Auckland
Regional Council
TE RAUHĪTANGA TAIAO

Environmental Condition and Values of Mangere Inlet, Whau Estuary and Tamaki Estuary

November TR 2008/031

Auckland Regional Council
Technical Report No.031 November 2008
ISSN 1179-0504 (Print)
ISSN 1179-0512 (Online)
ISBN 978-1-877483-72-1

Technical Report, First Edition

Reviewed by:

Name: Melanie Skeen
Position: Stormwater Advisor
Stormwater Action Team
Organisation: Auckland Regional Council
Date: 14 September 2008

Approved for ARC Publication by:

Name: Paul Metcalf
Position: Group Manager
Environmental Programmes
Organisation: Auckland Regional Council
Date: 26 October 2009

Recommended Citation:

KELLY, S., 2008. Environmental Condition and Values of Mangere Inlet, Whau Estuary and Tamaki Estuary. Prepared by Coast and Catchment Ltd for Auckland Regional Council. Auckland Regional Council Technical Report 2008/031.

© 2008 Auckland Regional Council

This publication is provided strictly subject to Auckland Regional Council's (ARC) copyright and other intellectual property rights (if any) in the publication. Users of the publication may only access, reproduce and use the publication, in a secure digital medium or hard copy, for responsible genuine non-commercial purposes relating to personal, public service or educational purposes, provided that the publication is only ever accurately reproduced and proper attribution of its source, publication date and authorship is attached to any use or reproduction. This publication must not be used in any way for any commercial purpose without the prior written consent of ARC. ARC does not give any warranty whatsoever, including without limitation, as to the availability, accuracy, completeness, currency or reliability of the information or data (including third party data) made available via the publication and expressly disclaim (to the maximum extent permitted in law) all liability for any damage or loss resulting from your use of, or reliance on the publication or the information and data provided via the publication. The publication and information and data contained within it are provided on an "as is" basis.

Environmental Condition and Values of Mangere Inlet, Whau Estuary and Tamaki Estuary

Shane Kelly

Prepared for
Auckland Regional Council

Coast and Catchment Ltd.
PO Box 193, Clevedon, Auckland
Ph: 09 536 6238
shane@coastandcatchment.co.nz

Contents

Reviewed by: Approved for release by:

1 Executive Summary

Information on the environmental quality and values of Tamaki Estuary, and the Mangere and Whau Inlets were reviewed in relation to stormwater impacts. In the Tamaki Estuary, the best environmental quality and greatest habitat diversity occurs between Tahuna Torea spit and the mouth of the estuary. Tahuna Torea is a particularly important feature, with significant coastal vegetation and bird values. Exposed reef and sandy habitats also add to habitat quality and benthic diversity of the outer Tamaki. Habitat diversity decreases between Tahuna Torea and Panmure Bridge, and this is reflected by a reduction in species diversity. Contaminant concentrations are relatively low in the mid-Tamaki, but water quality at Panmure Bridge is notably poorer than at Bucklands Beach. Analyses of benthic health suggest that stormwater contaminants have affected the composition of benthic communities in this area. However, intertidal sand and mud flats still contain benthic communities with high species diversity and abundance, particularly between Tahuna Torea and Point England. Intertidal sand and mud flats between Tahuna Torea and Panmure Bridge are also important foraging areas for a variety of wading birds, including several endangered species. Areas of salt marsh and salt meadow in Wakaaranga Creek are also significant.

An environmental break-point occurs in the vicinity of Panmure Bridge, with sediments becoming muddier and more contaminated above the bridge. Mangrove forests are also more extensive in the upper reaches of the Tamaki. Zinc and copper concentrations are relatively high in the upper Pakuranga and Middlemore areas, and are continuing to increase rapidly. A number of other metal and organic contaminants also exceed low-level sediment quality guideline values in these areas. Modelling indicates that zinc concentrations will increase in most parts of the upper Tamaki for the foreseeable future, although they are predicted to stabilise at very high concentrations (>2000 mg/kg) in Otara Creek.

Benthic community health is degraded at all sites above Panmure Bridge, with sites in the upper Pakuranga and Middlemore areas having the worst ecological condition. Despite this, the upper Tamaki still contains functioning benthic communities that continue to provide a range of functions and services. The area is also utilised by a range of bird and fish species.

The coastline of Mangere Inlet has been highly modified by "reclamation" and industrial development, and the coastal environment has a long history of contamination. Environmental quality improved after the Mangere Wastewater Treatment Plant (MWWTP) was built, but stormwater contaminants, unauthorized discharges from industrial sites and the discharge from the MWWTP still affect water and sediment quality. Mangere Inlet is dominated by muddy sediments, which are moderately contaminated with copper and zinc on the northern shore of the inner inlet. Isolated hot spots of contamination also occur in this area. In contrast, sites on the southern shore and outer inlet appear to have relatively good sediment quality. Mussels, oysters and flounder collected from Mangere Inlet tend to have relatively high concentrations of organic contaminants in their tissues, and relatively high concentrations of lead have been found in the blood of South Island pied oystercatchers.

Benthic community health is significantly degraded above Mangere Bridge, and moderately degraded between Mangere Bridge and Hillsborough. However, the inlet still contains functioning benthic communities that continue to provide a range of functions and services. The area is a national hotspot for coastal bird diversity and is also utilised by a number of endangered bird species. Mangroves in Mangere Inlet have expanded from "nothing" in 1959 to covering ca. 110 ha in 2001/2006. A 2001 survey of fish at 30 sites in the Manukau Harbour also indicated that fish diversity and abundance was relatively high within the inlet. The entrance to Tararata Creek was notable for the highest abundance of yellow-eyed mullet, while a site off Kiwi Esplanade had the highest abundance of sand flounder.

The inner Whau is a sheltered inlet with relatively broad, mangrove fringed mudflats and a narrow central channel. The outer channel extends into the central Waitemata Harbour, where it drains extensive, and highly productive, intertidal sandflats. Pollen Island Marine Reserve adjoins the southern bank of the outer channel. The inner Whau is one of the most contaminated coastal waterways in the Auckland region, with particularly high concentrations of zinc in estuarine sediments. Copper, lead, mercury and PAH concentrations are also elevated. The most likely cause of contamination is diffuse urban stormwater run-off, but isolated hot spots associated with unauthorized discharges of industrial waste and/or stormwater, also occur within the inlet. Zinc and copper concentrations are continuing to increase rapidly within the inner Whau (south of the Northwestern Motorway and including the upper Whau), and modelling suggests that this trend will continue for the foreseeable future if zinc loads are not reduced. In contrast, sediment contaminant levels are low and water quality is relatively good in the outer Whau. Benthic community health varies from good in the outer Whau channel (north of the Northwestern Motorway) to highly degraded in the upper Whau. The outer Whau has very high ecological values due to the diversity and abundance of species, which includes extensive and dense shellfish beds. The area is therefore utilised by large numbers of wading and coastal birds, including a number of endangered species. Historical data suggests that benthic communities in the inner Whau were significantly degraded between 1982 and 2007, culminating in the loss of communities dominated by cockles, pipis and wedge shells from the inner Whau. However, the inner Whau still contains functioning benthic communities that continue to provide a range of functions and services.

A 2001 survey of fish at 31 sites in the Waitemata Harbour indicated that fish diversity and abundance was relatively high immediately south of the Northwestern Motorway bridge at the entrance to Whau Inlet, but it declined down the Whau channel. Speckled sole, yellow-bellied founder and exquisite goby were particularly prevalent, and numbers at the bridge site were the highest recorded in the Waitemata Harbour.

2 Introduction

Urban stormwater contamination is recognised as a significant threat to the marine environment. In older parts of Auckland, it is commonly conveyed directly to the coast via a pipe network and the urban stream system. Stormwater washes a range of urban contaminants off roads, paved and unpaved areas, buildings and other surfaces and can also convey high sediment loads from developing or re-developing catchments. Untreated wastewater is another common component of urban stormwater, due to overflows from the wastewater system, illegal wastewater connections to the stormwater system, exfiltration-infiltration between systems, and pump failures.

Sediment, wastewater and other stormwater contaminants have a range of effects on the coastal environment. The most obvious long-term impacts of sedimentation are the infilling and "muddying" of estuaries, and the associated expansion of mangroves. Sheltered estuary side branches are particularly susceptible to sedimentation and mangrove expansion, but this process can also occur in large, exposed waterways such as southern parts of the Firth of Thames. The other effects of sedimentation are less noticeable, but equally significant (see Gibbs and Hewitt 2004). Thick, catastrophic deposits of sediment (>20 mm), which can occur if heavy rainfall causes mass erosion, rapidly kill almost all bottom-dwelling organisms. Thin sediment deposits also reduce the diversity and abundance of benthic organisms, even in muddy habitats where the species present might be expected to have a greater tolerance to sediment. Over time, the deposition of fine sediment can alter the characteristics of benthic habitats, by reducing ambient grain size. Most benthic organisms can tolerate only a limited range of sediment textures, so the shift toward fine sediment leads to a corresponding shift towards communities adapted to living in fine sediments. Suspended sediment reduces light levels in the water column, affecting photosynthesis and primary production. It also affects the physiological condition of filter feeders by reducing feeding efficiency and potentially inhibits the feeding activity of other species such as visual predators.

Heavy metals are a ubiquitous component of urban stormwater. In Auckland the key metals of concern are copper, lead and zinc. However, a range of other metal, non-metallic, microbiological and organic (ie natural or synthetic carbon based compounds) contaminants may also be present in stormwater run-off, and lead to localised contamination. These include nutrients, faecal contaminants, fuels, oils, polycyclic aromatic hydrocarbons (PAHs), legacy pesticides (such as DDT, lindane, diedrin and chlordane), legacy synthetic compounds (such as PCBs) and newer emerging contaminants.

Metals and organic contaminants have a range of toxicological effects, which can affect the behaviour, reproduction, fitness and/or survival of marine organisms. As a result, marine communities in polluted systems are characterised by high proportion of tolerant species and fewer sensitive species. This pattern is apparent in some marine ecosystems adjoining urban catchments in the Auckland region (Anderson *et al.* 2006). Ecological communities with elevated concentrations of these metals tend to have reduced numbers of large bivalves, such as pipis, cockles and wedge shells, generally lack rare species, and also tend to be dominated by small bivalve species and small worms (Hewitt *et al.* submitted for publication).

The effects of wastewater discharges relate mainly to issues associated with human health, organic matter, nutrients and gross pollutants. Microbiological contaminants (ie bacteria and viruses) discharged to the environment can cause disease in humans who swim, or undertake other activities in polluted water, or who consume fish, shellfish or other food items gathered from polluted areas. Bacterial activity associated with the breakdown of organic material in wastewater can lead to anoxia (low oxygen levels), which dramatically affects biological systems and geochemical processes. High nutrient levels degrade water quality and promote nuisance algal growth, while gross pollutants affect the aesthetic values in the coastal environment.

