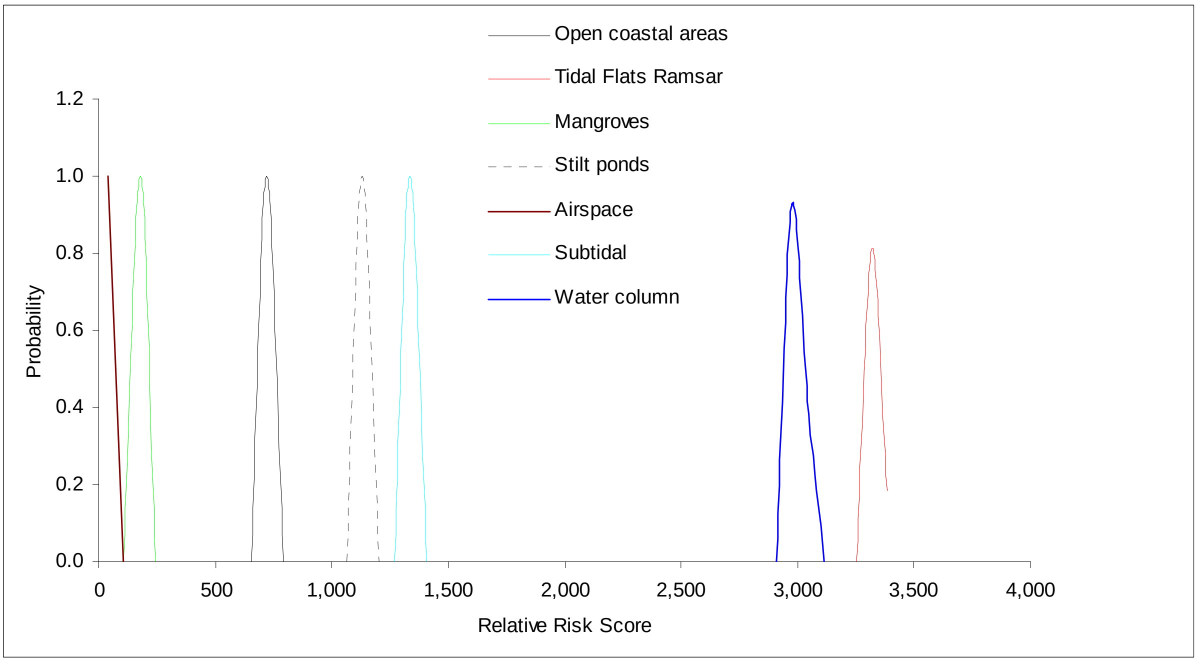

**Figure 12. Monte Carlo Results of the RRM predictions for Habitats using the predicted risk scenario. Lines do not depict continuous distribution but are outlines of discreet distribution.**

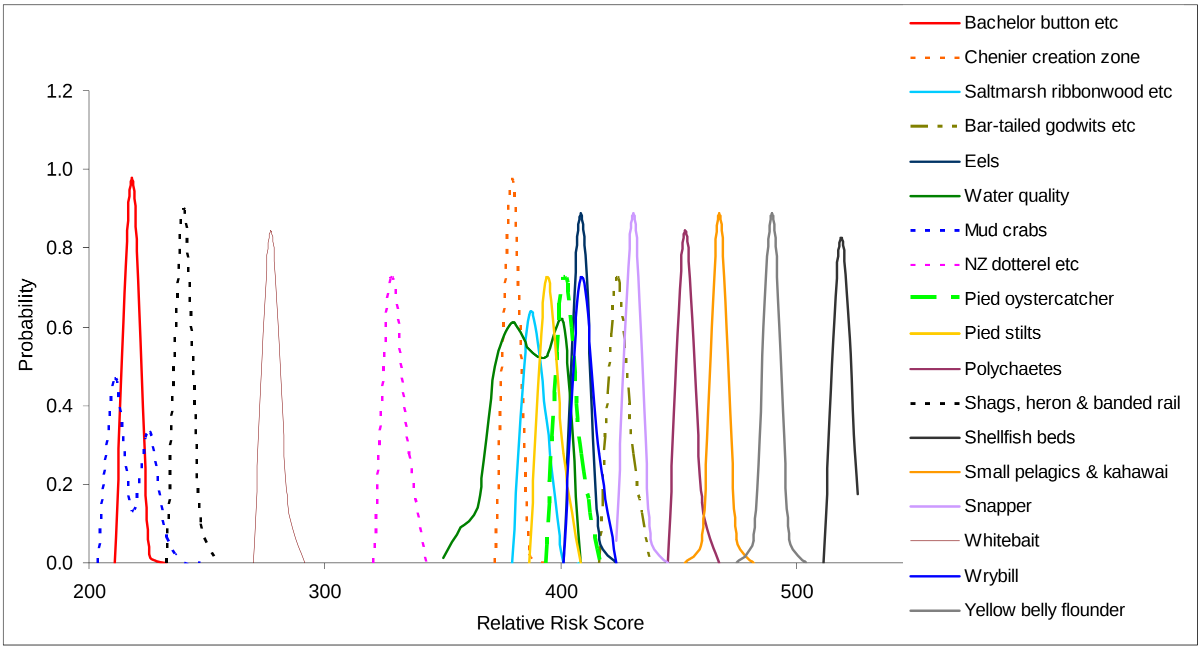


**Figure 13. Monte Carlo Results of the RRM predictions for Endpoints using the predicted risk scenario. Lines do not depict continuous distribution but are outlines of discreet distribution.**

# 6 Conclusions

The main objectives of this study were to use the RRM as a framework for discussions about ecological values of the Ramsar site and the threats to these values, as well as to use the model to compile current information, calculate the risks and identify area of uncertainties for the various components that make up the Ramsar site. The risk characterisation results indicated that the sources that pose the greatest risk category are non-point sources.

The high risk score predicted for agricultural land use is not surprising considering the extensive dairy farming that dominates the catchments. Agricultural activities can contribute nutrients, sediments and contaminants to receiving streams, estuaries, bays, coastal and offshore waters. Sediment and contaminant loads contribute the major environmental risk to the Ramsar site from agricultural land use, and habitat loss and nutrients were also found to be a high potential risk, particularly in the worst case scenario. Agricultural land use also provides a potential source of pest species such as goats, and provides suitable habitat for predatory pest species such as mustelids and cats. Not much information is available on the impacts of terrestrial predators on the Ramsar site, but cats have been found to prey on non-breeding wrybills, variable oystercatchers and white-fronted terns (Battley & Moore 2004). To what extent these species would have been present in the absence of agricultural land use is unclear.

