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Population Biology and Foraging Ecology of Waders in the Firth of Thames - Update 2007

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Population Biology and Foraging Ecology of Waders in the Firth of Thames: Update 2007

Phil F. Battley and Bill Brownell, Editors

Collaborating Seabird Coast Organisations:
Miranda Naturalists' Trust
Tikapa Kahawai Coastal/Marine Advisory Service
EcoQuest Education Foundation

Seabird Coast

Reviewed by:	Approved for release by:
Megan Stewart	Dominic McCarthy
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Photo 1 (Phil Battley): Roosting wrybill.

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Executive Summary

Battley, P.F.; Brownell, B. (2007) Population biology and foraging ecology of waders in the Firth of Thames: update 2006.

The Firth of Thames is a large intertidal embayment southeast of Auckland, New Zealand. Renowned for its populations of migratory birds, it was designated a Ramsar site in 1990. The abundance of desirable food, mainly consisting of intertidal-dwelling shellfish and worms, has historically been the principal attraction for the migrants, along with safe high-water coastal roosts. The Ornithological Society of New Zealand and Miranda Naturalists' Trust have conducted biannual shorebird surveys of the Firth of Thames since the early 1960s, with the last detailed analysis of trends in shorebird numbers covering the period up to 1998.

In this report, a complete analysis of changes in shorebird numbers from 1960/61 to 2005 is presented (Chapter 2). The existence of a parallel dataset from the Manukau Harbour enabled comparisons of both sites in attempts to discern whether population changes are likely to be due to local effects in the Firth of Thames or to large-scale factors (such as changes in overall productivity of birds). Additionally, characteristics of the benthic communities of the Firth of Thames intertidal mudflats are described and the diet of the key wading bird species outlined (Chapter 3).

The 45-year count series reveals substantial changes in the coastal bird community over time. The distribution of roosting shorebirds in the Firth of Thames has changed with the spread of mangroves across the southern shores of the Firth. Areas that formerly held substantial numbers of birds have largely been abandoned, and some species that used these areas have declined substantially in number. Other species have increased over time, most notably the pied oystercatcher, though there is the suggestion of a recent decline in numbers. The species the Firth of Thames is most important for, the wrybill, has declined over the past 30 years. Over the same period, numbers have risen in the Manukau Harbour, suggesting a gradual redistribution of the population.

Populations of Arctic-breeding shorebirds varied locally (e.g. red knots increased in the Manukau Harbour) and in relation to 'global' factors (e.g. bar-tailed godwit populations at both sites had two general peaks in both summer and winter, implying that changes in reproductive success are partly involved in population levels). However, there were generally only poor correlations between international migrant shorebird counts in the Firth of Thames/Manukau Harbour and breeding success estimates of the same species in southeastern Australia. There were nevertheless qualitative matches between population trends for a few species between New Zealand and Australia.

Since 2004 our collective understanding of the natural and anthropogenic processes affecting the highly estuarine southern part of the Firth of Thames has increased significantly. But, to date, there is a very incomplete knowledge base of the habitat use, diet and energy intake of the shorebirds that depend on the Firth's southern intertidal zone. Chapter 3 focuses on the macrobenthos communities of the southern Firth and summarises what is known about them in terms of species composition and abundance in relation to the structure of the sediments. The feeding habits, diet and possible impacts on preferred prey species of five of the principal species of waders using the Firth are appraised.

Due to major land use changes over the past two centuries, the intertidal zone extending from south of Miranda in the west around to the Waihou River in the east, is now characterised by a depauperate benthic macrofauna living in a potentially limiting habitat of soft shifting sediments and highly turbid water.

The report identifies several key questions for resource managers, particularly the issue of loss of habitat for shorebirds, of both intertidal feeding and open shore roosting habitat.

Chapter I. General Introduction

Bill Brownell[+]
[+] Tikapa Kahawai Coastal/Marine Advisory Service, 30 Pukekereru Lane, Kaiaua, RD 3 Pokeno, NZ 2473

1 Background to this Study

In 2001 the marine farming industry demonstrated considerable interest in developing significant areas for mussel spat catching in the western half of the Firth of Thames. This project was commissioned by the Auckland Regional Council (ARC) to assist it in its decision making processes in relation to possible aquaculture developments in this area. The ARC recognized that an ecosystem approach was needed in order to understand fully the physical and biological implications of any existing activities and future resource use proposals for the Firth. Numerous studies have already been carried out by the ARC and Environment Waikato (EW), and various monitoring programmes are in place that focus on charting the effects of marine farming, nutrient loading and sedimentation in the Firth.

The National Institute of Water and Atmospheric Research (NIWA) has also been carrying out extensive studies of the primary productivity of the Firth and the wider Hauraki Gulf since the early 1990s (Zeldis et al. 2005).

The Muddy Feet Project (Brownell 2004) put the Firth of Thames ecosystem into a clearer perspective, by pulling together an extensive resource of information dealing with fish and fisheries, birds, coastal vegetation and terrestrial animals, mangrove forests, benthic ecology and hydrology. Muddy Feet Phase II (Brownell 2007) is building on this information in tandem with a specially designed Relative Risk Model (Elmetri and Felsing 2007), focusing on the principal stressors and their sources, and the habitats and species groupings affected. This is then put into the context of identifying the opportunities for improvement available to statutory and technical agencies within the policy/planning mandates and problem-solving tools that guide their actions.

As the principal justification for establishment of the Firth of Thames Ramsar site, the migratory waders (also known as shorebirds) and the benthic invertebrates that sustain them, have become a cornerstone of numerous studies focusing on this vital ecosystem and the biological indicators of its overall health. This report covers two aspects relevant to the understanding and management of the shorebirds that use the Firth of Thames.

The first is an analysis of long-term trends in shorebird numbers in the Firth of Thames and the Manukau Harbour using Ornithological Society of New Zealand (OSNZ) biannual bird census results. Regular movements of waders between the two harbours are well documented. These data have previously been reported on for the period 1960-1998 (Veitch & Habraken 1999). The current report (Chapter II) presents more detailed analyses of all shorebird populations from 1960 to 2005.

The second is a review of relevant studies on the relationships between key shorebird species and their benthic intertidal prey. Little is known about the diet and prey consumption of waders in New Zealand, and even less about on the impact of birds on the population biology of their prey. However there is a substantial body of work on shorebirds internationally, much of which is potentially relevant to New Zealand. Section III of this report extrapolates some of the most relevant information available, and ties it together with what is currently known about the Firth of Thames.

The scope of this study is not broad enough to make any predictions about potential impacts on waders and their food supply by potential marine farming operations in the Firth of Thames under any given method, magnitude and/or location. However, it will serve as baseline of information to assist with evaluation of the potential impacts of future resource use proposals in the Firth.

A direct baseline of benthic community composition and abundances at one point in time has recently been published for another major tidal flat site of international importance to waders (Farewell Spit, northwest Nelson; Battley *et al.* 2005).

The extremely high use of the littoral zone of the Firth of Thames by wildlife of immense conservation value indicates a need for more specific national protection mechanisms. Currently, minimal protection is afforded under the Ramsar designation together with the guiding principles behind the Hauraki Gulf Marine Park, of which it is a part.

A much greater understanding of the intertidal and shoreline habitats used by the numerous avian species involved is needed, so that the essential ecosystem services can be managed sustainably by the two regional councils with jurisdiction over the Firth (ARC and EW), as well as the Department of Conservation, the Ministry of Fisheries and the three district councils (Franklin, Hauraki and Thames-Coromandel) responsible for management of the coastal fringe where the birds roost.

2 Migratory Waders in New Zealand

New Zealand has a number of important estuarine feeding and roosting grounds frequented by migrant wading birds. Along with the Kaipara Harbour, Manukau Harbour and Farewell Spit, the Firth of Thames is one of the principal gathering places for waders in New Zealand. It is recognised, particularly through its Ramsar site designation, as being an internationally important wader sanctuary.

The adjacent large estuaries of the Firth of Thames and Manukau Harbour (southeast and southwest of Auckland, respectively) both host significant numbers of various indigenous New Zealand migrants. They are also two of the terminal points of the East Asian-Australasian Flyway used by about five million shorebirds that migrate annually (between July and October) from Siberia and Alaska for summer in the southern hemisphere, and return between March and June to their northern breeding grounds (Barter 2002). Over 100 000 waders use the Firth of Thames and the Manukau Harbour through the year (Veitch & Habraken 1999).

Many estuaries in East Asia of critical importance to these birds are already severely encroached upon by urban development, and/or face increasing pressures from human activities and land use in the surrounding catchments. Twice a year the international migrants using the East Asian-Australasian Flyway pass over some of the densest human populations in the world, and the wetlands and estuaries in East Asia that they habitually use along the way for feeding and resting are increasingly threatened by human occupation and use.

As a terminus for migrating waders, it is of great importance that the Firth of Thames ecosystem continues to provide abundant food (benthic invertebrates), protection from predators, sheltered roosting areas and high water quality. The migrants depend on these factors to sustain themselves nutritionally for between three and seven months each year in this location.

3 Firth of Thames Ramsar Site

The *Convention on Wetlands of International Importance Especially as Waterfowl Habitat* is an intergovernmental treaty, adopted on 2 February 1971 in the Iranian city of Ramsar, and is commonly known as the Ramsar Convention. Although the emphasis originally was on the provision of habitat for waterfowl and waders, the Convention has in recent years broadened its scope, recognizing the importance of wetland ecosystems for biodiversity conservation and for the well-being of human communities.

Three of the six existing Ramsar sites in New Zealand (Firth of Thames, Farewell Spit and Manawatu Estuary) are recognised for their capacity to sustain nationally important numbers of waders.

The Firth of Thames Ramsar Site (established January 1990) comprises the intertidal area of the southern and western shores of the Firth of Thames between Kaiaua and the west bank of the Waihou River near Thames. The margins of the Ramsar site are defined by the extremes of mean low water spring tides (MLWS), and mean high water springs (MHWS), and covers between 8500 and 9000 hectares (depending on shifting sediment deposits over time). The vast, open inter-tidal mudflats, the mangrove communities that now cover much of the upper reaches of the intertidal zone, and the terrestrial areas adjacent to the mudflats are built on varying proportions of marine and land-derived sediments, old shell banks and vegetative debris (Brownell 2004).

A total of 132 species of birds has been recorded at the Firth of Thames, primarily in the environs of Kaiaua/Miranda at the northwestern end of the Ramsar site. Of these, about sixty species are either abundant or common; the remainder are occasional or rare visitors. The Firth of Thames hosts approximately 35 000 waders each year (mainly along the Miranda Coast and the wider Ramsar site extending further to the south and east). Of these, about 11 000 are Arctic breeders from Siberia and Alaska.

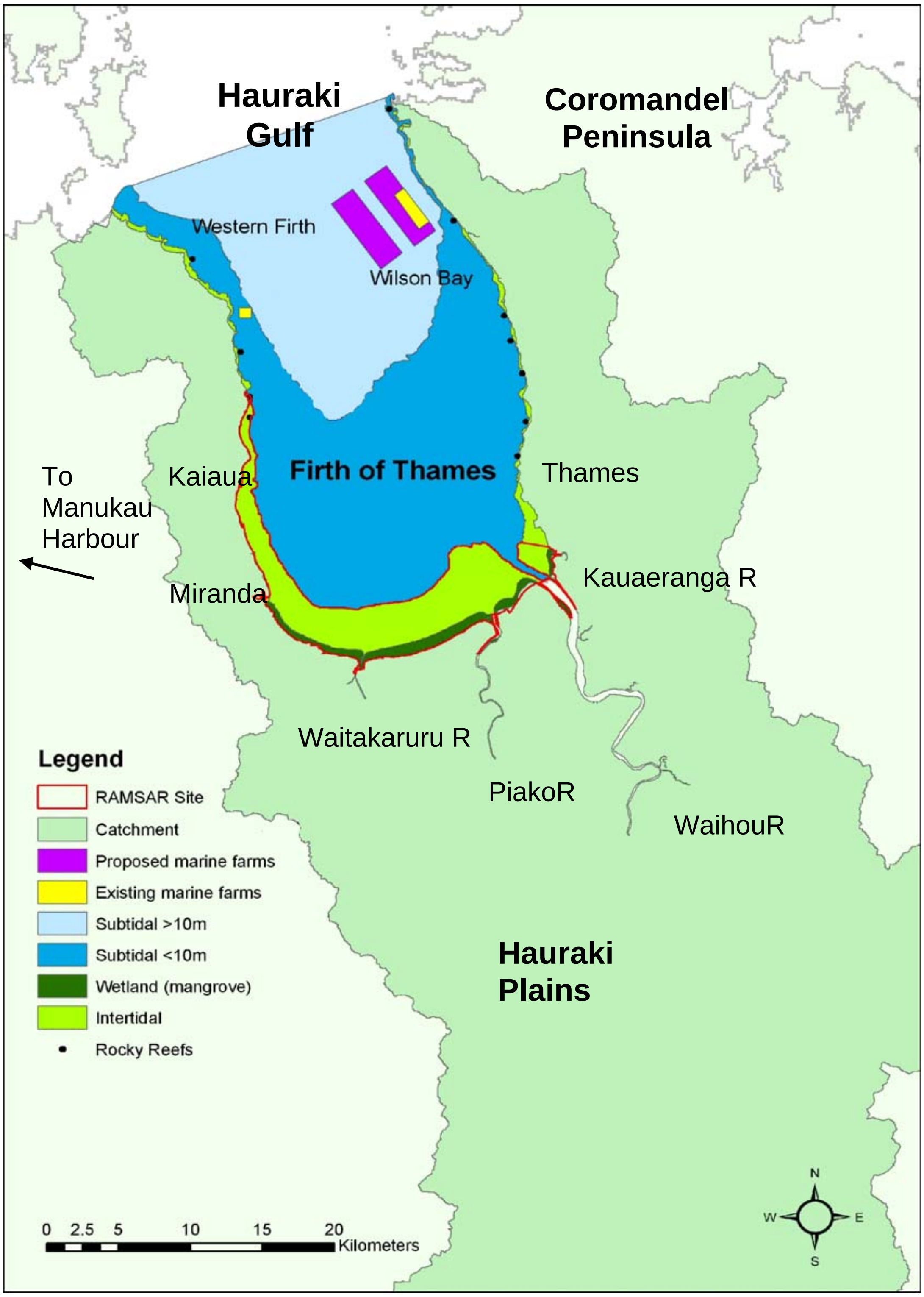
The shallow mud and silt tidal flats exposed at low tide in the Firth of Thames provide important feeding grounds for waders (Figure 1). These tidal flats vary from one to 2.5 km in width at low water on a spring tide, and have historically held an abundance of favoured food items (such as polychaete worms, shellfish, crabs and shrimps). The waders are not only in competition with each other for this resource, but also with other marine organisms and human shellfish gatherers. The relative abundances and sizes of these potential food items are also determined to varying degrees by natural cycles such as recruitment and growth, availability of plankton, detritus or other invertebrates (their own food supply), and external impacts such as sedimentation, nutrient supply and contaminants.

In addition to adequate food supplies, safe, undisturbed, roosting areas are critical for wading birds. These places are increasingly limited in the Firth of Thames, due to encroachment of mangroves along the southern and western margins of the Firth, changes in the saltmarsh and grassland flora along the shores, and increased human activity (subdivision, camping, bird watching and dairy farming).

The section of Ramsar site coast that lies between Taramaire (just south of Kaiaua) and the Pukorokoro (Miranda) Stream is the most important wader area of the Firth of Thames at high tide. The Stilt Ponds (shallow coastal lagoons), situated at the southern end of the area, also provide food for many waders, particularly pied stilts (*Himantopus himantopus*), banded dotterels (*Charadrius bicinctus*), wrybills (*Anarhynchus frontalis*) and sharp-tailed and pectoral sandpipers (*Calidris acuminata* & *C. melanotus*). These pools are attractive as a high-tide roosting site for bar-tailed godwits (*Limosa lapponica*) and lesser knots (*C. canutus*). Large flocks of wrybills frequently roost along the Stilt Pond margins, as well as on the shell banks at the mouth of the Taramaire Stream and elsewhere along the Miranda Coast.

The Ramsar Site provides not only habitat for the waders, but an array of wetland and estuarine habitats for many other coastal birds such as white-faced heron *(Ardea novaehollandiae)*, banded rail (*Gallirallus philippensis)*, shags *(Phalacrocorax spp.* and *Strictocarbo sp.)* and fernbird *(Bowdleria punctata)*. The shellbanks of this area provide vital roosting sites for large numbers of shorebirds, but are also important as breeding sites for up to 1000 pairs of white-fronted terns (*Sterna striata*) at Taramaire, black-billed gulls (*Larus bulleri*) at Miranda, three species of shags (*Phalacrocorax spp.*) that nest mainly in the fringing mangroves, and a few pairs of the nationally vulnerable northern New Zealand dotterel (*C. obscurus aquilonius*).

Figure 1: Firth of Thames showing Ramsar site with its intertidal mudflats and mangroves. Catchment of 3600 km² in light green (mainly drained by Waihou & Piako river systems).



4 Geography, Geology, Hydrology and Productivity

The Firth of Thames, or Tikapa Moana, is a shallow marine embayment, which lies in the northern part of the Hauraki Rift, bounded by fault lines along the Hunua and Coromandel ranges. It lies at the base of the narrow northern extension of New Zealand's North Island and is bounded to the east by the Coromandel Peninsula. The Firth's arbitrary northern boundary, merging into the greater Hauraki Gulf, is situated due east of Auckland, running from Thumb Point (NE Waiheke Island) to Coromandel Harbour, approximately following the line of 36°44' S latitude, between 175°11' and 175°31' E longitude (Figure 1). The Firth is between 20 and 26 km wide and reaches a maximum depth of 35 m near its northern limits.

The Firth of Thames is the primary receiving environment for the ~3600 km^2 Hauraki Catchment. The southern half of the Firth (south of a line drawn between Tararu in the east and Kaiaua in the west) is very shallow, with a maximum depth of 5 m (mainly in the middle) at mean low water spring tides (MLWS). For nearly all of the coastal area covered by the Ramsar designation, the intertidal zone experiences no more than a 1.5 m change in altitude over its maximum width of 2.5 km.

Wind and tidal currents cause a net retention of a great volume of sediments brought into the southern half of the Firth by rivers and streams. Current studies by NIWA on the interactions between mangroves and sedimentation in the Firth reveal that at some locations along the Firth's southern margin there is a build-up of sediments of up to 100 mm per year (Swales 2006).

Distribution of the entrained sediments entering the Firth of Thames varies with the dynamic water circulation system of the Firth. The three major influences that control the circulation systems present in the Firth are the East Auckland Current, the tidal currents and prevailing winds.

The mean annual air temperature is about 13ºC, and the average annual rainfall approx. 1200 mm (Young and Harvey, 1996). Surface temperatures in the open waters of the Firth range from 14°C to 24°C in a "warm" year, 11°C to 22°C in a "cold" year (depending on the phase of the El Niño cycle), and there is usually less than one degree difference between top and bottom temperatures in depths of 10-12 m off Waimango Point (Brownell 2004).

The Hauraki Catchment is a significant source of nutrients for the waters and mudflats of the entire Hauraki Gulf, though the upwelling of deep ocean waters at the north-eastern margin of the Gulf is by far the greatest source of nutrient supply, particularly during El Niño periods (Zeldis *et al.*, 2000). The high plankton productivity resulting from these elevated levels of deep-water nutrients, along with nutrients coming in as runoff from the catchment, plus the decomposition of detritus (mainly from the leaves of mangroves and marsh grasses), supports abundant fish and littoral invertebrate populations (especially shellfish) in the Firth of Thames.

5 Justification for the Project

Even though there is only minimal coastal development so far (mainly on the Thames Coast and in the mouths of the Waihou and Waitakaruru Rivers) and some pastoral farming along the south and west coasts of the Firth of Thames, there are potentially serious impacts on the nearshore marine ecosystem and coastal fringe that are critical to the survival of coastal birds. These actual and potential impacts include:

- Siltation – smothering of intertidal invertebrate populations from sedimentation derived mainly from old deposits retained in the Firth Basin, plus current inputs from pastoral farming and some plantation forestry harvesting in the Hauraki Catchment (Figure 1),
- Nutrient enrichment - (natural manures, chemical fertilizers, decomposing plant material),
- Contaminants – pesticides, herbicides, fungicides, heavy metals and other toxins retained in the sediments from past and current mining, agriculture and industry in the catchment,
- Coastal subdivision – sewage and stormwater toxins and excavation-derived sediments from residential developments (mainly in the Thames-Kopu area, and small settlements along the Kaiaua coast),
- Expansion of marine farming - possibility (depending on scale, locations and cumulative effects) of restricting the food supply (phyto- and zooplankton) of resident filter feeding invertebrates and fishes, creation of favourable habitat for undesirable invertebrate species, ingestion of large quantities of fish eggs by cultured mussels, and changes to the benthic ecology as a result of biological and non-biodegradable material originating from current shellfish (and, possibly, future cage fish) farming operations.
- Seabed mining (not currently practiced),
- Climate change – short-term cycles (El Niño-Southern Oscillation) and long-term changes (sea level rise, mean water temperature increase, droughts, floods),
- High-tide roost site destruction, disturbance and weed encroachment,
- Predation by introduced mammals.

There are other studies being undertaken at the time of writing that are relevant to the topics to be addressed, particularly research work coordinated by Dr Phil Battley (Massey University and OSNZ) on estimating survival rates in godwits, knots and wrybills, and determining whether Arctic-breeding waders use networks of estuaries while in New Zealand. Also, the Muddy Feet Phase II Study and Relative Risk Analysis model, focusing on the Ramsar site (coordinated by Environment Waikato), is leading to a blueprint for action on environmental issues and procedures, many of which have direct implications for the birds and the benthic invertebrates.

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Photo 2 (Geoff Moon) –Pied oystercatchers and bar-tailed godwits coming in to roost on the shellbank.

Photo 3 (Geoff Moon) – Godwits waiting for the tide to go out.

Chapter II. Shorebird counts in the Manukau Harbour and Firth of Thames (Tikapa Moana) 1960 – 2005

Phil F. Battley+, Suzanne J. Moore* and A.M. (Tony) Habraken*

+ Ecology Group, Massey University, Private Bag 11-222, Palmerston North NZ

* Miranda Naturalists' Trust, RD 3 Pokeno NZ 2473

Summary

The Ornithological Society of New Zealand has conducted annual summer (October-December) and winter (May-July) high tide censuses of coastal birds in the Manukau Harbour and Firth of Thames since 1960. This report summarises the population changes at these sites of the regularly occurring shorebirds (Order Charadriiformes, Suborder Charadrii) from 1960/61-2005.

No shorebird species could be regarded as generally stable and consistent from year to year over the last 45 years. Two species, the pied oystercatcher *Haematopus ostralegus* and variable oystercatcher *H. unicolor*, have shown significant increases in their populations. Our largest shorebird, the Eastern curlew *Numenius madagascariensis* has declined.

The southern shores of the Firth of Thames have been colonised by dense stands of mangroves *Avicennia marina* during the study period. As the mangroves have increased, the use of these southern sites by many shorebird species has decreased to the point where most sites are no longer used. This change in roost usage is particularly noticeable for wrybills *Anarhynchus frontalis*, golden plovers *Pluvialis fulva*, red knots *Calidris canutus*, and whimbrels *Numenius phaeopus*.

Some of the variation between years in the counts of Arctic-breeding species can be related to differences in productivity, as assessed by the proportion of juveniles in catches in southeast Australia. There is a good correlation between winter numbers of turnstone *Arenaria interpres* in the Manukau Harbour and proportion of juveniles caught in southeast Australia the previous season. However, for many species this is complicated by variation in the ages at which the birds migrate to New Zealand and in the age at which they first return to the breeding grounds.

During the past 45 years two new shorebird species have begun breeding in the Auckland region. The spur-winged plover *Vanellus miles* has shown a rapid increase and is now well-established throughout the region, while the black-fronted dotterel *Charadrius melanops* is still in very low numbers and only known to breed at Puketutu in the Manukau Harbour. Over the same period, the endemic banded dotterel *Ch. bicinctus* appears to have been lost as a breeding species from the Manukau Harbour and Firth of Thames.

Keywords: shorebird, wading bird, population change, Firth of Thames, census

1 Introduction

The Manukau Harbour and the Firth of Thames (Tikapa Moana) have long been recognised as two of the most important shorebird sites in New Zealand. In spring thousands of Arctic-breeding shorebirds arrive to spend the northern winter at these sites. They are joined in late summer by large numbers of shorebirds that breed elsewhere in New Zealand. Another group of shorebirds breeds locally and remains in these areas year-round.

Many of New Zealand's internal migrants breed on braided rivers – where they have been adversely affected by introduced plants and mammals, human disturbance, hydroelectric development and water extraction (Maloney *et al.* 1997, Maloney & Murray 2002). At least one internal migrant, the New Zealand pied oystercatcher, has benefited from agricultural development by extending its breeding habitat to include farm paddocks (Heather & Robertson 1996).

The migratory nature of many shorebirds means that they rely on a network of sites to complete their life cycles successfully. In addition to suitable wintering grounds (such as the Manukau Harbour and Firth of Thames) and secure breeding grounds, migrants often require sites to refuel while on migration.

New Zealand's Arctic-breeding species travel to and from New Zealand along a route known as the East Asian-Australasian Flyway (EAAF), and many make refuelling stops in the Yellow Sea. These East Asian stopover sites are under tremendous human pressure. The reclamation of vast areas is ongoing, large scale river damming reduces sediment flows into many estuaries, and pollution is a serious problem (Barter 2002). Many migrant species are very difficult to monitor on the breeding grounds (the birds are often highly dispersed and well camouflaged, and the sites poorly known) or on stopover sites (the sites are poorly known and/or access is too difficult e.g. North Korea). This means that monitoring migrant shorebirds on the non-breeding grounds is the only feasible way to detect even large-scale changes in shorebird abundance on the EAAF.

The Manukau Harbour and the Firth of Thames are particularly important for shorebird monitoring for two reasons: (1) both host large proportions of the total New Zealand population of many shorebird species, and (2) long-term count data are available for both sites.

The Manukau Harbour is the most important non-breeding site nationally for three Arctic-breeding shorebirds (bar-tailed godwits, red knots and Eastern curlews; Sagar *et al.* 1999) and two species that breed only in New Zealand (wrybills and pied oystercatchers; Dowding & Moore 2006). It is the second most important wintering site for pied stilts, the third most important site for black and dark hybrid stilts outside the Upper Waitaki Basin, and holds more than 1% of the northern New Zealand dotterel and banded dotterel populations (Dowding & Moore 2006).

The Firth of Thames is the most important wintering site nationally for pied stilts and sharp-tailed sandpipers, the second most important wintering site for wrybills, whimbrels and curlew sandpipers, and the third most important wintering site for pied oystercatchers and Eastern curlews, (Sagar *et al.* 1999, Dowding & Moore 2006). Like the Manukau Harbour, the Firth holds more than 1% of the northern New Zealand dotterel population in winter and is one of the top 10 sites outside the Upper Waitaki Basin for wintering black and dark hybrid stilts (Dowding & Moore 2006).

Published partial counts of shorebirds for both sites are available from as early as 1940 (for example, Fleming & Stidolph 1951, Sibson & McKenzie 1944). However, these early counts tended to focus on only one or a few species and did not cover all of the roosts within a site. Good site coverage is very important when considering trends in the populations of highly mobile species such as migratory shorebirds. Missed sites can lead to difficulties in detecting changes in abundance as birds may disappear from less favoured sites first, while numbers remain relatively constant at favoured sites (Gill *et al.* 2001). Comprehensive counts of all shorebird species at multiple roosts in the Manukau Harbour and Firth of Thames began in 1960.

Dramatic ecological changes (especially with regard to habitat) in the Manukau Harbour and Firth of Thames over the past 50 years (Veitch & Habraken 1999; Brownell 2004), and applications for large-scale marine farming in the Firth of Thames have given rise to a need to update what is known about numbers of shorebirds in the Auckland region. Veitch (1978) considered trends in shorebird populations in the Manukau Harbour and Firth of Thames based on data gathered from 1960 to 1975. Veitch & Habraken (1999) examined the data gathered from 1960 to 1998, primarily addressing whether there were increases or decreases in bird numbers, giving less attention to the magnitude or uniformity of population changes over shorter timeframes.