The effects of stormwater in the coastal environment vary depending on:

1. the quantity and quality of the stormwater discharge(s);
2. the physical, chemical and ecological characteristics of the receiving environment; and
3. human amenity, aesthetic and cultural values.

The purpose of this report is to review available information on item (2) above for three “supersites” being investigated by the Auckland Regional Council (ARC), ie Tamaki Estuary; Whau Estuary; and Mangere Inlet (Figure 1). Each “supersite” consists of a marine receiving environment subject to stormwater inputs from two local councils. Integrated catchment management plans (ICMPs) being prepared by Waitakere, Auckland and Manukau City Councils are required to identify the best practicable option (BPO) for managing stormwater contaminants discharged into these systems. Among other things, the BPO must have regard to the nature of the discharges and the sensitivity of the receiving environment. An understanding of the environmental characteristics and values of the receiving environments is therefore needed before an assessment of sensitivity can be carried out.

The physical characteristics of the receiving environment have a significant influence on whether stormwater contaminants are diluted and flushed from the system. Relatively small receiving environments with poor flushing characteristics tend to accumulate stormwater contaminants. In contrast, contaminants do not tend to accumulate in energetic, open coastal receiving environments because they are widely dispersed and diluted.

The ecology of natural marine systems is closely linked to geophysical and associated chemical characteristics. Important chemical processes include (but are not limited to) nutrient cycling, sediment geochemistry and salinity. The geophysical properties that affect ecological characteristics are much broader than those related to flushing. They include: habitat structure (eg reef, mud, sand etc.); scale (ie the size of the system or habitat); geography (eg location in relation to other habitats, latitude, east or west coast etc.); geomorphology (eg estuary size and shape); exposure; climate, currents; and, depth. Physical and chemical parameters constrain the types of species and communities that can occur at a location. Within the constraints imposed by the physical and chemical properties of a site, the actual occurrence and make-up of marine communities is determined by ecological processes[1]. Stormwater primarily alters the physical and chemical characteristics of the receiving environment. This changes ecological communities by adversely affecting sensitive species, who cannot tolerate the changes, and favouring species which are more tolerant to the new (albeit degraded) environmental conditions, and who may also benefit from the loss of sensitive species. Indirect ecological effects can also occur if stormwater induced changes to one species or

---

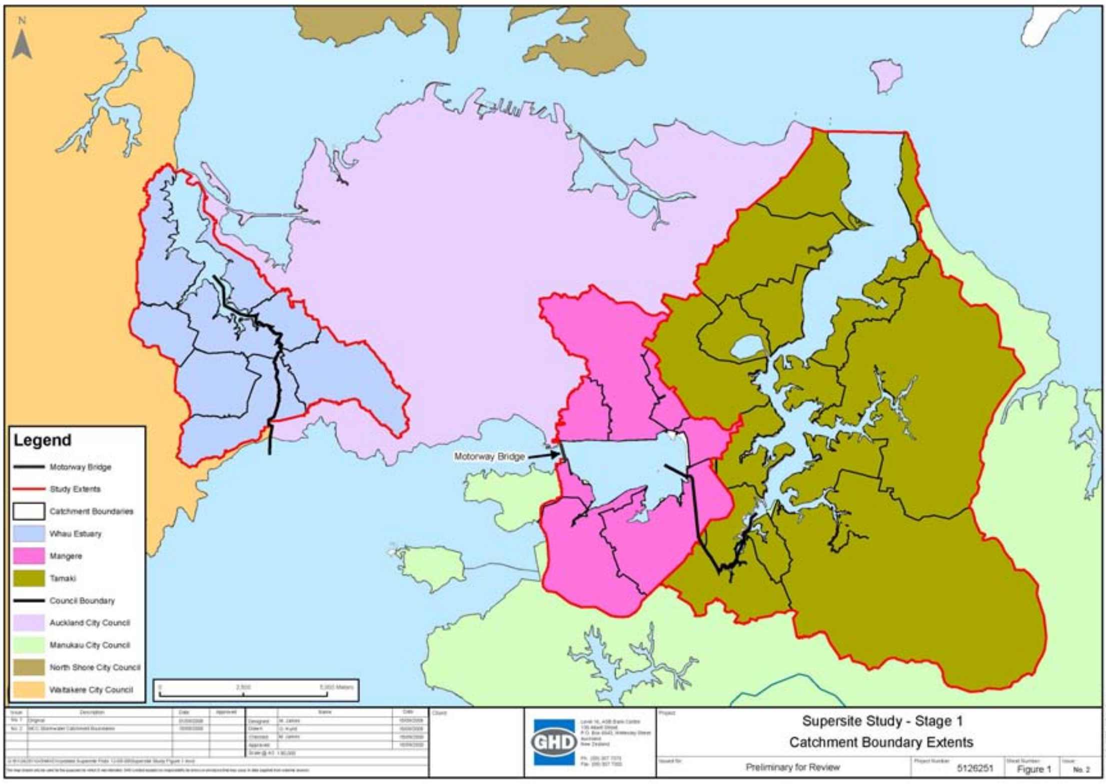
[1] Ecological processes include the tolerance range of individual species, ecological competition, trophic interactions, behaviour, adult mobility, larval dispersal and other life history characteristics.

community affects another species or community (eg mangrove expansion leads to the loss of mud-flat or sand-flat habitat).

In order to assess sensitivity to the ecological impacts of urban stormwater, it is necessary to have an understanding of the ecological communities present and the chemical and physical characteristics of the receiving environment. A review of available scientific papers, reports, and monitoring and research data was therefore carried out to summarise information of the environmental values and quality of Tamaki Estuary, Whau Inlet and Mangere Inlet. The review identified a wide variety of information, of varying quality and relevance. Not all of this has been included in the main body of the report, which focuses on the use of scientifically credible information, with an emphasis towards the more detailed and/or contemporary sources. In this respect, information obtained through the ARC's monitoring and investigation programmes were a key data source. A bibliography is also provided, which lists a range of additional reference material that is not included in the main body of the report.

Figure 1

Location and extent of the Tamaki Estuary (green), Mangere Inlet (pink) and Whau Estuary (blue) "supersites".



3 Tamaki Estuary

3.1 General description

Tamaki Estuary is a ca. 17 km tidal inlet that forms the eastern boundary of Auckland City's urban isthmus and the north-western boundary of Manukau City. The estuary covers an area of approximately 1600 ha, and has a predominantly urban catchment of approximately 11,500 ha. The main channel has a maximum depth of ca. 14 m but much of it is less than 5 m deep (Abrahim and Parker 2002). Several tributaries radiate out from the main channel, the largest of which are: Pakuranga Creek, Panmure Basin, Otahuhu Creek and Otara Creek. Water exchange between the main channel and Otara Creek is constrained by a weir, which was built to ensure a continuous supply of cooling water for the Otahuhu Power Station.

A large proportion of the estuary consists of low relief, intertidal sand/mudflats. Mangrove forests occur in depositional areas of the main body, and are fairly extensive in the upper reaches of the estuary and in its tributaries. A ca. 2 km narrowing of the main body between Pakuranga Creek and the Panmure Wharf Reserve provides a natural separation between the upper and outer estuary. Stronger current flows are created by this constriction. Below this, the estuary broadens out and the catchment narrows. Therefore, stormwater run-off volumes are likely to be relatively minor and estuarine dilution and flushing substantially greater in the outer estuary (ARC 1992). Another dominant and ecologically important feature of the outer estuary is Tahuna Torea spit, which extends out from the western shore and forms a constriction at the southern end of Bucklands Beach.

The geology of the estuary catchment is comprised of four geologic units (Abrahim 2005):

1. Waitemata group of sandstone and mudstone beds, which are only exposed in a low cliff at Point England and in the intertidal reef platforms adjacent to Tahuna Torea spit. Elsewhere they are covered by recent sediments and volcanic rocks.
2. Quaternary rhyolitic tephra deposits, which consist of white, pumice-rich, poorly consolidated sediment that originates from eruptive centres in the central North Island. These deposits form Point England and much of the adjacent reserve.
3. Basaltic volcanic rocks from the late Quaternary. These basalts and associated ashes mainly form the coastal area south of Point England to Otahuhu Creek.
4. Alluvium deposits (Pleistocene), which dominate catchments on the southern and eastern shores of the estuary. The estuary banks south of Tahuna Torea also consist of these soft, eroded sediments.

Human association with the Tamaki dates back to around 900 A.D. Prior to ca. 1840, the Tamaki catchment was occupied by Maori communities, who relied heavily on the natural resources of the area and extensive gardens where kumara, taro, yams, and gourds were cultivated. Maori population size and agricultural activity fluctuated widely through time, because peaceful settlement was regularly disrupted by warfare (Stone 2001). Tamaki Estuary was strategically important because of the narrow corridor of land that separates the upper reaches of Otahuhu Creek from Mangere Inlet on the west coast. This feature was utilised by both Maori and early Europeans, as its low elevation and short distance eased the portage of canoes and boats between the east and west coasts and, together with the Waiuku portage, also provided a critical link to the Waikato River. The short extent of the portage was highlighted by an early British trader, Walter Brodie, who claimed to have dragged a whale across it in forty minutes (Stone 2001). Unfortunately, the eastern end of this historic site is now overgrown with invasive plants, contains large amounts of rubbish, and has multiple stormwater and wastewater discharge points (Figure 2).

Figure 2

The eastern end of the Te To-waka portage in the upper Otahuhu Creek.

European settlement started in the mid-to-late half of the 19th century. Abrahim and Parker (2002) describes three phases of European land use in Tamaki catchments:

1. A period of forest clearance and grain farming from 1850.
2. A switch to dairy farming at the start of the 1900s.
3. More varied pastoral land use from about 1945 (eg diary, horse breeding, market gardening, pig and poultry farming), together with an increasing shift to residential, commercial and industrial development.

Many parts of the estuary have been heavily modified since the 1950s. Changes include "reclamation", and the construction of bridges, wharves, marinas, breakwaters, a weir (Otara Creek), stormwater ponds (the Grange Golf Course), and boat ramps. Three main bridges dissect the main body of the estuary: Panmure Bridge and the Pakuranga Motorway in the mid-estuary, and State Highway One in the upper estuary and Otahuhu Creek. Ti Rakau Drive also crosses the upper Pakuranga Creek, and Highbrook Drive crosses Otara Creek. All these bridges carry significant volumes of traffic.

Five mooring management areas are located in the lower reaches of the estuary, below Pakuranga Creek (Figure 3). Together, these areas have provision for 1685 moorings (Auckland

Regional Plan: Coastal). Half Moon Bay Marina and ferry terminal, and the Buckland Beach Yacht Club marina are located on the eastern shore, south of Tahuna Torea spit. Half Moon Bay Marina has berths for over 400 boats, and associated hardstand and boat maintenance facilities for up to 100 boats. The Buckland Beach Yacht Club marina has berths for around 100 boats. Substantial wharf and, in some cases, haul-out facilities are also located around Panmure Bridge, along the Mount Wellington industrial foreshore and at Otahuhu Power Station.