Sedimentation resulting from soil erosion leads to multiple problems in the receiving waters. Sedimentation is often one of the major causes of water quality problems because of the associated reduction of light availability which in turn affects growth rates of phytoplankton and seabed algal communities. Deposition of mud may have short and long-term impacts by reducing species diversity of bottom dwelling animals (*e.g.* Thrush *et al.* 2004), thereby changing the structure of these communities. Increased concentrations of suspended sediments also influence nutrient and oxygen availability, and thereby negatively impact on filterfeeders such as horse mussels, pipi and cockles (Hewitt *et al.* 2001; Ellis *et al.* 2002).

The recent dramatic expansion of the mangrove forests (Brownell 2004) is thought to be at least partly attributable to the increased availability of mud flat habitat caused by sedimentation. From cores taken within the mangrove forests of the Firth of Thames, Swales (2006) found that the sediments being trapped amongst the mangroves have been in the Firth of Thames for a while, which is why Firth sediments are ranked as the third highest source of risk. Climate change features as a high potential risk in the worst case scenario, but high uncertainties are associated with this risk estimate because of a lack of information on the exact effects of climate change in New Zealand.

The high risk attributed to contaminants reflects recent field work from the inner Firth of Thames (some of the sampling stations were within the Ramsar site), showing that the sediments were enriched in mercury, lead, cadmium, copper, zinc and arsenic (Kim 2007). Of these, arsenic and mercury were both found to be present in concentrations exceeding the Australian and New Zealand Environmental Conservation Council (ANZECC) low interim guideline values for sediment quality (ISQGs) for the protection of aquatic ecosystems, indicating 'a moderate level of risk to aquatic organisms' from these metals (Kim 2007). Of these contaminants, mercury is regarded as the most potentially significant, due to its potential to bioaccumulate in organisms and biomagnify up a food web (Scheulhammer *et al.* 2007). Kim (2007) tentatively attributed the arsenic and copper enrichment to historical mining and/or weathering of sulphide-rich minerals in coastal areas of the Coromandel range. Mercury enrichment was found particularly at the mouth of the Piako River, suggesting that a potential source could be the wetlands situated in the Piako catchment, with the mercury entering the Firth of Thames in dissolved form through the drainage system on the Hauraki Plains (Kim 2007). Two potential specific sources of enriched cadmium and zinc are phosphate fertilisers for cadmium and facial eczema remedies for zinc. However, correlation data also suggests that significant amounts of zinc and cadmium entered the Firth of Thames from the Waihou River, and this is more likely to reflect a contribution from past mining in the Karangahake area (Kim 2007). Contaminants may also deserve a high rank because if sediment loading to the Firth is reduced (*e.g.* through successful controls on suspended sediment inputs), it may lead to an increase in the concentrations (expressed in units of mg/kg) of contaminants in deposited sediments. Making inroads into solving one problem may have the effect of making the subsidiary contamination issue more acute. This is because suspended sediments are (on a weight basis) relatively low in contaminants and act to dilute the contaminant load (expressed in mg). A reduction in sediment inputs causes less dilution in deposited sediments (*i.e.* more mg of contaminant per kg of sediment).

Nutrient enrichment would generally promote eutrophication, leading to an increase in phytoplankton and seabed algal production, giving rise to a range of effects. Excessive algal growth (*i.e.* an algal bloom) results in a wide range of water quality problems, including the production of large amounts of particulate organic matter, which degrades and deoxygenates bottom waters, potentially leading to the death of benthic invertebrates and fish from lack of oxygen. The accurate prediction of the risk from nutrients to the Ramsar ecological values was restricted by the limited data available on *e.g.* the synergistic pathways related to algal growth and nutrient recycling within the Ramsar marine systems, which led to high uncertainty for risk predictions associated with this stressor. Although it is beyond the scope of this study to address in detail, it must be highlighted that the lower risk prediction is not supported by the likely past and present high loads of nutrients entering the system. The rationale for the low score given to this stressor was the lack of current observable effects of nutrient enrichment in the Firth, combined with limited information on the fate of nutrients once they enter the Firth system. Nutrient loads are often linked to sediments and associated contaminants, and the likely effects of nutrient runoff are complicated by the dynamics of the nutrients and the assimilation capacity of the Firth system. The high uncertainties suggest that it would be useful to examine nutrient levels, dynamics and effects in the inner Firth of Thames in more detail in future studies.

The highest loads of sediments, contaminants and nutrients are often associated with seasonal or periodic flood events. The frequency of these flood events may change with global climate change effects, which is why the worst case scenario predicted that climate change is likely to be a large contributor of risk to the area in the future. The results show the biggest potential risk associated with climate change to be habitat loss (sea level rise). Climate change is a global issue driven by many sources of stressors including agricultural practices. For example, New Zealand studies have shown that agricultural activities, particularly dairy farming (through microbial reduction of nitrogen fertilizers and gaseous waste from the animals), contribute 51% of the overall greenhouse gas emissions of New Zealand (*e.g.* nitrous oxide and methane) (MFE 2003). These studies have shown that nitrous oxide has increased by 2.2% since the year 2000. Nitrous oxide is naturally scarce in the atmosphere and is considered the greenhouse gas of greatest concern, because it has a greater greenhouse warming effect than carbon dioxide.

In terms of assessment endpoints, the biggest risk was found to be associated with less tolerant species inhabiting the tidal flats (*e.g.* shellfish and polychaetes), yellow belly flounder and small pelagic fish species. The reason for this is that these species utilise both the inter- and subtidal seabed, (and some of them use mangroves too) and are potentially threatened by any risks that might affect these areas as well as the overlying water column. As such, these species were found to be at greatest risk because of the large number of stressors associated with the habitats they use. Conversely, the endpoints that were found to be at lowest risk were those comprising the species of coastal vegetation that are only marginally exposed to tidal influences (bachelor's button, sedges, Maori musk, burmedic short grassland, ryegrass). The analyses found these plants to be at low risk because they are dependent only on one major habitat being intact (open coastal areas). It could be argued that where a species is widely distributed (*i.e.* using several of the model's habitats) risks of adverse impacts would be reduced, and conversely that a narrowly distributed set of species (such as the coastal vegetation species mentioned above) is more vulnerable to risks. This was not taken into account in the RRM analysis, and the risks to endpoints therefore need to be interpreted carefully.