In our report we consider trends in the populations of the 16 most common shorebird species plus two less common species, the black stilt and the black-fronted dotterel, which has recently begun breeding in the Manukau Harbour, based on data gathered from 1960 to 2005 (see Table 1.1 for names, migratory behaviour and conservation status of these species). We focus on apparent local population changes within the 45-year period from 1961-2005 in both the Manukau Harbour and the Firth of Thames, and compare the trends in these two important neighbouring sites. More detailed attention is given to local changes in the Firth, as this site has recently been under investigation for large-scale marine farming.

Photo 4 (Phil Battley) – Well-fed godwits returning to roost from a day of feeding on the mudflats.

Table 1.1. Birds included in this report. Conservation ranks are from Hitchmough *et al.* (2007); threatened species are graded from 1 (highest risk of extinction) to 6 (lowest threat risk).

English name	Maori name	Scientific Name	Status	Conservation rank
Pied oystercatcher	Torea	*Haematopus ostralegus*	Internal migrant	Not threatened
Variable oystercatcher	Toreapango	*Haematopus unicolor*	Internal migrant & resident	Not threatened
Pied stilt	Poaka	*Himantopus himantopus*	Internal migrant & resident	Not threatened
Black stilt	Kaki	*Himantopus novaezelandiae*	Internal migrant	1 Nationally critical
Northern New Zealand dotterel	Tuturiwhatu pukunui	*Charadrius obscurus aquilonius*	Internal migrant & resident	3 Nationally vulnerable
Banded dotterel	Tuturiwhatu	*Charadrius bicinctus*	Internal migrant[1]	C5 Gradual Decline
Black-fronted dotterel		*Charadrius melanops*	Resident	Coloniser
Wrybill	Ngutu pare	*Anarhynchus frontalis*	Internal migrant	C3 Nationally Vulnerable
Pacific golden plover		*Pluvialis fulva*	Arctic migrant	[2]
Spur-winged plover		*Vanellus miles*	Resident	Not threatened
Turnstone		*Arenaria interpres*	Arctic migrant	[2]
Red knot	Huahou	*Calidris canutus*	Arctic migrant	[2]
Curlew sandpiper		*Calidris ferruginea*	Arctic migrant	[2]
Sharp-tailed sandpiper		*Calidris acuminata*	Arctic migrant	[2]
Red-necked stint		*Calidris ruficollis*	Arctic migrant	[2]
Eastern curlew		*Numenius madagascariensis*	Arctic migrant	[2]
Whimbrel		*Numenius phaeopus*	Arctic migrant	[2]
Bar-tailed godwit	Kuaka	*Limosa lapponica*	Arctic migrant	[2]

[1] Possibly no longer breeds in the Manukau Harbour or the Firth of Thames.
[2] Arctic migrants are not ranked by Hitchmough *et al.* (2007).

2 Methods

2.1 Study sites

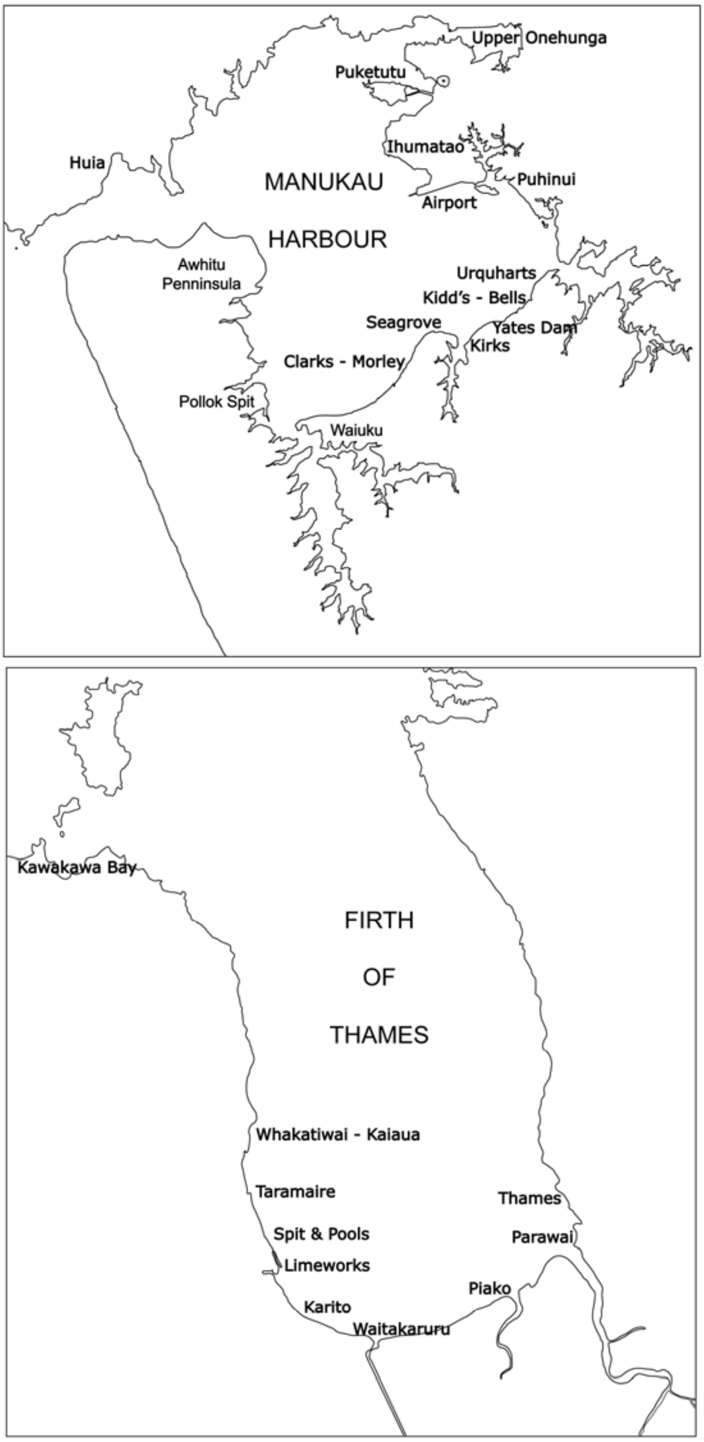
Counting sites are listed in Appendix 1 and 2, shown in Figure 2.1 and described in Veitch & Habraken (1999). The key habitat changes in recent years are: increased coastal development at both sites, the creation of a new sandbank at the mouth of the Waihou River in the southeastern Firth, and the further spread of the introduced grasses *Spartina* spp. and the native mangrove *Avicennia marina* in the Firth.

Spartina is present on the western, eastern and southern shores of the Firth of Thames: two patches were found in Kaiaua in 2005 (Moore 2005), numerous patches are present around the Waihou roost near Thames, and in tidal canals and mudflats around Waitakaruru. Control of the Kaiaua *Spartina* began in 2006 (Graham 2006). There has been no *Spartina* control in other areas of the Firth to date (J. Roxburgh, Hauraki Area Office, Department of Conservation, pers. comm.). *Spartina* is also present in the Manukau Harbour; the most recent Manukau *Spartina* survey estimated that just under 12 ha of tidal flat had been colonised (Jamieson 1994). The Auckland Regional Council (ARC) has undertaken *Spartina* control in the Waiuku estuary in the last few years and initial control work was carried out on the Manukau foreshore from Clarks Beach to Karaka in December 2005 (Dave Galloway, Biosecurity Team Leader North, ARC, pers. comm.). It is the ARC's long-term goal to eradicate *Spartina* from the east coast of the Auckland Region and the Manukau Harbour (ARC 2002).

In 1961 there were only isolated stands of mangroves in the Firth of Thames, but by 1977 a continuous fringe of mangroves had formed along the southern coast (Woodley 2004). Widths of mangrove belts at 11 sites from Miranda to the Waihou River in 1977 ranged from 85-627 m; in 2002 the same sites ranged from 218-904 m wide (Brownell 2004). This expansion filled in what were formerly major roosting areas along the southern shores of the Firth (the Piako, Waitakaruru and Karito roosts). Mangroves have also colonised the landward side of the Access Bay shell spit (which has moved south towards the old Limeworks) and are now establishing around the Stilt Ponds - the main remaining onshore roost at Miranda (Woodley 2004). At the Taramaire roost mangroves have also increased, even though in recent years the canal has been regularly drained and cleaned keeping it open and flowing directly to the sea. Mangroves are a native species and an integral part of northern New Zealand’s estuarine systems, but their rapid expansion and the resulting exclusion of shorebirds from affected areas are a cause for concern.

In July 1960 the Ornithological Society of New Zealand (OSNZ) carried out the first comprehensive count of shorebirds at the main roosts known in the Manukau Harbour. In November 1960 counts were made at the main roosts known in both the Manukau Harbour and the Firth of Thames. Since then the OSNZ has counted shorebirds at all of the main roosts at both sites twice a year. During these counts teams of experienced volunteer observers from the OSNZ count the number of shorebirds roosting at high tide on coastal areas and adjoining grasslands.

Figure 2.1. Survey areas in the Manukau Harbour (upper) and Firth of Thames (lower).



2.2 Counts

Each site is split into a number of sections (Appendix 1), each of which is assigned to a team. Teams are provided with maps and detailed instructions of the boundaries of their section, which minimises the risk of two teams unknowingly counting the same area or of a section being missed. Any birds leaving or arriving in the section during the count are noted along with their time of arrival or departure to try to minimise double-counting. Data are recorded on standard forms and reviewed by the co-ordinator within a few days, which allows any uncertainties to be clarified while they are still fresh in the observer's memory.

Although the counts would ideally occur concurrently to reduce the chance of double-counting or missing any birds that move between the two sites, due to the limited pool of experienced observers the counts have traditionally been held on consecutive weekends. Summer counts are usually held in November, but in some years have been made in October or December. Winter counts are usually held in June, but have also been made in May or July in some years.

2.3 Analysis

Census totals for each species are summarised by bar-charts for each site and season with the 5-year running mean overlain to facilitate viewing long-term changes. Summary statistics (mean population ± standard deviation) are tabulated in 5-year periods between 1961 and 2005. Where appropriate, comparison is made with estimates of breeding success (percentage of first-year birds in catches) measured in Victoria, southeast Australia (Minton *et al.* 2005). There are no measures of accuracy of the counts in these censuses, but we assume that there have been no systematic changes in the magnitude or direction of errors in the counts.

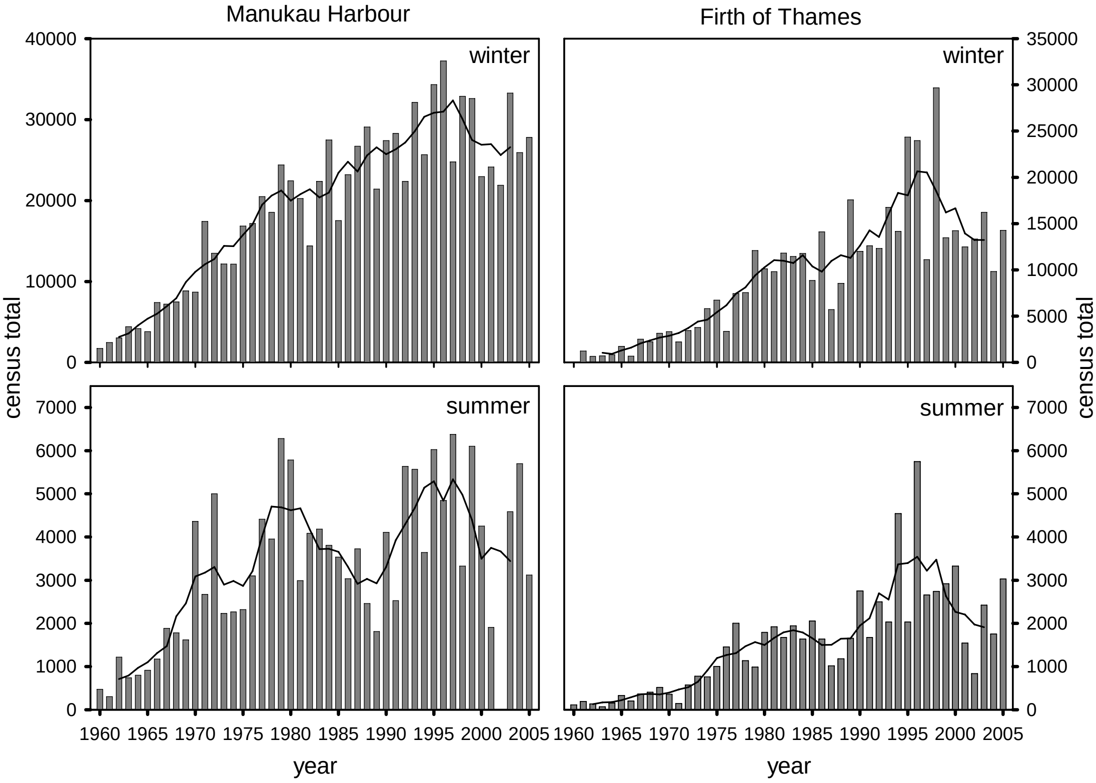
Additional count data from around New Zealand are drawn from OSNZ's Classified Summarised Notes scheme (CSN), published near-annually in *Notornis*.

3 Results

3.1 Pied oystercatcher

Pied oystercatchers do not breed in the Manukau Harbour or Firth of Thames. Birds counted at these sites in November are non-breeding subadult birds (aged 1-4 years, Heather & Robertson 1996), while June counts comprise both adult and subadult birds. Matching national trends (Sagar *et al.* 1999), from the 1960s to late 1990s there was a steady increase in pied oystercatcher numbers at both sites (Fig. 3.1.1; Table 3.1.1). Winter counts in the Manukau Harbour increased from less than 5000 birds in the early 1960s to a peak of 37 251 in 1996; corresponding numbers in the Firth of Thames increased from 1200 birds in 1961 to just under 30 000 birds in 1998. At both sites numbers decreased overall from the late 1990s.

Figure 3.1.1. The number of pied oystercatchers in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.

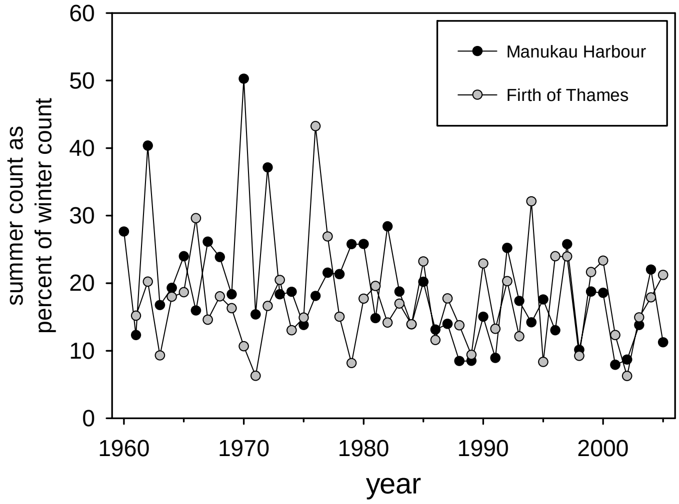


Over the full period of analysis, numbers in winter (when adults as well as subadults are present) on the Firth of Thames and the Manukau were quite strongly correlated with each other (Spearman's rank-order correlation rs = 0.850). The correlation for numbers of immature birds counted in summer censuses was lower (rs = 0.693). While similar proportions of the winter population oversummered on the Manukau and the Firth (Manukau, 19.1 ± s.d. 8.5%, n = 46; Firth, 17.3 ± 7.1%, n = 45), there was only a weak correlation between the proportions that oversummered in a given year at the two sites (r_s = 0.234; Fig. 3.1.2). In the Firth of Thames, the number of pied oystercatchers present in summer matched the numbers in winter moderately well throughout the analysis period (r_s = 0.834; Fig 3.1.2), but there were some notable exceptions. For example, particularly high numbers of birds in the winters of 1995 and 1998 were not followed by high counts of immatures in the next summer census. In the Manukau Harbour, the total winter population continued to increase overall through the 1980s, despite the number of immatures counted in summer censuses decreasing through that period. These findings suggest that while increases in oystercatcher productivity must be a large factor in the increased population in the Auckland region, there are either other factors involved (such as changes in adult survival or the number of adults migrating to the Auckland region) or the census data poorly represents the fine-scale variation in seasonal and annual variation in oystercatcher numbers.

Table 3.1.1. Summary statistics of pied oystercatcher numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau Harbour				Firth of Thames			
	winter	s.d.	summer	s.d.	winter	s.d.	summer	s.d.
1961-65	3568	819	794	333	1030	454	171	96
1966-70	7916	779	2164	1259	2377	1056	366	113
1971-75	14 404	2551	2898	1189	4397	1840	648	323
1976-80	20 601	2906	4706	1310	8105	3288	1471	428
1981-85	20 388	4954	3721	480	10 734	1334	1844	182
1986-90	25 555	3158	3029	930	11 596	4650	1644	679
1991-95	28 549	4812	4679	1520	16 039	4978	2553	1149
1996-00	30 086	6015	4980	1274	18 493	7955	3474	1293
2001-05	26 595	4326	3442	1678	13 223	2359	1913	842

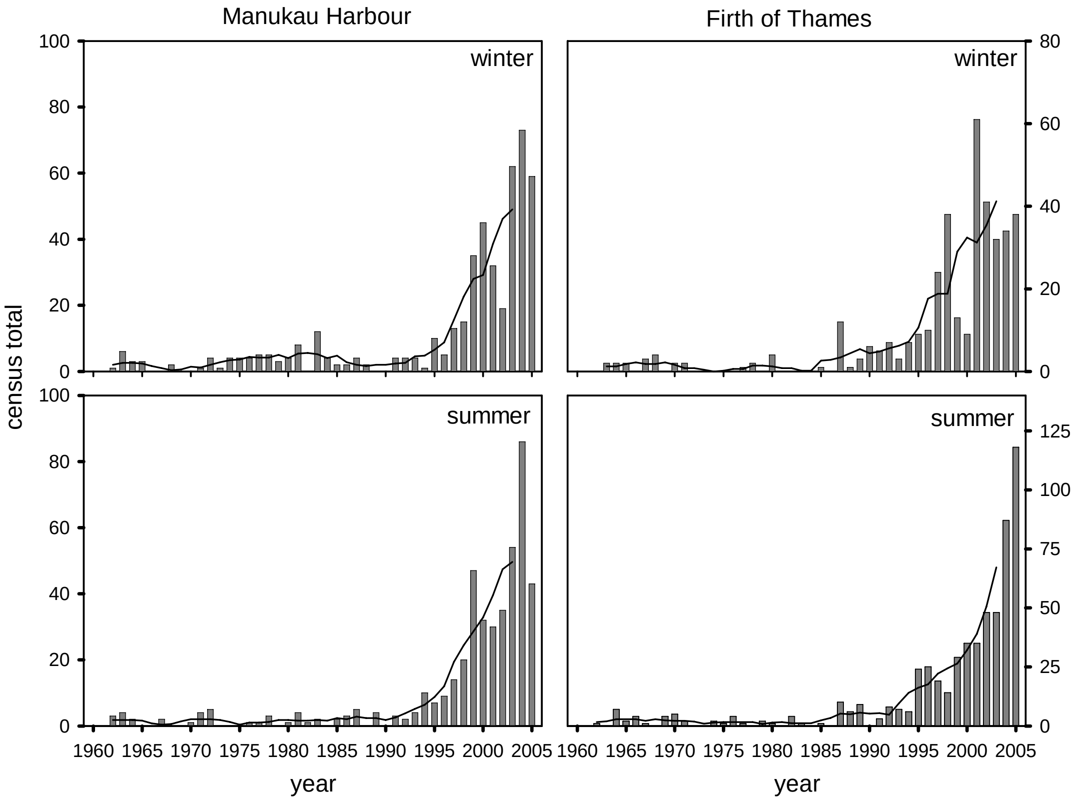
Figure 3.1.2. Summer counts as a percent of the preceding winter count for pied oystercatchers.



3.2 Variable oystercatcher

Variable oystercatchers were present in the Manukau Harbour and the Firth of Thames in only small numbers from the 1960s to the early 1990s, after which they increased substantially with populations now regularly exceeding 50 birds at both sites (Fig. 3.2.1; Table 3.2.1). Numbers in the Firth tended to be higher in summer than in winter (in 8 of the 11 years from 1995-2005 the summer census was higher) but this does not reflect birds breeding locally. Up to 25 non-breeding birds were recorded in November censuses at Kaiaua on the western shore of the Firth; even higher numbers (up to 66) were recorded in the Thames-Parawai stretch on the eastern shore, few of which were breeders. Variable oystercatcher numbers are increasing nationally, and the increased Firth of Thames population may be largely composed of birds overflowing from sites in Coromandel and north of Auckland where predator control is undertaken (Dowding & Moore 2006), though numbers have also increased in Canterbury without pest control (Crossland 2001). Variable oystercatchers have been recorded delaying breeding for seven years (Dowding & Moore 2006) and pied oystercatchers (*Haematopus ostralegus*) in Europe have been known to wait for up to 14 years before breeding (van de Kam *et al.* 2004), so the substantial summer non-breeding population may represent pre-breeding birds.

Figure 3.2.1. The number of variable oystercatchers in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.



On the Manukau Harbour neither summer nor winter counts are systematically higher than the other. As in the Firth, the increasing number of variable oystercatchers in the Manukau may be attributed to predator control further north. On 24 November 1996 a bird banded as a chick at the Wade River (K-5252), northeast of Auckland, was sighted at Pollock Spit in the Manukau Harbour aged 2 years and 11 months, paired and on a territory (AMH unpubl. data). This bird was still present at Pollock Spit on 20 June 2004. Previously, variable oystercatcher breeding in the Manukau was limited to the Awhitu Peninsula, but this has steadily extended south and east along the southern shores of the harbour at a similar rate to the population increase (AMH unpubl. data).

Table 3.2.1. Summary statistics of variable oystercatcher numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau Harbour				Firth of Thames			
	winter	s.d.	summer	s.d.	winter	s.d.	summer	s.d
1961-65	3	2	2	2	1	1	2	3
1966-70	0	1	1	1	2	2	3	2
1971-75	3	2	2	2	0	1	1	1
1976-80	4	1	1	1	1	2	2	2
1981-85	5	5	2	1	0	0	1	2
1986-90	2	2	2	2	4	5	5	5
1991-95	5	3	5	3	6	2	10	8
1996-00	23	17	24	15	19	12	24	8
2001-05	49	23	50	22	41	12	67	34

3.3 Pied stilt

There have been no systematic changes in numbers of pied stilts in winter in the Manukau Harbour and the Firth of Thames (Fig. 3.3.1). Five-year averages ranged from 3064 to 4407 birds in the Manukau Harbour and 2572 to 4284 in the Firth (Table 3.3.1). Numbers were highly variable, with differences between adjacent years of up to 4600 birds in the Manukau Harbour (average 1040) and 8800 in the Firth (average 1730). Because stilts feed in wet pastures as well as on tidal flats, some of this variation may reflect differences in the wetness of surrounding areas rather than true changes in numbers.

Numbers in the summer census have gradually declined since the 1970s at both sites (Fig. 3.3.1): the 5-year averages for 2001-2005 are less than half that of the 1981-1985 (Manukau) and 1976-1980 (Firth) averages (Table 3.3.1). Pied stilts are early breeders (peak of egg laying in lowland sites is August-October; Heather & Robertson 1996) so the November census probably includes a large number of birds that have finished breeding. Stilts are not currently overly common breeders around the shores of the Manukau Harbour and Firth of Thames so most birds recorded in censuses have probably migrated there from other sites. As the long-term decreases in summer censuses are not matched by equivalent decreases in winter counts, it is possible that the stilts wintering in the Manukau and Firth of Thames are breeding later or migrating further than they were in the 1970s and 1980s. It may be that locally breeding pied stilts are declining due to habitat loss caused by increased drainage of pasture (particularly in the Firth of Thames) forcing the birds to seek alternative breeding sites further inland.

Figure 3.3.1. The number of pied stilts in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.

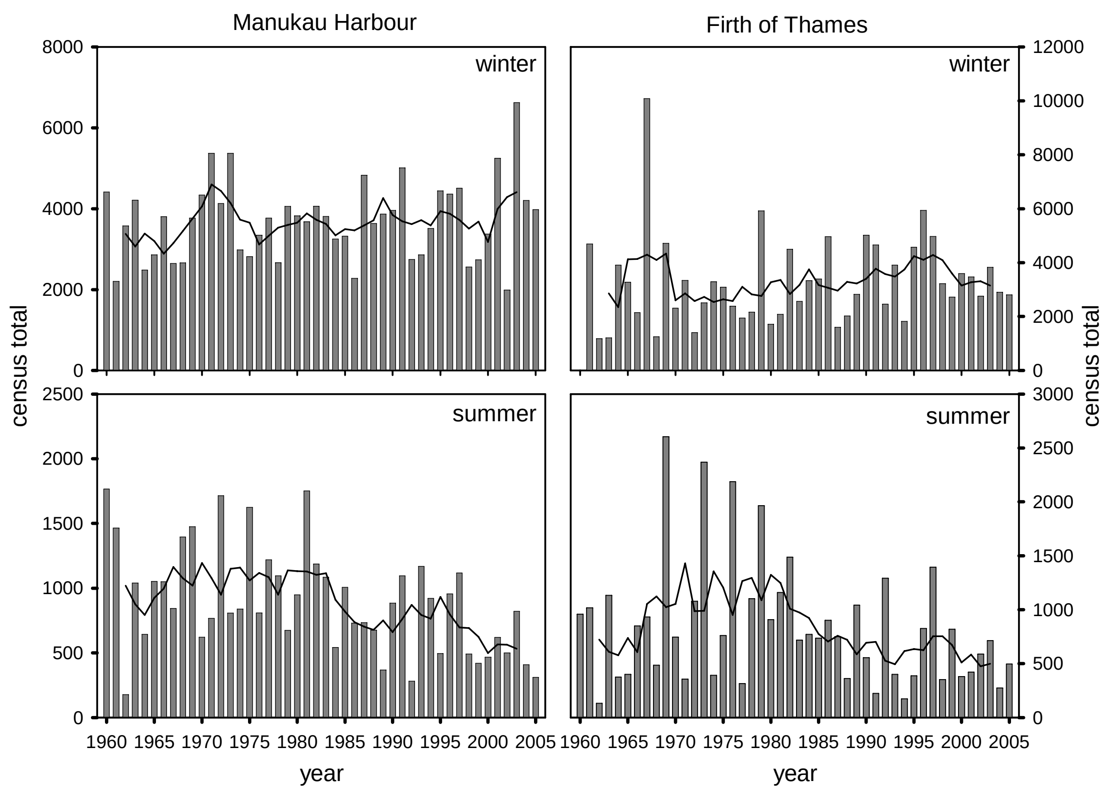


Table 3.3.1. Summary statistics of pied stilt numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau winter	s.d.	summer	s.d.	Firth winter	s.d.	summer	s.d.
1961-65	3064	822	875	486	2747	1821	611	438
1966-70	3443	756	1077	362	4292	3483	1123	844
1971-75	4132	1236	1150	476	2572	796	990	824
1976-80	3531	548	949	218	3101	1632	1295	773
1981-85	3622	339	1114	433	2836	1109	974	340
1986-90	3713	920	678	190	2962	1319	722	271
1991-95	3713	990	793	388	3573	1387	495	456
1996-00	3505	900	690	323	4284	1310	753	424
2001-05	4407	1710	532	198	3309	460	499	166

3.4 Black stilt

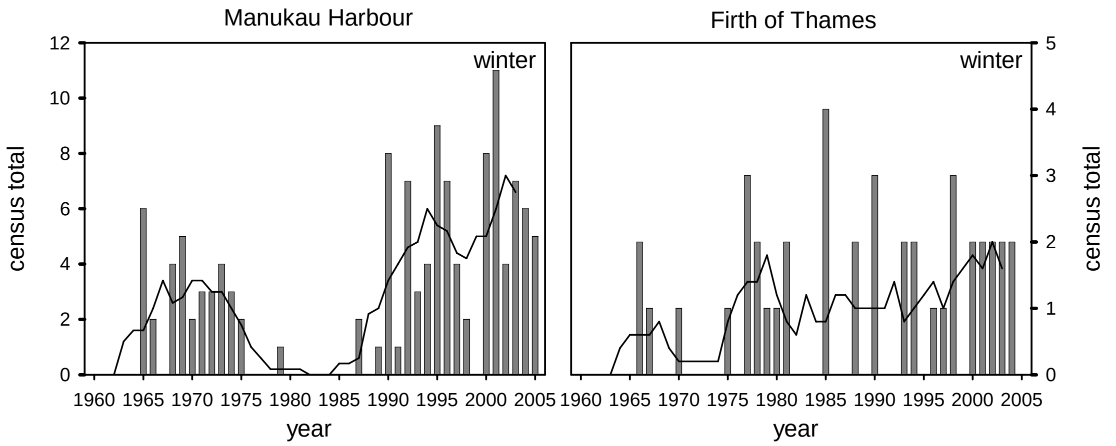
Counts of black stilts are complicated by the existence of pied stilt-black stilt hybrids and the white mottling visible on the abdomen of some sub-adult black stilts (Pierce 1984). During census any dark-plumaged hybrids (those classified as nodes F to I by Pierce 1984) are included as black stilts in the counts since these birds are managed like black stilts (Reed 1998) and some observers may find it difficult to distinguish sub-adult black stilts from adult dark hybrids. Although most black stilts are non-migratory, each year around 10-15% of the population (which comprised 48 adult black stilts in 2000; Maloney & Murray 2002) migrates from the Upper Waitaki Basin to coastal non-breeding grounds, including the northern harbours.