Otara Lake was formed 1968, by the construction of a weir across the mouth of the Otara Creek tributary. The lake provides a constant supply of cooling water for the Otahuhu power station. The top of the weir is approximately at mean sea level, so it is overtopped around half tide each tidal cycle, which allows water to flow in and out of the lake. Removable gates are occasionally used to drain the lake or to carry out maintenance (Croucher *et al.* 2005b).

The estuary receives discharges from stormwater and occasionally, wastewater networks throughout its length. The major industrial areas that discharge stormwater into the estuary are: Tamaki; Mount Wellington; and, East Tamaki. Smaller commercial/industrial areas are located around Hunters Corner Papatoetoe, Bairds Rd Papatoetoe, parts of Otahuhu, Otara, Pakuranga, Cascades Rd, Highland Park, and Botany. The remaining areas of catchment are predominately residential, with a diminishing rural component.

The Tamaki Estuary came to regional and national attention in December 1984, when a large fire at an industrial premise adjacent to the estuary (ICI Ltd.) led to the significant discharge of chemicals. The consequences of that incident led to the formation of the Tamaki Estuary Steering Group, which has representation from tangata whenua and other agencies with an interest in the state of the Estuary (Auckland District Health Board, Auckland City Council (ACC), Manukau City Council (MCC) and the ARC (ARC 1992).

Today, the Tamaki contains seven primary coastal protection areas (CPAs 44 to 50) (Figure 3 and Table 1). Coastal protection areas 45 and 50 are divided into two sub-areas, and CPA 49 is divided into 4 sub-areas. The primary reasons for the CPA designations are:

- Geology and landforms: CPA44, CPA46, CPA48, CPA49b and CPA50.
- Wading birds: CPA45, CPA47 and CPA 48.
- Mangroves: CPA45b.
- Wildlife habitat: CPA49.
- Intertidal banks: CPA48 and CPA49.

Seven sediment, and associated contaminant, settling zones are also identified in ARC (2002a) and included in the Auckland Regional Plan: Coastal (Figure 3). The rationale for the determination of settling zones is provided in ARC (2002a and 2002b). Settling zones can be nominally defined as areas where 75 per cent of catchment derived sediment and sediment bound contaminants settle out and accumulate. At the time of writing, Auckland City Council and Metrowater were undertaking a technical review to determine whether these designations are appropriate. The alternative dispositional zones proposed by Auckland City Council and Metrowater are provided in Appendix 3: Depositional Zones Identified by Auckland City Council – Metrowater.

Figure 3

Coastal protection areas (CPAs) and areas of significant conservation value (ASCV) in Tamaki Estuary. The sediment and contaminant settling zones identified in the Auckland Regional Plan: Coastal are also shown.

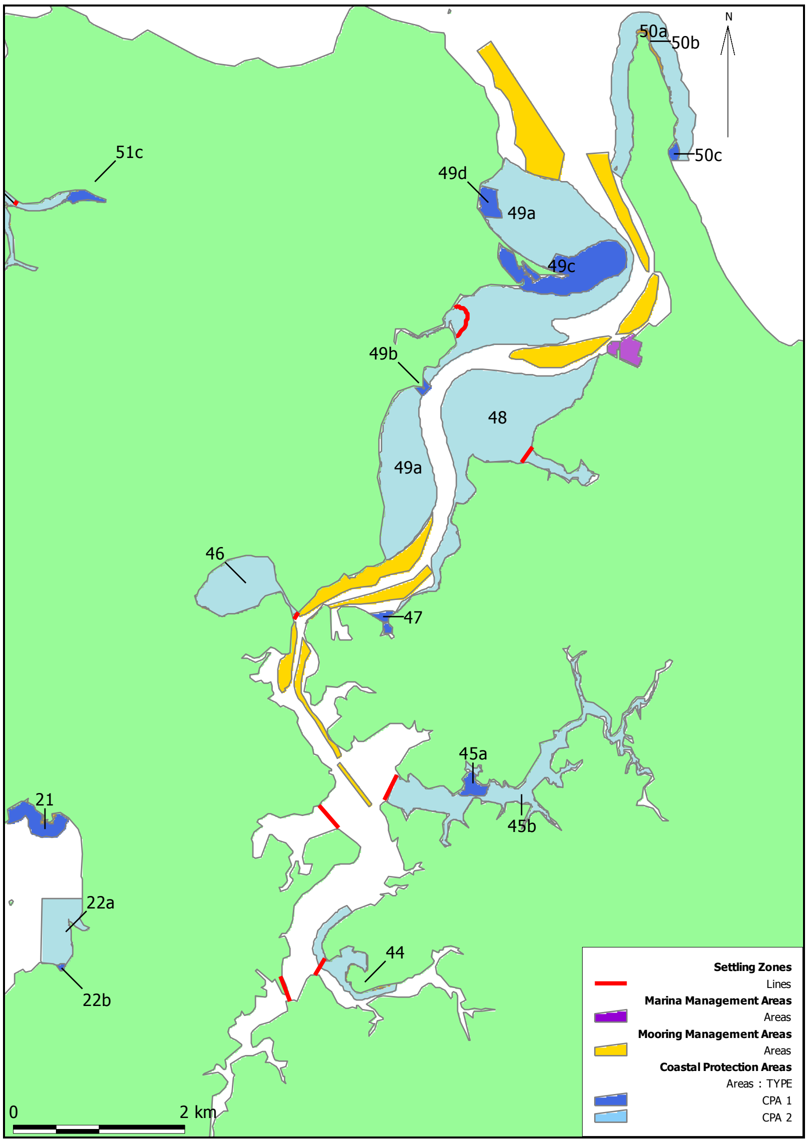


Table 1

Coastal protection areas (CPAs) and areas of significant conservation value (ASCV) in the Tamaki Estuary.

Protection Type	**CPA / ASCV No.**	**Description**
Coastal Protection Area 2	44	**Waiouru Tuff Mound**: A Waiouru Tuff Mound, often incorrectly referred to as Pukekiwiriki, is an indistinct, crater-like depression about 300m in diameter. The crater is breached to the SW by tidal creeks and has an eight metre terrace along the Tamaki River. One of the oldest members of Auckland Volcanic Field, this geological landform is considered to be regionally important.
Coastal Protection Area 1	45a & b	**Pakuranga Creek and Roost**: Pakuranga Creek roost (45a) is one of the roosting sites used by some of the hundreds of wading birds that feed within the Tamaki Estuary. The whole of the Tamaki Estuary is a regionally important wildlife habitat and has been selected by the Department of Conservation as an Area of Significant Conservation Value (ASCV). This roost is associated with the values of Coastal Protection Areas 47, 48, and 49 and forms an integral part of the wildlife habitat values of the estuary. The mangrove areas of Pakuranga Creek (45b) are regarded as the best example of mangrove habitat in the Tamaki Estuary.
Coastal Protection Area 2 & Area of Significant Conservation Value	46 / 62	**Panmure Basin Explosion Crater**: An explosion crater and associated tuff ring that is naturally breached to form a tidal lagoon. This landform is still relatively complete and is considered to be regionally important. The Department of Conservation has selected this area as an Area of Significant Conservation Value (ASCV).
Coastal Protection Area 1	47	**Tamaki River East Roost**: One of the roosting sites used by some of the hundreds of wading birds that feed within the Tamaki Estuary. This roost is associated with the values of Coastal Protection Areas 45, 48, and 49.
Coastal Protection Area 2 & Area of Significant Conservation Value	48 / 61	**Tamaki East Bank**: This intertidal bank is a feeding ground for the hundreds of wading birds that use the Tamaki Estuary. This feeding ground is associated with the values of Coastal Protection Areas 45, 47, and 49. This area also includes part of the Farm Cove ignimbrite, most of which is above mean high water spring (MHWS).
Coastal Protection Area 2 & Area of Significant Conservation Value	49a-d / 60	**Tahuna Torea to Point England**: The spit and associated northern and southern intertidal banks, together comprise a wildlife habitat of regional importance. This area is associated with the values of Coastal Protection Areas 45, 47, and 48. At Point England (49b) is a small geological exposure of rhyolitic co-ignimbritic accretionary lapilli from the Taupo Volcanic Zone, which is exposed as a thin bed near the base of an eroded low sea cliff. The site is considered to be nationally important and has been selected by the Department of Conservation as an Area of Significant Conservation Value (ASCV).
Coastal Protection Area 2	50a & b	**Musick Point**: Two exposures in the cliffs and intertidal platforms are considered to be geologically important. One (50b) is an over thrust fold involving flysch beds and the other (50c) is the best example in the region of an anticline visible in three dimensions. Both of these geological features are considered to be regionally important.
Area of Significant Conservation Value	79	

3.2 Hydrodynamics

The hydrodynamics of Tamaki Estuary were modelled as part of the Coastal Receiving Environment Assessment (CREA) carried out by Auckland City Council and Metrowater. Full details of that modelling are presented in Croucher *et al.* (2005a and 2005b) and are summarised below.

Under fair weather conditions, current velocities are typically less than 1 $m.s^{-1}$ except where the current passes through a constriction or other obstacle eg the entrance to Panmure Basin and Otara weir. Maximum current velocities in the main channel tend to be lowest above Otahuhu Creek and greatest on the constricted bends of Panmure, Point England and Tahuna Torea. The upper reaches of the estuary are almost dry at low tide, as are large areas of the outer estuary in the vicinity of Tahuna Torea. However, the large main channel remains filled at all times. At high tide the estuary is almost completely underwater.

Modelling indicates that flows in the main channel of the estuary are largely unaffected by stormwater run-off. However, localised effects on water velocities are apparent near consolidated outfalls. For instance, large storm events increase both water flows and water levels in the upper Tamaki, above Otara Creek.