Overall the application of the RRM to the Ramsar site was useful. The work confirmed that the RRM is a rapid, powerful, flexible and cost effective tool that can provide an overview of the relative risks to a site from multiple sources, generating outputs that resource managers can use to aid decision-making. The overall scope of this study was to establish the RRM as a tool for the Ramsar site management. This tool can be used, and expanded upon, by management agencies and other stakeholders. The model was configured for a number of endpoints and stressors that are likely to be representative of most stakeholder concerns, but should new issues be raised, the existing model configuration can easily be modified with new input. As such, the RRM results presented here are considered a starting point for discussion and a guide to prioritise management actions.

The relative risk model was found to provide a useful framework for discussion with stakeholders about environmental and ecological values, and threats to these. The process of going through the exercise with stakeholders (*i.e.* compiling and documenting existing information, assigning scores to denote the importance of sources and habitats and devising conceptual models describing the links between sources, stressors, habitats and endpoints), ensured that all information was brought forward and incorporated. This bringing together of information meant that the modelling started with participants all having the same base knowledge from which to start scoring the importance of model parameters. Preliminary scores were assigned in workshops, and any disagreements between participants (representatives of management agencies) were discussed until consensus was reached. The close involvement of resource managers with the modelling process hopefully ensured that model results would be taken seriously by all involved, which is essential for uptake of recommendations from the Muddy Feet Phase II project.

It could be argued that the conclusions from the RRM study could be reached without going through a process of setting up and applying a model. Like all models, the relative risk model produces results based on the information supplied to it, in this instance participants' scoring of model parameters and their interconnections. In the process, efforts were made to ensure that scores were based on good information, and that uncertainty estimates reflected the amount and quality of information available. However, by necessity, a semi-quantitative method such as the RRM still uses subjective information, and it is possible that the same conclusions would have been reached through a different process. The main value of using the RRM was that it provided a solid framework for discussions with multiple management agencies about risks. This framework was based on factual information which could be documented, thereby potentially ensuring a much more robust analysis than could be achieved through more informal discussions or by any management agency on its own.

An additional report (Brownell, in press) identifies priority actions to reduce key risks to the Ramsar site. This was achieved through identifying what can be done to minimise each of the risks included in the model, and who should do it, and comparing this to what management agencies are currently doing or have plans to do in the near future. Actions not covered by existing work programmes are prioritised in the report, as are any identified information needs, and recommendations are provided to all agencies involved.

The second main objective of this study was to identify and quantify uncertainty in the information about various components of the Ramsar site. We found that many types of uncertainty exist in this risk assessment, but the largest cause of uncertainty is the lack of knowledge/data. One primary reason for this is that this risk assessment is the first model to examine the Ramsar site from a whole-of-catchment perspective. As future studies fill in the data gaps, uncertainty will be reduced.

The uncertainty analysis suggests that the model parameters with the most influence on risk score uncertainty are the exposure and effect filters for a mixture of sources, stressors, and habitats. Based on these uncertainty analysis results and our review of the available information, we created a list of the most pressing information needs for the Ramsar site to aid in the development of future studies to help reduce the uncertainty:

Data for climate change, particularly the combined effects of predicted sea level rise and subsidence in the Firth of Thames, and an assessment of the effects of sea level rise on the extent of the habitats considered in this report.

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

- Estimate of the size of roosting and feeding habitat available to shorebirds; investigations determining whether mangrove expansion reduces the size of habitat available for shorebirds or whether the intertidal area seawards of the mangroves is building up at rates similar to the expansion of mangroves.
- Further investigations determining the sources and likely effects of the elevated mercury concentrations found in sediments of the lower Firth of Thames.
- Quantification of nutrient concentrations in water and sediments of the Ramsar site, a quantification of the major sources of nutrients, and assessment of any likely effects of nutrient enrichment on the components of the Ramsar site.
- Phytoplankton or algal growth limitation at the Ramsar site.
- Effects in the wider Firth from nutrient and sediment discharges.
- Quantification of the biosecurity risks to the Ramsar site from marine farming at Wilson Bay.

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

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# Appendix I. Exposure Filters

Key:
C = Contaminants,
N = Nutrients,
S = Sediments,
F = Harvesting & Exploitation,
H = Habitat loss,
D = Disturbance,
IS = Invasive Species
Shaded cells indicate Monte Carlo medium or high uncertainty assigned.

**(1) Agricultural land use (dairy)**

| | **Risk Region** | **RAMSAR** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 3[A] | 1 | 3[B] | 0 | 0 | 0 | 2[D] |
| | Mangroves | 3[A] | 1[B] | 0 | 0 | 0 | 0 | 0 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 1[C] | 0 | 1[D] |
| | Stilt Ponds | 2[A] | 1[B] | 2[B] | 0 | 1[C] | 0 | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 2[A] | 1[B] | 3[B] | 0 | 0 | 0 | 0 |
| | Water column < 2 m | 2[A] | 2[B] | 2[B] | 0 | 0 | 0 | 0 |

[A] Potential contaminants from agriculture include zinc and cadmium. Mercury could also run off peaty wetlands where these are drained (Kim 2007). If these enter the coastal marine area, they could persist.

Site specific data (Kim 2007) indicates that elevated levels (still below ISQG-Low value) of mercury in intertidal sediments have been found within and east of the Ramsar site - Medium uncertainty.

Although currents will take effluents from the Waihou and Piako Rivers (the likely sources of the mercury) towards the east (away from the Ramsar site), there is still potential for damage to the site and surroundings, as well as to human and bird consumers of shellfish from the area (Scheulhammer *et al.* 2007). Mangrove colonisation also has the potential to alter mercury cycling and chemistry in this ecosystem. No other high levels of contaminants were found in intertidal sediments that could be caused by agricultural land use (*i.e.* where cadmium and zinc are found, concentrations are below sediment quality guideline values). As contaminants are bound to fine sediments, and these are trapped in mangroves, a filter of 3 was given to mangroves. Stilt ponds are subject to tidal inundation only occasionally, and in the subtidal and water column, land-derived sediments are assumed to be diluted with sediments already in the Firth, hence filter of 2. Agricultural runoff contains faecal contaminants that can persist in the water column. Findings from EW monitoring show that faecal contaminants are high at some Firth of Thames locations north of the Ramsar site. Faecal contaminants only harm humans, hence filter value of 2.