Typically more black and dark hybrid stilts wintered in the Manukau Harbour (average of 3 from 1960-2005), than in the Firth of Thames (average of 1 from 1960-2005). An apparent increase in the number of black and dark hybrid stilts over-wintering in the Manukau Harbour (Fig. 3.4.1) since the early 1980s may have been largely due to black stilt eggs being cross-fostered to pied or hybrid stilts from 1981 to 1987, as many of these cross-fostered black stilts followed their migratory foster parents when they left the Upper Waitaki Basin at the end of the breeding season (Reed *et al.* 1993).

Table 3.4.1. Summary statistics of black stilt numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau winter	s.d.	summer	s.d.	Firth winter	s.d.	summer	s.d.
1961-65	1	3	0	0	0	0	0	0
1966-70	3	2	0	0	1	1	0	0
1971-75	3	1	0	0	0	0	0	0
1976-80	0	0	0	0	1	1	0	0
1981-85	0	0	0	0	1	1	0	0
1986-90	2	3	1	1	1	2	0	0
1991-95	5	3	1	1	1	1	0	0
1996-00	4	3	0	0	1	1	1	1
2001-05	7	3	1	1	2	0	1	1

Figure 3.4.1. The number of black stilts wintering in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.



3.5 New Zealand dotterel

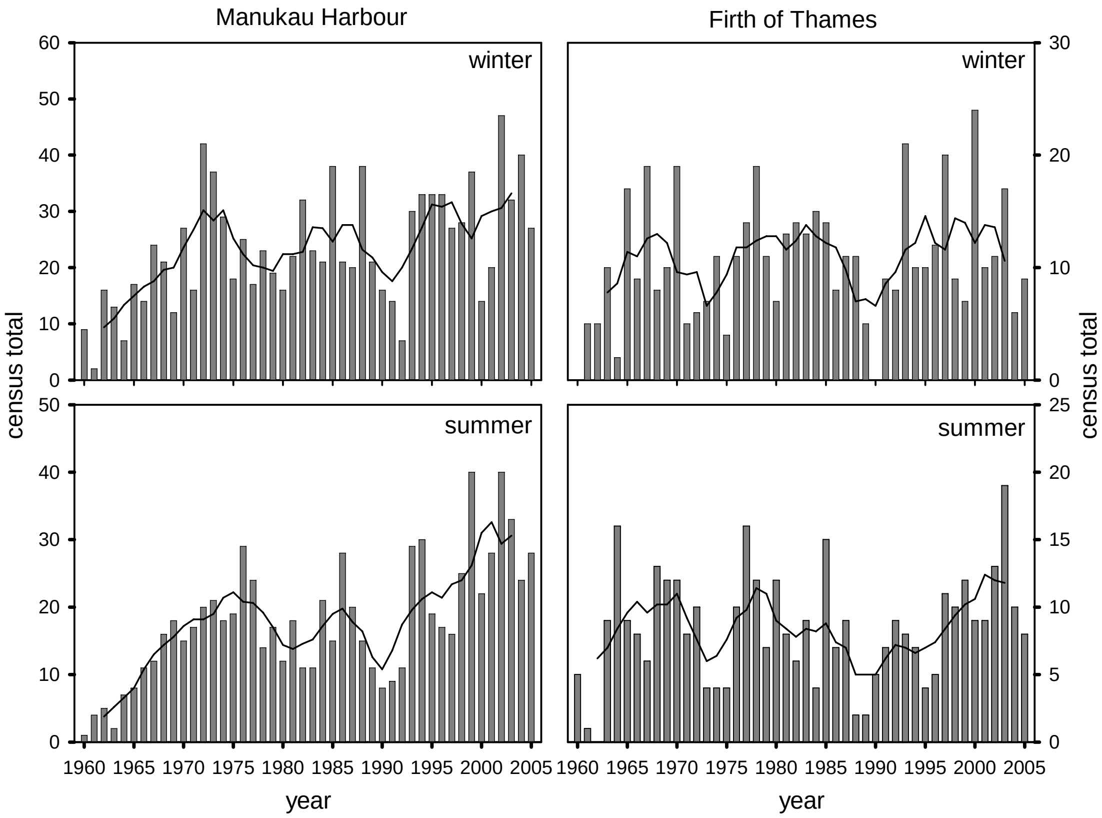
Numbers of New Zealand dotterel in the Manukau Harbour increased in both winter and summer censuses from the early 1960s to the early-mid 1970s (Fig. 3.5.1). They then showed smaller decreases and increases during the 1980s before increasing through the 1990s to the extent that Manukau summer counts in 2001-2005 were six times higher than in 1961-1965 (Table 3.5.1). Numbers in the Firth of Thames showed no systematic variation over time (Fig. 3.5.1), though numbers were lowest in the mid-1970s and the late 1980s-early 1990s. At both sites there is a tendency for numbers to be higher in winter than summer, but only by a small number (Manukau, higher in 30 years, lower in 13, average 6 birds more in winter; Firth, higher in 29 years, lower in 15, average 2 birds more in winter). This suggests that the winter population comprises mainly locally resident birds and their offspring. Larger differences between seasons in some years (up to 23 birds in the Manukau, 15 in the Firth) could reflect census inaccuracies, immigration or high productivity.

Immigration is known to occur in the Manukau where banded birds (mainly younger non-breeders) have come from northern localities and remained to stay and breed. These movements are probably the result of population expansion brought about by the benefits of predator controls in the north. In the Firth of Thames, New Zealand dotterel now breed at only a few locations, and as few as three pairs are known to have attempted to nest between Kaiaua and Thames in 2005. A bird marked in the Bay of Plenty nested on the western Firth in 2004. A bird banded as a chick at Opoutere nested on the Waihou shellbank from November 1999 to November 2005 (AMH unpubl. data). Additionally, there seems to be a tendency for birds to wander after losing a mate, potentially temporarily increasing the Manukau and Firth winter populations (AMH unpubl. data).

Table 3.5.1. Summary statistics of New Zealand dotterel numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau				Firth			
	winter	s.d.	summer	s.d.	winter	s.d.	summer	s.d.
1961-65	11	6	5	2	6	3	7	7
1966-70	20	6	14	3	13	5	10	3
1971-75	28	11	19	2	10	6	6	3
1976-80	20	4	19	7	12	5	11	3
1981-85	27	7	15	4	12	3	8	4
1986-90	23	9	16	8	10	3	5	3
1991-95	23	12	20	10	10	8	7	2
1996-00	28	9	24	10	12	5	9	3
2001-05	33	11	31	6	14	7	12	4

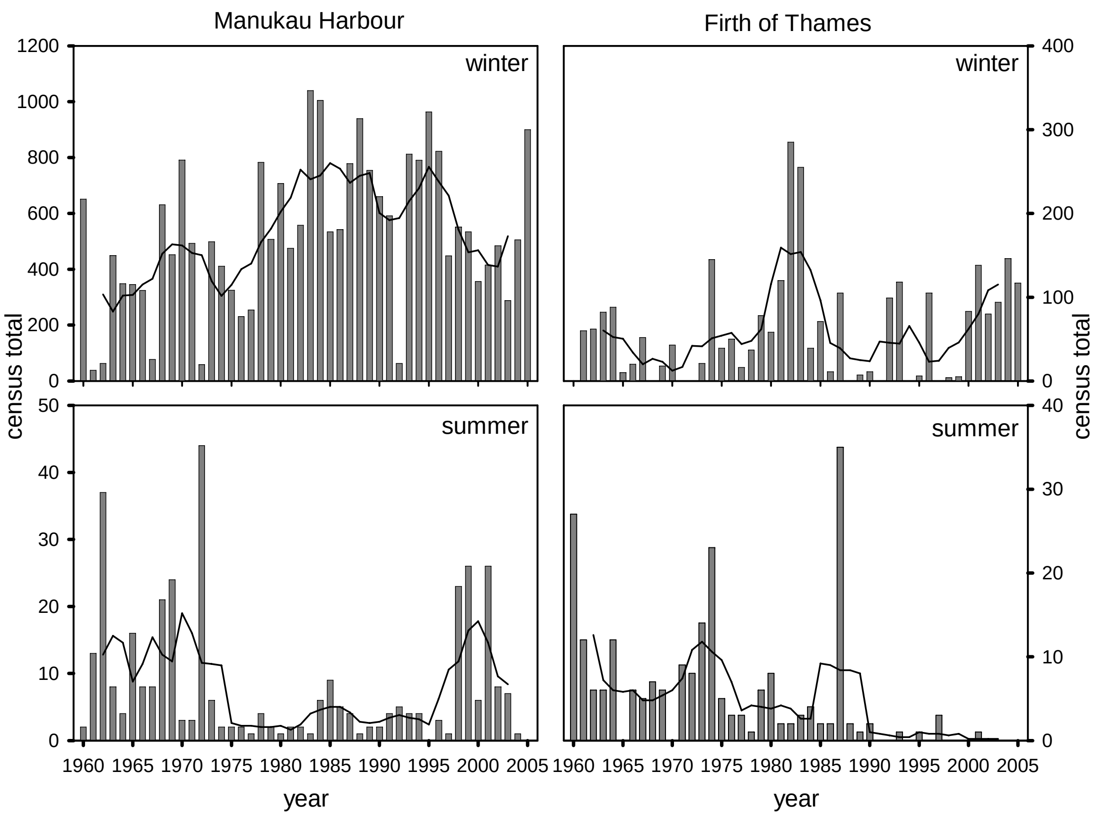
Figure 3.5.1. The number of New Zealand dotterel in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.



3.6 Banded dotterel

Overall, banded dotterel winter counts increased over time in the Manukau Harbour, particularly from the mid-1970s to the mid-1980s, though numbers subsequently decreased from 1995 to 2003 (Fig. 3.6.1). However, banded dotterels can be difficult to count accurately, as they often use pastures for roosting and can elude counters, so it is not clear whether the large variation between years represents true population differences. In the Firth of Thames a peak in numbers is evident in 1982 and 1983 (Fig. 3.6.1), but otherwise numbers have mostly hovered at around 100 or less individuals. This does not tell the true story of dotterels wintering in the Firth, however, as Fleming & Stidolph (1951) recorded "1000 plus" at Waitakaruru in June 1940 and 2000 in March 1950. No banded dotterels were counted there in any of the winter censuses from 1961 to the present day. Habitat changes in the southern Firth of Thames have apparently drastically reduced the attractiveness of the area to banded dotterels. High numbers were also recorded by Fleming & Stidolph (1951) at Mangere in the Manukau Harbour in 1940 (e.g. 1000 on 23 April, 500 on 16 May) but here, unlike the Firth of Thames, similarly high numbers continued to be recorded during the OSNZ surveys.

Figure 3.6.1. The number of banded dotterels in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.



Summer census numbers of banded dotterels have always been low in the Manukau Harbour and the Firth of Thames (Fig 3.6.1; Table 3.6.1). The virtual absence of banded dotterels in the Firth of Thames in November since the late 1980s indicates that they have been lost as a breeding species there. The last record known to us of breeding on the western Firth was in 1983 (B. Chudleigh, pers. comm.).

Table 3.6.1. Summary statistics of banded dotterel numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau winter	s.d.	summer	s.d.	Firth winter	s.d.	summer	s.d.
1961-65	249	186	16	13	73	14	7	5
1966-70	455	276	13	9	20	20	5	3
1971-75	357	181	11	18	42	60	12	7
1976-80	496	253	2	1	44	23	4	3
1981-85	722	276	4	3	151	113	3	1
1986-90	735	147	3	2	39	46	8	15
1991-95	644	351	3	2	46	58	0	1
1996-00	542	175	12	12	24	45	1	1
2001-05	518	230	8	10	108	31	0	0

3.7 Black-fronted dotterel

Black-fronted dotterels breed throughout Australia and began to colonise New Zealand in the late 1950s, dispersing from their first colony in the Hawkes Bay (Heather & Robertson 1996). The species has only been recorded in the Firth of Thames once; on 8 June 2001 a single juvenile black-fronted dotterel was seen outside the Miranda Naturalists' Trust Centre (K. Woodley, Shorebird Centre Manager, pers. comm.).

A single black-fronted dotterel was recorded in the Manukau Harbour in June 1970, the first time that the species had been seen as far north as the Manukau (Sibson 1972). The next census record was in November 2000 when two were recorded at Puketutu. That year a pair of black-fronted dotterels nested near the former Mangere Sewage Ponds and subsequently produced two juveniles (Gill 2001), the first breeding record north of Rotorua for this species (AMH unpubl. data). Since then one or two black-fronted dotterels have been present at Puketutu in five of the six subsequent summer surveys, and two were recorded at Huia in November 2003. Apart from the 1970 record, black-fronted dotterels have been present in the Manukau in winter in only three years (four at Huia and four at Puketutu in 2003, three at Puketutu in 2004, 13 at Puketutu in 2005).

3.8 Wrybill

The Firth of Thames and Manukau Harbour have long been recognised as the key non-breeding sites for wrybills and hold around 85% of the total population (Dowding & Moore 2006). Apart from one count of 7500 birds in 1967 (which must represent an error in counting) Firth of Thames census totals have not exceeded 4007 birds (in 1973) and have declined overall from the early 1970s to the present day. At the same time, counts increased in the Manukau Harbour, particularly since 2000 (Fig. 3.8.1) so that now the Manukau Harbour holds the majority of the local wrybill population (Fig. 3.8.2). However, this increase in the Manukau is not necessarily due solely to birds from the Firth of Thames relocating to the Manukau Harbour as the total combined population counted during censuses has increased by more than 50% since 1990 (Fig. 3.8.3). It is not entirely clear whether this apparent population increase is real or whether improved knowledge of roosting behaviour in the Manukau Harbour is partly involved.

Figure 3.8.1. The number of wrybills in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.

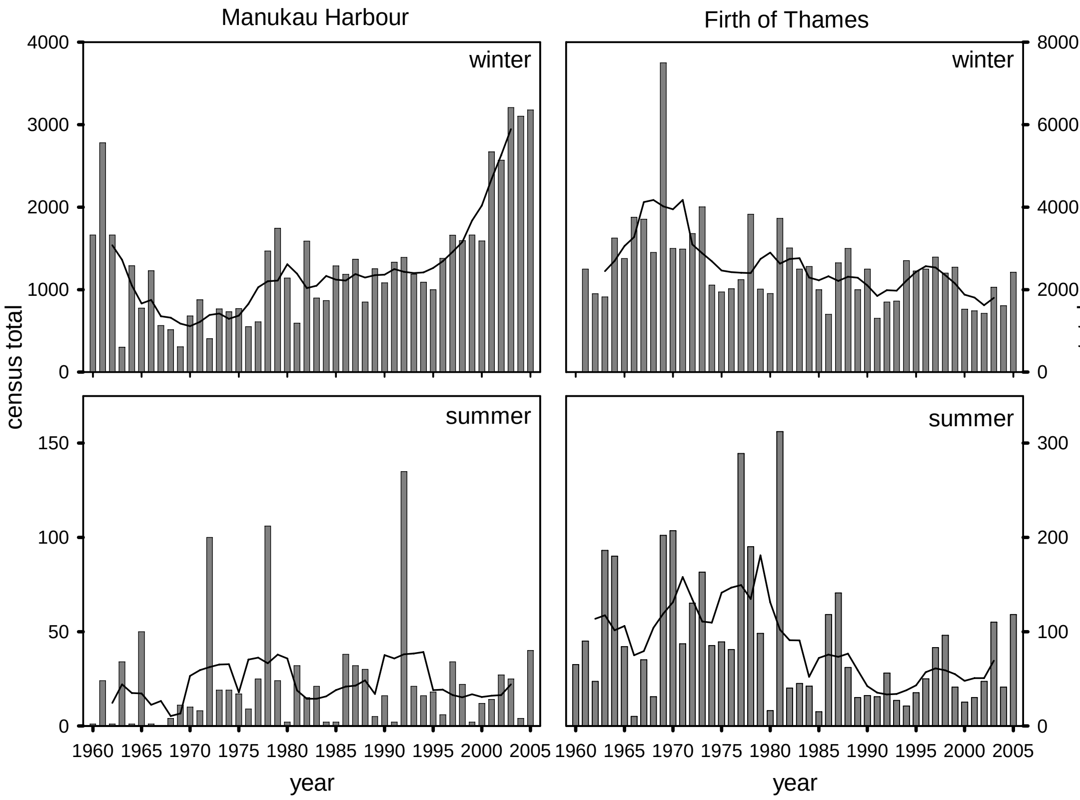


Figure 3.8.2. The proportions of wrybills wintering in the Manukau Harbour and the Firth of Thames. Lines give the percent of the combined Manukau and Firth total, not the estimated national total.

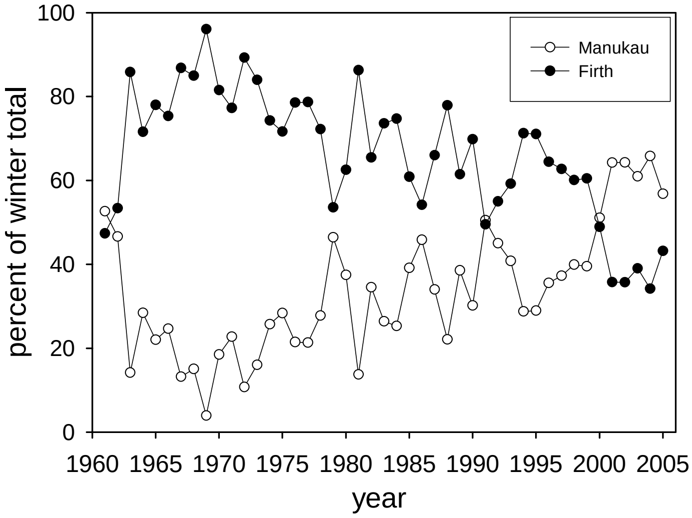
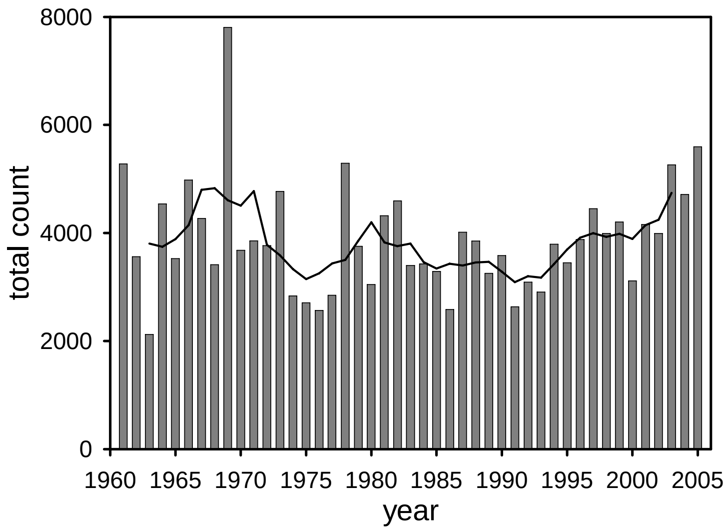


Figure 3.8.3. Total number of wrybills wintering in the Manukau Harbour and the Firth of Thames.



Unlike other species where the census during the non-breeding period can give a good estimate of breeding success (as first-year birds do not migrate to the breeding grounds), this is not so for wrybills. In the Firth of Thames at least, numbers of wrybills decline through the spring-early summer breeding season as some young birds travel to the South Island. There is a suggestion in the Firth summer censuses of higher numbers in the 1960s and 1970s than later on; this is not apparent in the Manukau.

At the local level, the distribution of wrybills within the Firth and Manukau Harbours has changed over the years. In the 1960s and 1970s large flocks roosted along the southern shores of the Firth of Thames, with up to 1700 at Karito, 2000 at Waitakaruru and 2500 at Piako (this is also where the record of 5500 in 1969 is from). Since 1980 large numbers of wrybills have been seen only infrequently: 200 in 1981 at Piako, 2000 in 1987 at Karito and, at Waitakaruru, 500 in 1990 and 200 in 1995. This local decline is probably due to the expansion of mangroves along the coastal belt between the stopbanks and the sea in the southern Firth.

In the Manukau Harbour, sites such as Puketutu, the airport and the Karaka coastline always held wrybills from the 1960s onwards. Wrybills are discouraged from using the airport grounds because of air strike risks and were not recorded in the "Airport' section during winter censuses through most of the 1980s and early 1990s. Since 1994 they have frequently been present in the "Airport' section during censuses (up to 600 birds). Wrybills were first recorded in the Onehunga count section in 1995 when 150 birds were found. Since then, they have used this area continuously with a peak of 1400 birds in 2001. Finally, the number of wrybills in the Puketutu survey section (the former Mangere Sewage Ponds) has increased from an average of 537 (maximum 900) from 1985-1995 to 957 (maximum 1750) from 2000-2005. This could reflect the improved feeding opportunities in the former settling ponds, which in 2002 were decommissioned and are now open to the sea and tidal cycles again, and/or declining roosting options nearby (e.g. Wiroa Island, near Auckland International Airport, where mangrove growth has reduced visibility for roosting birds, causing usage to decline).

Table 3.8.1. Summary statistics of wrybill numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau winter	s.d.	summer	s.d.	Firth winter	s.d.	summer	s.d.
1961-65	1361	945	22	21	2368	662	117	62
1966-70	658	346	5	5	4121	1943	104	94
1971-75	709	179	33	38	3091	689	111	35
1976-80	1102	523	33	42	2406	800	135	106
1981-85	1046	391	14	13	2740	678	91	124
1986-90	1147	196	24	13	2210	625	77	51
1991-95	1199	163	38	54	1985	591	34	13
1996-00	1577	116	15	13	2536	151	59	30
2001-05	2945	302	22	14	1620	252	69	41

3.9 Pacific golden plover

Prior to 1987, golden plover were often encountered in the southern Firth in summer with highest numbers in the late 1970s and early 1980s (a peak of 246 in 1976; Fig. 3.9.1). Mangroves have since colonised this area, making the habitat unsuitable for many shorebird species. After 1986 very few (less than 10) golden plovers were recorded in the Firth annually, until the 2005 census (which was a very good year for golden plovers nationally) when 47 were recorded at the Miranda Limeworks. Golden plover numbers in the Manukau in summer were variable with peaks in the early 1970s (118 in 1972) and late 1980s (80 in 1987 and 1990). The main peak in golden plover numbers in the Firth of Thames (1976-1980) coincided with low numbers in the Manukau Harbour suggesting that the birds may have preferred to use the Firth rather than the Manukau during this period. Although the most recent peak in numbers in the Manukau was subsequent to the decline in the Firth, golden plover numbers at both sites have been low for most of the last decade.

Few golden plovers spend the southern winter in New Zealand (an average of 3 nationally from 1983-1994; Sagar *et al.* 1999). In some winters a few individuals have been observed in the Manukau; none has been recorded in the Firth during the winter census (Table 3.9.1).

Figure 3.9.1. The number of golden plovers in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.

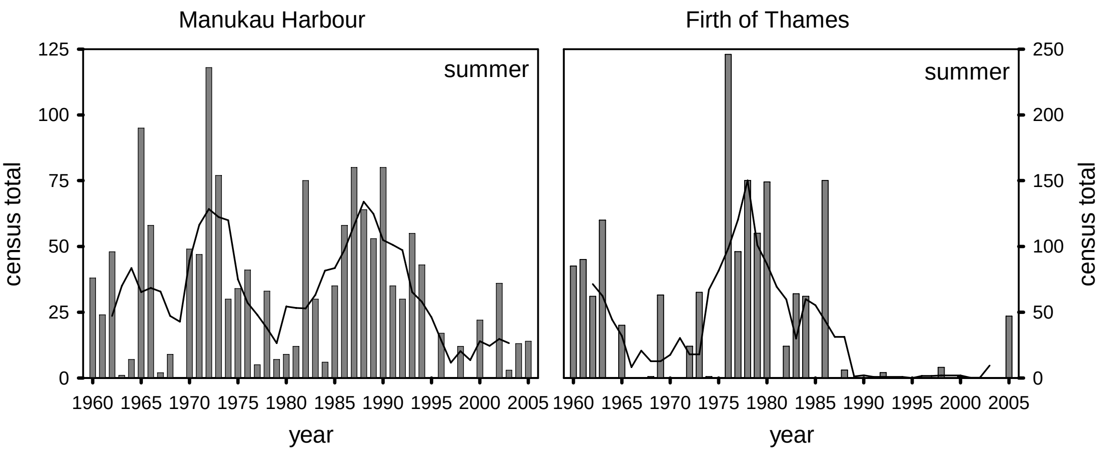


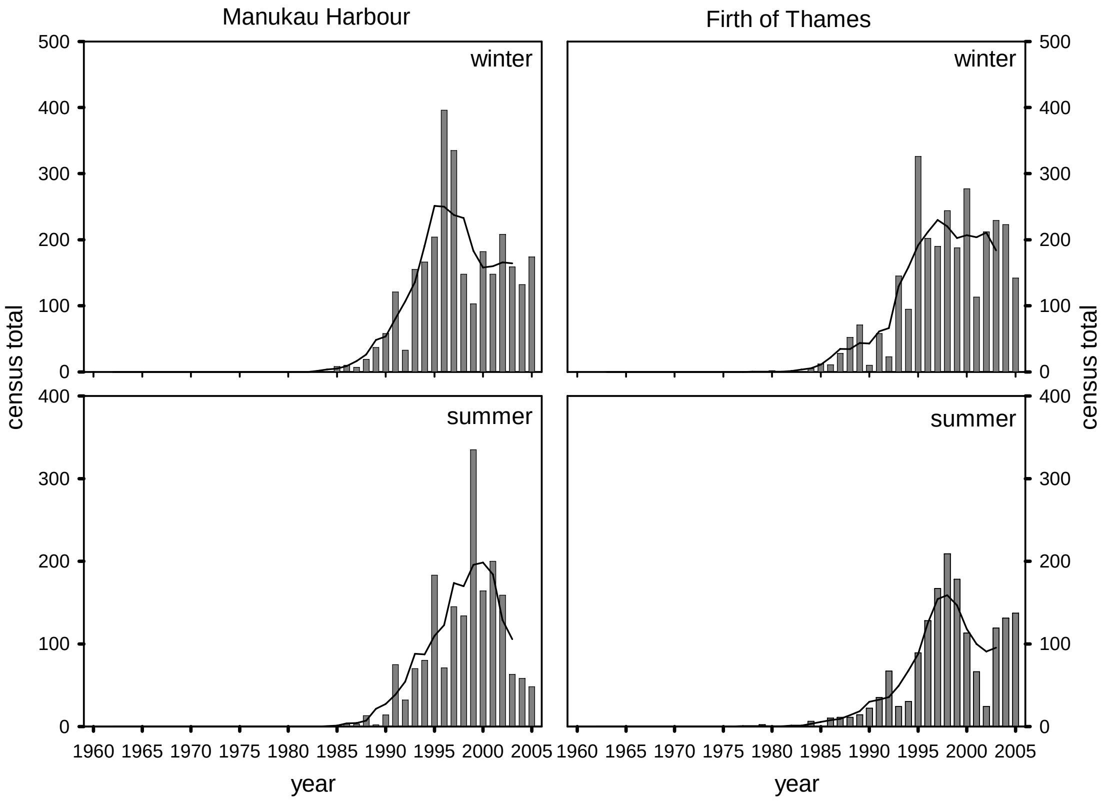
Table 3.9.1. Summary statistics of golden plover numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau				Firth			
	winter	s.d.	summer	s.d.	winter	s.d.	summer	s.d.
1961-65	0	1	35	38	0	0	62	46
1966-70	0	0	24	28	0	0	13	28
1971-75	1	1	61	37	0	0	18	28
1976-80	0	0	19	17	0	0	150	59
1981-85	0	0	32	27	0	0	30	32
1986-90	0	1	67	12	0	0	31	66
1991-95	0	0	33	21	0	0	1	2
1996-00	0	0	10	10	0	0	2	3
2001-05	0	0	13	14	0	0	9	21

3.10 Spur-winged plover

Spur-winged plovers were first recorded in a Manukau Harbour census in winter 1985. Their numbers rapidly increased and peaked at 396 birds in winter 1996 and 335 birds in summer 1999 (Fig. 3.10.1). After records of singles or pairs in 1977, 1979 and 1980 in the Firth of Thames, spur-winged plovers have been recorded constantly in winter censuses since 1984 and summer censuses since 1986, peaking at 326 in winter 1995 and 209 in summer 1998. Summer counts have declined from 1999 (Firth of Thames) and 2000 (Manukau) though numbers in the Firth increased again from 2003-2005.