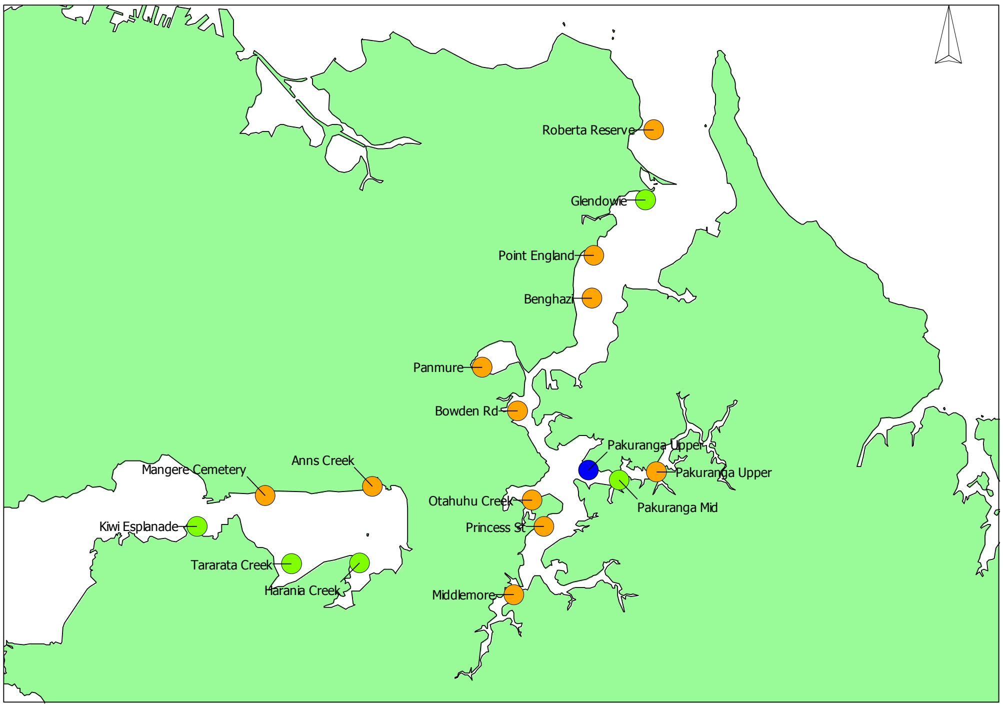
3.3 Sediment characteristics, accumulation and contamination

3.3.1 ARC monitoring and investigations

The ARC monitor sediment samples collected from 10 sites in Tamaki Estuary at 2- to 5-year intervals (Figure 4). Samples are analysed for the concentrations of copper, lead and zinc in the fine (<63 µm) and total (<500 µm) sediment fractions (McHugh and Reed 2006, Kelly 2007b). An analysis of tin, arsenic, cadmium, mercury, and antimony was also carried out at the three state of the environment (SoE) monitoring sites in the Tamaki, in 2005 (Middlemore, Pakuranga Upper and Pakuranga Lower) and the concentrations of a range of organic compounds are also determined periodically at these sites (Reed and Webster 2004, McHugh and Reed 2006). The organic compounds include PAHs, PCBs, DDT, chlordane, lindane, dieldrin, methoxychlor, endosulfan and hexachlorobenzene. Galai particle size analysis is also carried out on sediments collected from each site to monitor long-term changes in sediment characteristics (note that statistical analyses of sediment texture have not been carried out). Sediment grain size was also analysed in samples collected from eight of the 10 sites, for monitoring ecological responses to stormwater contamination (Anderson *et al.* 2006, Kelly 2007b). These samples were analysed by wet sieving each sediment sample and weighing the material in each of 5 size classes. Sediment texture was presented as percentage weight in: gravel (>2 mm), coarse sand (2 mm to 500 µm), medium sand (500 µm to 250 µm), fine sand (250 µm to 63 µm) and silt and clay (<63 µm). Raw data from these programmes was obtained for Tamaki Estuary, re-plotted and summarised below.

Figure 4

Auckland Regional Council sediment monitoring and investigation sites in Tamaki Estuary and Mangere Inlet. Orange sites are stormwater contaminant monitoring sites (ie RDP sites) (ie which include state of the environment (SoE) sediment contaminant monitoring sites (see Appendix 1: Copper , Lead and Zinc Concentrations Obtained from ARC Monitoring and Investigations)). Blue sites are additional SoE sediment contaminant monitoring sites and green sites were validation sites used in the development of the benthic health model (Anderson *et al.* 2006).



Principle co-ordinate analysis and plots of raw Galai data (volume) collected from nine of the 10 monitoring sites in 2004/2005 indicates that the sediment characteristics of the monitoring sites can be differentiated by two features:

- Relatively high volumes of sediment in size classes between 0 and 62.5 µm differentiate Otahuhu Creek and Panmure from the other Tamaki sites (Figure 5a and Figure 7).
- A gradient in the relative volume of sediment in the size class 62.5 to 125 µm and 125 to 250 µm differentiated the other sites (Figure 5b).

The volume of sediment in the coarser fraction (ie 125 to 250 µm) increased from Point England, Bowden Rd, Pakuranga Upper, Middlemore, Benghazi, Pakuranga Lower and Princess Street (Figure 5b). This pattern of sediment texture is notable because it does not show simple longitudinal gradient of increasingly coarse sediment along the estuary. Relatively coarse sediments were obtained from sheltered, upper estuarine sites such as Middlemore and Princess Street, whereas relatively fine sediments were obtained from some lower sites such as Point England.

The results of the Galai analyses differ from those obtained by wet sieving sediment samples (Anderson *et al.* 2006). Patterns obtained by wet sieving are more consistent with the expected distribution of sediments in the estuary (Figure 6), with finest sediments occurring in the most sheltered areas (Figure 7). Accordingly, Panmure and Otahuhu Creek had the finest sediments, with fine sediments also occurring in the Pakuranga Upper and Middlemore sites. Coarsest sediments were obtained from the outer-most site, ie Benghazi, whereas an intermediate mix of grain sizes was obtained from the mid-estuary sites: mid-Pakuranga, Princess and Bowden.

Figure 5

Principal co-ordinate analysis of the volume of sediment in each of eight particle size classes (2.0 to 3.9 µm, 3.9 to 7.8 µm, 7.8 to 15.6 µm, 15.6 to 31.3 µm, 31.3 to 62.5 µm, 62.5 to 125 µm, 125 to 250 µm, and 250 to 500 µm). Sediment texture is similar for sites that are close together in the plots and dissimilar for sites that are widely separated. The overlying vector diagram indicates the influence (in terms of direction and strength) of each particle size class on the observed distribution. Analyses were carried out on sediment samples collected from a) all 9 Tamaki sites, and b) with Panmure and Otahuhu Creek excluded. Sediment volumes were estimated using Galai particle size analysis.

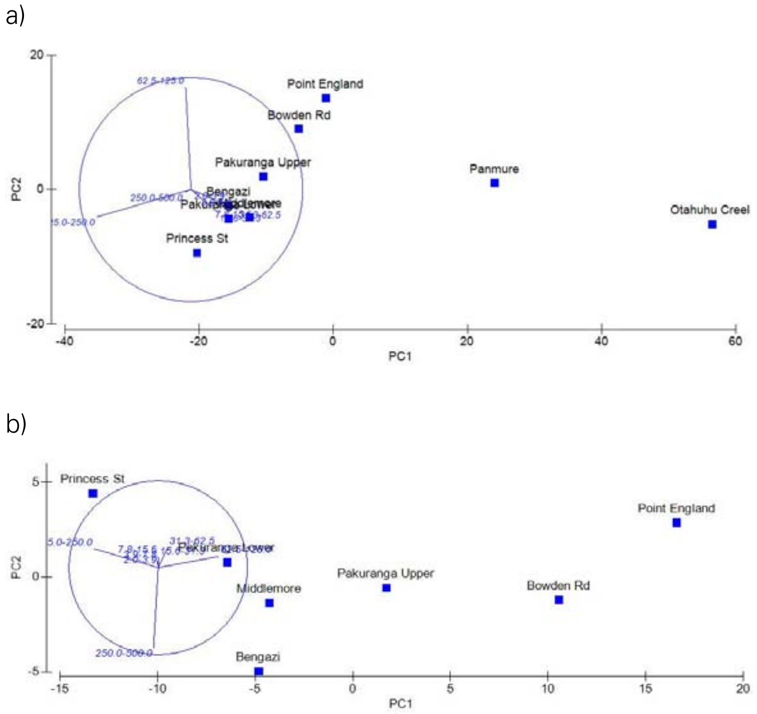


Figure 6

Principal co-ordinate analysis of sediment weight (as a per cent of total weight) in each of four particle size classes (<63 µm, 63 to 125 µm, 125 to 500 µm, and >500 µm) obtained by wet sieving samples from sites in the Tamaki Estuary. Samples were collected for ecological monitoring and the associated development of ARC's benthic health model (Anderson *et al.* 2006). Sediment texture is similar for sites that are close together in the plot and dissimilar for sites that are widely separated. The overlying vector diagram indicates the influence (in terms of direction and strength) of each particle size class on the observed distribution.

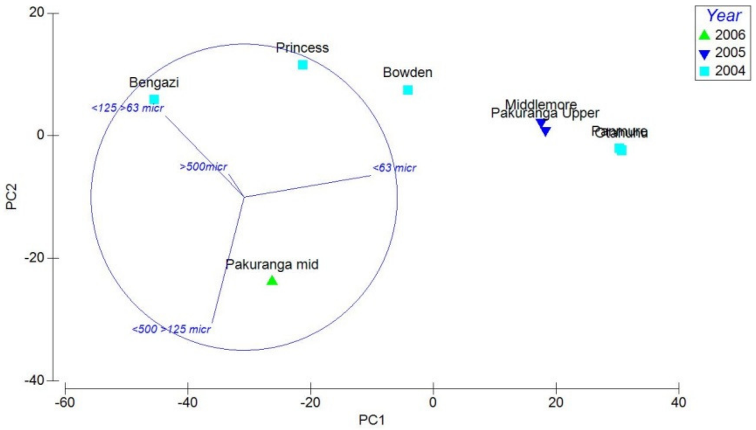
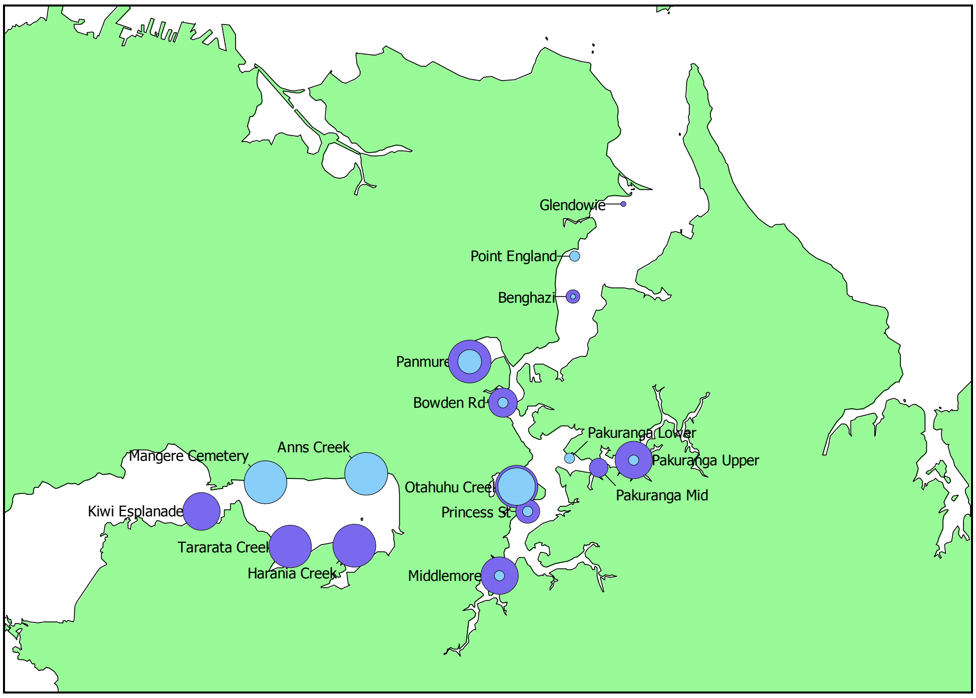


Figure 7

Distribution of fine sediment (<63 µm) in Tamaki Estuary and Mangere Inlet. The size of the circle is proportional to the percentage of fines. Dark circles represent percent weight values obtained from wet sieved sediments, and light circles represent sediment volume obtained from Galai analysis.