[B] Assigned filter of 1 to benthic habitats because the release of nutrients from agriculture to these habitats is episodic, that is occurs only periodically during storm or high runoff events, so most pastoral land can actually minimise or absorb normal (*i.e.* low intensity) showers of rainfall. However, High uncertainty because no data. Uncertainty for intertidal areas low, as data (Turner & Carter 2004) indicates that the Firth intertidal sediments have relatively low levels of TOC and N. Filter value of 0 and no uncertainty for sediment impact on mangroves, as sedimentation is thought to favour mangrove spread. Filter of 2 for Water Column, as NIWA (Broekhuizen & Zeldis 2006) modelling of impacts of nutrients on water quality in the Firth shows some persistence of agricultural nutrients in inner Firth at present day levels of farming, but little risk of blooms.

[C] Habitat loss could result from drainage of wetlands, and from stock access. However, Ramsar site protected under the EW Coastal Plan, so drainage of wetlands low risk. Stock have access to some intertidal areas and to the stilt ponds, but don't often get into the mud (Brownell, pers. comm.).

[D] Invasive species could occur from agricultural activities - *e.g. Spartina* distribution in intertidal area linked to stock access (Graeme 2006). May also affect Open Coastal areas, but here most vegetation not native anyway, and birds not dependent on native vegetation. Medium uncertainty for intertidal (as data indicates that stock are spreading *Spartina*), High for terrestrial as no data. There are no significant invasive weeds in the stilt ponds (Brownell, pers. comm.), and because of their limited extent we are relatively certain of that (so Low uncertainty).

### (2) Forests

| | Risk Region | RAMSAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 0 | 0[A] | 1[B] | 0 | 0 | 0 | 0 |
| | Mangroves | 0 | 0[A] | 0 | 0 | 0 | 0 | 0 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stilt Ponds | 0 | 0[A] | 1[B] | 0 | 0 | 0 | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 0 | 0[A] | 1[B] | 0 | 0 | 0 | 0 |
| | Water column < 2 m | 0 | 0[A] | 1[B] | 0 | 0 | 0 | 0 |

[A] Plantation forestry could release nutrients, that could affect inter- and subtidal habitats. However for the current study it was assumed that the loads from forestry are minimal as forestry activities are distant from the Ramsar site (low linkage), no sewage effluent spray irrigated in forests draining into FoT, and low levels of fertiliser used in general forestry (Blackie, pers. comm.), hence assigned 0 filter values with Low uncertainty. Data from Coromandel Peninsula catchments detects no impacts of nutrients on streams unless spray irrigation of sewage ongoing.

[B] Sedimentation from forests will most likely not, but could, cause sediment loading in the coastal marine habitats, the severity depending on slope and linkage to rivers. Forests are distant from Ramsar site, so low connectivity, hence 1 filter value. Medium uncertainty, because only data we have is distance from forests to Ramsar site. Sediments can have +ve effect on mangroves, hence 0 filter value.

### (3) Urban & Industrial Land use and Development

| | Risk Region | RAMSAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 1[A] | 1[B] | 1[C] | 0 | 0 | 0 | 0 |
| | Mangroves | 1[A] | 1[B] | 0 | 0 | 1[D] | 0 | 0 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 1[D] | 0 | 0 |
| | Stilt Ponds | 1[A] | 1[B] | 1[C] | 0 | 0 | 0 | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 2[E] | 0 |
| | Sub-tidal < 2 m | 1[A] | 1[B] | 1[C] | 0 | 0 | 0 | 0 |
| | Water column < 2 m | 1[A] | 1[B] | 1[C] | 0 | 0 | 0 | 0 |

[A] The extent of urban land use is limited in the area (Thames is the only larger settlement near coast). However, there are potential impacts through urban development further inland reaching sites via rivers. Kim (2007) indicates that contaminants from urban and industrial land use do not reach the Ramsar site at present levels of urban development, hence score of 1. Low uncertainty as sites close to urban settlements, or sources of contaminants from these, were sampled. Value for all other potentially affected habitats also 1, including Water Column, as some contaminants from urban areas persist (for long enough to do damage) in the water column, *e.g.* fuels.

B Urban/rural areas including marinas, roads and industrial sites could release nutrients. However, note that point source discharges are not included here. Filter based mainly on assumptions, and not on site-specific data. Filter value 1 because it is likely that minimal nutrient loads arise from non-point sources of urban and industrial land use in region. High uncertainty for all habitats apart from intertidal, as EW data (Felsing *et al.* 2006) indicates that there is no sign of elevated nutrient levels at the Ramsar site, or on intertidal flats just off Thames. Medium uncertainty for Water Column, where ARC TP208 indicates that nutrients arising from urban areas do not persist in the water column.

C Not all urban land uses release sediments. Some uses release none, some more. High sediment loads is often during construction *i.e.* short term (*e.g.* Hicks, 1994), but studies from Auckland show that there is a 10 to 100 fold increase in sediment yield from construction sites, compared to pastoral land (ARC TP 90 1999). Sediments released from urban areas are often coarser than those released from agricultural land uses. Assigned 1 filter because sediments from urban land use are unlikely to reach Ramsar site at present levels of urban development - low linkage as residual currents flow north from Thames and north-east from the rivers entering the Ramsar site. High uncertainty - no site specific data.

D Urban & Industrial development potentially causes habitat loss, through development in Open Coastal Area and potential reclamation of intertidal/subtidal area. However, stilt ponds contained in the QEII Trust Findlay Reserve, which cannot be developed, and development in the Ramsar site prohibited under EW's coastal plan. Open Coastal Area and Mangroves only habitats potentially affected. For these, EW Coastal Plan rules offer some protection to Mangroves, so Medium uncertainty.