Figure 3.10.1. The number of spur-winged plovers in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.



Primarily pastoral birds, numbers of spur-winged plovers recorded reflect farmland habitat changes and flocking behaviour more than anything related to intertidal or high tide roost habitats.

Table 3.10.1. Summary statistics of spur-winged plover numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau				Firth			
	winter	s.d.	summer	s.d.	winter	s.d.	summer	s.d.
1961-65	0	0	0	0	0	0	0	0
1966-70	0	0	0	0	0	0	0	0
1971-75	0	0	0	0	0	0	0	0
1976-80	0	0	0	0	0	1	1	1
1981-85	2	4	0	0	3	5	1	3
1986-90	26	21	7	6	34	27	14	5
1991-95	136	65	88	56	129	119	49	28
1996-00	233	126	170	99	220	39	159	39
2001-05	164	29	106	69	184	53	95	49

3.11 Turnstone

Turnstone numbers have always been highly variable between years in the Manukau Harbour and Firth of Thames (Fig. 3.11.1) but at both sites numbers were highest from around the mid-1970s to the mid- (Manukau) or early- (Firth) 1990s (Table 3.11.1). In the Manukau Harbour, turnstones gradually increased from an average of 200 birds in the 1960s to around 400 birds over 1975-1995. In the Firth of Thames the increase was later, starting in 1974 and increasing from an average of 41 birds from 1960-1973 to 130 from 1974-1993.

In general, periods with high summer populations were also characterised by high winter populations, though the proportion of the summer count recorded in winter varied greatly between years (Fig. 3.11.2) and in some years the winter count was higher than the preceding summer count.

Similar variability in proportions of overwintering turnstones has been documented previously in New Zealand (Sagar *et al.* 1999: 3-45% of national counts from 1983-1994) and Australia (Hewish 1987: 9-57% at counted sites from 1982-1986). Overwintering birds are expected to be first-years (Thompson 1973), and the variability of winter counts suggests that turnstones may have highly variable breeding success from year to year. Two additional explanations for high winter proportions in the Auckland region are: (1) that young turnstones may continue to arrive in New Zealand through the summer, boosting the winter population relative to the previous summer count and, (2) over-wintering birds from elsewhere in New Zealand move to the Auckland region during the southern autumn. Turnstone breeding success was apparently high in 1991 (Minton *et al.* 2005) and was reflected in an unusually high winter 1992 count in the Manukau Harbour. A subsequent year of high breeding success (1997) did not result in an increase in the population of south Auckland turnstones.

Figure 3.11.1. The number of turnstones in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.

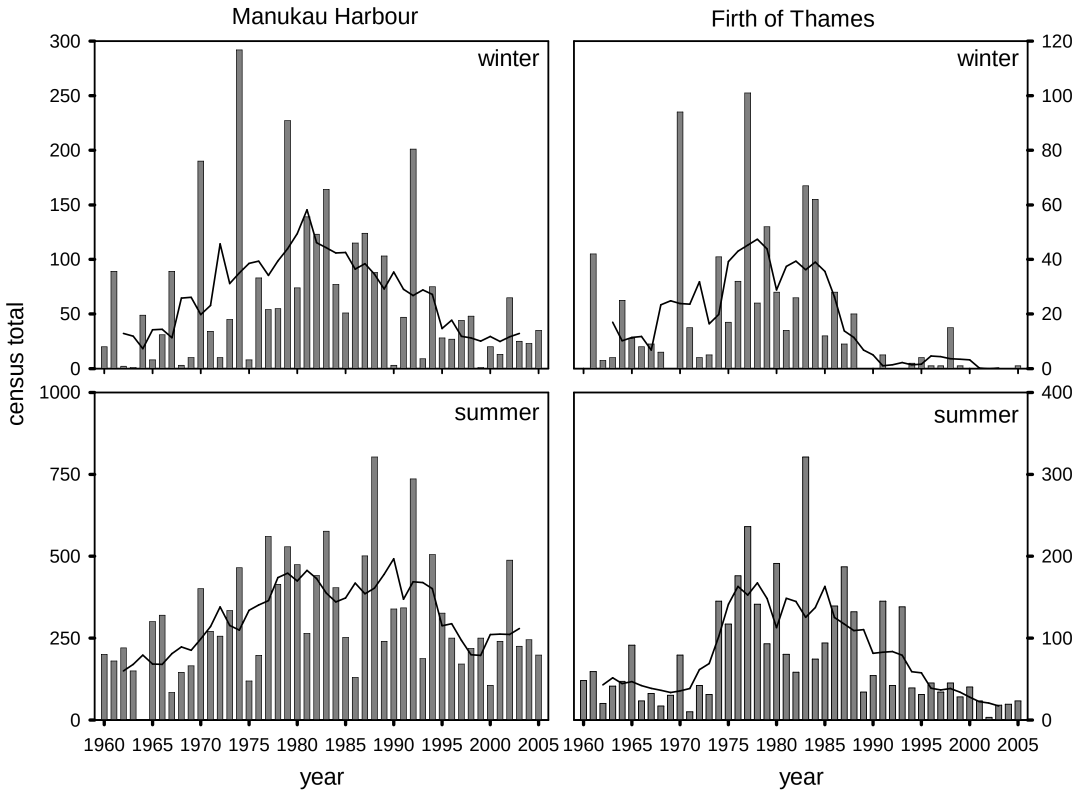


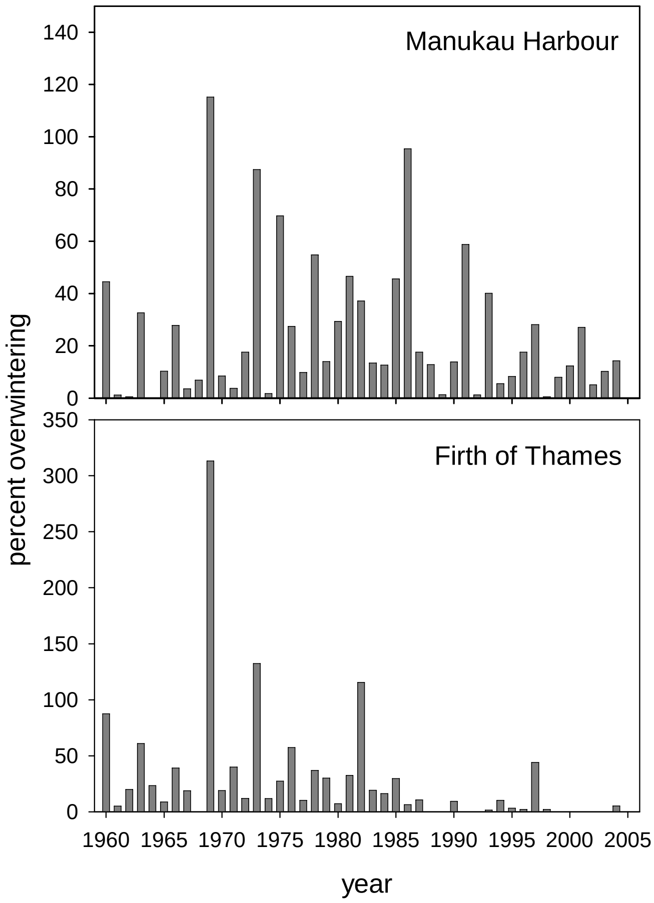
Table 3.11.1. Summary statistics of turnstone numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau				Firth			
	winter	**s.d.**	**summer**	**s.d.**	**winter**	**s.d.**	**summer**	**s.d.**
1961-65	30	39	170	110	19	19	52	26
1966-70	65	78	223	132	7	4	36	25
1971-75	78	121	289	126	32	38	69	59
1976-80	99	73	435	144	45	34	167	54
1981-85	111	46	387	134	39	24	125	110
1986-90	87	49	403	262	14	11	109	64
1991-95	72	76	419	210	1	2	79	57
1996-00	28	19	199	61	4	6	38	7
2001-05	32	20	279	118	0	0	17	8

Numbers of turnstones in the Firth of Thames have been low in winter since 1989 (none in nine years, <5 in three years and 15 birds in one year) and consistently low (<50 birds) in summer since 1994 (Fig. 3.11.1). The decreases in the Manukau Harbour have been proportionately smaller, though numbers present in summer since 2000 are on average 36% lower than they were in 1976-1980 (Table 3.11.1).

Turnstones in the Firth of Thames have always favoured the western shores for roosting, particularly Taramaire in the 1960s and 1970s, the Spit & Pools in the late 1970s and 1980s and the Limeworks in the 1980s and 1990s. High numbers (up to 109) were recorded in the Whakatiwai-Kaiaua section in the 1980s and 1990s. In recent years (2004-2006) turnstones have only used Kaiaua late in the summer (PFB unpubl. data); the reason for this change in timing is unknown.

Figure 3.11.2. **Percent of turnstone summer census numbers present in the following winter census.**



3.12 Red knot

Red knots increased greatly in the Manukau Harbour from the 1960s to 1980 (Figure 3.12.1), after which numbers fluctuated regularly between 10 000 and 20 000 birds, and peaked at 31 860 in 1995. Subsequently, numbers levelled off at around 9000 birds (Fig. 3.12.1; Table 3.12.1). Counts in winter (of 1-, 2- and some 3-year old birds; Battley 1999) were moderately correlated with counts in the previous summer (Spearman's r_s = 0.515) and the long-term trends for summer and winter populations were similar from the late 1970s onwards. The winter peaks in 1968, 1970 and 1971, however, did not match any unusual summer peaks. Trends differed in the Firth of Thames. Initially commoner than in the Manukau Harbour, numbers peaked in the late-1960s to mid-1970s (with high counts of 9860, 11 600, 11 400 and 11 103 in that period) and then declined to an average of just over 3000 birds from 1991-

1995 (Table 3.12.1). They subsequently increased again and now number approximately twice what they did in the early 1990s (Table 3.12.1).

Winter counts in the Firth were highly variable (Fig. 3.12.1) and bore little relation to summer counts (r_s = 0.212). Detailed counts and colour-banding studies from 2003-2006 have shown that numbers of knots in the Firth gradually dwindle through the winter and Firth of Thames birds may relocate to the Manukau and Kaipara Harbours (PFB unpubl. data). Winter counts in the Firth are an unreliable measure of population abundance. Frequent movements of knots between the Firth and the Manukau Harbour in summer as well as winter (PFB unpubl. data) mean that censuses should be made as close together in time as is possible. Additionally, the majority of first-year knots passes through southeastern Australia en route to New Zealand, some birds residing there for a year or more before migrating to New Zealand (Riegen *et al.* 2005). These birds may continue to move into New Zealand through the summer and thus be present for a winter census but not the preceding summer one.

Breeding success of knots, assessed via catches totalling more than 100 birds in southeast Australia, was recorded as very good in 1990 and good in 1995, 1997, 2000 and 2001 (Minton *et al.* 2005). These are shown in relation to the combined winter population of knots in the Manukau Harbour and Firth of Thames (Fig. 3.12.2), with years of good breeding success marked by small circles above the bars. It is evident that if high winter counts in New Zealand represent arrivals of first-year and immature birds, then there is a variable period during which birds reside in Australia. The 1990 cohort is probably reflected in increased 1991 and 1992 populations (movements as age 1 and 2), the 1995 cohort not until 1997 (age 2), the 1997 cohort not at all, the 2000 cohort in 2001 (age 1) and possibly 2002 (age 2), the 2001 cohort only in 2002 (age 1).

The movements of colour-banded birds show that the Manukau Harbour and Firth of Thames knot populations are currently not independent, though it is not clear how frequently birds move between these sites or what proportion of the local populations are involved. The very different population trends in the Manukau and the Firth suggest that the populations respond to local changes in attractiveness (most likely bivalve food supplies) and that some birds at least are able to sample the two habitats within the same season. As with other species, knots were regularly counted from Karito to Piako in the southern Firth until 1994 but are now found only along the western shores and at the mouth of the Waihou River, the only remaining open roosts. This is attributed to the steady encroachment of mangroves along the southern parts of the coast.

Table 3.12.1. Summary statistics of red knot numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau				Firth			
	winter	**s.d.**	**summer**	**s.d.**	**winter**	**s.d.**	**summer**	**s.d.**
1961-65	423	172	1267	1447	263	211	5287	2437
1966-70	1409	1302	2675	1857	312	399	7084	3461
1971-75	1551	2277	4966	2856	1388	1643	7038	2571
1976-80	2729	2675	11781	6987	331	350	6618	3204
1981-85	2278	1058	15689	4890	1169	1531	4734	2278
1986-90	3600	1103	15285	5024	175	296	4073	495
1991-95	3812	633	21100	7725	658	752	3084	2096
1996-00	1900	1755	11309	2816	151	124	3951	1147
2001-05	2143	1065	9301	783	298	353	6285	697

Figure 3.12.1. The number of red knots in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.

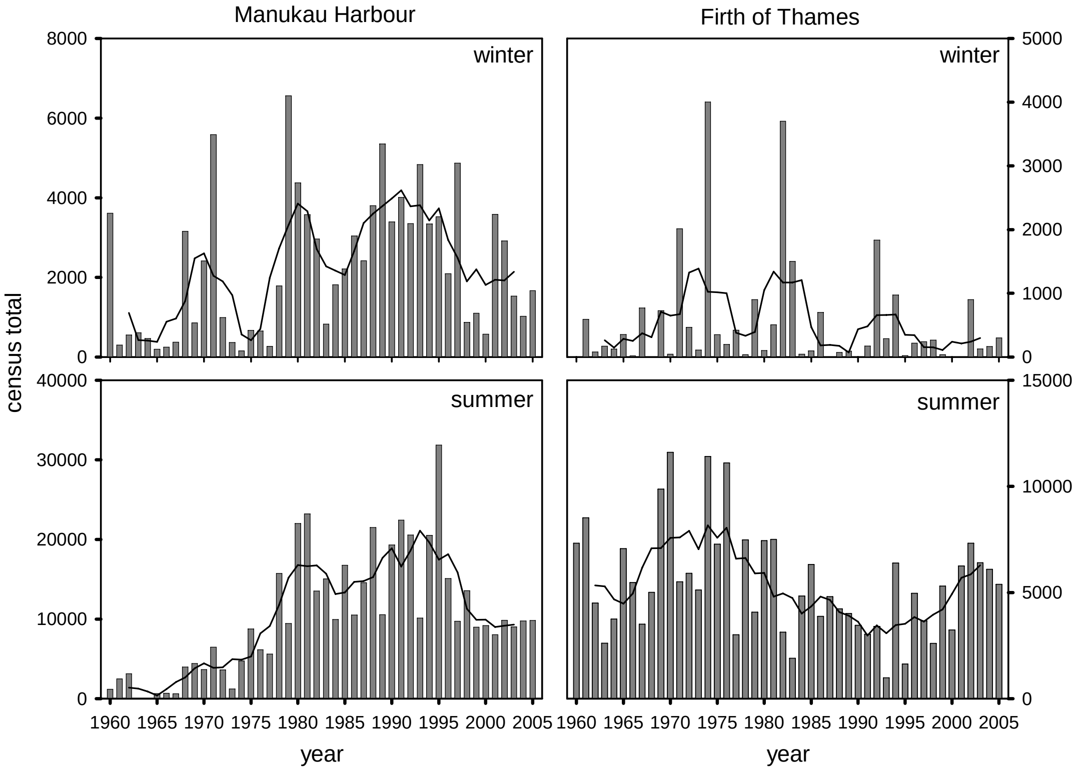
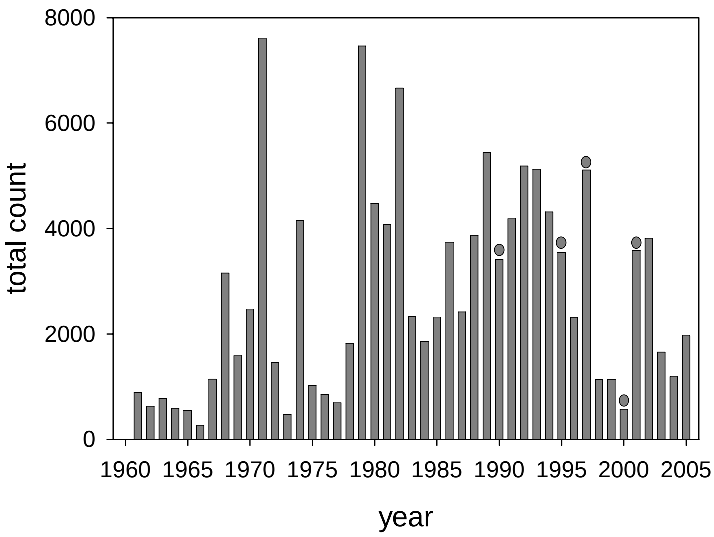


Figure 3.12.2. Winter knot counts in the Manukau Harbour and Firth of Thames combined. Dots above bars denote years with high breeding success measured in southeast Australia.



3.13 Curlew sandpiper

Small numbers of curlew sandpipers were intermittently recorded in Manukau Harbour summer censuses up to 1990 (Fig. 3.13.1), after which they have been annual visitors, peaking at 17 birds in 1995 (following a winter count of 15). In the Firth of Thames summer censuses, curlew sandpipers had a small peak around 1970, a higher sustained population of around 20 or more birds from 1976-83, and then a third peak caused largely by high counts in 1992 (36) and 1994 (30). The 1991 breeding season was exceptional, with the highest proportion of juveniles in 25 years of monitoring in southeast Australia recorded over the 1991-92 non-breeding season (45%; Minton *et al.* 2005). This probably explains the high winter 1992 counts in the Manukau (22 birds) and the Firth (15).

Nationally, 1992 was the exceptional year for curlew sandpipers in the 11-year period of formal OSNZ national surveys, with 88 birds in winter and 136 in summer (Sagar *et al.* 1999). There was no synchrony between other winter peaks in the Manukau Harbour and Firth of Thames (1977 and 1983 in the Firth, 1995 in the Manukau). Of these, the 1982 breeding season had good breeding success and the 1994 season moderate; the 1976 season preceded monitoring (Minton *et al.* 2005).

Figure 3.13.1. **The number of curlew sandpipers in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.**

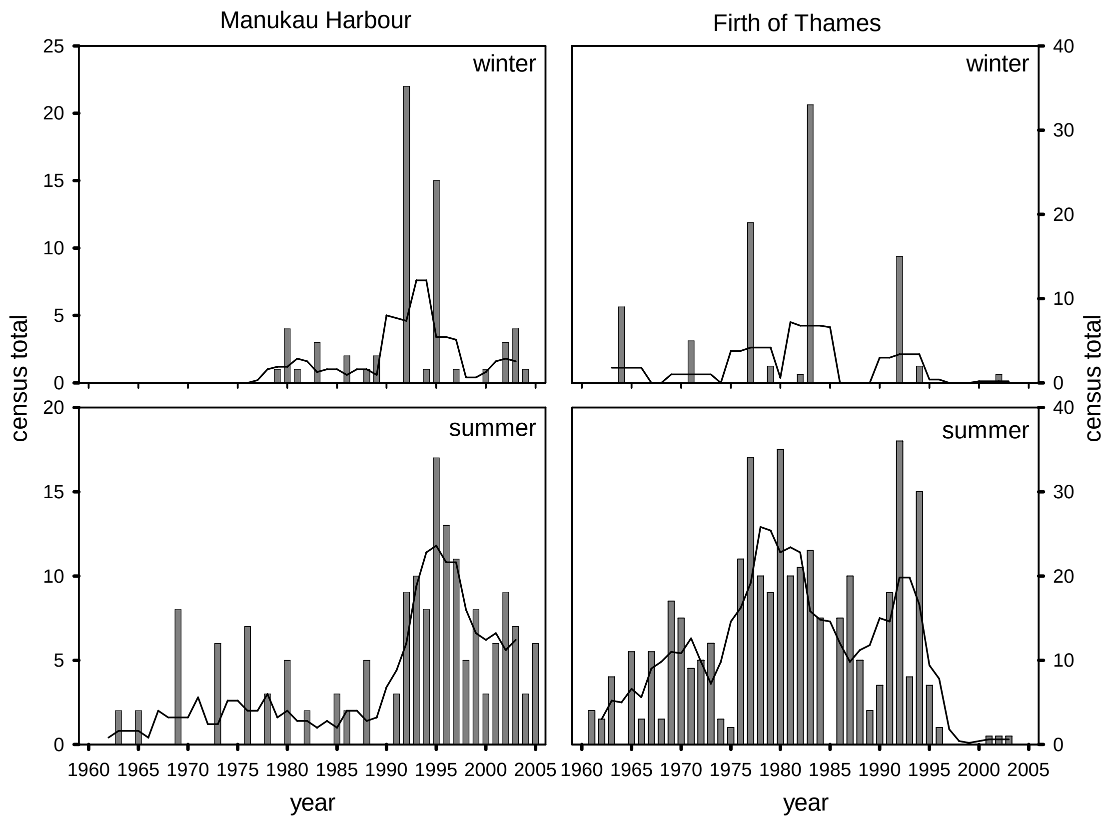
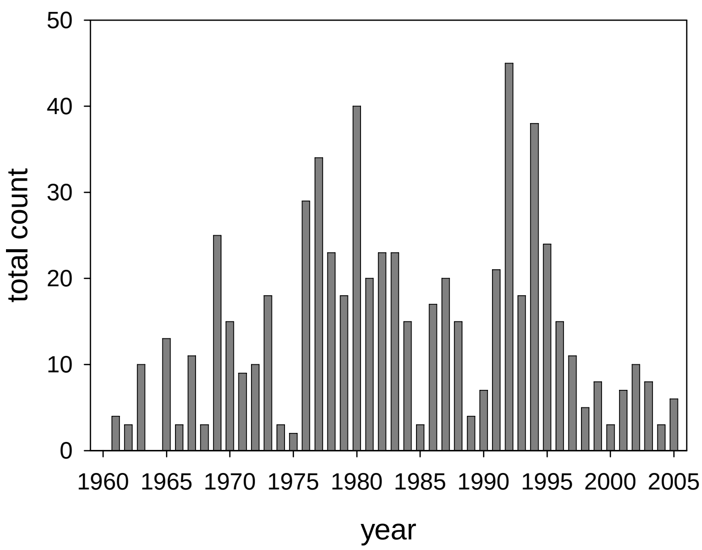


Table 3.13.1. Summary statistics of curlew sandpiper numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau				Firth			
	winter	s.d.	summer	s.d.	winter	s.d.	summer	s.d.
1961-65	0	0	1	1	2	5	5	4
1966-70	0	0	2	4	0	0	10	7
1971-75	0	0	1	3	1	2	7	4
1976-80	1	2	3	3	4	8	26	8
1981-85	1	1	1	1	7	15	16	9
1986-90	1	1	1	2	0	0	11	6
1991-95	8	10	9	5	3	7	20	13
1996-00	0	1	8	4	0	0	0	1
2001-05	2	2	6	2	0	0	1	1

Curlew sandpipers have been virtually absent from the Firth of Thames since 1995 (Fig. 3.13.1). Favoured roost sites for curlew sandpipers in the Firth were Taramaire and the Spit & Pools throughout the 1980s and early 1990s. It is not clear whether their subsequent near absence in the Firth is related to changes at these sites. While three birds banded at Miranda in 1992 were subsequently recorded in the Manukau Harbour (2, 2, and 6 years after banding; New Zealand Wader Study Group, unpubl. data), the decline in the Firth cannot simply represent birds relocating over time as the combined Manukau plus Firth population has declined since 1995 (Fig. 3.13.2). The age structure of the curlew sandpiper population in New Zealand is unknown. One bird banded in the Manukau Harbour as a second-year has subsequently been recorded in Victoria, Australia, suggesting that it changed countries before adulthood (New Zealand Wader Study Group and Australasian Wader Studies group, unpubl. data).

Figure 3.13.2. The total number of curlew sandpipers in the Manukau Harbour and Firth of Thames during the summer census.



3.14 Sharp-tailed sandpiper

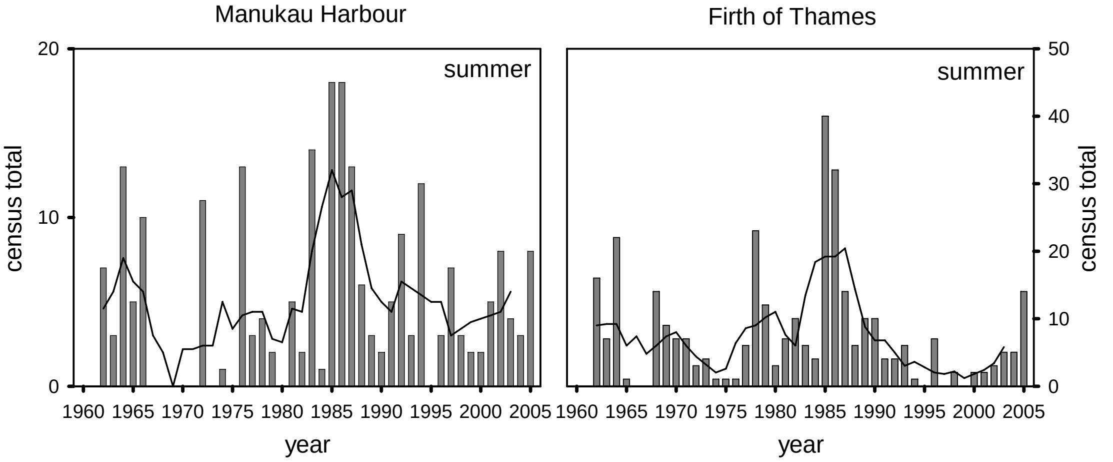
Sharp-tailed sandpipers are typically slightly more numerous in the Firth of Thames than the Manukau Harbour, though neither site holds particularly many (Table 3.14.1).