The sediment-contaminant monitoring and investigations carried out by the ARC since 1998 have been using comparable methods of sample collection and contaminant analysis. These programmes provide a robust set of sediment quality data for the estuary.

Sediment-contaminant concentrations are typically compared against sediment quality guidelines, which usually provide a set of low and a high values. The low values are nominally indicative of contaminant concentrations where the onset of biological effects is expected to occur (eg ERL and TEL (see below)). These values provide an early warning, which allows timely management intervention to prevent or minimise adverse environmental effects. The high values are nominally indicative of contaminant concentrations where significant biological effects are expected (eg PEL and ERM (see below)). These values indicate that adverse environmental effects are already likely to be occurring, and management intervention may be required to remediate the problem.

A number of sediment quality guidelines are used in the Auckland region. Three commonly used guidelines are:

- Effects Range Low (ERL) and Effects Range Medium (ERM) sediment quality guidelines developed by the National Oceanographic and Atmospheric Administration (Long and Morgan 1990). These guideline values were derived from contaminant studies were biological effects were observed.
- Threshold Effect Levels (TEL) and Probable Effects Levels (PEL) developed by the Florida Department of Environmental Protection (MacDonald *et al.* 1996). TEL and PEL values take into account studies that showed biological effects plus those that showed no effects (c.f. ERLs and ERMs which were derived from effects data only). TEL and PEL values tend to be more conservative (ie protective) than ERL and ERM values described above.
- The ARC's green, amber and red environmental response criteria (ERCs), which were derived from a combination of the TEL and ERL values described above (with rounding) (ARC 2002b). Amber and red ERCs therefore provide an early warning of potential effects. Their purpose is to trigger investigations into the causes and consequences of contamination, and to prompt an appropriate management response to prevent or minimise adverse environmental effects. Biological effects are considered to be unlikely when contaminant concentrations are within the green range.

Reference is made to all of these sediment quality guidelines in this report. A comparison of copper, lead and zinc guideline values is provided in Appendix 2.

Data on copper, lead and zinc concentrations were pooled from three ARC datasets: SoE monitoring, stormwater contaminants monitoring, and the benthic health model (Appendix 1). Plots of the data indicate that highest concentrations of all three metals occur in the sheltered upper reaches and side-arms of Tamaki Estuary (Figure 8 to Figure 10). Pakuranga Creek, Panmure lagoon, Otahuhu Creek and the upper estuary on the western side of the southern motorway (ie Middlemore); have significantly elevated concentrations of copper, lead and zinc. Total zinc concentrations exceed effects range low (ERL) sediment quality guideline values at all four locations. Total copper and lead concentrations also exceed threshold effects level (TEL) sediment quality guideline values (ie amber ERC values), and in the upper parts of Pakuranga Creek copper concentrations exceed ERL concentrations.

Concentrations of copper, lead and zinc decline towards the main channel of the upper estuary, but generally remain above TEL values (ie in the amber ERC band). The exceptions are copper and lead concentrations at the Princess St site, which are below TEL values. The concentrations of all three metals are relatively low in the outer estuary, remaining below TEL sediment quality guideline values at all sites beyond Benghazi (ie they are within the green ERC band) (Figure 8 to Figure 10).

Figure 8

Map showing relative sediment concentrations of total zinc (mg/kg) in Tamaki Estuary and Mangere Inlet (see Appendix 1 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is <TEL, blue TEL – ERL, yellow ERL to probable effects level (PEL), orange PEL to ERM and red is > ERM).

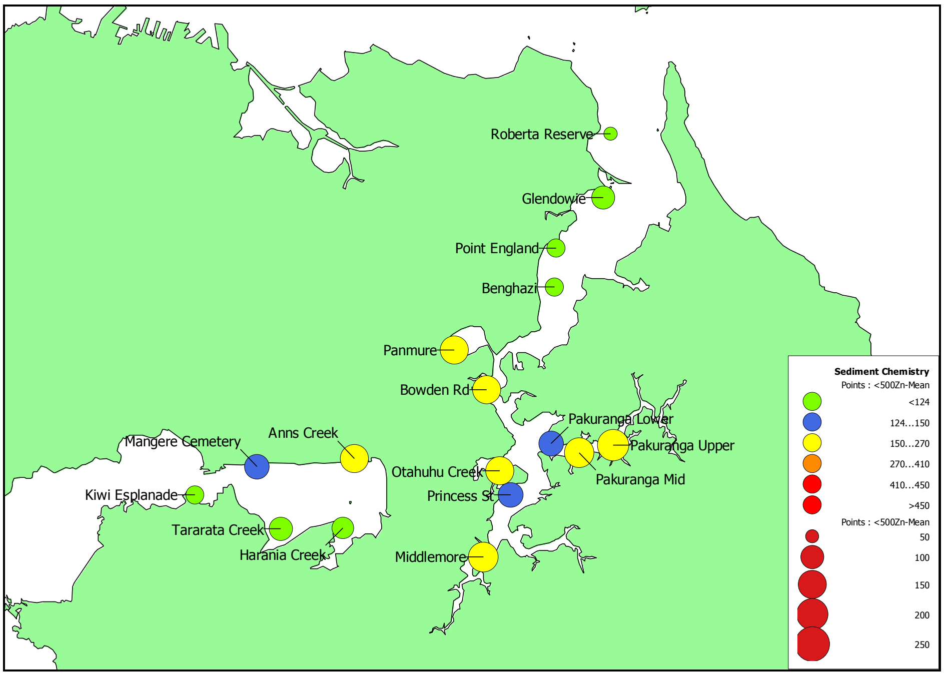


Figure 9

Map showing relative sediment concentrations of total copper (mg/kg) in Tamaki Estuary and Mangere Inlet (see Appendix 1 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is <TEL, blue TEL – ERL, yellow ERL to PEL, orange PEL to ERM and red is > ERM).

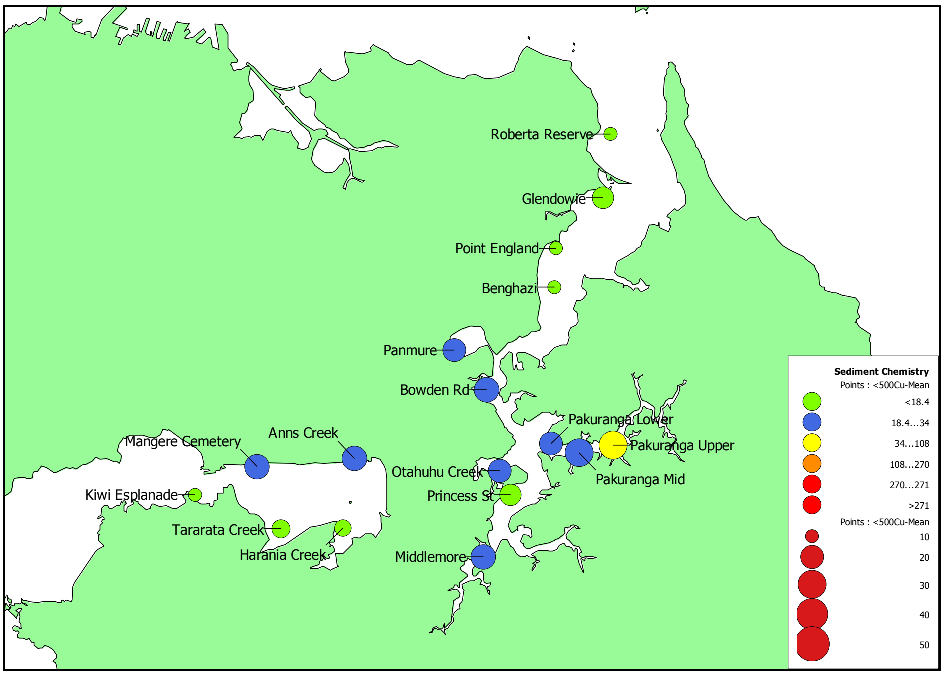
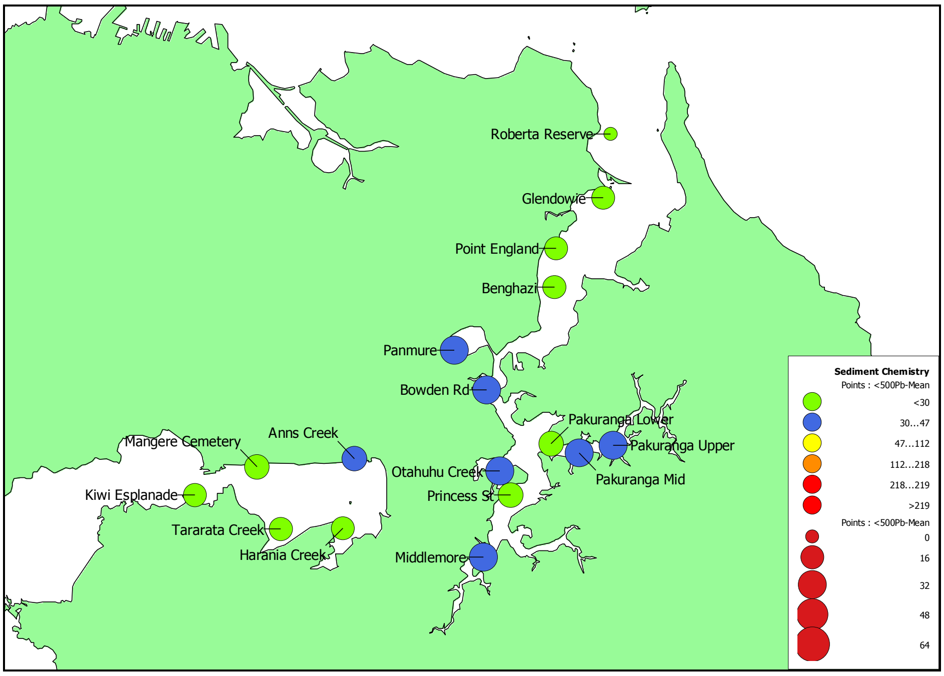