E Urban activities, especially Aircraft flying, will cause disturbances to all bird species (*e.g.* aerobatic activities based at Ardmore Airfield). However, no site specific data particularly for aircraft traffic and disturbance levels, so filter value based on conceptual model and High uncertainty assigned.

**(4) Shipping (*i.e.* ballast water, boat hulls)**

| | Risk Region | RAMSAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 1[A] | 0 | 0 | 0 | 0 | 0 | 2[B] |
| | Mangroves | 1[A] | 0 | 0 | 0 | 0 | 0 | 1 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stilt Ponds | 1[A] | 0 | 0 | 0 | 0 | 0 | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 1[A] | 0 | 0 | 0 | 0 | 0 | 1[B] |
| | Water column < 2 m | 1[A] | 0 | 0 | 0 | 0 | 0 | 2[B] |

Very little shipping goes on in area, most boats are fishing boats.

A Contaminants could persist in these habitats, depending on the contaminant (*e.g.* mercury, zinc, lead) and origin of ballast/bilge water (however, small risk that boats release contaminated water given the patterns of boat use in the inner Firth of Thames). Antifoulants from boat hulls can contain high levels of contaminants, but these have been shown not to leach very much from normal boat traffic (the majority of the contaminant leaching occurs where boats are cleaned and moored for longer time periods (Stewart 2003). Bilge water can contain petrochemicals, but these do not persist long in the marine environment. Thus assigned filter values of 1. Medium uncertainty for intertidal area as contaminant survey of EW (Kim 2007) shows no contaminants in intertidal sediments that can be attributed to shipping. High uncertainty for other habitats, as no data available.

B Many activities (especially ballast water, ship and boat hulls) could introduce invasive species. Undaria is established on marine farms in Wilson Bay, and Styela is confirmed in Miranda, Kaiaua, and Wilson Bay. However, sources of these exotic species are not defined. Filter value of 2 for intertidal Ramsar area, as Styela has been found there, and for Water Column as larvae of invasive species could persist in this habitat. Vegetation report (Graeme 2006) shows no invasive species in mangroves that could be caused by shipping, so filter of 1 and Low uncertainty. Brownell reports no significant invasive species in Stilt Ponds, so filter of 0 and Low uncertainty. High uncertainty for Subtidal and Water column, as no data.

### (5) Fishing (recreational and commercial)

| | Risk Region | RAMSAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 0 | 0 | 0 | 1[A] | 1[B] | 0 | 2[C] |
| | Mangroves | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stilt Ponds | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 0 | 0 | 0 | 2[A] | 0 | 0 | 1[C] |
| | Water column < 2 m | 0 | 0 | 0 | 2[A] | 0 | 0 | 2[C] |

[A] Medium fishing activity occurs in the study area (see potential effect in Source table). However, no site-specific data, filter for subtidal and water column based solely on conceptual model and uncertainty High. Only intertidal fishing is shellfish harvesting, which is thought to be at low levels (Brownell, pers. comm.), so filter value of 1 and Medium uncertainty.

[B] Shellfish harvesting does cause habitat loss. However, no site-specific information is available for shellfish gathering in and around the Ramsar site, although observations (Brownell, pers. comm.) indicate very low use levels throughout the site. Medium uncertainty because some observations are available. No dredging in area.

[C] Fishing (via *e.g.* boat hulls) could introduce invasive species. Undaria is established on marine farms in Wilson Bay, and Styela is confirmed in Miranda, Kaiaua, and Wilson Bay. However, sources of these exotic species are not defined. Filter value of 2 for intertidal as Styela confirmed present there (Medium uncertainty). Vegetation report shows no invasive species in mangroves that could have come from fishing boats, so filter of 1 and Low uncertainty. Brownell reports no significant invasive species in stilt ponds, so filter of 0 and Low uncertainty. In the subtidal there is not a lot of hard substrate for invasive species to attach to, so filter of 1. Larvae of invasive species may persist in water column, hence filter of 2. High uncertainty because no data for subtidal or water column.

### (6) Marine Farms (Bivalve Aquaculture)

| | Risk Region | RAMSAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 0 | 0[A] | 0[A] | 0 | 0[B] | 0 | 2[C] |
| | Mangroves | 0 | 0 | 0 | 0 | 0[B] | 0 | 1[C] |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stilt Ponds | 0 | 0[A] | 0[A] | 0 | 0 | 0 | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 0 | 0[A] | 0[A] | 0 | 2[B] | 0 | 1[C] |
| | Water column < 2 m | 0 | 0[A] | 0[A] | 0 | 0 | 0 | 2[C] |

[A] Exposure to nutrients and sediments (*i.e.* organic rich and fine grained sediment, and various fouling organisms) associated with marine farming of mussels will most likely occur, but will be confined to habitats within and close to the farm. Farms are net consumers of nutrients and distant (>20 km) from Ramsar site, hence filter values of 0 (however, they may be closer to potential Western Firth AMA). Value of 0 assigned to mangroves, as nutrients and sediments are thought to have positive effects. Low uncertainty for any habitat that might be impacted by sediments, as modelling data indicates this is not likely to occur (Oldman & Senior 2000). Medium uncertainty for nutrients, because of potential transport of fouling organisms although observations by flounder fishermen indicate that fouling organisms are only found in significant numbers north of Thames.

[B] Habitat loss may occur from mussel farming as a result of fouling organisms from the mussel line cleaning process landing in intertidal areas. Most of the biological material lost from mussel farms will be heavy (*e.g.* shells, or attached to shells), and farms are currently distant from habitats. Should an AMA be established in Western Firth, this will be closer to site. Score of 0 and Medium uncertainty for intertidal areas because of distance to Ramsar site. Score of 2 and High uncertainty for subtidal area, as this is closer to farms. Debris from mussel farms (fouling material) found south of Wilson Bay, confined to north of Thames, but potential risk.

[C] Invasive species most likely will not, but could, persist in these habitats depending on Marine Farm management. Mussel farms are suitable substrate for exotic species, and there is potential translocation of stock from one part of the country to other. As noted, Undaria is established on marine farms in Wilson Bay and Styela is confirmed in Kaiaua, Miranda and Wilson Bay. However, no information available to confirm the marine farming practices are the cause of these invasions, and sources of these exotic species are not defined. Styela found on intertidal flats, so filter value of 2 with Medium uncertainty. Vegetation report shows no invasive species in mangroves that could be caused by marine farming, so filter of 1 and Low uncertainty. Observations show no significant invasive species in stilt ponds (Brownell, pers. comm.), so filter of 0 and Low uncertainty. Low risk of invasive species establishment in soft sediments of subtidal area, but no information, so filter of 1 and High uncertainty. Larvae from invasive hydroids and seasquirts may persist for some time in the water column, so filter of 2 and High uncertainty.