Numbers at both sites were dominated by especially high counts in 1985-86 (18 in the Manukau, 40 and 32 in the Firth; Fig. 3.14.1). In the Firth of Thames most birds have been counted at the Spit & Pools (regularly up to 1991) and the Limeworks (which contains the Stilt Ponds, currently the main site) sections; 29 were counted at Piako in 1985. Few sharp-tailed sandpipers spend the southern winter in New Zealand (Sagar *et al.* 1999) and they have been counted in winter censuses only six times in the Manukau Harbour (maximum 7 birds) and twice in the Firth of Thames (maximum 12 birds).

Table 3.14.1. Summary statistics of sharp-tailed sandpiper numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau winter	s.d.	summer	s.d.	Firth winter	s.d.	summer	s.d.
1961-65	0	0	6	5	0	0	9	10
1966-70	0	0	2	4	0	0	6	6
1971-75	0	0	2	5	1	1	3	2
1976-80	0	0	4	5	0	0	9	9
1981-85	1	1	8	8	2	5	13	15
1986-90	1	2	8	7	0	0	14	10
1991-95	1	3	6	5	0	0	3	2
1996-00	0	0	3	2	0	0	2	3
2001-05	1	1	6	2	0	0	6	5

Figure 3.14.1. The number of sharp-tailed sandpipers in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.



3.15 Red-necked stint

Red-necked stints have declined in the Firth of Thames over the past 40 years and are now only seen intermittently (Fig. 3.15.1). Periodic high productivity is suggested by years with high over-wintering numbers, such as 1964 and 1983, though these peaks were not evident for the Manukau Harbour and 1982 was not a particularly good breeding season for stints spending the non-breeding season in south-east Australia (Minton *et al.* 2005). Numbers in the Manukau Harbour showed three distinct high periods: from 1964-69, around 1980-87, and from 1998 onwards. The second peak overlapped with successive years of high over-wintering numbers, and small numbers of birds frequently over-wintered from the mid-1990s onwards. The different trends between the Firth of Thames and the Manukau Harbour imply that local factors affect the populations. Most stint records in the Firth from the 1960s to the late 1970s were at Taramaire, in the mid-1980s at the Spit & Pools, and in the late 1990s at the Limeworks. It is possible that feeding opportunities available towards high tide have declined over time as mangroves have infilled the upper level mudflats (such as those within the old 'Access Bay' shellbank) and made the Firth of Thames a less profitable environment for stints. Small shorebirds typically require the longest feeding times (Zwarts *et al.* 1990) and red-necked stint is a species that is known to take advantage of supratidal foraging habitats (Dann 1999).

Figure 3.15.1. The number of red-necked stints in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.

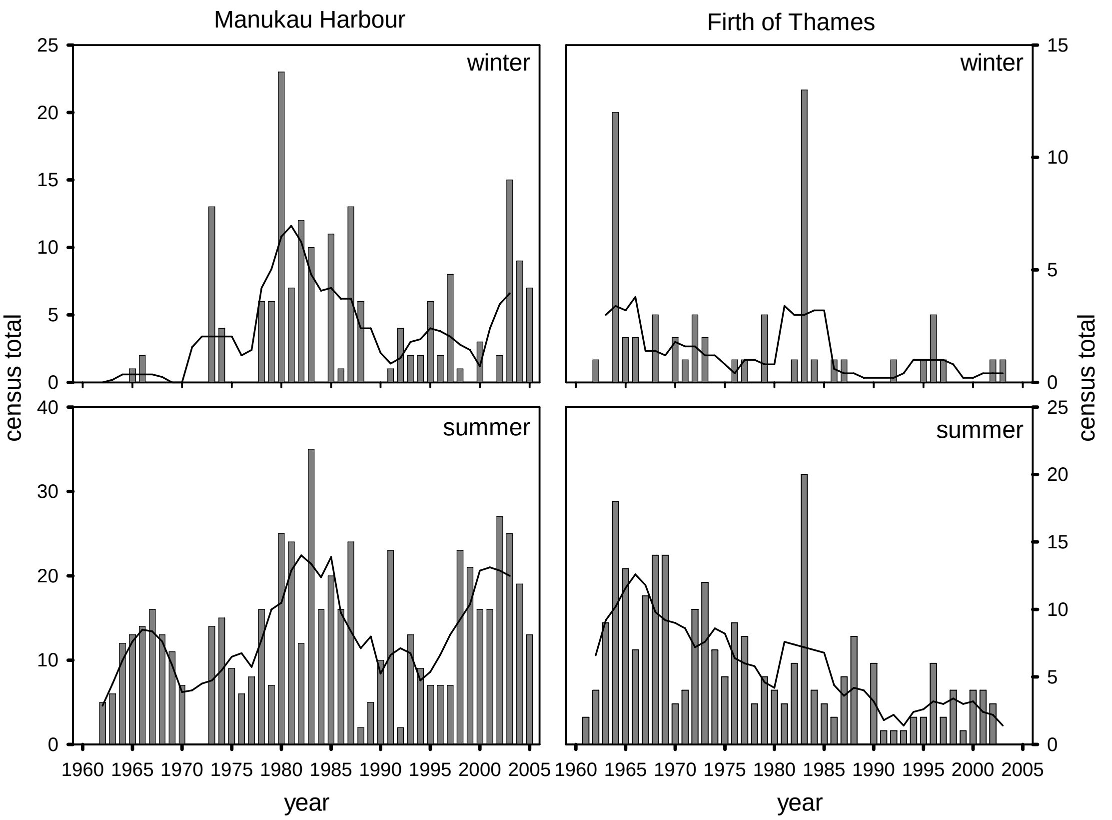


Table 3.15.1. Summary statistics of red-necked stint numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau				Firth			
	winter	s.d.	summer	s.d.	winter	s.d.	summer	s.d.
1961-65	0	0	7	5	3	5	9	7
1966-70	0	1	12	3	1	1	10	5
1971-75	3	6	8	7	1	1	8	3
1976-80	7	9	12	8	1	1	6	3
1981-85	8	5	21	9	3	6	7	7
1986-90	4	6	11	9	0	1	4	3
1991-95	3	2	11	8	0	1	1	1
1996-00	3	3	15	8	1	1	3	2
2001-05	7	6	20	6	0	1	1	2

3.16 Eastern curlew

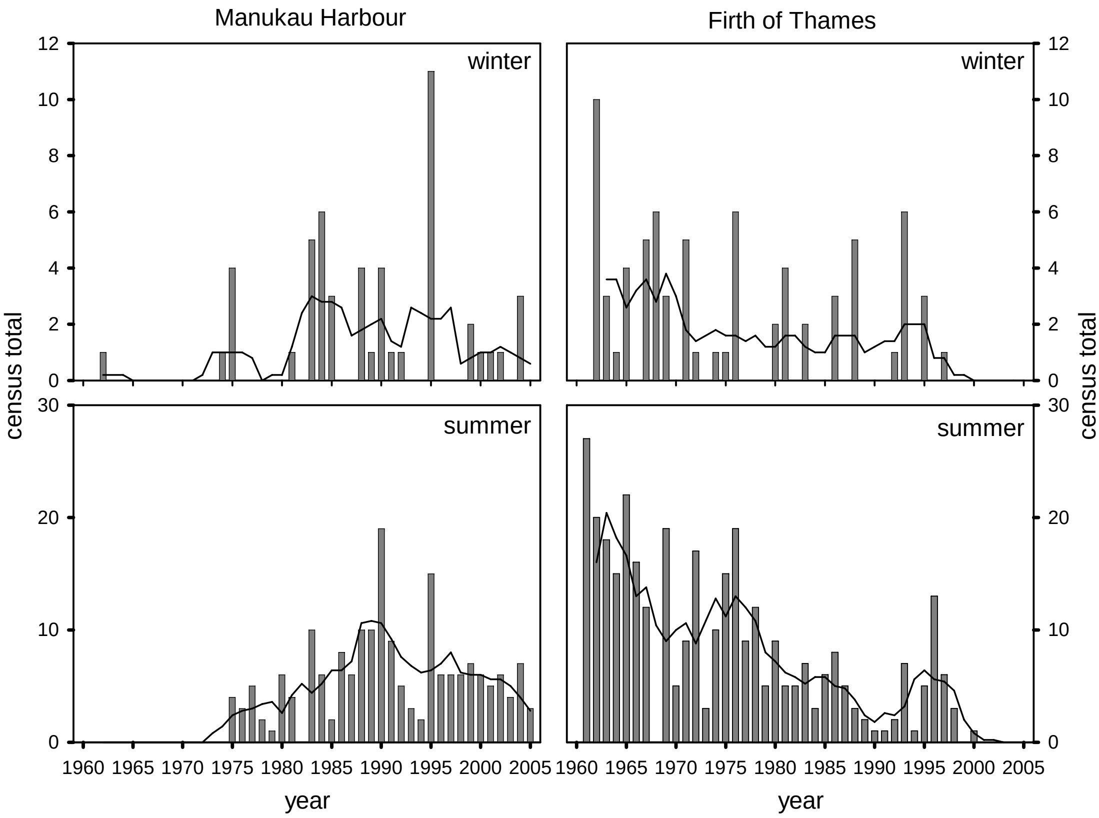
Curlews declined strongly in the Firth of Thames from 27 birds in 1961 to being only occasional visitors since 2000 (Fig. 3.16.1), with only temporary increases in the mid-1970s and the mid-1990s. As is expected of a large, presumably long-lived bird with delayed maturity, immature curlews frequently remained in the Firth during the northern breeding season. There was no strong trend in numbers of overwintering birds, in contrast to the declining summer population.

Curlew were recorded in the Manukau Harbour in just a few winter censuses before 1975, thereafter they were virtually annual, peaking at 19 birds in 1990. Combined numbers of curlews at both sites, while variable between years, were fairly stable overall during the 1980s (when the Manukau Harbour population was increasing) suggesting that a shift of birds from the Firth to the Manukau may have been occurring (Fig. 3.16.2). Numbers have strongly declined since 1995, a relatively good year for curlew populations. Twenty-eight curlew were counted at Farewell Spit in January 1995 (Schuckard 2002) and a high Manukau and Firth combined winter count that year of 14 birds suggest that 1994 was a good breeding season.

Table 3.16.1. Summary statistics of Eastern curlew numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau				Firth			
	winter	s.d.	summer	s.d.	winter	s.d.	summer	s.d.
1961-65	0	0	0	0	4	4	20	5
1966-70	0	0	0	0	3	3	10	8
1971-75	1	2	1	2	2	2	11	5
1976-80	0	0	3	2	2	3	11	5
1981-85	3	3	4	4	1	2	5	1
1986-90	2	2	11	5	2	2	4	3
1991-95	3	5	7	5	2	3	3	3
1996-00	1	1	6	0	0	0	5	5
2001-05	1	1	5	2	0	0	0	0

Figure 3.16.1. The number of Eastern curlews in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.



3.17 Whimbrel

The number of whimbrels counted in Manukau summer census increased through the late 1970s, 1980s and early 1990s peaking at 24 in November 1994 (Fig. 3.17.1). Because whimbrels are a species that can be difficult to census well (roosting in mangroves, arriving late in the tide at roosts and being vulnerable to disturbance) it is not clear whether their apparent absence in the Manukau Harbour from 1997 –2000 is real or not. In most winters less than 8 whimbrels were found in the Manukau, except for July 1985 when 15 were present. 1985 was also the peak winter count for whimbrels in the Firth with 19 present.

The number of whimbrels counted during the Firth summer census increased from the late 1970s through to the mid 1980s (peak of 47 in December 1985) and has remained relatively high since. From 1977 to 1994 most of the Firth's whimbrels were found at the Piako roost. Since 1995 all whimbrels counted during summer censuses in the Firth have been using the Waihou roost. The change in roost site is likely due to habitat changes at these two sites. From the mid 1990s the Piako roost was increasingly colonised by mangroves, while at the same time a rolling series of mobile sandbanks developed in the mouth of the Waihou River, providing a roost relatively free of human disturbance.

Figure 3.17.1. The number of whimbrels in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.

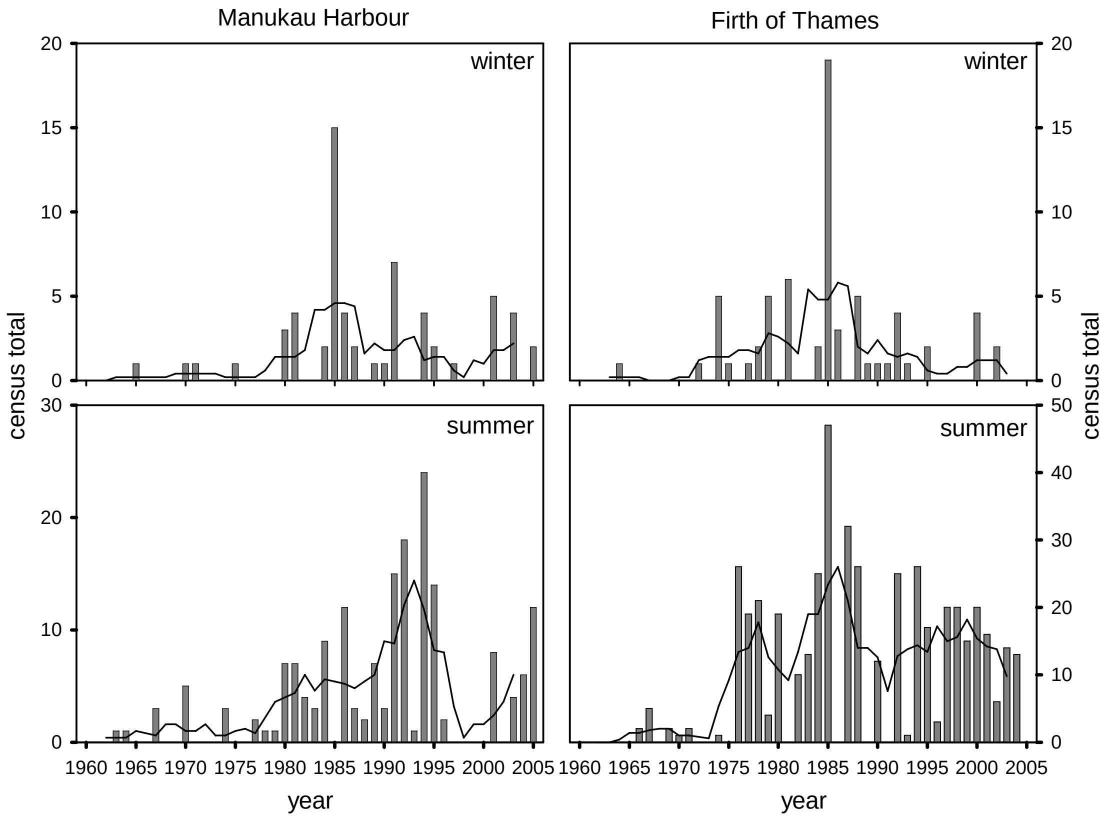


Table 3.17.1. Summary statistics of whimbrel numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau winter	s.d.	summer	s.d.	Firth winter	s.d.	summer	s.d.
1961-65	0	0	0	1	0	1	0	0
1966-70	0	0	2	2	0	0	2	2
1971-75	0	1	1	1	1	2	1	1
1976-80	1	1	2	3	2	2	18	8
1981-85	4	6	5	4	2	3	19	18
1986-90	2	2	5	4	6	8	14	15
1991-95	3	3	14	8	1	2	14	13
1996-00	0	0	0	1	0	1	16	7
2001-05	2	2	6	4	1	2	10	7

3.18 Bar-tailed godwit

Numbers of godwits in summer followed broadly similar trends in the Manukau Harbour and Firth of Thames. Numbers increased from the mid- to late-1960s to the early- to mid-1970s before declining through the 1980s (Fig. 3.18.1). This decline was more pronounced in the Firth of Thames, and lasted for longer, with numbers present in the early 1990s being half that of the early 1970s (Table 3.18.1). Both populations increased again to the mid-late 1990s before declining again. Similar trends are evident in the numbers of subadults (ages 1, 2 and 3) remaining through the southern winter (Fig. 3.18.1): high counts in the Manukau from 1969-73 and again from 1988-93, in the Firth in 1969-70, 1973-74, and from 1989-93 (with a lesser peak from 1997-2000). This implies that the population dynamics of bar-tailed godwits in the Auckland region are driven to a large degree by changes in productivity, though the presence of three age-classes in winter makes it difficult to discern changes in breeding success.

Figure 3.18.1. The number of bar-tailed godwits in the Manukau Harbour and Firth of Thames from 1960 to 2005. Bars represent census counts. Lines give the 5-year running mean.

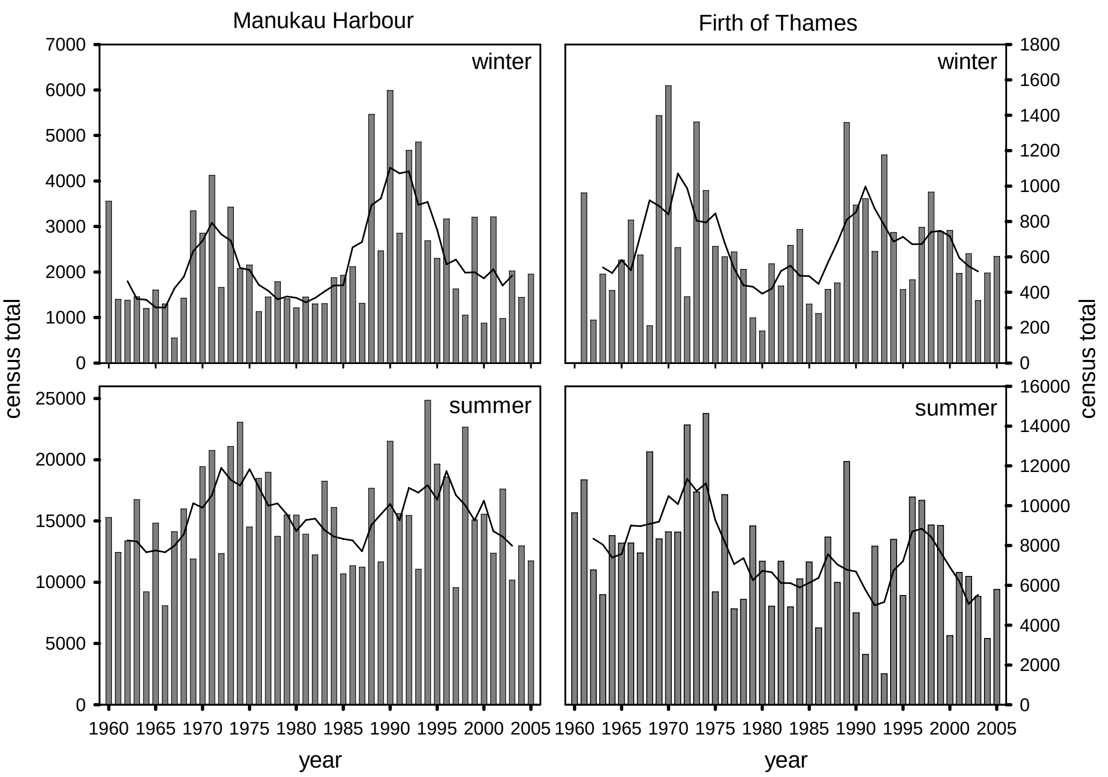


Table 3.18.1. Summary statistics of bar-tailed godwit numbers from 1961-2005, grouped into 5-year periods.

Years	Manukau winter	s.d.	summer	s.d.	Firth winter	s.d.	summer	s.d.
1961-65	1408	145	13 321	2807	540	267	8035	2164
1966-70	1895	1163	13 909	4272	919	561	9087	2056
1971-75	2689	1040	18 352	4644	805	377	10 739	3742
1976-80	1399	255	16 434	2216	439	206	7367	2429
1981-85	1573	308	14 240	3007	550	170	6108	1130
1986-90	3471	2112	14 685	4675	680	444	7047	3371
1991-95	3475	1198	17 322	5197	778	290	5163	3070
1996-00	1986	1130	16 289	4826	740	176	8435	2858
2001-05	1921	835	12 971	2791	518	105	5522	1325

4 Discussion

Over the 45 years from 1961 to 2005, no shorebird population in the Manukau Harbour or Firth of Thames could be regarded as having been consistent from year to year and generally stable. The most consistent long-term trends have occurred in pied oystercatchers (continuous increase then a recent decrease), variable oystercatcher (dramatic recent increase), spur-winged plover (recent increase and probable decrease), and Eastern curlew in the Firth of Thames (decrease). Pied stilts have shown no strong long-term trend, but there were very large differences in counts between years. Most of the Northern Hemisphere migrants have had periods of both relatively high and relatively low populations.

The population size at a given site depends on the balance between productivity, immigration, emigration and survival. Breeding productivity affects the inputs of young birds into the population; local survival affects the recruitment of young birds into the adult population (many shorebirds have delayed maturity, taking up to four years to reach adulthood) and the numbers of resident adults present. Factors outside the local area affect survival rates of migrants; and site-faithfulness determines whether birds that use an area continue to do so over time. There is little information on any of these factors for even the common shorebird species in New Zealand.

4.1 Site-faithfulness

In terms of site-faithfulness, preliminary data on individual movements of red knots and bar-tailed godwit (PFB, University of Otago and OSNZ, unpubl. data) indicate that while adult godwits are highly site-faithful, knots are much less so, and there is frequent movement between the Firth of Thames, Manukau Harbour and Kaipara Harbour. Each winter in recent years, numbers of knots in the Firth have gradually dropped from May to August, and resightings of colour-banded birds showed that these birds moved to the Manukau Harbour. Wrybills have been documented moving around the Auckland harbours within a season, though the extent of this is not known (Dowding & Moore 2006). For mobile species such as knots, local population changes may reflect short-term decisions about where to reside as well as underlying mortality and productivity factors. Local numbers of highly site-faithful birds such as godwits are expected primarily to reflect changes in productivity and survival rather than changes in residency. Supporting this idea, numbers of godwits in the Manukau and the Firth have followed similar general trends over the past 45 years, while numbers of knots have not, with the Manukau population increasing from the 1960s to the 1990s. Major changes in the Manukau Harbour over that period include the construction of the Mangere Sewage Ponds and the loss of major intertidal eelgrass (*Zostera*) beds. Given knots' global preference for bivalve prey (Piersma *et al.* 1994, Battley 1996, van Gils *et al.* 2005), it is likely that a major population increase in knots would be associated with an increase in opportunities to forage on small shellfish.

4.2 Comparisons with Australia

Long-term monitoring of migratory shorebird productivity has not been attempted in New Zealand. The longest-running dataset on productivity (measured as the proportion of juvenile birds in cannon-net catches) is from Victoria, southeast Australia (Minton *et al.* 2005). There are also long-term population monitoring data for some sites in southeast Australia. For knots and godwits it is known that New Zealand and Victoria host birds from the same population; it is a fair presumption that the small numbers of many other Arctic-breeding species in New Zealand also come from the same general populations as their conspecifics in Victoria. Comparisons of population changes in New Zealand with population and productivity data from Victoria may reveal whether large-scale population changes are behind any local changes in New Zealand.

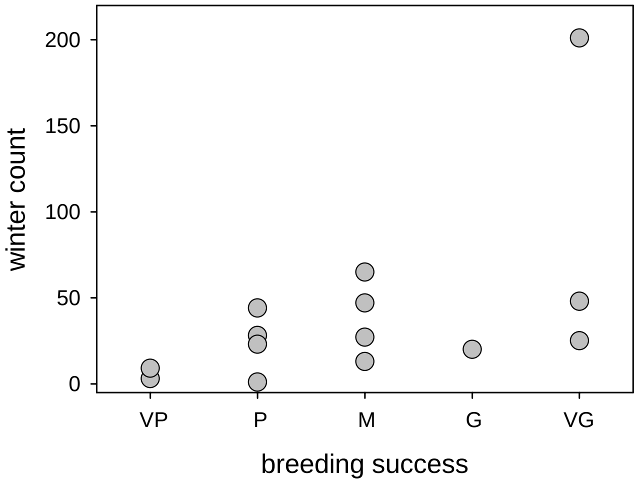
4.3 Australian productivity estimates

Published productivity data from Victoria date back to 1978 for red-necked stint (data from all 26 years), 1979 for curlew sandpiper (25 years of data), sharp-tailed sandpiper (23 years), red knot (13 years) and bar-tailed godwit (15 years), and 1989 for ruddy turnstone (14 years) (Minton *et al.* 2005). Sample sizes vary between species, with extremely high total numbers of two species (92 899 red-necked stints and 21 122 curlew sandpipers), high numbers of one (6065 sharp-tailed sandpipers) but much lower numbers of the others (1541 knots, 1689 godwits and 2052 turnstone). The percentage of juveniles in catches was used to categorise each breeding season as very poor, poor, moderate, good or very good. Plots (not shown) of the summer and winter counts in New Zealand against the breeding success categories for each species showed no strong relationships between apparent breeding success and census counts.

As juveniles generally constituted a small percentage of the total catch in Australia (median percentages over time of 9.3% for turnstone, 9.6% for curlew sandpiper, 10.2% for sharp-tailed sandpiper, 13.3% for bar-tailed godwit and 14.5% for red-necked stint), 'spikes' in the population caused by high productivity may be evident only in those species in which most or all first-years over-winter on the non-breeding grounds but second-years return to the breeding grounds (such as the red-necked stint and curlew sandpiper). In Victoria, winter numbers of red-necked stint were strongly and significantly correlated with the percentage of juveniles in the previous season. Curlew sandpiper numbers were also well correlated, at least when total populations were moderately high (they declined from the mid-1990s; Minton *et al.* 2005). In the Manukau and Firth data, no such relationship was evident for either stints (Spearman rank correlation r_s = 0.033 for the Manukau, 0.169 for the Firth) or curlew sandpipers (r_s = -0.160 for the Manukau, -0.330 for the Firth).

The only species for which a moderate correlation was present was the turnstone in the Manukau Harbour (r_s = 0.574; Fig. 4.1). The relationship is not dependent upon the single very high count of 201 birds after a very good breeding year: the trend of increasing numbers with breeding success still has a moderate correlation (r_s = 0.487) with that point excluded. In years of very poor apparent breeding success (and in one year of poor success) wintering numbers of turnstones were very low. When breeding success was moderate or above, moderate numbers were always present; and the one year with high numbers coincided with a year of very high breeding success (Fig. 4.1). In that year (breeding season 1991) the juvenile proportion in Victoria in summer was twice as high as in the next most successful year (122 of 152 birds or 80.3% were juvenile). The following summer census (1992) had the second-highest count of turnstones in the Manukau Harbour, so some of the variability in numbers is attributable to changes in productivity in this species.

Figure 4.1. Winter numbers of turnstone in the Manukau Harbour in relation to breeding success the previous season assessed via summer cannon-net catches in southeast Australia. Breeding success codes represent very poor, poor, moderate, good and very good.



As discussed earlier, results for the red knot are complicated by knots' habit of settling temporarily in Australia as young birds before later moving to New Zealand. The juvenile proportions measured for red knots in Victoria are therefore unreasonably high (biologically speaking), with juvenile proportions of 14.2 – 100% in summer catches (median 41.8%). Furthermore, overwintering knots in New Zealand comprise a mix of first-, second- and third-year birds and birds do not necessarily move to New Zealand at a fixed age. Likewise, first-, second- and third-year bar-tailed godwits overwinter in New Zealand, and we do not know whether juveniles are randomly distributed across southeast Australia and New Zealand. Efforts are underway to bring together all relevant datasets on godwit populations of the subspecies *baueri* that breeds in Alaska and winters in southeast Australia and New Zealand, and develop a detailed population model for them (B.J. McCaffery, U.S. Fish & Wildlife Service, and PFB).