Figure 10

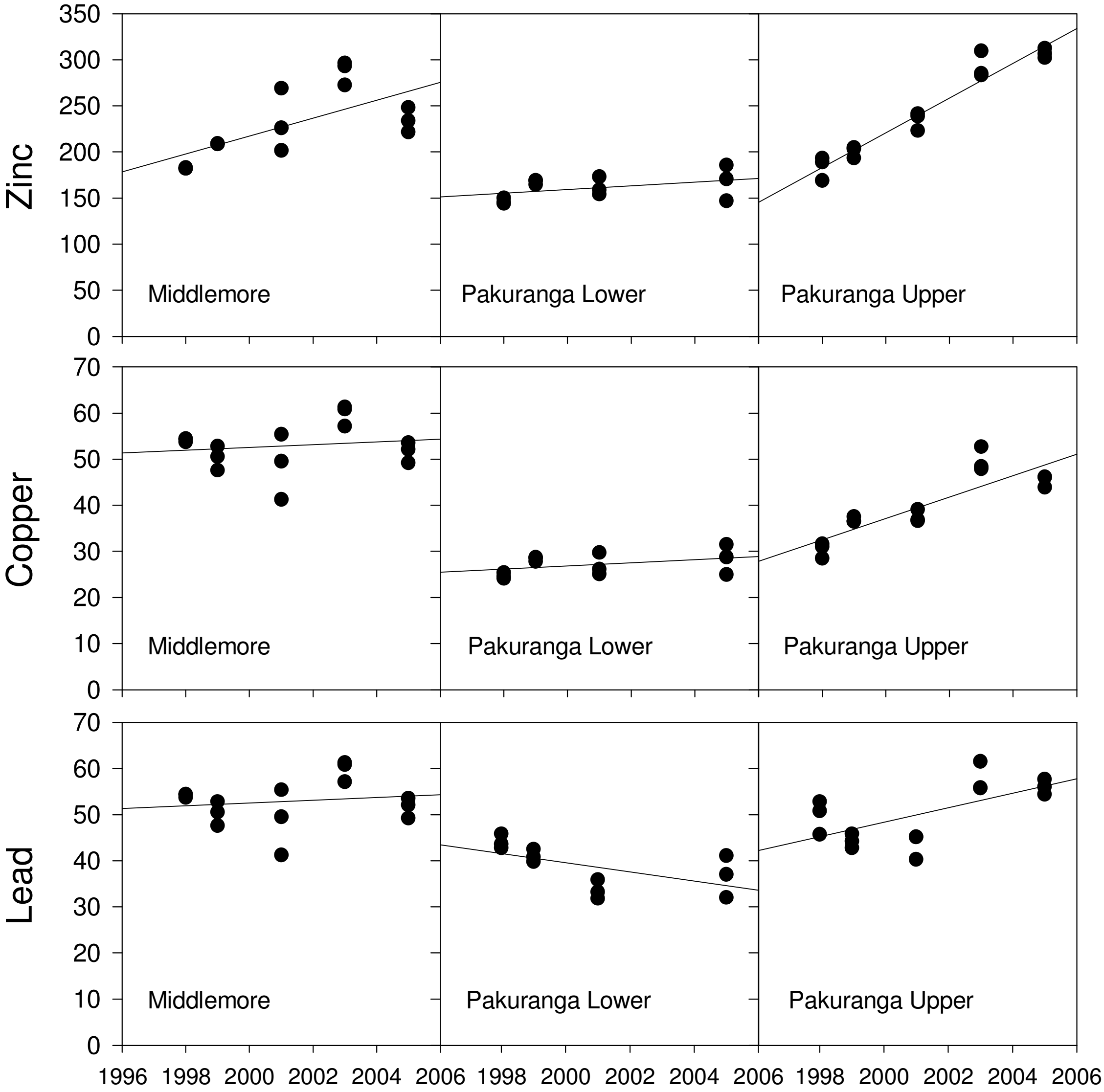
Map showing relative sediment concentrations of total lead (mg/kg) in Tamaki Estuary and Mangere Inlet (see Appendix 1 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is <TEL, blue TEL to ERL, yellow ERL to PEL, orange PEL to ERM and red is > ERM).



Repeated sampling of the upper and lower Pakuranga Creek and Middlemore sites between 1998 and 2005 has allowed trends in the concentrations of copper, lead and zinc in the fine sediment fraction to be determined (McHugh and Reed 2006, Kelly 2007b). Linear regression indicates that, over this period, statistically significant increases have occurred in the concentration of copper and zinc in the upper Pakuranga and Middlemore sites. Lead concentrations have also increased significantly in the upper Pakuranga. In contrast, the concentrations of copper and zinc did not change significantly in the lower Pakuranga site between 1998 and 2005, and lead concentrations showed a statistically significant decline (Figure 11). Over that period, zinc concentrations in the fine sediment fraction increased by 18.8 and 9.7 mg/kg per year at the upper Pakuranga and Middlemore sites respectively and copper concentrations by 2.3 and 1.6 mg/kg per year respectively. For the upper Pakuranga site, this equated to a 67 per cent increase in 1998 zinc concentrations and a 49 per cent increase in copper concentrations over a 7-year period. The Middlemore site experienced a 29 per cent increase in zinc and 34 per cent increase in copper concentrations over the same 7-year period.

Figure 11

Trends in the concentrations (mg/kg) of zinc, copper and lead in the <63 µm sediment fraction (extracted using weak acid digestion) at the Middlemore and upper and lower Pakuranga monitoring sites in Tamaki Estuary.



ARC monitoring suggests that the sediment concentrations of most of the other metal and organic contaminants that have been measured, are generally low relative to available sediment quality guideline values (Reed and Webster 2004, McHugh and Reed 2006), and tend to be mid-range relative to other SoE monitoring sites. The exceptions are:

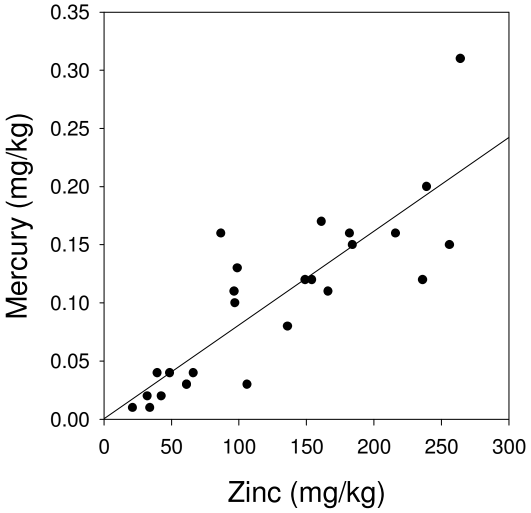
- mercury concentrations in sediments from the Middlemore site, which exceed ERL sediment concentrations;
- high molecular weight PAHs in sediments from the Middlemore site, which exceed TEL concentrations; and

- arsenic concentrations, which exceeded TEL concentrations in sediments from the Middlemore site, and ERL concentrations in sediments from the lower and upper Pakuranga sites.

Highest arsenic concentrations occur in some of the “cleanest” SoE monitoring sites (eg Big Muddy Estuary, Long Bay and Cheltenham) (McHugh and Reed 2006), suggesting that arsenic levels are naturally elevated in marine sediments in the Auckland region. The concentrations observed in Tamaki Estuary are therefore likely to be within the natural range, so arsenic contamination is not considered to be a significant issue. Mercury concentrations tend to be elevated at urban sites subject to stormwater run-off. Consequently, plots of the ARC’s SoE monitoring data indicate that there is a relatively strong relationship between mercury concentrations and other urban stormwater contaminants, such as zinc (Figure 12).

Figure 12

Relationship between total zinc and total mercury concentrations in coastal sediments. A linear regression has been fitted to the data ($R^2 = 0.72$).



The main cause of elevated PAH concentrations at the Middlemore site is likely to be the southern motorway, which runs adjacent to the site. Although the environmental risk posed by PAHs in the Auckland region is generally considered to be low, Depree and Ahrens (in press) cautioned that the combination of elevated metal concentrations and PAH concentrations in the upper Tamaki could pose a risk to resident biota. A detailed analysis of this risk has not been carried out.

Sediment contamination and characteristics have also been examined in a number of other research investigations. Bruce Williamson and Andrew Swales’ research in Pakuranga Creek during the 1990s is of particular note, given that it underpins much of current thinking on stormwater contamination in the Auckland region. The history of stormwater contamination in Pakuranga Creek was reconstructed by Swales *et al.* (2002). Aerial photographs from 17 years of a 42-year period were used to determine urban land cover changes in the Pakuranga catchment. This information was used to construct a history of catchment sediment loads using the Basin New Zealand (BNZ) sediment run-off model. The sedimentation and contamination history of the estuary was also reconstructed from dated sediment cores and associated metal profiles. Sedimentation rates in the pre-Polynesian and Polynesian periods ranged from 0.2 to 0.6 mm/year throughout the estuary. These increased to 0.8 to 1.6 mm/year coincident with deforestation and the switch to agricultural land use in the early European (mid-1800s to 1950s) period. Urbanisation dramatically increased sedimentation rates in the upper estuary, where sedimentation rates have been 32.6 mm/year since the 1960s. In lower sections of the estuary, sedimentation rates during the urban period ranged from 1.7 to 3.8 mm/year, with a clear trend of declining sedimentation away from catchment source. Urbanisation was accompanied by a rise in the concentration of heavy metals in estuarine sediments from ca. 1960. Patterns of zinc, copper and lead concentrations down Pakuranga Creek also suggested that most of the catchment metal load is trapped within the creek.

Williamson and Morrisey (2000) and Morrisey *et al.* (2000) (also see Williamson *et al.* 1998) developed and tested an urban stormwater contaminant model (USC1 model) for Pakuranga Creek. Model predictions agreed reasonably well with historic changes in zinc, lead and copper concentrations in estuarine sediments obtained from sediment surface and core samples. Note that the model was not used to provide predictions of future metal concentrations.

Abrahim and Parker (2002) also estimated sedimentation rates from core samples collected from mid-to-lower reaches of Tamaki Estuary. Pine pollen and caesium 137 (^{137}Cs) isotopic analysis were used to date cores, with pine pollen indicating the onset of significant European settlement, and ^{137}Cs indicating radioactive fallout from atmospheric nuclear testing (which in Auckland peaked in 1964-65). Sedimentation rates increased significantly from pre-European values of ca. 2 mm/year to a maximum of 17 mm/year on the northern shore of Tahuna Torea, ostensibly due to the disturbance of surface soils by farming and urbanisation. Coincident with the increase in sedimentation rates was a decrease in the proportion of mud, and an increase in sand-sized sediment particles. This was attributed to the clearance of natural vegetation, which created higher water run-off energies and allowed the transport and deposition of coarser sediments. Abrahim (2005) also found that in the main body of the estuary, sedimentation rates increased from the upper to lower estuary.

Abrahim and Parker (2002) also examined changes that have occurred in the concentrations of cadmium, copper, lead and zinc using core samples collected from the main body of the estuary in the mid-to-lower reaches. A sharp increase in the concentration of all four metals has occurred since urbanisation began. Of particular note is the relatively high level of cadmium enrichment (probably associated with the use of fertilizers and industrial activity), and the high level of copper enrichment adjacent to Tahuna Torea (which may be due to antifoulant leaching from moored boats) (Figure 13).