### (7) Point Sources (domestic and industrial, including: sewage treatment plants, stormwater drains, dairy ponds, dairy factories)

| | **Risk Region** | **RAMSAR** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 1[A] | 1[B] | 0 | 0 | 0 | 0 | 0 |
| | Mangroves | 1[A] | 1[B] | 0 | 0 | 0 | 0 | 0 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stilt Ponds | 1[A] | 1[B] | 0 | 0 | 0 | 0 | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 1[A] | 1[B] | 0 | 0 | 0 | 0 | 0 |
| | Water column < 2 m | 2[A] | 1[B] | 0 | 0 | 0 | 0 | 0 |

[A] No direct domestic or industrial discharge from catchment to FoT water, except Thames District Waste Water Plant (DWWP), but contaminants/nutrients could arise from current and historical (past) sources. Contaminants could be transported via river and be bound to sediment. Kim (2007) indicates that contaminants at the Ramsar site that could be caused by point source emissions are below ANZECC low guidelines. Because of distance from point source discharge to Ramsar site, contaminants were scored at 1 for all benthic habitats. Bacterial contamination found frequently at beaches north of Thames (EW 2004), so filter of 2. Medium uncertainty where data are available, high where not.

[B] No direct domestic or industrial discharge from catchment to FoT water, except Thames DWWP, but nutrients from waste water treatment plants and dairy farm pond effluents discharged to rivers and waterways are likely to reach Ramsar site. Also, total phosphorus loads of rivers entering the Ramsar site are significant and similar to loads from non-point sources (HGF SoE report 2004). However, no evidence of nutrient enrichment detected from EW's sediment monitoring at the Ramsar site, so current risk low - filter value of 1 for benthic habitats. Higher risk of nutrients in water column, so assigned filter value of 1. High uncertainty for all but intertidal flats where data is available.

### (8) Accidental Spills

| | Risk Region | RAMSAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 2[A] | 0 | 0 | 0 | 0 | 0 | 0 |
| | Mangroves | 2[A] | 0 | 0 | 0 | 0 | 0 | 0 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stilt Ponds | 2[A] | 0 | 0 | 0 | 0 | 0 | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 2[A] | 0 | 0 | 0 | 0 | 0 | 0 |
| | Water column < 2 m | 2[A] | 0 | 0 | 0 | 0 | 0 | 0 |

[A] Contaminants most likely will not, but could, persist in these habitats (including water column), depending on the contaminant. No accidental spills data set available at this time. Assigned High uncertainty, and filter values based solely on conceptual model, not site-specific data.

### (9) Human Recreation

| | Risk Region | RAMSAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Mangroves | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 2[A] | 2[A] | 0 |
| | Stilt Ponds | 0 | 0 | 0 | 0 | 1[A] | 1[A] | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Water column < 2 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[A] Human recreation, particularly visitors to the Ramsar site (which includes about 12,000 visitors a year, mostly school children and bird watchers) from around the world. Visitor activities within these sites can result in disturbances to birds and cause habitats loss due to trampling. Observations indicate that visitors rarely enter the mudflats, or the mangroves, so filter of 0 and Low uncertainty. Visitors may enter minor stilt ponds that are not obvious, hence filter of 1. Most visitors on open coastal area, but few observations/data on open coastal and stilt ponds, so High uncertainty.

### (10) Climate Change (including temperature change, increased risk of flooding and extreme weather, sea level rise)

| | Risk Region | RAMSAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 1[A] | 1[B] | 2[B] | 0 | 3[C] | 1[D] | 2[E] |
| | Mangroves | 1[A] | 1[B] | 0 | 0 | 3[C] | 1[D] | 1[E] |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 3[C] | 1[D] | 2[E] |
| | Stilt Ponds | 1[A] | 1[B] | 2[B] | 0 | 3[C] | 1[D] | 2[E] |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 1[A] | 1[B] | 2[B] | 0 | 3[C] | 1[D] | 2[E] |
| | Water column < 2 m | 0[A] | 1[B] | 2[B] | 0 | 0 | 0 | 2[E] |

[A] Increased floods may increase erosion, which may include contaminated soils (*e.g.* zinc from dairy farming). However, most erodable soils are steeper than those used for dairy, and increase in general soil erosion would lead to a dilution of contaminated soil runoff, so assigned score of 1 and Medium uncertainty. Sediment-bound contaminants likely to be major source of contaminants, so score of 0 for water column, with Medium uncertainty.

[B] Climate change may increase frequency and intensity of storms events (increasing rainfall intensity and flooding), and produce/modify wave action, which in turn may affect sedimentation loads, and movements/deposition in FoT habitats. Phosphorus (bound to sediments) and sediment loads are likely to increase because of climate change, but nitrogen loads are unlikely to change. Hence filter value of 1 for nutrients, and 2 for sediments. Storms are episodic, so effects intermittent. High uncertainty for all but impacts on mangroves, where we suspect that nutrients have positive impact.

[C] Sea level rise is likely to cause habitat loss. Predicted sea level rise and storm surges which is defined as a temporary rise of mean sea level along the coast over a few hours or days are a concern globally as well as in New Zealand, particularly in low lying coastal areas such as the Thames region (Bell *et al.* 2000). Sea level rise in New Zealand was up to 16 cm in the last century (Hannah 2004).

[D] Increased erosion, resuspension, reworking, shoreline inundation *etc.* is likely to result from sea level rise and more extreme weather. This may lead to increased disturbance to some habitats. Assigned filter value of 1, and High uncertainty.

[E] Climate change is likely to lead to changes in water and air temperature, and this combined with consequent habitat changes will increase the likelihood of invasive species invading successfully. Assigned filter value of 2 and High uncertainty (given we don't know how much temperatures are likely to change, and in what direction) for all habitats apart from mangroves, for which data (Beard 2006) shows higher growth rates at increased temperatures, which means that mangroves are less likely to be out competed if climate change leads to an increase in temperature.