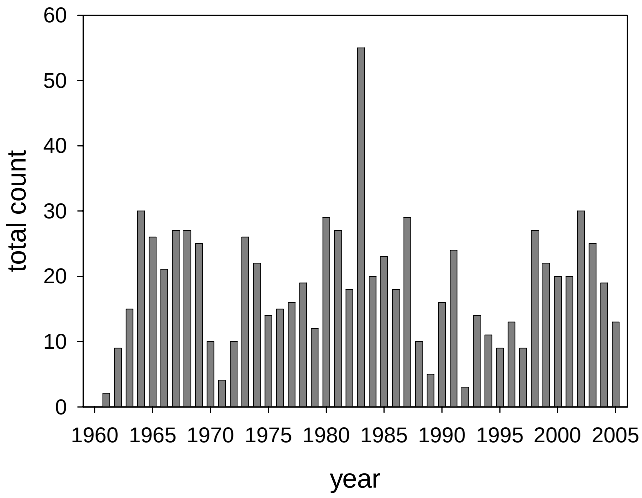
4.4 Population trends in Australia

Population monitoring data have been published for a small number of species in the Coorong region of South Australia and six sites in Victoria (Gosbell & Grear 2005). Curlew sandpipers declined dramatically in the Coorong from around 40 000 birds in 1981 to 4300 in 2001 before increasing to 13 400 by 2003. This decline was matched in Victoria where numbers counted dropped from around 38 000 in 1984 to less than 8000 in 2003. Though the numbers concerned are trivial in comparison, qualitatively the Manukau and Firth trends combined (Fig. 3.13.2) are similar to those in Australia: a decline from the early 1980s, an increase in the early-mid 1990s then a decrease to the present time.

Red-necked stint numbers in Victoria decreased slightly through the 1980s to 1992 but gradually increased thereafter and are now more numerous at the counting sites than in the 1980s. At the site with the highest numbers of stints in New Zealand, Lake Ellesmere in Canterbury, very high counts were made in the early 1980s (214 in 1981-82 and 128 in 1983-84: OSNZ CSN). Maximum counts reported in CSN (which are not necessarily the total population) decreased to a low of 45 in 1994-95 before increasing to 2000-01 when 115 were counted. The trend therefore broadly mirrors that of the Victorian sites. For the Manukau and

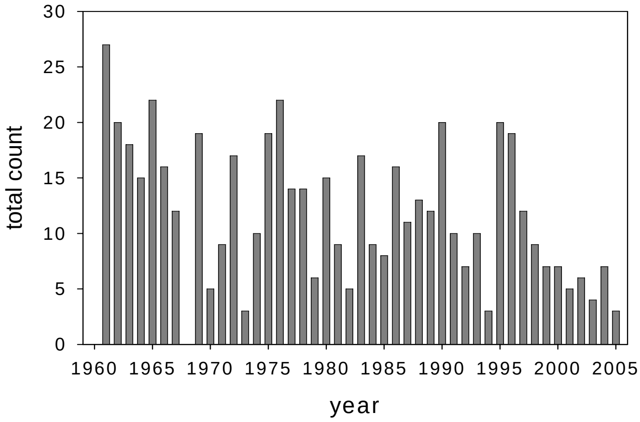
Firth combined (as there seems to have been a shift away from the Firth: Fig. 3.15.1), total numbers are similar in the early 2000s to what they were in the early 1980s, after periods with low counts in the late 1980s and early-mid 1990s (Fig. 4.2). Overall, it seems that the small, almost extralimital, New Zealand stint populations (compared with an Australian population of 260 000: Bamford & Watkins 2005) may show similar long-term fluctuations to those in southeast Australia, implying similar causes are involved.

Figure 4.2. Red-necked stint numbers in the Manukau Harbour and Firth of Thames combined.



These similarities between population fluctuations in Australia and New Zealand suggest that for some species even small changes in numbers in the Auckland region reflect large-scale population processes. It is precisely these small populations in which declines or increases can be accurately detected (in terms of minimal counting error). The buffer theory (Brown 1969) proposes that there are preferred (often high-quality) sites and other less preferred sites, and that population changes may be disproportionately represented at the less preferred sites. If New Zealand sites are peripheral to preferred non-breeding areas in Australia, then population changes may occur first at these peripheries. Eastern curlews in the Manukau and the Firth (even allowing for a shift from the Firth to the Manukau) have declined overall since the 1960s (Fig. 4.3). Southeast Tasmania is also on the periphery of curlew distribution, and curlew numbers here dropped on average 2% each year since 1965, declining from around 280 birds to less than 100 (Wilson 2001). In contrast, curlew numbers in Victoria did not undergo any systematic change from 1981-2000. The declines in New Zealand and Tasmania could represent a population reduction in the buffer zones of the curlew distribution.

Figure 4.3. Eastern curlew numbers in the Manukau Harbour and Firth of Thames combined from OSNZ summer censuses.



4.5 Local changes in roost sites

Pronounced changes in the local population of several shorebirds in the Firth and/or Manukau are evident. Pacific golden plovers have decreased at both sites, but the changes have not been synchronous. In the Firth of Thames numbers peaked in the late 1970s, but by the late 1980s they were virtually absent; in the Manukau the recent decline started only in the late 1980s. While numbers in New Zealand may be correlated with those in Victoria (Wilson 2001 showed a close match between Victorian counts and New Zealand national census data from 1983-1993), the virtual absence of Pacific golden plover in the Firth probably is habitat-related (the preferred roosting areas in the southern Firth having been encroached upon by mangroves). Red-necked stints have declined in the Firth but not the Manukau since the 1960s and turnstones have declined to a lower level in the Firth than in the Manukau, suggesting that local conditions in the Firth have become less favourable for these species. Wrybills have increased recently in the Manukau Harbour while slowly declining in the Firth of Thames, but this change could as easily reflect an increase in habitat quality for wrybills in the Manukau as a decrease in the Firth.

Habitat changes at individual roost sites have been reflected in major shifts in the distribution of many species in the Firth of Thames. The Karito, Waitakaruru and Piako sections of the southern Firth were key roost sites for many species from the 1960s to the 1980s, but due to mangrove growth they are now only irregularly used by low numbers of birds. One species that was typically recorded only in those sections (Pacific golden plover) has only been recorded intermittently in the Firth since 1986 and has been absent from the southern sections since 1989.

On the eastern side of the Firth, a sandbar began to develop near the Waihou River mouth in the mid-1990s, which is included in the Parawai-Thames count section. Red knots were only recorded in this section three times from 1960-1994, but have averaged 2180 since 1996. Whimbrels were found mostly at Piako up to 1994, but have been only at the Waihou roost since 1995. Prior to 1995 more than 400 bar-tailed godwits had only been recorded twice in the Parawai-Thames section, but since then they have averaged 2388 in summer censuses.

Another change has occurred in the western Firth with the southwards growth of the shellbank that formed 'Access Bay' in the 1980s and the Bay's subsequent infilling with mangroves. The 'Spit & Pools' section in the 1980s was virtually opposite where the Miranda Naturalists' Trust Shorebird Centre now is, but southward currents have caused the shellbank (which was wide and open to the sea) to grow towards the Limeworks and closer to shore. The spit has grown about 2 km over the past 20 years and mangroves now cover almost all the mud between the spit and the shore. The Spit & Pools regularly held 500-4800 knots from the 1970s to 1995 with only three birds seen on one census thereafter. Knots were common at the Limeworks from the 1960s to the early 1980s, but were infrequently recorded there from 1986-95. Since 1996 on average 2776 knots have used the Limeworks count section, which now comprises the spit tip and the Stilt Ponds. This is an example of the preferred roosts changing from the Limeworks to the Spit & Pools when conditions were favourable, and back to the Limeworks once the Spit & Pools became unsuitable. The same pattern is shown for bar-tailed godwits.

4.6 Nesting sites and local breeders

As with non-breeding shorebirds, the suitability of sites for breeding birds may change over time as coastline morphology and vegetation change. Minimal disturbance and low predation rates are also critical for successful breeding. Ferrets (*Mustela furo*), stoats (*Mustela erminea*), feral cats (*Felis catus*), hedgehogs (*Erinaceus europaeus*) and possibly rats (*Rattus* spp.) are predators of shorebird nests on riverbeds and beaches (Dowding & Murphy 2001, Keedwell *et al.* 2002, Sanders & Maloney 2002). Cats and stoats are also known predators of adult breeding (cats and stoats) and non-breeding (cats) shorebirds (Dowding & Murphy 2001, Sanders & Maloney 2002). The growth of mangroves and associated sediment trapping around the Waihou River sandbank in the Firth has been such that the mud is essentially dry on neap tides, allowing predators such as cats to reach the site. Battley & Moore (2004) documented cat predation on variable oystercatcher and white-fronted tern chicks as well as on non-breeding wrybills at the Waihou roost. Evidence of cat predation on non-breeding wrybills and pied oystercatchers has also been recorded at Miranda (PFB unpubl. data). It is likely that predation by introduced mammals, and disturbance by cattle if not fenced well, contribute to the frequent abandonment of black-billed gull nests at Miranda. Growth of introduced weeds over formerly bare shellbanks provides cover for these predators and is a management issue that has received little attention to date. Whether Australasian harriers (*Circus approximans*) affect breeding birds is unknown.

One of the greatest changes to coastal margins in recent years is the increase in recreational use, often involving vehicles. In the Firth of Thames, the Taramaire stretch of beach is now a near-continuously used site for campervans. In the 1980s shorebirds used to roost along this beach (B. Chudleigh, pers. comm.) but now rarely do so. Just north of Taramaire the Rangipo stretch of beach had virtually no disturbance up to the 1990s due to a hostile homeowner on the beachfront. This home was removed in the 1990s and there is now frequent 4-wheel drive and horse activity along the beach. There has been no successful New Zealand dotterel or variable oystercatcher breeding at Rangipo in recent years (PFB, pers. obs.). Migrant shorebirds are also now infrequent on this beach. This increase in disturbance and especially in vehicle use on beaches directly threatens the viability of these sites for breeding birds.

It should be noted that human impacts on nesting birds are not new. Banded dotterels used to breed in both the Firth of Thames and the Manukau Harbour (more than 20 pairs breeding along Kaiaua – Miranda coast in 1951 [Stidolph 1952]; pair seen with chicks at Miranda in 1983 [B. Chudleigh, pers. comm.]; pair plus chick at McFarlane's Beach, Manukau Harbour in 1935 [Potter 1949]). However, no banded dotterels are known to have nested in the Firth in the last 12 years (K. Woodley, Shorebird Centre Manager, pers. comm.) and they have also been lost as breeding birds from the Manukau Harbour. Similarly, although the numbers of New Zealand dotterels using the Firth of Thames as a flock site have increased over the past 45 years, this is likely due to increased recruitment in managed areas elsewhere in northern New Zealand (birds banded at Opoutere and Matakana Island have been observed in the Firth of Thames), as the number of pairs breeding locally has declined. The combined effects of predation, disturbance and habitat loss are probably to blame for the decline in breeding shorebirds at these sites.

Summer censuses are not good at assessing breeding success of resident species. Even if a species is recorded nesting there is no guarantee of success and birds are often still incubating or even nest-building during census times. Given how long-lived coastal birds can be (e.g. Davies 1997, Johnson *et al.* 2001) it may be many years until poor reproduction results in a population decrease. It is likely that useful information on shorebird (and other waterbird) breeding in the Firth and Manukau Harbour resides in field notebooks of Ornithological Society and Miranda Naturalists' Trust members. Compiling existing information and commencing surveys of known breeding sites would provide useful information on the health of resident shorebird populations.

4.7 How effective are surveys for population monitoring?

To describe trends in shorebird populations accurately we need to distinguish biologically significant declines or increases from short-term fluctuations. Under the current survey system there is effectively one survey annually for adults (combined with immatures and juveniles) of most species. This single count is taken to be an accurate estimate of the population at that time, though the true precision of the count is a function of the accuracy of counting and the detection of all birds. For instance, in 1969 the winter count of wrybills in the Firth of Thames (Fig. 3.8.1) was abnormally and in retrospect erroneously high, probably due to a serious counting error. While shorebirds tend to roost in obvious flocks along the shoreline, some species utilise other areas such as farmland at high tide and may be missed during a survey. Repeat surveys would give some measure of the constancy of counts, though as these depend on a limited pool of volunteers and are limited by the suitability of tides (spring tides are preferred), it is unlikely that the current survey frequency will be increased. Underhill & Prŷs-Jones (1994) concluded that for counts of waterbirds in British estuaries in winter, a single count could not be regarded as representative of the winter as a whole.

Another factor affecting the usefulness of the counts for population monitoring is that the survey times vary depending on suitability of tides in different years, and there has been substantial variation in timing between years, particularly in early years (e.g. Manukau Harbour winter counts 5 June – 1 August, summer counts 18 October – 22 December; Firth of Thames winter counts 19 May – 24 July, summer counts 18 October – 15 December). Dates have been well standardised since the early 1990s (Manukau Harbour winter 13 June – 2 July since 1993, summer 14–29 November since 1993; Firth of Thames winter 7–30 June since 1992, summer 4–21 November since 1993). While these census dates were chosen to represent times of stable populations (i.e. no major arrivals or departures expected of migratory species), this may not always be true. Juvenile red knots almost certainly enter the New Zealand population throughout the southern summer, as juveniles (which can be visually distinguished in the field) are extremely rare in October-November (PFB and AMH, pers. obs.), yet are frequently found in cannon-net catches in autumn and winter. In some winters pied oystercatchers have been recorded migrating south as early as 21 June from the Manukau Harbour (OSNZ CSN) and 25 June from Miranda (K. Woodley, Shorebird Centre Manager, pers. comm.), preceding the winter census. If there was a significant shift over time in the migration phenology of a species like the pied oystercatcher, then an apparent decline in recent years (see Fig. 3.1.1) could result from earlier departures of some of the birds. Such an effect would not explain a decrease in the numbers of immatures remaining in summer, however.

However accurate the census results are, the species accounts show that major population changes have occurred in most species over the past 45 years. Some countries have detailed species-specific 'alert' systems that trigger when counts show a certain level of decline (e.g. British Trust for Ornithology – see Maclean *et al.* 2005). These are based on fairly comprehensive, multi-site, long-term datasets that are lacking in New Zealand. Furthermore, because the cause of change for most species in New Zealand is unknown it is difficult to assess whether a change in a population reflects natural fluctuations similar to those in the past, changes in ecological integrity or environmental conditions away from the site of interest, or local factors that affect residency and/or survival.

Bar-tailed godwit counts in the Firth decreased almost tenfold from 14 620 in 1974 to 1556 in 1993 before increasing again. Does this mean that the recent decrease of 48% in the Manukau and 36% in the Firth from 1998 to 2005 is not significant and worthy of concern? There is no guarantee that the agents of change are the same now as they were in previous decades and therefore no guarantee that future trajectories will be similar. This is a major limitation of surveys as a population monitoring tool – they illustrate what has happened but do not identify the demographic agents behind the changes.

Detailed population modelling based on current field-generated survival and productivity estimates is needed to predict population trajectories (e.g. Baker *et al.* 2004). Demographic studies based on mark-recapture methods are underway on the two most common Arctic-breeding migrant species (bar-tailed godwit and red knot) and on one endemic species (wrybill) (PFB and New Zealand Wader Study Group) that should shed light on changes in survival and productivity in these species. Because of the variability in these measures and the slowness to generate estimates, these studies need to continue as long-term projects for the full benefits to accrue.

4.8 Other species

Finally, the Manukau Harbour and Firth of Thames are also important breeding and non-breeding sites for non-shorebird species including shags, waterfowl, herons, gulls and terns. Census data exist for these taxa but no analysis has been done to date. Writing up these data would provide a fuller appreciation of the changes in the status of birds at these sites.

Photo 5 (Geoff Moon): Bar-tailed godwits waiting at the edge of the shellbank for the tide to recede.

5 Acknowledgements

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7 Appendices

7.1 Appendix 1. Main census counting areas within the Manukau Harbour

Section name	Access	Description
Huia	Public	Small bays
Onehunga	Public	Main roost on Kiwi Esplanade, also includes the Upper Harbour and fields at Ambury
Puketutu	Public	Main roost on the shellbanks near the bird hide (walking access from Ambury), also includes the crater lake by water treatment plant
Ihumatao	Public	Pasture and ploughed fields past the Stonefields
Airport	Public	Fields around Warehouse and other shops
	Private	Need access permission from Auckland Airport
Puhinui	Public	Main roost on mudflat by MCC reserve, Prices Road, also includes Papakura and Weymouth waterfront
Urquharts	Private	Paddocks inside stopbank and a small shellbank (paddocks can be viewed from road).
Kidds	Private	Shellbank at Karaka and paddocks inside stopbank
Yates Dam	Private	Dam (mostly used by waterfowl).
Kirks	Private	Mudflats and fields
Seagrove	Private	Fields and small foreshore area
Clarks Morley	Private	Main roost site is on foreshore, access through farmland
	Public	Extends through to Clarks Beach, includes shellbank and mudflat
Waiuku	Public	Sandspit by the Yacht Club and local sportsfields
	Private	Gordons Road roost on a small shellbank and fields
Pollok Spit	Private	Opposite Clarks Beach, shellbank and sandspit
Awhitu Peninsula	Public	Bays and beaches

Photo 6 (Keith Woodley) – Important wader roosting site at Miranda shellbank, stilt ponds and Chenier plain.

7.2 Appendix 2. Main census counting areas within the Firth of Thames

Section name	Access	Description
Whakatiwai – Kaiaua	Private	Wharekawa Quarry and gravel pits
	Public	Kaiaua foreshore and nearby paddocks either side of East Coast Road as far south as the bridge just north of the Miranda Naturalists' Trust Centre (i.e. includes all roosts at Kaiaua and Rangipo
Taramaire	Public	Main roost is either side of the Taramaire stream. Birds also includes nearby paddocks on either side of East Coast Road.
Spit & Pools	Public	The ponds across the road from the Miranda Naturalists' Trust Centre, Access Bay and one paddock north of the Centre either side of East Coast Road.
Limeworks	Private[1]	Stilt Ponds, Miranda shellbank and paddocks on either side of East Coast Road.
Karito	Private	Looking south from Miranda shellbank towards mangroves on south side of stream, walk along stopbank to pumpshed to view behind mangroves. Paddocks can be viewed from road.
Waitakaruru	Private	Paddocks and drains (some can be viewed from road).
Piako	Private	Paddocks and drains (some can be viewed from road).
Parawai-Thames:		
Orongo	Private (paper road)	Paddocks and small area of mudflat with mangroves rapidly encroaching
River & shellbank	Private	Fields around the Waihou River bridge. Shellbank accessed behind Gun Club and paddocks around the Thames Airfield.
Thames	Public	Includes Karaka Creek Bird Hide (near Thames Pak n Save), sports fields around Thames, the Thames Dump and Tararu Boat Club and beaches north to and including the pied shag colony at Tararu on north side of Tararu Stream. Doesn't include any sites north of there.

[1] Although this site is privately owned, the public is allowed free access.

Chapter III. Benthic production, environmental constraints and wader foraging in the Firth of Thames Ramsar site

Bill Brownell[+], Jan K. Boyer[*] and Jennifer L. Walsh[*]
[+] Tikapa Kahawai Coastal/Marine Advisory Service, 30 Pukekereru Lane, Kaiaua, RD 3 Pokeno, NZ 2473
[*] EcoQuest Education Foundation, 1204 East Coast Rd., Kaiaua, RD 3 Pokeno, NZ 2473

Summary

The benthic environment of the southern Firth of Thames, particularly the intertidal area designated a wetland of international importance under the Ramsar Convention, has been significantly modified by sedimentation, particularly in the past 40-50 years. Deforestation, mining and burning in the catchment during the 19th and 20th centuries, combined with conversion of the great Hauraki flood plain into intensive agriculture, created a gradual process of sediment runoff from the land and subsequent deposition in the Firth of Thames. This process has accelerated since an emerging mangrove forest began to facilitate the further retention of sediments in the intertidal zone since the late 1950s.

The southern Firth of Thames was historically a productive habitat for a diverse benthic macrofauna dominated by polychaete worms and molluscs. Now, the intertidal zone extending from south of Miranda in the west around to the Waihou River in the east, is characterised by a depauperate benthic macrofauna living in an unfavourable habitat of soft shifting sediments and highly turbid water.

This report focuses on the macrobenthos communities of the southern Firth and summarises what is known about them in terms of species composition and abundance in relation to the structure of the sediments. The feeding habits, diet and possible impacts on preferred prey species of five of the principal species of waders using the Firth (variable oystercatcher *Haematopus unicolor,* pied oystercatcher *Haematopus ostralegus finschi,* wrybill *Anarhynchus frontalis,* red knot *Calidris canutus* and bar-tailed godwit *Limosa lapponica)* are appraised.

Keywords: wading bird, sedimentation, mangroves, benthic, invertebrate, macrofauna, molluscs, polychaetes, crabs, spatial variation, seasonal variation, Ramsar site

1 Intertidal Habitat in the Firth of Thames

The Firth of Thames catchment covers a range of land use types, including agriculture, residential and industrial development, mining, production forestry and conservation. In the Waikato Region (3600 km^2 of which is occupied by the Firth of Thames catchment) 43% of the land is classified as prone to severe erosion (Environment Waikato 2005). Sedimentation and nutrient loading from the land have altered the ecology of the Firth, and this is particularly demonstrated by the increase in mangrove *Avicennia marina* forest coverage in the Ramsar site from about 50 ha in 1963 to over 1200 ha by the end of 2004 (Brownell 2004).

The principal question concerning the sustainable management of the waders and their feeding habitats in and around the Firth of Thames Ramsar site is the degree to which the quantity and the productivity of benthic habitats are being compromised. Veitch & Habraken (1999) note that significant changes had already occurred over the past 50 years. One apparent change, which is not adequately documented, is the loss over time of productive benthic invertebrate habitat along most of the southern margin of the Firth due to encroachment by mangroves. The biggest concern of resource managers today is whether the remaining productive intertidal habitat responsible for sustaining the still strong numbers of visiting waders (concentrated in a stretch of about 12 km between Kaiaua and the Miranda Hot Springs) is being degraded by ongoing environmental stressors, especially sedimentation.

As land use in the catchment intensifies, further increases in sedimentation rates may continue to change the benthic community structure of the Firth of Thames, particularly in the broad, nearly flat intertidal zone that is flanked by a thick cushion of sediment-retaining mangroves. The cumulative effects of stressors from many sources (agricultural land use, urban & industrial land use, point sources, forestry, climate change, etc.) are probably significant, but difficult to calculate in the absence of robust integrated monitoring programmes. The Firth basin also retains a significant legacy of stored sedimentation deposits from the past, which contribute greatly to accretion in the intertidal zone, facilitated by the immense stopbanking system created in the 1st half of the 20th century and by the extensive networks of mangrove roots and pneumatophores that resulted (Swales 2006, Brownell 2004).

Increased sedimentation into an estuarine ecosystem causes a decrease in diversity and reduces the overall ecological heterogeneity, resulting in displacement of benthic species, disruption of predator/prey cycles, decrease in food abundance, and shifts in community structure (Gibbs & Hewitt 2004). Studies of the effects of sedimentation at Roebuck Bay (Australia) demonstrated that key environmental variables, such as silt content and grain size, determine the choice of habitat by benthic communities (Pepping 1997). As increased sedimentation rates alter the sediment composition of the estuary, many resident benthic species will tend to die off and the area will not be recolonised by their larvae. The reduced amount of suitable habitat in neighbouring areas then becomes a limiting factor in terms of overall abundances of the species affected.

Morrison *et al.* (2002) found that most of the ground truthing samples taken in the upper Firth, where sedimentation deposits are currently accumulating at an accelerated rate, yielded little or no live shellfish, but often significant quantities of old shells and fragments. Keeley (in Brownell 2004) reported low levels of abundance and diversity of benthic invertebrates from most sampling sites in the intertidal zone along the southern margin of the Firth. Results of limited field studies such as these lend support to local perceptions of much higher levels of shellfish production in the past, resulting in the shelly beaches of the aerial photos of 1963 and before. Solid evidence exists in the form of many shelly beach remnants still scattered around the Hauraki Plains, and the historic Chenier shell ridges of the Miranda coastal zone.

Immediately to the northwest of the Firth of Thames in the Waitemata (Auckland) Harbour, Hayward *et al.* (1997) documented several major benthic faunal changes compared to the 1930s when Powell (1937) did his classic studies of the intertidal molluscan communities there. Two of the main causes of this were sedimentation and changing land use, particularly as a result of urbanisation. Cummings *et al.* (2003) report that resident benthos adapt much more readily to smothering by 'like' sediment (similar to their habitual substrate) than to 'exotic' sediment (of different grain size and organic matter composition), and that mortality increases following deposition of sediments with high silt-clay content. It is the significant increase in fine grain size, organically rich, terrestrial sediments in recent times that has caused the changes to the distribution and abundance of benthic invertebrates.

The intertidal zone of the southern Firth of Thames consists of mobile mud layers over silty material, often on top of old sand bars and shell beds (Morrison *et al.* 2002). Every tidal cycle and strong wind creates waves and currents that stir up sediments in the intertidal zone and in the basin itself, causing high levels of turbidity and sediment movement, modifying the conditions associated with substrate and filter feeding essential to the success of the benthic invertebrate communities upon which the waders (and many mobile marine species) are so dependent. Essential microbenthic algal production is also restricted by the limited light penetration and the shifting of sediments.

Carter & Gibberd (2003) note that rates of sedimentation in the estuaries of the Coromandel Peninsula prior to human settlement were 0.1-0.2 mm yr^{-1}, while more recent anthropogenic uses of the catchment have resulted in sedimentation rate increases of up to 10 mm yr^{-1}. Sediments are now accumulating on the intertidal flats of the Firth of Thames at a much higher rate (25 mm per year) than in many east coast Auckland estuaries (2–4 mm per year), and this increases to 50–100 mm per year within the mangrove habitat (Swales 2006). The most obvious effect of this is the rapid advancement of mangroves into the intertidal, averaging 20 m per year (Swales 2006).

Annual estimated sediment input in tonnes per km^2 from the combined catchment (total of 4106 km^2) into the Firth of Thames is 56 T km^2 yr^{-1} (Mead & Moores 2004). This is a relatively low rate compared to the national average for estuaries. Some of this gets carried as suspended solids into the open ocean. The amount of sedimentation building up over time in the intertidal zone depends largely on tidal flushing patterns, and, to a lesser degree, on major wind events. In the case of some estuaries like the Firth of Thames, dense bands of fringing mangroves play a significant role in the retention of these sediments, and thus the high rate of deposition currently occurring in the Firth of Thames (especially at the Ramsar site).

Environment Waikato's Regional Estuary Monitoring Programme (Carter & Gibberd 2003; Turner & Carter 2004; Felsing *et al.* 2006) is measuring the composition and accretion rates of sediments and the diversity and abundance of invertebrates at selected locations in the Firth of Thames. Unfortunately only three stations are in the Ramsar site (two within the area of greatest wader feeding activity at Kaiaua-Miranda, and the other near the mouth of the Waihou River). Sediment samples are collected from the invertebrate monitoring plots in order to analyse a number of physical and chemical characteristics (such as grain size, organic matter content and photosynthetic pigment concentration) that are known to influence the distribution and abundance of benthic macrofauna (Turner & Carter 2004).

Gibbs & Hewitt (2004) investigated the effects of suspended solids on adult cockles *Austrovenus stutchburyi* and pipi *Paphies australis*, finding that both were able to feed effectively in an environment of increased suspended sediments for periods of up to one week, while concentrations above 400 mg l^{-1} for a week or more were detrimental to cockles. Hancock & Hewitt (2004) looked at the effects of total particulate matter (TPM) on shell fish, focusing mainly on age and exposure time. They found that responses to TPM are species specific, that juvenile shellfish are more adversely affected than adults of the same species, and that longer exposure limits growth.

The polydorid polychaete *Boccardia syrtis* was adversely affected by sediment rates exceeding 80 mg l^{-1} after 9 days (Gibbs & Hewitt 2004). The wedge shell *Macomona liliana* was adversely affected by sediment levels over 300 mg l^{-1}, most having died after 14 days. Gibbs & Hewitt (2004) also report that as the depth of fine sediments over stable substrate increases, the ability of polychaete worms and shrimps to move through the sediments decreases, with 3 mm of sediment being the general threshold of tolerance for these two groups.