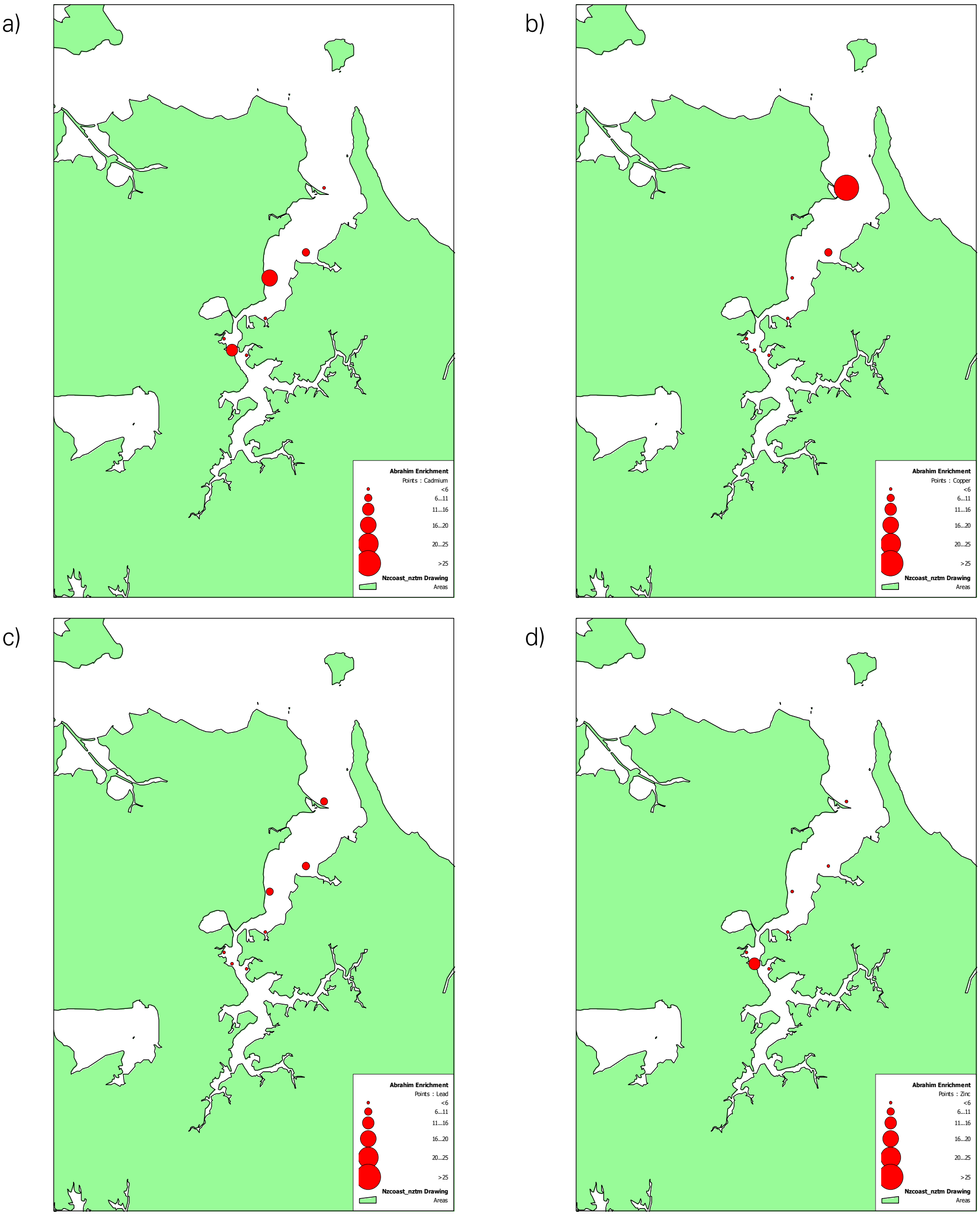
Croucher *et al.* (2005b) provide predictions of sediment and zinc accumulation in 14 "deposition zones" of Tamaki Estuary, using a particle tracking model and estimates of catchment sediment and zinc run-off from 16 consolidated outfalls. Predicted sedimentation rates ranged from 0.02 mm/year to 2.9 mm/year, with highest accumulation rates occurring in Otara Lake. Other sheltered areas with elevated sediment accumulation rates (0.2 to 0.7 mm/year) included Pakuranga Creek, Panmure Basin, the main estuary body between these two areas, and Middlemore (ie above the outlet to Otara Creek). In contrast, sedimentation rates in Otahuhu Creek were relatively low (0.09 mm/year), presumably because of small sediment loads. Sites below Panmure had relatively low sedimentation rates of <0.09 mm/year.

150-year predictions of zinc accumulation in the silt fraction were also provided for each of the deposition zones. Since 2005, Auckland City and Metrowater have collected more detailed land use information and are revising the zinc loads used in the CREA models. This information will be used to update predictions of zinc accumulation in Tamaki Estuary, and may lead to substantial changes in the results. The following summary should therefore be treated with an appropriate degree of caution.

Highest accumulation rates and ultimate concentrations of zinc were predicted for Otara Creek and Panmure Basin, with zinc concentrations at Otara Creek reaching an equilibrium with the stormwater outfall and stabilising around the year 2060. Zinc concentrations in Panmure Basin were predicted to continue increasing over the full 150-year period. Accumulation rates tend to decrease from the upper-Mid Tamaki to the Outer Tamaki, except in the area around Half Moon Bay, where zinc is predicted to accumulate faster than in the surrounding deposition areas (probably due to trapping by marina structures). Over the course of the simulation, zinc concentrations in the lower Pakuranga Creek and adjacent area of the main estuary body were also predicted to surpass those in the upper Pakuranga Creek, Otahuhu Creek, Middlemore and the upper main body of the estuary. Zinc concentrations in the upper Tamaki regional discharge programme (RDP) sites (ie above Panmure) were predicted to all exceeded ERM sediment quality guidelines by 2043 if zinc discharge loads are not reduced. Reducing zinc loads by as little as 35 per cent led to substantial reductions in ultimate zinc concentrations, but even 85 per cent reductions could not prevent ERM guideline values being exceeded at two of the five depositional areas in the upper Tamaki for which predictions were presented (ie Panmure and upper Tamaki Lower). Zinc load reductions of 75 per cent to 85 per cent were required to prevent ERM values being exceeded in the Otahuhu Creek, upper Tamaki and Middlemore deposition areas.

Figure 13

Maximum enrichment of a) cadmium, b) copper, c) lead, and d) zinc over background concentrations, determined by core samples (adapted from Abrahim and Parker 2002).



3.4 Biological contamination

Much less information is available on shellfish quality in Tamaki Estuary compared with sediment quality. The ARC has conducted:

- annual state of the environment mussel contaminant monitoring at a single site, beneath Panmure Bridge, in Tamaki Estuary since 1999 (see Kelly 2007a);

- a one-off survey of organic contaminants in cockles, oysters, mussels and mud snails in 1994 (Mills 1994). Shellfish were analysed for organochlorine pesticides, PCBs and PAHs, and were screened for chlorophenols; and
- a one-off survey of organochlorine pesticides, PCBs and PAHs in mussels from Bucklands Beach and Panmure in 1994 (Mills and Fahey 1995).

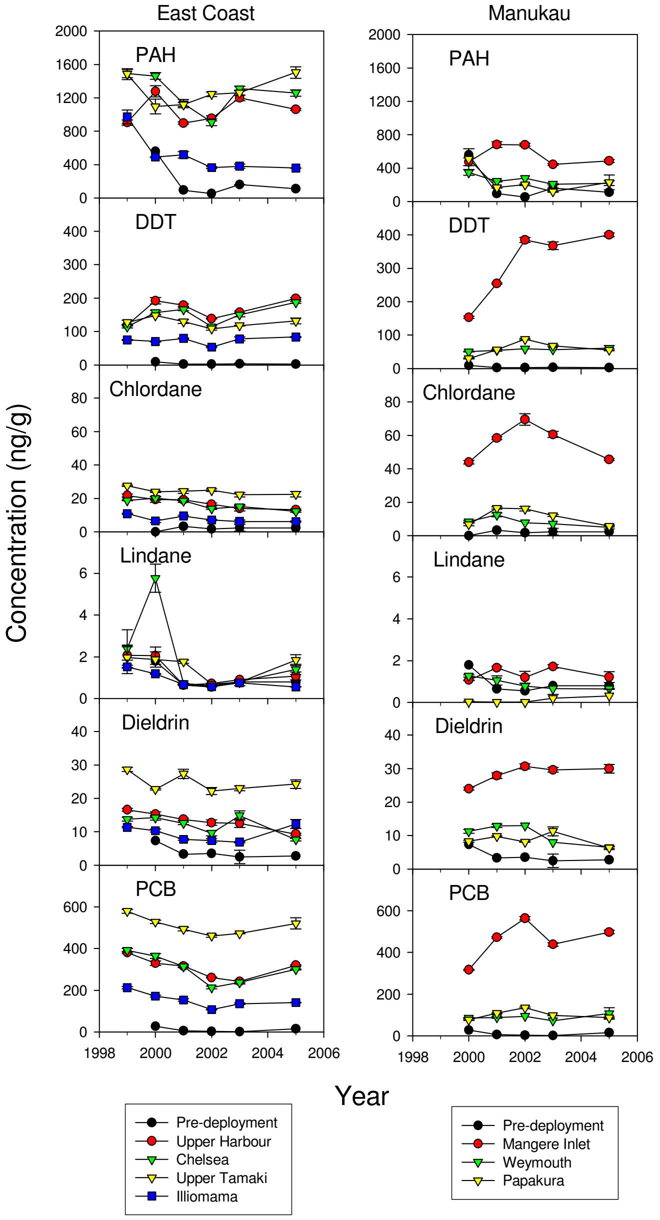
State of the environment monitoring provides the most contemporary information on shellfish contaminants in the Tamaki. This indicates that PAH concentrations in mussels grown in the Tamaki Estuary and Waitemata Harbour are consistently higher than in mussels grown in the Manukau Harbour or the east coast reference site (Illiomama: Rangitoto Island) (Kelly 2007a, see Figure 14). Chlordane, dieldrin and PCB concentrations are also consistently higher in mussels from the Tamaki compared with those from most Waitemata and Manukau Harbour sites. The exception is Mangere Inlet, where elevated concentrations of all three groups of compounds also occur (Kelly 2007a). The concentration of organic contaminants in Tamaki mussels has been relatively stable since monitoring began in 1999.

Copper concentrations also tend to be higher in Tamaki mussels (note that sediment metal concentrations tend to provide a greater level of discrimination among sites) and a substantial increase in mussel copper concentrations was observed in 2006 (Kelly 2007a). Although concentrations of copper and organic contaminants are elevated in Tamaki mussels, they are unlikely to occur at high enough levels to cause ecological or health effects.