**(11) Mangrove expansion (increased mangrove growth competing with other habitats for space)**

| | Risk Region | RAMSAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 0 | 0 | 2[A] | 0 | 3[B] | 0 | 0 |
| | Mangroves | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stilt Ponds | 0 | 0 | 2 | 0 | 3 | 0 | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 0 | 0 | 2[A] | 0 | 2[B] | 0 | 0 |
| | Water column < 2 m | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[A] Mangrove expansion has been shown to increase sedimentation intertidally by slowing water movement. Assigned filter value of 2 for benthic habitats, Medium uncertainty for intertidal flats, as pneumatophores are known to cause sediment deposition (Young & Harvey 2006), but we are uncertain of effects outside pneumatophore zone. Low uncertainty for stilt ponds, as observations indicate mangroves are spreading and are causing infilling, and High uncertainty for subtidal, as the effects of mangroves on subtidal habitat is unknown.

[B] Mangrove expansion in the Ramsar site is at the expense of other habitat space and has caused habitat loss particularly for birds (Battley & Brownell 2007). Assigned filter of 3 to intertidal flats, and Medium uncertainty, because data indicates habitat loss. For stilt ponds, observations indicate habitat loss (Woodley & Brownell, pers. comm.), and because the stilt ponds are smaller and observations are likely to cover a larger proportion of that habitat, uncertainty is Low. For subtidal areas the habitat loss caused by mangrove expansion is unknown, so filter of 2 and High uncertainty.

**(12) Firth of Thames Sediment (historical sediment deposition in the Firth is mixing and contributing to sediment loads on Ramsar)**

| | Risk Region | RAMSAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Stressor** | **C** | **N** | **S** | **F** | **H** | **D** | **IS** |
| **Habitats** | Tidal Flats_Ramsar site | 0 | 0 | 3[A] | 0 | 0 | 0 | 0 |
| | Mangroves | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stilt Ponds | 0 | 0 | 2[A] | 0 | 0 | 0 | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 0 | 0 | 3[A] | 0 | 0 | 0 | 0 |
| | Water column < 2 m | 0 | 0 | 3[A] | 0 | 0 | 0 | 0 |

[A] Recent work by NIWA (Swales 2006) shown that most of the present sedimentation within the mangroves of the Ramsar Site originates from the Firth of Thames. The ultimate source of the sediments is still the land, but not the present day landuse. Sedimentation is known to be the most important contaminant in many New Zealand estuaries, adversely affecting intertidal flats and subtidal environments (*e.g.* Lohrer *et al.* 2004; Mead & Moores 2004), so filter value of 3 and Medium uncertainty. Lower connectivity with stilt ponds, so filter of 2, and high uncertainty. The impacts of sedimentation on users of the water column are well documented for other sites in New Zealand, but no site specific data, so filter of 3 and High uncertainty.

# Appendix II. Effects Filters

| | Risk Region | RAMSAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Endpoint | Chenier creation zone | Bachelor's button, sedges, Maori musk, Bur medic short grassland, ryegrass | Saltmarsh ribbonwood, mingimingi shrub, glasswort saltmarsh | Pied oystercatcher | Bar-tailed godwits, lesser knot, curlew sandpiper | New Zealand dotterel, variable oystercatcher, black-billed gull, white-fronted tern, Caspian tern | Wrybill | Shags, heron and banded rail | Pied stilts |
| Habitats | Tidal Flats_Ramsar site | 3[A] | 1[B] | 2[C] | 3[E] | 3[F] | 2[G] | 3[H] | 1[I] | 3[J] |
| | Mangroves | 0 | 0 | 1[C] | 0 | 0 | 0 | 0 | 3[I] | 0 |
| | Open Coastal areas | 1[A] | 3[B] | 2[C] | 3[E] | 3[F] | 3[G] | 1[H] | 1[I] | 1[J] |
| | Stilt Ponds | 0 | 0 | 0 | 1[E] | 2[F] | 1[G] | 3[H] | 1[I] | 3[J] |
| | Airspace | 0 | 0 | 0 | 3[E] | 3[F] | 3[G] | 3[H] | 3[I] | 3[J] |
| | Sub-tidal < 2 m | 1[A] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Water column < 2 m | 0 | 0 | 2[C] | 0 | 0 | 0 | 0 | 0 | 0 |

| | Risk Region | RAMSAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Endpoint | Snapper | Yellow belly flounder | Small pelagics and kahawai | Eels | Whitebait (inanga and smelt) | Shellfish beds (e.g. cockles, macomona, mactra, oysters, nucula) | Polychaetes | Mud crabs (three species) | Water Quality |
| Habitats | Tidal Flats_Ramsar site | 1[K] | 3[L] | 2[M] | 2[N] | 1[O] | 3[P] | 3[Q] | 1[R] | 1[S] |
| | Mangroves | 1[K] | 3[L] | 2[M] | 3[N] | 0 | 0 | 1[Q] | 1[R] | 0 |
| | Open Coastal areas | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Stilt Ponds | 0 | 0 | 0 | 0 | 0 | 0 | 1[Q] | 1[R] | 0 |
| | Airspace | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sub-tidal < 2 m | 3[K] | 3[L] | 3[M] | 1[N] | 1[O] | 2[P] | 2[Q] | 1[R] | 1[S] |
| | Water column < 2 m | 3[K] | 2[L] | 3[M] | 2[N] | 2[O] | 3[P] | 3[Q] | 0[R] | 3 |

Overall: assigned High uncertainty when little was known about dependence of endpoint on habitat; Medium uncertainty when it is known that habitat is not used extensively by endpoint, and Low uncertainty when the use of habitat and ramifications of potential impacts on habitat to endpoint is well known.

[A] Chenier Banks are unique in New Zealand and one of the world's finest examples of this rare coastal landform. They serve as protection against coastal erosion, including for saltmarsh communities. It is important that banks can continue to accrete. The main stressor is habitat loss caused by space competition - the formation of Chenier plains reliant on shell produced in low intertidal and high subtidal area, as well as clear intertidal flats that shells can be deposited on. High uncertainty because dependence on different habitats not fully understood.