Figure 1.1. Cross section of a typical Firth of Thames mudflat invertebrate community of mainly molluscs and polychaete worms that are the principal prey species of many wader species. (Courtesy of Keith Woodley)

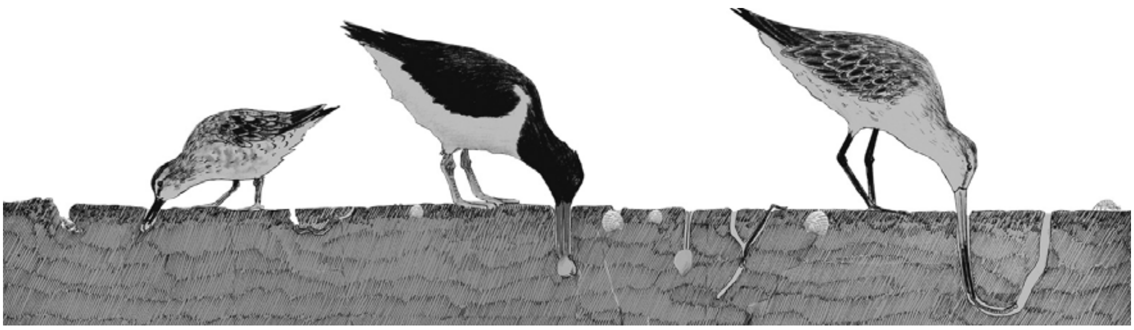


Table 1.1 lists some common Firth of Thames Ramsar site invertebrate species and their tolerance levels for varying percentages of mud in their habitat, and also notes if they are prey preference for sandy substrate, and all except the last five have greater tolerance for sand than mud. Gibbs & Hewitt (2004, p. 35) graphically demonstrate the variety of changes that can be triggered in estuarine soft-sediment communities by the influx of varying concentrations of deposited or suspended terrestrial sediments.

There are also many indirect effects associated with increased rates of sedimentation on intertidal invertebrate communities. Sediments transported by terrestrial runoff are accompanied by varying amounts and compositions of nutrients, which can be of value to intertidal invertebrate communities if in the right forms and concentrations. Nutrient enrichment, particularly from nitrogen and phosphorus, correlates with increased algal blooms, decreasing light penetration and disruption of the productivity of phytoplankton (Broekhuizen *et al.* 2002) that is the cornerstone of the food web involving intertidal invertebrates and their wader predators (Fig. 1.1). Nutrient inputs into estuarine systems increase and decrease seasonally. Seasonal variations of nutrient inputs into estuaries are strongly influenced by heavy rains and long dry spells (Pepping 1997), and this can greatly decrease the growth rates and overall viability of benthic fauna due to shortages of primary food production and extremes of salinity.

Table 1.1. Benthic species that are known to occur in the Firth of Thames Ramsar site in relation to muddy sediment tolerance. Overall preferences refer to: SS = strong sand, S = sand, I = minimal mud OK, M = mud, MM = strong mud. X indicates known prey species for red knot (knot), variable oystercatcher (VOC) and/or pied oystercatcher (POC). After Norkko *et al.* 2001, Gibbs & Hewitt 2004.

Benthic Invertebrates		Shorebird predators			Mud tolerance (%)		
Taxa	Fauna group[1]	Knot	VOC	POC	Optimum range	Maximum range	Preference
Aonides oxycephala	Polych				0-5	0-5	SS
Paphies australis	Bivalve	x	x	x	0-5	0-5	SS
Notoacmea helmsi	Gastrop				0-5	0-10	SS
Cominella glandiformis	Gastrop	x	x	x	5-10	0-10	SS
Anthopleura aureoradiata	Anemon				5-10	0-15	SS
Diloma subrostrata	Gastrop	x	x	x	5-10	0-15	SS
Macomona liliana	Bivalve	x	x	x	0-5	0-40	S
Orbinia papillosa	Polych				5-10	0-40	S
Boccardia syrtis	Polych				10-15	0-50	S
Nucula hartvigiana	Bivalve	x			0-5	0-60	S
Scoloplos cylindrifer	Polych				0-5	0-60	S
Austrovenus stutchburyi	Bivalve	x	x	x	5-10	0-60	S
Arthritica bifurca	Bivalve				55-60	5-70	I
Musculista senhousia	Bivalve				55-60	0-60	I
Heteromastus filiformis	Polych				10-15	0-95	I
Aquilaspio aucklandica	Polych				65-70	0-95	I
Macropthalmus hirtipes	Crab		x	x	45-50	0-95	I
Theora lubrica	Bivalve				45-50	5-65	M
*Nereid**	Polych		x	x	55-60	0-100	M
*Nemertean**	Worm				55-60	0-95	M
*Oligochaete**	Worm		x	x	95-100	0-100	MM
Amphibola crenata	Gastrop			x	95-100	0-100	MM
Helice crassa	Crab		x	x	95-100	40-100	MM

[1]Polych = Polychaete worm, Gastrop = Gastropod, Anemon = Anemone. *Unidentified species.

Another indirect effect from increased sedimentation is longer-term substrate modification that limits the available habitat for estuarine vegetation, especially seagrass Zostera meulleri2, which provides extremely desirable habitat for benthic fauna. The great abundance and diversity (91 taxa) of intertidal invertebrates at a similarly significant wader feeding ground (Farewell Spit) is partly attributable to the extensive coverage of Zostera (Battley et al. 2005). Seagrass is now virtually non-existent in the southern Firth of Thames, due to both a lack of appropriate stable substrate and a surfeit of suspended sediments which block out light and coat the blades of the grass, interrupting photosynthesis.

[2] We use *Z. muelleri* rather than *Z. capricorni* to refer to the intertidal seagrass found in New Zealand. When reclassifying this species, the wrong species name was inadvertently used by Don Les (Battley *et al.* 2005).

Increased sedimentation and nutrients from the land also facilitate the development of mangroves, providing an optimum enriched, and relatively protected, muddy substrate. Along the southern and southwestern margins of the Firth of Thames the progradation of mangroves is progressing at an accelerated rate, with a total coverage of well over 1200 ha (Brownell 2004) and many more hectares of new seedlings all along the leading edge now firmly established (in 2007).

Some recent studies point to a negative correlation between the increase in mangroves and the abundance of benthic invertebrates in the Firth. Alfaro (2006) and Deeney (2003) report that study areas with the highest density of mangroves had the lowest diversity of benthic species. Mangroves, in fact, are merely an indicator of the changing near shore benthic habitat affected by sedimentation, and further facilitated by the extensive system of mangrove roots and pneumatophores. The only macroinvertebrates that really thrive in this environment are mud crabs *Helice crassa* and pulmonate mud snails, or titiko *Amphibola crenata*.

Though many observers suspect that favourable benthic habitat for the principal wader prey species is diminishing due to advancing sediment layering in the southern Firth of Thames, no reliable evidence of this has been presented so far.

2 Overview of the Diets and Foraging of Shorebirds

Shorebirds converge on the Firth of Thames from as far afield as Siberia and Alaska, and demonstrate an immense diversity of behaviour in terms of breeding, roosting, migratory patterns, diurnal movements and the mechanics of food collection and preparation. But all waders that spend significant portions of their lives in the Ramsar site of the Firth of Thames have one particular feature in common: the need and the ability to exploit the abundant marine life ensconced in the "mudflats", only available to them when the tide is out (or in, by a depth of no more than a few centimetres). Figure 2.1 shows the critical connections between the waders, their prey that live in the mudflat communities, and the other species and forces that interact to define large estuarine ecosystems like the Firth of Thames.

The prey species targeted by waders are collectively known by a number of terms:

- benthic, intertidal or marine *invertebrates*
- *macrofauna* or *macrobenthos*
- benthic or mudflat *communities* or *prey species*

The term "macro" is an important qualifier. Every foraging wader has its own criteria for optimum prey size, form, structure and ease of access. Most of the invertebrates (in terms of species and numbers) inhabiting the mudflats are too small or too inaccessible to bother with. Most of the prey consumed by waders in the Firth of Thames are either polychaete worms or bivalve molluscs, and they need to be of a certain size to be of any interest to the predator. Constraints on the diet of different species mean that only a subset of what is present will represent a harvestable food resource (Zwarts & Blomert 1992).

The harvestability of macrobenthos by waders is limited by three main factors (Zwarts & Blomert 1992; Zwarts & Wanink 1994):

- *Accessibility* – whether a given item can be reached by a bird (mainly that it is not too deep in the sediment)
- *Ingestibility* – whether individuals can be swallowed (size, shape, toughness of shell) or their flesh accessed (if shells need to be broken or opened first)
- *Profitability* – whether the energy return from the prey item makes the time spent catching and processing it worthwhile; this depends on the density and the energetic value of the target species

The combination of these factors delimits the *harvestable fraction* of the total benthos; this is often only a small proportion of what is apparently on offer. Specific prey choice by waders depends on the species of bird, the foraging mode employed by the individual, and the characteristics of the prey. If birds are foraging optimally they will feed on the prey that supplies the most energy per foraging effort. This is the net energy intake, the return to the bird after the costs of catching and processing the prey have been accounted for. Specifically, because waders feed in tidal environments, they are forced to spend the high tide periods away from their feeding grounds. They must commute to forage, which introduces a travel cost.

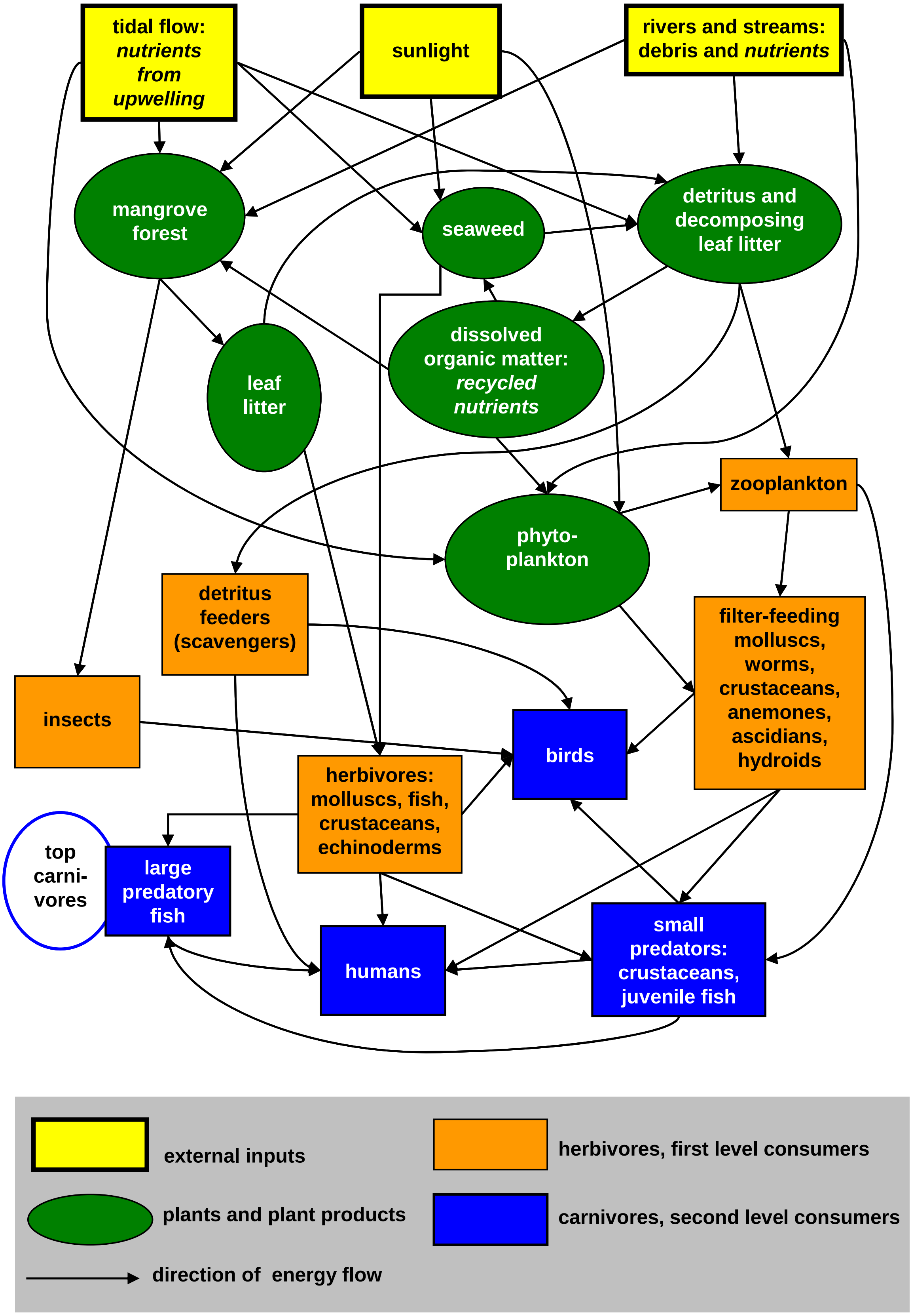
Once at a foraging area a bird must locate prey. This is affected by prey density, depth and behaviour (e.g. whether there are surface indications that a prey item is present in the sediment). The bird may choose to neglect certain prey on offer because they are too small, too large or too skinny to be either ingestible or profitable.

What a bird actually takes is therefore a function of:

- the distribution of the prey on both large and local scales (can a bird reach the patch and still get a benefit; once there does it forage at this point, or another?),
- the prey's life history characteristics (e.g. burying depth, surface activity, absolute size, condition) and, for some birds,
- how many of its conspecifics there are (high bird numbers can mean high interference or food stealing, or changes in the behaviour of the prey making them harder to locate). For some species of shorebird these factors can be measured in the laboratory and field and the strength of the relationship between benthos and birds can be modelled (e.g. van Gils *et al.* 2006).

Waders in general are practiced opportunists within boundaries, selecting the most profitable prey within a subset of the benthos instead of limiting themselves to one prey species. For instance, red knots *Calidris canutus* are known mollusc specialists, only rarely taking prey such as polychaete worms, but strongly selecting certain bivalve species in some conditions but not in others (Zwarts & Blomert 1992; Battley 1996). When the preferred prey of Eurasian oystercatchers *Haematopus o. ostralegus* in the Dutch Wadden Sea (mussels *Mytilus edulis* and cockles *Cerastoderma edule*) declined, birds switched prey to *Macoma balthica* and *Mya arenaria* and were able to retain a constant population although their preferred food supply had become scarce (Beukema 1994). The preferred foods of a wader consistently prove to be those which provide the most energy per unit of foraging effort.

Figure 2.1. Schematic food web for the Firth of Thames intertidal ecosystem.



The tidal flats targeted by foraging waders are commonly composed of at least as much sand as mud (usually more). Their most valuable features in terms of the ability to sustain diverse and dense populations of invertebrates are their habitat qualities and the relative accessibility of food for the inhabitants. Habitat implies structure, which is lacking in silt and mud and shifting fine grains of sand. Most of the Ramsar site seems, in fact, unsuitable for wader foraging due to the "soft" characteristics of the sediments, and failure to offer the ecological servicing typical of "good" mudflats:

- poor habitat (substrate) quality for most of the target food species,
- intense turbidity, making filter-feeding very inefficient or impossible for any resident invertebrates,
- most of the successful residents of this environment, such as the bivalve *Mactra ovata tristis*, are too deep and their shells are too hard for them to be of any use to waders,
- normally effective prey locator senses fail the birds due to the conflicting olfactory messages of the highly organic mud, and very poor visibility,
- no place to stand – even the "lightweight" birds sink too far into the muddy sediments, and have no "pulling power" even if they do find suitable prey.

At Farewell Spit, where 91 species of benthic macrofauna were collected, grid sampling of the 9900 hectare intertidal flats to the south of the Spit revealed that they are true sand flats with a significant seagrass component and virtually no traces of truly fine sediment (Battley *et al.* 2005; Ballance *et al.* 2006). At the Firth of Thames Ramsar site Keeley found only 23 species of benthic macrofauna (sampling in substrates that were primarily composed of mud) and Maddison and Keeley (sampling in a more sandy area targeted by foraging birds) found 29 species (in Brownell 2004). [Note that as the Farewell Spit study had far more sample sites and core samples than the Firth of Thames studies, the difference in diversity may not be as great as these figures suggest.] The site sampled by Maddison and Keeley is close to the Miranda site reported in Turner & Carter (2004) and Carter & Gibberd (2003), which is variable in sediment makeup over time but predominantly consists of fine and very fine sand with 10-30% medium to coarse sand.

The Kaiaua sampling site was "consistently the muddiest site" (Turner & Carter 2004), though it must be noted that there are no sampling stations in the entire intertidal zone between the northern side of the Miranda Stream mouth and the eastern side of the Wairoa River mouth (see Chapter 1, Figure 1). It is also rockier around Kaiaua than further south in the Firth. These, together with the narrowness of the intertidal band, may explain why there is normally only minimal wader feeding activity north of Kaiaua. There is seemingly only patchy wader feeding activity (mainly close to the low tide mark) along the whole southern margin of the Firth from the Karito Canal (4 km north of Waitakaruru) to the mouth of the Waihou River.

Worms, crabs, burrowing shrimps, shellfish, anemones and other substrate dwellers need to be able to settle into a relatively stable environment that is not going to be swept away or collapse upon them. The best habitats therefore have little wave action, and preferably have some living vegetative matter (seagrass or algal films) and some coarse-grained sand held together by some silt/mud (just enough to make it relatively stable). Additionally, they will have good access to generous supplies of phytoplankton and zooplankton for the filter feeders, patches and snippets of encrusting algae for the grazers, and ample amounts of detritus floating by for the scavengers (Figure 2.1).

The mudflats southeast of Miranda, mainly from mid-tide to the low-tide margin for an indeterminate distance, seem to be of the highest 'quality' in terms of relative amount of foraging effort observed. The "high quality" areas generally support an abundance of bivalves, gastropods, crustaceans, polychaete, oligochaete, and nemertean worms, echinoderms, and cnidarians. It is important to note, however, that the "mud rule" does not always hold true. Bar-tailed godwits *Limosa lapponica* (particularly the long-billed females) are adept in mud that supports polychaetes, as are wrybills. Birds will adapt to muddier conditions than normal as long as they still can efficiently capture prey and those prey are present in harvestable quantities.

This study gives general consideration to the 18 wader species treated in Section II, and focuses particularly on the feeding behaviours of five of the most common waders found around the shores of the Firth of Thames. The bar-tailed godwit and red knot are Arctic migrants that spend October through March in the Firth. The wrybill *Anarhynchus frontalis* and pied oystercatcher *H. ostralegus finschi* are domestic migrants which arrive in March and remain in the Firth over the winter. The variable oystercatcher *H. unicolor* is a resident species which is present in the Firth year-round. Immatures of all the migrants are present year-round.

Bar-tailed godwit catching a worm. (Drawing by Keith Woodley)

2.1 Feeding mechanisms

Most benthic organisms burrow into the substrate for various reasons, but particularly to escape detection. Most birds are visual predators, but waders are often tactile predators as well, locating prey out of sight beneath the mud. Red knots have Herbst corpuscles - special structures at the tip of their bill which allow them to sense pressure changes in wet sediments and to detect buried bivalves (Piersma *et al.* 1998). Waders that lack these corpuscles can still search for buried prey by probing and sweeping the sediment with their long bills.

Once a wader has found prey, it must be able to capture, swallow, and digest it. Larger waders such as godwits and oystercatchers use their long bills to extract prey from deep in the mud. Because many invertebrates require access to the sediment surface or water column for respiration, feeding or excretion, some potential prey become available only for short periods. Lugworms *Abarenicola affinis* excrete processed sediment on the surface – at that moment they are vulnerable to predation by oystercatchers and godwits. Buried bivalves can suffer siphon-nipping when extending their siphons up to feed in the water column or on the surface (Zwarts 1986; de Goeij *et al.* 2001). Other bivalves live near the surface but are too thick-shelled to be opened (such as the cockle *Austrovenus stutchburyi*). They are not invulnerable to bird predation however: oystercatchers can open cockles that are gaping, and knots can crush small individuals in their gizzard. Because waders must be able to penetrate a shell or swallow prey whole, the largest organisms present are not necessarily the ones that get eaten.

Waders do not eat every organism they can – they select the ones that return the most energy per unit of time spent foraging, so that they can achieve optimal benefit. Seeking a happy medium is generally the rule: very small benthic fauna are not profitable because they contain little meat in proportion to the energy spent in seeking and capturing them, and likewise very large ones are often ruled out because it takes too much time and energy to eat them.

Photo 7
(Brian Chudleigh):
Pied oystercatcher intensely occupied with the cockle harvest.

2.2 Benthic macrofauna – food for waders (among others)

The abundance and diversity of benthic fauna are influenced by both environmental and anthropogenic factors. Benthic communities on tidal flats are prone to considerable spatial and temporal variations between sites, as well as from season to season, or year to year, at the same sites (Zwarts *et al.* 1992). Table 2.1 demonstrates the differences in relative abundances of the dominant invertebrate species at three anchor points at opposite ends of the Ramsar site based on sampling conducted by Environment Waikato (Turner & Carter 2004; Felsing *et al.* 2006).

Spatial variation occurs naturally as a result of variance in substrate, exposure to tides and wave action, salinity, temperature and the dispersal ability of benthic species.

Additional changes can result from invasive species such as the introduced Asian date mussel *Musculista senhousia* and the tube worm *Chaetopterus sp.*, which effectively smothers other benthic fauna.

It is notable that the polychaete *Aonides oxycephala* was the dominant species in all of twelve quarterly samples from relatively sandy substrates at Miranda and four of six half-yearly samples at the Waihou mouth. Funnell *et al.* (2003) note that *Aonides oxycephala*, also a key sandy mudflat species in the Manukau Harbour, showed decreasing abundance (prior to February 2003) at several sites in the ARC-NIWA Manukau monitoring programme, suggesting that this sandy substrate-loving species could be declining due to a greater amount of fine sediments either in the water or on the sediment (substrate) surface.

Temperature differences and bird and fish predation are important factors influencing seasonal availability of benthic organisms. Flounder and eels are known plunderers of long soft animals like various polychaete species, glass eels and burrowing shrimps that share the unfortunate habits of sticking their heads up out of their holes at the wrong times. Schooling juvenile fishes, such as snapper and jack mackerel, are capable of having a quick and devastating effect on invertebrate populations when they sweep through a benthic community.

Table 2.1. The five most common species/taxonomic groups in descending order of importance on each sampling date for the three permanent monitoring stations in the Firth of Thames Ramsar site (April 2001 – April 2004).

Sampling date	Kaiaua (KA)	Miranda (MI)	Waihou (GC)
APRIL 2001	*Theora* *Nucula* *Aricidea* Nereididae *Austrovenus*	*Aonides* *Austrovenus* *Macomona* *Anthopleura* *Arthritica*	*Aonides* *Paphies* polychaetes *Austrovenus* Isopoda
JULY 2001		*Aonides* *Macomona* *Austrovenus* Nereididae *Capitellidae*	
OCTOBER 2001	*Nucula* Capitellidae Phoxocephalidae *Theora* shrimps/Mysids	*Aonides* *Macomona* *Austrovenus* *Notoacmea* Nereididae	*Aonides* *Paphies* *Austrovenus* polychaetes shrimps/Mysids
JANUARY 2002		*Aonides* *Paracorophium* *Macomona* amphipods *Austrovenus*	
APRIL 2002	*Austrovenus* *Nucula* bivalves *Magelona* *Capitellidae*	*Aonides* *Austrovenus* *Macomona* Nereididae bivalves	bivalves *Aonides* isopods Nereididae polychaetes
OCTOBER 2002	*Nucula* Capitellidae *Austrovenus* *Magelona* *Arthritica*	*Aonides* Capitellidae other polychaetes Nereididae Corophiidae	*Aonides* other polychaetes other bivalves Nemerteans Nereididae
JANUARY 2003		*Aonides* shrimps/Mysids *Macomona* other polychaetes Nereididae	
APRIL 2003	*Nucula* *Austrovenus* Capitellidae *Macomona* *Magelona*	*Aonides* *Austrovenus* Nereididae *Corophiidae* *Macomona*	*Aonides* *Austrovenus* other polychaetes *Macomona* Isopods
JULY 2003		*Aonides* *Orbinia* *Macomona* *Austrovenus* Corophiidae	
OCTOBER 2003	*Nucula* Capitellidae *Magelona* Nereididae *Austrovenus*	*Aonides* *Orbinia* *Macomona* *Austrovenus* Capitellidae	*Aonides* *Macomona* *Paphies* other bivalves other polychaetes
JANUARY 2004		*Aonides* *Macomona* other bivalves *Austrovenus* Corophiidae	
APRIL 2004	*Nucula* *Austrovenus* *Macomona* Shrimps/Mysids other bivalves	*Aonides* other crustaceans *Austrovenus* *Macomona* other bivalves	*Paphies* other polychaetes *Aonides* other amphipods *Colurostylis*

In some cases, migrant bird predation depletes benthic populations seasonally (O'Connor and Brown 1977; Marsh 1986; Zwarts & Blomert 1992), and this is an issue that needs to be further investigated in the Ramsar site, as the summer numbers of foraging waders are typically quite densely distributed over the remaining desirable feeding grounds at low tide.

A study in the Manukau Harbour detected a small influence of bird predation on the populations of intertidal invertebrates over varying time scales (Thrush *et al.* 1994).

Some questions arise in the context of the Firth of Thames and its intertidal community. Firstly, how tightly linked are the populations of birds in the Firth of Thames to the benthic food resources? Second, how well will the invertebrate primary consumers (this critical second-level echelon of the food web) fare in the long run, in the face of diminishing habitat and continued strong predation pressure by birds, fishes and humans? Third, what are the potential impacts of human-induced resource use activities in future, such as the expansion of marine farming and its possible direct effects on bottom communities, as well as depletion of the phytoplankton food source?

"The key issue is not whether these far field effects occur, but rather how quickly (in time and space) they are dissipated" (Broekhuizen *et al.* 2002). Monitoring studies of Stage I at Wilson Bay (about 200 hectares of a projected 1200 hectare mussel farming area across the Firth of Thames from the Ramsar site) have identified some near-farm effects regarding benthic communities and plankton drawdown (Zeldis *et al.* 2005). But available information (Elmetri *et al.* 2005, Elmetri & Felsing 2007, Gibbs 2005, Zeldis *et al*. 2005) suggests that these effects are unlikely to influence invertebrate populations targeted by waders in the Ramsar site. However, the potential for cumulative effects of marine farming in the Firth (when combined with all other sources of risk to the Ramsar site) remains uncertain, particularly as the projected expansion progresses.

3 Feeding ecology of five shorebird species

Mudflats are often occupied by thousands of birds of several species, but waders that coexist tend to partition the food on a mudflat. Each species is efficient at preying upon certain invertebrates at certain depths. Extensive information is available on the diets of red knot and bar-tailed godwit because they are found around the globe, and a significant amount of research has been achieved outside of New Zealand. Pied oystercatchers are found only in New Zealand and Australia, and variable oystercatchers are endemic to New Zealand, but both are extremely closely related to the Eurasian oystercatcher that has been extensively studied in Europe. Relevant information is briefly summarised by species below and key dietary items tabulated in Appendices 1-5.

3.1 Red knot

Red knots are renowned mollusc specialists, feeding on small bivalves that are swallowed whole (the upper limit is set by the circumference of the shell – maximum 30 mm; Zwarts &

Blomert 1992). The shells are crushed in the knot's thick, muscular stomachs (accordingly they have the heaviest gizzard for their body mass of any shorebird: Battley & Piersma 2005). They locate bivalves using pressure sensors in their bill tips, while gastropods are found by sight (Piersma *et al.* 1998). Knots have shorter bills than many waders, and so can only feed on benthic invertebrates in the upper 3 cm of substrate (Zwarts & Blomert 1992). Based on local faecal analysis Battley *et al.* (2005) identified the relevant prey items for knots on Farewell Spit to be *Paphies australis* ≤ 16 mm, *Austrovenus stutchburyi* ≤14 mm, all sizes of *Nucula hartvigiana* (which did not exceed 9 mm in length), all gastropods ≤ 5mm and all amphipods and isopods.

No detailed and long-term studies of the diet of knots in the Firth of Thames have been undertaken. Piersma (1991) confirmed during a short visit in 1990 that knots fed on molluscs. Shell mass in faeces comprised 90% *Myadora boltini*, 5% *N. hartvigiana*, and 5% *Macomona liliana*. In 1992 no *Myadora boltini* were present at the same site and the diet comprised 98% *Nucula hartvigiana* and 2% *Austrovenus stutchburyi* (P.F. Battley in Higgins and Davies 1993). Anderson (2003) observed that *Austrovenus stutchburyi*, *Nucula hartvigiana* and *Myadora boltini* composed the majority of the diet of red knots at Miranda. Thus, even in a limited pool of options, the dominant shellfish present and taken seems to vary considerably between years.

3.2 Bar-tailed godwit

Bar-tailed Godwits have the longest bills of the five waders examined here. These bills allow them to reach deep into the mud and obtain prey out of the reach of knots or oystercatchers. Female godwits have longer bills than males – 69-97 mm for males, 97-129 mm for females (P.F. Battley, unpubl. data) – which allows for resource partitioning within the species. On firmer substrates including the rocky tidal flats near Kaiaua, foraging birds are almost exclusively male (P.F. Battley, unpubl. data). In soft mud such as off the Miranda shellbanks it is almost invariably females that feed deeply (up to the bases of their bills) on the outgoing or incoming tides. While godwits feed predominantly on (large) polychaetes in many places (Piersma 1982; Battley 1996; Scheiffarth 2001) they are also capable of feeding on hard-shelled prey such as crabs and bivalves (Battley 1996; Scheiffarth 2001; Zharikov & Skilleter 2002, 2003). On Farewell Spit, Battley *et al.* (2005) calculated that the relevant portion of the invertebrate community for godwits was *Paphies australis* and *Macomona liliana* (≤ 15 mm), *Austrovenus stutchburyi*, the small black mussel *Xenostrobus pulex* (≤10 mm), *Nucula hartvigiana* (all sizes), all polychaetes ≥10 mm and all crabs.

Faecal analysis is not as reliable for godwits as for knots because soft-bodied prey may leave few or no remains to identify (but see Scheiffarth 2001). Visual observations can be successful in some situations, but their long bill enables godwits to swallow many prey items before their bill is extracted from the sediment. In these events, only a swallowing motion may be observed (Anderson 2003). In the Firth of Thames the polychaete worms *Aonides oxycephala*, *Nicon aestuariensis*, and *Orbinia papillosa* are strong candidates as godwit prey, as are crabs and small *Nucula* and *Austrovenus*. Male godwits have been seen feeding on small mussels (probably *Xenostrobus pulex*) near Kaiaua, prising the shellfish off rocks (P.F. Battley, unpubl. data).

3.3 Pied oystercatcher

Pied oystercatchers have been recorded feeding on a wide range of prey items (Baker 1974) but their preferred foods are larger bivalves and polychaete worms. Individual specialisation is well known in the Eurasian oystercatcher (from which the New Zealand pied oystercatcher is sometimes given specific status) (Durell *et al.* 1993) and probably occurs in New Zealand. Battley (1996) found that foraging oystercatchers on Farewell Spit almost never took an alternative prey type while foraging, but because birds were not individually marked he could not tell if this specialisation was long-term (over days, weeks or months) or short-term (within a single bout only).

Pied oystercatchers forage in wet tidal flats (near the tide edge or in shallow pools) where they search visually for partly open cockles or signs of polychaetes. They insert their bills into the gap between shellfish valves, sever the adductor muscles, and extract the meat. If the bivalve is closed, the oystercatcher may use its thick bill to hammer a hole in the shell (Baker 1974), though this method may not be used in all places. Whether sexual differences in bill morphology give rise to different dietary specialisation in New Zealand oystercatchers as they do in European ones (Durell *et al.* 1993) is unknown. Battley *et al.* (2005) treated the potential diet for pied oystercatchers on Farewell Spit as including *Paphies australis*, *Austrovenus stutchburyi* and *Macomona liliana* (all ≥ 15 mm), *Xenostrobus pulex* (≥10 mm), all polychaetes ≥ 20 mm, all *Anthopleura aureoradiata* (all of which are found in the Firth of Thames), plus all Holothuroidea and all *Edwardsia tricolor*.

Pied oystercatchers have been reported eating more benthic taxa than other species of wader (Baker 1974), although this could be due to their generally large, easily identifiable prey, and the fact that they often bring shellfish to the shore and break the shells within easy view of the observer. At Farewell Spit, oystercatchers concentrate on areas of sandflat that support the greatest densities of shellfish (particularly *Austrovenus stutchburyi*) and polychaetes (Battley *et al.* 2005). They also feed on mussels, which are taken mainly in the 16-22 mm size range (Battley 1996). They are often observed feeding on mussels that wash ashore after storms along the mainly rocky coast north of Kaiaua.

Modelling studies (Complex systems, Bayesian network) suggest the possibility that the recent increase in pied oystercatcher numbers, accompanied by minor changes to their foraging behaviour, could be putting some of the smaller migrants at a competitive disadvantage in terms of foraging success, especially in light of significant benthic habitat loss due to sedimentation (Gibbs 2005).

3.4 Variable oystercatcher

The diet and feeding behaviour of variable oystercatchers is very similar to that of pied oystercatchers. Variable oystercatchers are slightly larger, with a tougher bill, which allows them to eat larger bivalves, chitons and limpets (Baker 1974). Variable oystercatchers are most commonly found on rocky, exposed coasts searching for thick-shelled molluscs, rather than in estuaries, but they are also present on the sandy beaches, shellbanks and muddy shores of the southern Firth of Thames.

Variable oystercatchers have been observed eating most of the same benthic fauna as pied oystercatchers (Baker 1974). They often forage together with their pied cousins, particularly when mussels and scallops wash ashore on the Kaiaua coast after storms.

3.5 Wrybill

The Wrybill is endemic to New Zealand and has not been as extensively studied as its more worldly shorebird relatives. Its diet on the breeding grounds (South Island braided riverbeds) has been well described (Pierce 1979; Hughey 1997) but their diet on the non-breeding grounds is poorly described. Their feeding method is distinctive: they scoop their laterally curved bill through soft mud with a twist of the head (Turbott 1970), using it much as an avocet (*Recurvirostra* spp.) scythes its long upcurved bill through water. They can often be seen extracting small polychaete worms from this liquid mud, and the ability to use their bill in this fashion gives them a much larger 'touch area' than a pecking or probing bird would have. It is almost certain that polychaetes form the large majority of the diet of wrybills, though they have also been observed eating small bivalves (Anderson 2003). Wrybill are likely to feed on the common worms of the upper stratum of the Firth's mudflats such as *Aonides oxycephala*, *Nicon aestuariensis* and *Orbinia papillosa*. Many times, however, birds also peck the mud in a way that would seem quite unsuited for catching polychaetes. One possibility is that birds are testing the sediment for penetrability; another is that birds supplement their polychaete diet with biofilm, which has recently been suggested is a food source of small sandpipers (Elner *et al.* 2004).

Wrybill foraging is closely tied to the presence of very wet sediment: they are readily observed feeding adjacent to the beach at Taramaire, and in soft mud pools immediately offshore and at the mouth of Pukorokoro Creek at Miranda. Their feeding success is higher in the wet sediment close to shore than further out (Anderson 2003). In Auckland, wrybills sometimes shift from the Manukau Harbour to the Tamaki Estuary to feed in the soft mud on the outgoing tide (A.C. Riegen, Miranda Naturalists' Trust, pers. comm.).

The Firth of Thames has historically been the top site in New Zealand for non-breeding wrybills, but there seems to have been a gradual shift to the Manukau Harbour (Section II). The reasons for this are unknown. Given the dependence of the species on just two harbours, an analysis of the interactions between sediments, invertebrates and wrybill diet would be an important step towards understanding why this species is so limited in its non-breeding distribution.

3.6 Summary of potential prey for shorebirds in the Firth of Thames

As noted in the accounts above, specific information on the feeding ecology of waders in New Zealand is very limited. Most of the existing literature on foraging behaviour of wader species and their food preferences is based on research that has been carried out in the United Kingdom, the Netherlands and North America. There is also little information on what invertebrates are present in the Firth of Thames. Five studies, all with limited coverage, provide an overview of the benthic invertebrate species present, with some indications of their distribution and abundance (Blickstein 2001; Keeley 2004; Keeley & Maddison 2004; Turner & Carter 2004; Felsing *et al.* 2006). In Table 3.1 the predicted or observed diets from the previous section are combined with the known invertebrate species from the Firth of Thames to summarise the likely common species of benthos and their use as food sources by shorebirds.

Table 3.1. Common benthic macrofauna in the Firth of Thames and their probable relevance as prey to four species of wading bird (red knot [RK], bar-tailed godwit [BTG], pied oystercatcher [POC] and variable oystercatcher [VOC]). Indications of diet are listed on the basis of studies in the Firth of Thames and elsewhere, including known feeding on the same genus or genus group as is present in the Firth.

Phylum	Class	Family	Species	Common name	RK	BTG	POC	VOC	ref
Mollusca	Bivalvia	Carditidae	*Venericardia purpurata*				x		1,4
		Erycimidae	*Arthritica bifurca*						8
		Mactridae	*Mactra tristis australis*	trough shell					5
			Mactra ordinaria						5
		Mesodesmatidae	*Paphies australis*	pipi	x	x	x	x	1,2,3,9
		Myochamidae	*Myadora boltoni*		x				7
		Mytilidae	*Musculista senhousia*	Asian date mussel				x	5
		Ostreidae	*Saccostrea glomerata*						5
		Nuculida	*Nucula hartvigiana*	nut shell	x	x			1,2,5
		Semelidae	*Theora lubrica*	(introduced)					9
		Tellinidae	*Macomona lilliana*	wedge shell	x	x	x	x	1,3,5,7
		Veneridae	*Austrovenus stutchburyi*	cockle	x	x	x	x	1,2,5
	Gastropoda	Trochidae	*Diloma subrostrata*	mudflat top shell					7,9
Arthropoda	Decapoda	Grapsidae	*Helice crassa*	tunneling mud crab		x	x	x	3,5
		Pinotheridae	*Macrophthalmus hirtipes*	stalk-eyed mud crab		x			3,5
Annelida	Polychaeta	Capitellidae	*Heteromastus filiformis*						9
		Glyceridae	*Glycera lamellipodia*			x		x	6
		Magelonidae	*Magelona papillicornis*						4
		Nereididae	*Nicon aestuarensis*			x	x	x	4
			Perenereis natia vallata	ragworm		x	x	x	5,8
			Perenereis	ragworm		x	x	x	5,8
		Orbiniidae	*Orbinia papillosa*			x			4
			Scoloplos cyilindrifer			x			8,9
		Spionidae	*Aonides oxycephala*						9
			Aquilaspio aucklandica						9

[1]Baker 1974, [2]Battley 1996, [3]Battley *et al.* 2005, [4]Blickstein 2001, [5]Keeley 2004, [6]Keeley & Maddison 2004, [7]Piersma 1991, [8]Scheiffarth 2001, [9]Turner & Carter 2004

4 Seasonal and long term benthic population trends

Another important issue is the temporal variation in abundance and diversity of benthic fauna. Seasonal benthic fauna depletion could be particularly significant for the wader populations in the Firth of Thames, because unlike most of the stopover sites commonly studied in Europe, the Firth supports large populations of waders year-round. As benthic communities in the Firth are constantly subject to bird predation (not to mention the effects of several robust populations of bottom feeding fish species), they may not have the beneficial recovery time (from the predation pressures and habitat disturbance) characteristic of more distinctly seasonal sites, unless the winter and summer wader species effectively partition resources between them.

Intense bird predation is one cause of seasonal change in abundance and diversity of benthic fauna. O'Conner and Brown (1977) showed that oystercatchers in Irish estuaries fed on cockles in one location until the stocks were depleted, then moved to a new site, targeting the same species and gradually depleting them at the new site as well. Kalejta (1993) reports that bird predation does not necessarily have an effect on worm populations, because worms reproduce rapidly and throughout the year.

Bird predation pressure has the potential to affect benthic communities in the Firth of Thames, although the scale of this impact is unknown. In a popular red knot feeding area near Miranda, bivalve populations declined throughout a summer until they were so low the knots abandoned the site (G. Vaughan, Miranda Naturalists' Trust, unpublished data). It remains to be seen whether such seasonal depletion occurs throughout the entire Ramsar site, or only in small patches. The large differences in knot diet between years (section 3.1) indicate that substantial changes in the benthic shellfish fauna occur over time. The gradual shift by knots to the Manukau Harbour in winter (Section II) also suggests that seasonal prey depletion may be occurring.

Only two small studies in the Firth of Thames have monitored benthic fauna over time. The EcoQuest Miranda site was sampled in March, June, and September 2001 (Maddison & Keeley, in Brownell 2004). The worm *Orbinia papillosa* was most common in March, while *Nicon aestuariensis* dominated in June. The worms *Glycera lamellipodia* and *Magelona papillicornis* and the cockle (*Austrovenus stutchburyi*) were most abundant in September. Other organisms, such as the wedge shell *Macomona liliana* showed little seasonal variation in abundance. This study lasted only one year, not long enough to identify any trends.

Environment Waikato has monitored benthic fauna at five sites in the southern Firth of Thames since 2001 (results from three sites are reported in Table 1.2). The first four years of data (12 quarterly samples at two sites and seven biannual samples at three sites) have been published (Turner & Carter 2004; Felsing *et al.* 2006). This study focused on different indicator species, and employed different sampling techniques from the EcoQuest study, so only limited comparisons can be made between them. *Macomona liliana* again showed little seasonal variation, but *Austrovenus stutchburyi* was more abundant in April than in September. Other species surveyed showed some seasonal variations, but results are inconclusive thus far. This project is continuing, and an analysis of the data from July 2004 to the present could point to some significant seasonal variations and longer-term trends.

Two other short term surveys of benthic fauna in the Firth were undertaken in 2000-2001 (Blickstein 2001; Keeley in Brownell 2004). Unfortunately, differences in sample sites, types of corers and hand-held dredges used, and tide height at the time of sampling make it impossible to compare these with other studies.

Changes in density are not the only seasonal changes. Changes in body condition (flesh mass per unit length or shell mass) can be substantial through a year and affect the energetics of foraging. Measuring such differences requires a time series of probably two years or more. For example, Battley (1996) measured cockle condition on Farewell Spit over 12 months, and found condition was approximately twice as high at the end as at the beginning. It was therefore unclear what seasonal pattern existed as the data apparently incorporated annual changes as well.

Finally, reproduction and growth of invertebrates (particularly hard-bodied shellfish) over time affects the harvestable prey population. In cold-temperate zones reproduction may be periodic and dependent on (for example) a cold winter that reduces densities of predators of spat. In long-lived shellfish it may be possible to track the entire life of cohorts of clams and measure the effect of predation on them (Zwarts & Wanink 1993). There may be periods when there just simply has not been any reproduction to 'set the ball rolling' again.

There may also be size-related 'windows of predation' for invertebrates. A shellfish <15 mm in length will be vulnerable to predation by knots but once it exceeds this size it is safe forever from them. Unfortunately, if it continues to grow it will enter the predation window for the oystercatcher. In this way knots are indirectly in competition with oystercatchers (see Zwarts & Wanink 1984 for a scaled-up version in which oystercatchers are the junior partner to curlews *Numenius arquata* preying on *Mya arenaria*). Whether predation by knots results in any discernable change to an oystercatcher's food supply a year or more later is unknown. Equally so, we have no idea whether the vast increase in oystercatcher numbers over the past half century (see Section II) has affected the population dynamics of their prey.

5 Conclusions

The Firth of Thames is a fundamentally different ecosystem to what it was when the huge forests of the Hauraki Plains were intact and muddy sediment inputs to the Firth were minimal (and tending to pass through, rather than settle). The Firth was apparently far clearer and sandier than it currently is, and would have had a benthic fauna community substantially different from what is present today. In general, increased sedimentation leads to a reduction in diversity of the benthic fauna, as few species are able to cope with the unstable sediments that lack structure. Most of the invertebrate species known from the Firth prefer sandy sediments to muddy ones, and probably have greatly altered distributions and abundances from when the Firth was less silty.

The greatest area of sedimentation is along the southern shores of the Firth; this is also the least accessible and least studied part of the Firth. The indications are that sediments are very loose along these shores and are fairly barren in terms of benthic fauna. They may therefore be rather poor foraging habitat for the shorebirds for which the Firth is internationally famous. There are some small remaining sand-silt banks that sustain remnant populations of cockles (*Austrovenus stutchburyi)* but the banks tend to shift in response to winds and currents, with varying degrees of mortalities of benthic invertebrates in the process. There are no known observations of wader feeding in such patches.

While much is known from other locations of the diets of some of the shorebirds that occur in the Firth of Thames, little information is directly available from the Firth itself. Of the common shorebird species in the Firth, two feed predominantly on polychaetes (bar-tailed godwit and wrybill), one on molluscs (red knot) and one probably on a combination of the two (pied oystercatcher). The impact of changes to the intertidal zone will vary for different species of bird according to how their specific prey items are affected. Wrybills favour soft wet muddy sediment for foraging, and it is possible that siltation in the Firth has improved habitat quality in some areas for this species.

When assessing the food resources for shorebirds, simple numerical cataloguing of abundances provides insufficient indication of the effective food supply for the various shorebirds. This is because the relative utility of an item is a function of its accessibility (or harvestability by species), ingestibility and profitability. These factors can change with growth of the organism: it may be too large to be ingestible at some point; it may bury deeper in the sediment when it is older and larger and thus become inaccessible; it may become more profitable, energy-wise, as it gets larger. Relative utility of a food supply is also dependant on seasonal changes (in abundance, depth and/or flesh content) as well as annual differences in condition and size frequencies. There is currently a very poor knowledge of the habitat use, diet and energy intake of shorebirds in the Firth of Thames and how variable these are with seasonal, annual and long-term changes in invertebrate populations.

6 Recommendations

- An integrated restoration plan should be developed for the Coastal Marine Area of the Firth of Thames, with waders being the principal focus (covering in particular: feeding habitat, roosting habitat, weed encroachment and human disturbance). This should not only include the Ramsar site, but also the Thames Coast from Kopu north to Waiomu and the Wharekawa Coast from Kaiaua north to Matingarahi. This would be most effective if it could be carried out in an integrated manner by the five district councils, two regional councils, Ministry of Fisheries and two DoC conservancies concerned, similar to the Muddy Feet (Phase II) Project (Brownell 2007).
- The roosting and foraging sites of waders and other coastal dwelling birds in the Firth of Thames should be seriously considered for special protection under the Marine Protected Areas Policy Review of the Department of Conservation, Auckland and Waikato Conservancies (involving all principal stakeholders under an integrated approach that is fundamental to the Hauraki Gulf Marine Park Act). The CMA of Miranda has been identified as one of the marine conservation areas of greatest value in the Waikato Region (Lundquist *et al.* 2004).
- Instigate a comprehensive wader foraging and roosting research programme, to capitalize on the wealth of information that has been compiled through more than 45 years of research on the population ecology of the Firth of Thames waders. It should determine the degree to which shorebirds are influenced (and possibly threatened) by significant changes that are occurring in their environment:

    a. Chart the distribution of feeding waders (by species) in summer and winter around the southern and western tidal flats in the Firth of Thames. This could entail surveys by plane, boat and kayak depending on tidal stage and accessibility.
    b. Determine the species compositions, abundances and size-distributions of benthic invertebrates in areas identified as important shorebird foraging habitats.
    c. Determine the subset of the benthic community that is actually being utilised by the main shorebird species and evaluate the constraints on shorebird foraging. Assess the impact of shorebird foraging on the population biology of their principal prey species. Determine, where possible, the degree of competition from fish for the target prey species.
    d. Identify the sites adjacent to the intertidal zone that are used as high tide roosts by coastal birds and appraise the threats to them (which may include disturbance, predation, competition, habitat change, weed infestations and sea level rise).

- There is a need for strong reinforcement of the initiatives undertaken to date by the Miranda Naturalists' Trust and the Department of Conservation in the areas of public education, outdoor recreation and overall conservation awareness regarding the ecology of the waders and their Firth of Thames habitats. This requires more access points (including one or more boardwalks through the mangroves), better car and bus parking, more outdoor interpretive signage, more hides for observation, and more interactive educational materials to be applied in classrooms, visitor centres and presentations to interest groups. Along with this, there needs to be a people management plan so that disturbances from steadily increasing human movements are kept to an absolute minimum.

Photo 8 (Geoff Moon) – Mixed assemblage of waders roosting in the principal stilt pond near the Miranda (Pukorokoro) Stream in the mid-1980s before the fringing mangroves started to become dominant.

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8 Appendices – Targeted benthic prey species of five waders

8.1 Appendix 1. Diet of red knot in New Zealand

Phylum	Class	Family	Species	Common name	Firth	Source
Mollusca	Bivalvia	Myachamidae	*Myadora boltini*		x	1
		Nuculidae	*Nucula hartvigiana*	nut shell	x	1
		Tellinidae	*Macomona liliana*	large wedge shell	x	1
		Veneridae	*Austrovenus stutchburyi*	cockle	x	2
		Mesodesmatidae	*Paphies australis*	pipi	x	2
	Gastropoda	Batillariidae	*Zeacumantus sp.*			2
		Buccinidae	*Cominella sp.*			2
		Eatoniellidae	*Eatoniella c.f. lambata*			2
		Trochidae	*Diloma subrostrata*	mudflat top shell	x	1
			Micrelenchus tenebrosus	top shell		1
Arthropoda	Amphipoda	Corophiidae	*Paracorophium*	sandhopper	#	2
	Decapoda	Crangonidae		shrimp	#	2
	Isopoda			sea slater	#	2
Annelida	Polychaeta	Arenicolidae	*Abarenicola assimilis*	lugworm		2
Chordata	Osteichthyes	Pleuronectidae	*Rhombosolea plebeia*	sand flounder	x	2
				small fish	*	2

* = class of prey found in Firth, x = exact species of prey found in Firth, # = genus or family of prey found in Firth
Sources: 1 = Piersma (1991), 2 = Battley (1996)

8.2 Appendix 2. Diet of bar-tailed godwit in New Zealand

Phylum	Class	Family	Species	Common name	Firth	Source
Mollusca	Bivalvia	Mytilidae	*Xenostrobus pulex*	small black mussel	x	2
		Nuculidae	*Nucula hartvigiana*	nut shell	x	2
Arthropoda	Decapoda	Pinotheridae	*Macrophthalmus hirtipes*	stalk-eyed mud crab	#	
		Grapsidae	*Helice crassa*	tunnelling mud crab	#	1
		Crangonidae		shrimps		1
Annelida	Polychaeta	Arenicolidae	*Abarenicola*	lugworm		1
		Maldanidae	maldanids	bamboo worms		1
		Opheliidae	*Travisia olens*			1
		Orbiniidae	orbiniids		#	1
		Spionidae	spionids		#	1
	Oligochaeta	Lumbricidae		earthworms	#	2
Nemertea					*	

* = class of prey found in Firth, x = exact species of prey found in Firth, # = genus or family of prey found in Firth
Sources: 1 = Battley (1996), 2 = P.F. Battley (unpubl.)

Appendix 3. Diet of non-breeding wrybill in New Zealand

Phylum	Class	Family	Species	Common name	Firth	Source
Mollusca	Bivalvia				*	1
Arthropoda	Decapoda				*	
Annelida					*	1
	Polychaeta				*	2
Plant mat.					*	2

* = class of prey found in Firth, x = exact species of prey found in Firth, # = genus or family of prey found in Firth Sources: 1 = Burton (1972), 2 = Anderson (2003)

8.3 Appendix 4. Diet of non-breeding pied oystercatcher in New Zealand

Phylum	Class	Family	Species	Common name	Firth	Source
Mollusca	Bivalvia	Mesodesmatidae	*Amphidesma subtriangulatum*	tuatua		1
			Paphies australis	pipi	x	1
		Mytilidae	*Xenostrobus pulex*	small black mussel	x	2
		Tellinidae	*Macomona liliana*	large wedge shell	x	1
		Veneridae	*Austrovenus stutchburyi*	cockle	x	1
			Dosinia anus	ringed venus shell		1
			Dosinia subrosea	silky/fine dosinia		1
			Protothaca crassicosta	ribbed venus shell		1
	Polyplacophora	Chitonidae	*Chiton glaucus*	green chiton		1
			Sypharochiton pelliserpentis	snakeskin chiton		1
	Gastropoda	Amphibolidae	*Amphibola crenata*	mud snail	x	1
		Batillariidae	*Zeacumantus subcarinatus*	southern creeper		1
		Buccinidae	*Cominella glandiformis*	mud whelk	x	1
		Nacellidae	*Cellana radians*	radiate limpet		1
		Trochidae	*Diloma subrostrata*	mudflat top shell		1
			Melagraphia aethiops	spotted top shell		1
Arthropoda	Amphipoda	Talitridae	*Talorchestia*	amphipod	*	1
	Decapoda	Varunidae	*Hemigrapsus sexdentatus*	common rock crab		1
		Grapsidae	*Helice crassa*	tunnelling mud crab	x	1
		Palaemonidae	*Palaemon affinis*	NZ glass shrimp	*	1
	Isopoda		*Dynamanella huttoni*	isopod	*	1
Annelida	Polychaeta	Arenicolidae	*Abarenicola assimilis*	lugworm		2
		Glyceridae	*Glycera americana*		#	1
		Maldanidae	maldanids	bamboo worms		2
		Nereididae	*Nicon aestuariensis*	ragworm	x	1
			Perenereis nuntia	ragworm	x	1
		Opheliidae	*Travisia olens*			2
	Oligochaeta	Lumbricidae	*Allolobophora caliginosa*	earthworm	#	1
Cnidaria	Anthozoa	Actiniidae	*Anthopleura aureoradiata*	mud flat anemone	x	2
			Isactinia olivacea	green sea anemone		1

* = class of prey found in Firth, x = exact species of prey found in Firth, # = genus or family of prey found in Firth
Sources: 1 = Marchant & Higgins (1993), 2 = Battley (1996)

8.5 Appendix 5. Diet of non-breeding variable oystercatcher in New Zealand

Phylum	Class	Family	Species	Common name	Firth	Source
Mollusca	Bivalvia	Mesodesmatidae	*Paphies australis*	pipi	x	1
			Amphidesma subtriangulatum	tuatua		1
		Mytilidae	*Aulacomya maoriana*	ribbed mussel		
			Mytilus edulis aoteanus	blue mussel		
			Perna canaliculus	green-lipped mussel		
			Xenostrobus pulex	small black mussel	x	1
		Tellinidae	*Macomona liliana*	large wedge shell	x	1
		Veneridae	*Austrovenus stutchburyi*	cockle	x	1
			Dosinia anus	ringed venus shell		1
			Dosinia subrosea	silky/fine dosinia		1
			Protothaca crassicosta	ribbed venus shell		1
	Polyplacophora	Chitonidae	*Chiton glaucus*	green chiton		1
			Sypharochiton pelliserpentis	snakeskin chiton		1
	Gastropoda	Batillariidae	*Zeacumantus subcarinatus*	southern creeper		1
		Buccinidae	*Cominella glandiformis*	mud whelk	x	1
			Cominella lucida			
		Haliotidae	*Haliotis iris*	paua		
		Nacellidae	*Cellana denticulata*	dentate limpet		
			Cellana flava	golden limpet		
			Cellana ornate	ornate limpet		
			Cellana radians	radiate limpet		1
		Trochidae	*Melagraphia aethiops*	spotted top shell		
Arthropoda	Isopoda		*Dynamanella huttoni*	isopod		
	Amphipoda	Talitridae	*Talorchestia*	amphipod	*	
	Decapoda	Grapsidae	*Helice crassa*	tunnelling mud crab	x	1
		Varunidae	*Hemigrapsus sexdentatus*	common rock crab		1
Annelida	Polychaeta	Glyceridae	*Glycera americana*		#	1
		Nereididae	*Perenereis nuntia*		x	1

* = class of prey found in Firth, x = exact species of prey found in Firth, # = genus or family of prey found in Firth
Sources: 1 = Marchant & Higgins (1993)