[B] Vegetation grouped together because of minimal salt water exposure, therefore subject to similar stressors. Plants present within Open Coastal Areas and margins of intertidal area. Little knowledge of potential impacts of habitat alteration, so High uncertainty.

[C] Vegetation grouped together because of medium salt water exposure, therefore subject to similar stressors. Plants present within intertidal areas mainly, but some types of mingimingi will be present in Open Coastal Areas, and glasswort and sea primrose has been found under open mangrove canopy (Graeme 2006). All are subject to influences from water column, but to varying degrees. High uncertainty as limited knowledge of how impacts on habitats will affect Endpoints.

[E] Ramsar site top 2 site in winter for pied oystercatchers, which use intertidal flats and open coastal areas mainly. Because species is rare in stilt ponds, filter value of 1 assigned here. Medium uncertainty for all habitats apart from air space (because we know that pied oystercatchers are dependent on these habitats) and High uncertainty for airspace, as not sure how high the linkage is.

[F] Ramsar site important for these because: it holds 10% of the New Zealand population in winter, site has fifth highest abundance of lesser knots in summer nationally; bar-tailed godwits are migrants present in high numbers at site; site has second highest abundance of curlew sandpiper in summer nationally. Birds grouped because they have similar feeding and far-ranging migration habits (Woodley & Brownell, pers. comm.). We know that species highly dependent on intertidal flats and open coastal area, and less dependent on stilt ponds (although the bar-tailed godwit favours stilt ponds for roosting) (so Medium uncertainty).

[G] New Zealand Dotterel is endangered, black-billed gull is in serious decline, white fronted tern is in gradual decline, Caspian tern is nationally vulnerable. Ramsar site is important for these birds. Birds grouped because all are more localised (New Zealand) migrants (Woodley & Brownell, pers. comm.). This group of birds is comprised of coastal margin dwellers, which use the tidal flats less extensively than a lot of species. Because dotterels sometimes occur in stilt ponds, filter value of 1 here. High uncertainty for this group as very diverse, and different species tend to feed in slightly different areas.

[H] Site hosts 58% of New Zealand wrybill population in winter. Wrybills do not use the open coastal area much, because they are small birds, and can't see beyond tall grass, and therefore favour other areas. They regularly use the tidal flats for roosting. Medium uncertainty for all areas that we know the birds use, because still some uncertainty about impacts on species by adverse effects on habitat.

[I] Banded rail is sparse. Shag and heron numbers are increasing (Woodley & Brownell, pers. comm.). Mangroves are important for these species, but they don't use tidal flats, open coastal areas (only heron use this area) or stilt ponds much.

[J] Ramsar site has second highest abundance of pied stilts in winter nationally. These mainly use the stilt ponds and the tidal flats. Minimal use of open coastal areas. Medium uncertainty as limited data on effects of stressors and linkage to endpoint.

[K] Snapper juveniles use the intertidal flats as habitat, and mangroves too (but being intertidal, this is not their main habitat). Target species for customary, recreational and commercial fishermen. High reliance on subtidal and water column known, less certain about reliance on tidal flats and mangroves.

[L] Target species for customary, recreational and commercial fishermen. Concentrated within Ramsar site, where uses intertidal flats and mangroves extensively. Demersal species, so less dependent on water column.

[M] Mainly sprat, pilchards, yellow-eye mullet and juvenile kahawai. Important food source for seabirds (for kahawai mainly up to 2-3 year old population), other fishes and cetaceans. Target species customary, recreational and commercial fisheries for local consumption or bait. Yellow-eye mullet only species in group that use mangroves, so assigned 1 for this habitat. Not much is known about dependence on intertidal area, so High uncertainty here, otherwise Low.

[N] Target species customary, recreational and commercial fishermen. Use subtidal and water column habitats for going out to sea to spawn only, and are not found (but nobody is looking for them either) on intertidal flats. Medium uncertainty for all but mangroves, where catch data indicate they are present in high numbers.

[O] Use the Waihou river and (less) the Piako river. Target species for customary and recreational fishermen. Important food source for birds and fishes. Inanga spawning occurs in reed beds and other vegetation (*e.g.* pasture overgrowing estuarine and stream edges). Young fish may emerge from eggs from as early as two weeks after being spawned, with the onset of the next spring tide before being dispersed. The juvenile fish are dispersed out to sea, and it is thought that they live at or near the surface, feeding mostly on small crustaceans. So, time spent in the habitat around high-tide as eggs is quite limited. Inanga 'whitebait' (comprising 95% of the whitebait catch) are typically 160 days old when they undertake their inshore migration (following flood waters) in the spring. Feeding generally ceases during the migratory period. Eggs are deposited on clean subtidal sand. Feeding appears to be mainly on planktonic crustacean, and some planktonic algae while juvenile. However, feeding biology is largely unknown, although known to be varied, with some reliance on surface and mid-water feeding, and some bottom feeding. What the feeding preferences might be in the Firth of Thames is unknown, although water column is likely to be important (McDowall 1990). High uncertainty for all.

[P] Common bivalves, cultural and recreational importance as food source, important food source for birds and fishes. Filters assigned as per conceptual model. Assume that fewer shellfish beds found in subtidal areas (as FoT is very muddy), but some harder substrate patches were found in a recent survey (Morrison *et al.* 2003). Low uncertainty for intertidal area, as know shellfish are present (Felsing *et al.* 2006) and susceptible to stressors pertaining in this and water column habitats (NIWA and other research).

[Q] Polychaetes known to be present on intertidal flats (Felsing *et al.* 2006), and are typically less prominent in mangrove habitats (Felsing 2006). Some polychaetes are present in stilt ponds, and they are thought to be present subtidally (although no site-specific data). Many polychaetes are filter-feeders, and therefore very reliant on the water column.

[R] Important food source for birds. Present in medium numbers on intertidal flats, and in high numbers within mangroves. *Macrophthalmus hirtipes* occurs in the subtidal, but Helice crassa only in the intertidal (Judy Hewitt, pers. comm.). However, not very susceptible to the main stressors for these habitats, hence filter of 1. Low uncertainty for intertidal and mangroves, as dependence of mudcrabs on these habitats is known.

[S] Water quality is linked to the functioning of, and impacts on, these habitats. Assigned High uncertainty as little is known about the linkages between water quality and the impacts on the habitats, apart from water column.