The effects of habitat degradation (of which stormwater is a component) on cockles has also been examined in Tamaki Estuary. Stewart (2005) transplanted cockles from a “relatively pristine” site in Whangateau Harbour to four sites along a pollution gradient in Tamaki Estuary (ie Tahuna Torea, Farm Cove, and the entrances to Pakuranga Creek and Otahuhu Creeks). At the conclusion of the experiment, cockle tissue concentrations did not reflect the pollution gradient (but cockle survival did) and no clear relationship was observed between the concentrations of contaminants in sediments and the concentration of contaminants in transplanted cockle tissues. Furthermore, no significant difference was detected between tissue concentrations in cockles transplanted to the Tamaki and tissue concentrations in cockles from Whangateau Harbour.

Figure 14

Lipid normalised organic contaminant concentrations (ng / g (lipid)) of mussels trans-located into the east coast (left) and the Manukau Harbour (right), from 1999 to 2005. Values are also given for contaminant levels obtained from samples prior to deployment (From Kelly 2007a).



3.5 Water quality

The Auckland Regional Council has been continuously monitoring water quality at two sites in the Tamaki Estuary since 1991 (Buckland Beach (channel buoy 7) and Panmure Bridge). Monthly samples are collected by boat and analysed for: temperature; salinity; turbidity; suspended solids; nitrate; nitrite; ammonia-N; total and soluble phosphorus; faecal coliforms; enterococci; and, chlorophyll *a*. A review of water quality data was being carried out at the time of writing, so recent statistical analyses were not available. The data was therefore plotted and visually assessed for temporal trends and other patterns, and compared with other sites in the region. Nitrate and ammonia-N were also compared with ANZECC (2000) water quality guidelines.

Plots suggest that suspended solids concentrations at the Panmure site were relatively high throughout most of the 1990s, but appeared to decline between 1998 and 2000 (Figure 15). Since 2000, suspended solids concentrations in the Tamaki have been similar to those at sites in the Waitemata Harbour (Figure 16). The concentrations of nitrate and ammonia-N appear to have been relatively stable since monitoring began in 1991, but there may be a slight trend for declining total phosphorus concentrations at the Panmure site (Figure 15). Nitrate and ammonia-N concentrations have remained below ANZECC (2000) water quality trigger values throughout the monitoring period. Enterococci levels are generally low, but occasional spikes have occurred since 1991 (Figure 15). During the 1990s these spikes were quite frequent; however, there has been a substantial reduction in their occurrence since 1999.

Pooled data from the full monitoring period indicates that water quality at the Panmure site has been slightly poorer than at the Bucklands Beach site (ie ARC's No. 7 Buoy Site) (Figure 17). Median turbidity, suspended solids, nitrate, ammonia-N, total phosphorus, faecal coliform and enterococci levels were higher, and dissolved oxygen lower, at the Panmure site. Furthermore, the concentrations (or values) of most of these parameters have been are more variable and displayed greater extremes at the Panmure site. Dissolved oxygen concentrations at the Panmure site have frequently exceeded the ARC's amber ERC of 80 per cent saturation (22.6 per cent of samples between July 1993 and August 2007), but only rarely exceeded the red threshold of 65 per cent saturation (2.4 per cent of samples between July 1993 and August 2007).

Figure 15

Long-term trends in water quality at Panmure Bridge and the main channel at Buckland's Beach (channel buoy 7) in the Tamaki Estuary.

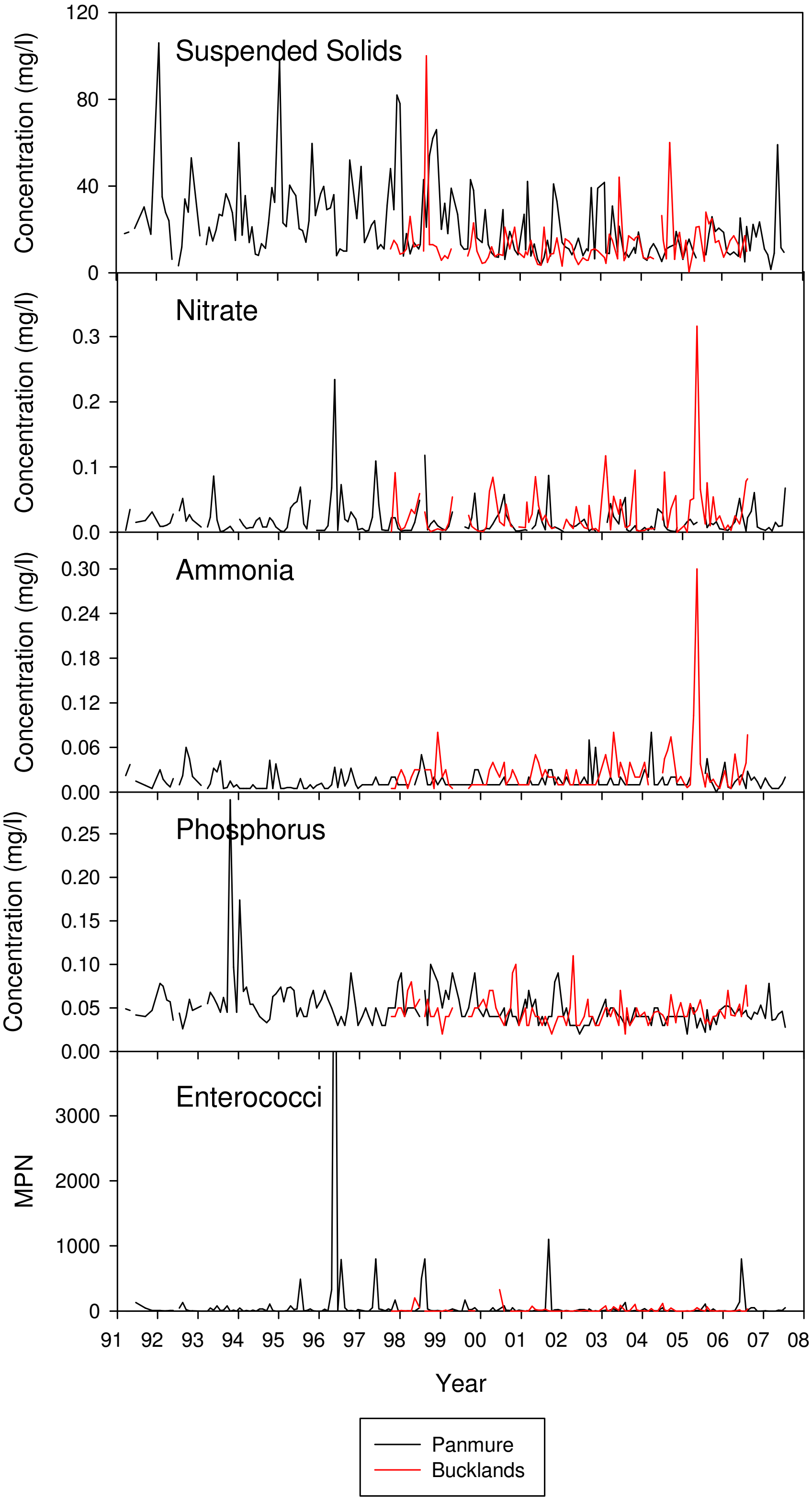


Figure 16

Boxplot of monthly suspended solids concentrations (mg/L) at the ARC's 27 water quality monitoring sites between 2000 and 2007. The sites are grouped by colour, with: east coast sites light green; Mahurangi yellow; Waitemata dark blue; Tamaki pink; Manukau Harbour light blue; and, Kaipara dark green. Boxes indicate median, 25th percentiles and 75th percentiles. Stems indicate 10th and 90th percentiles, while outliers are plotted individually.

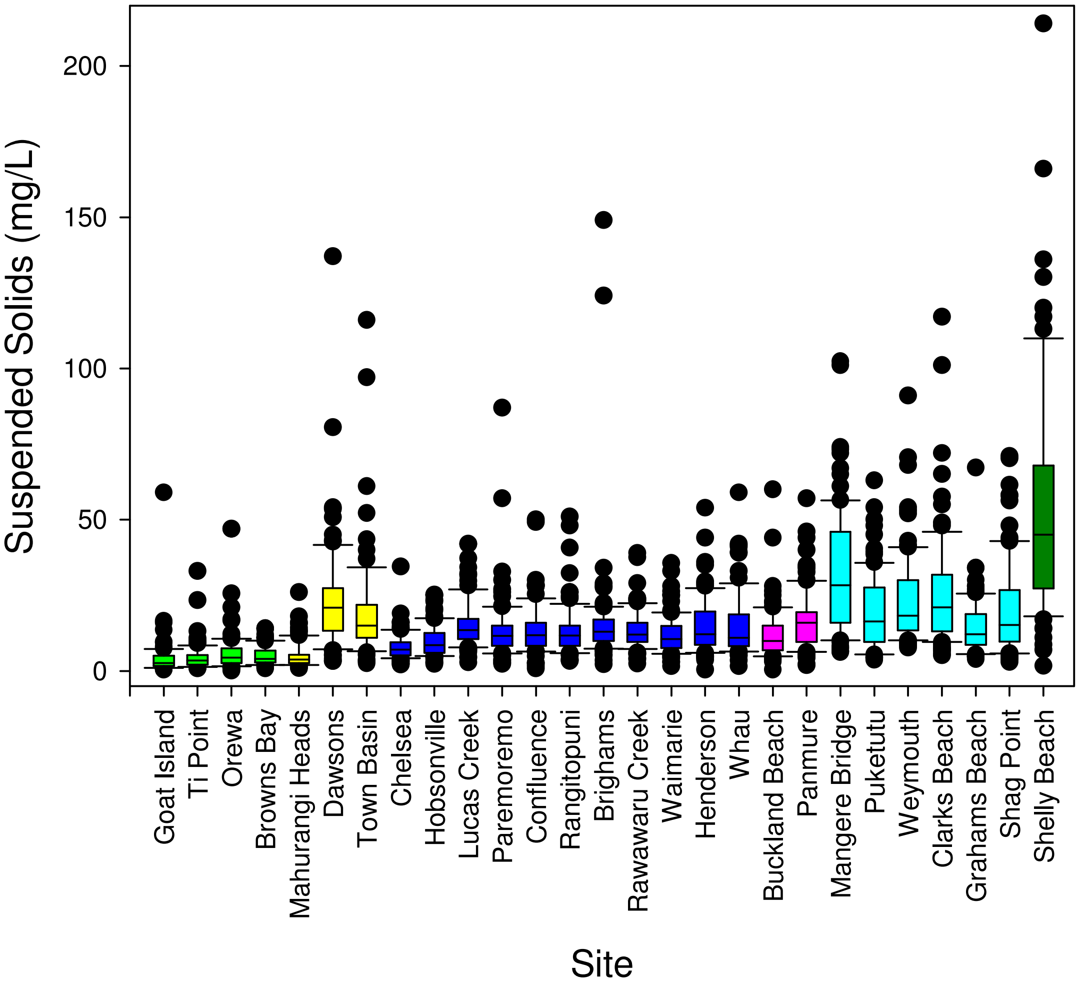
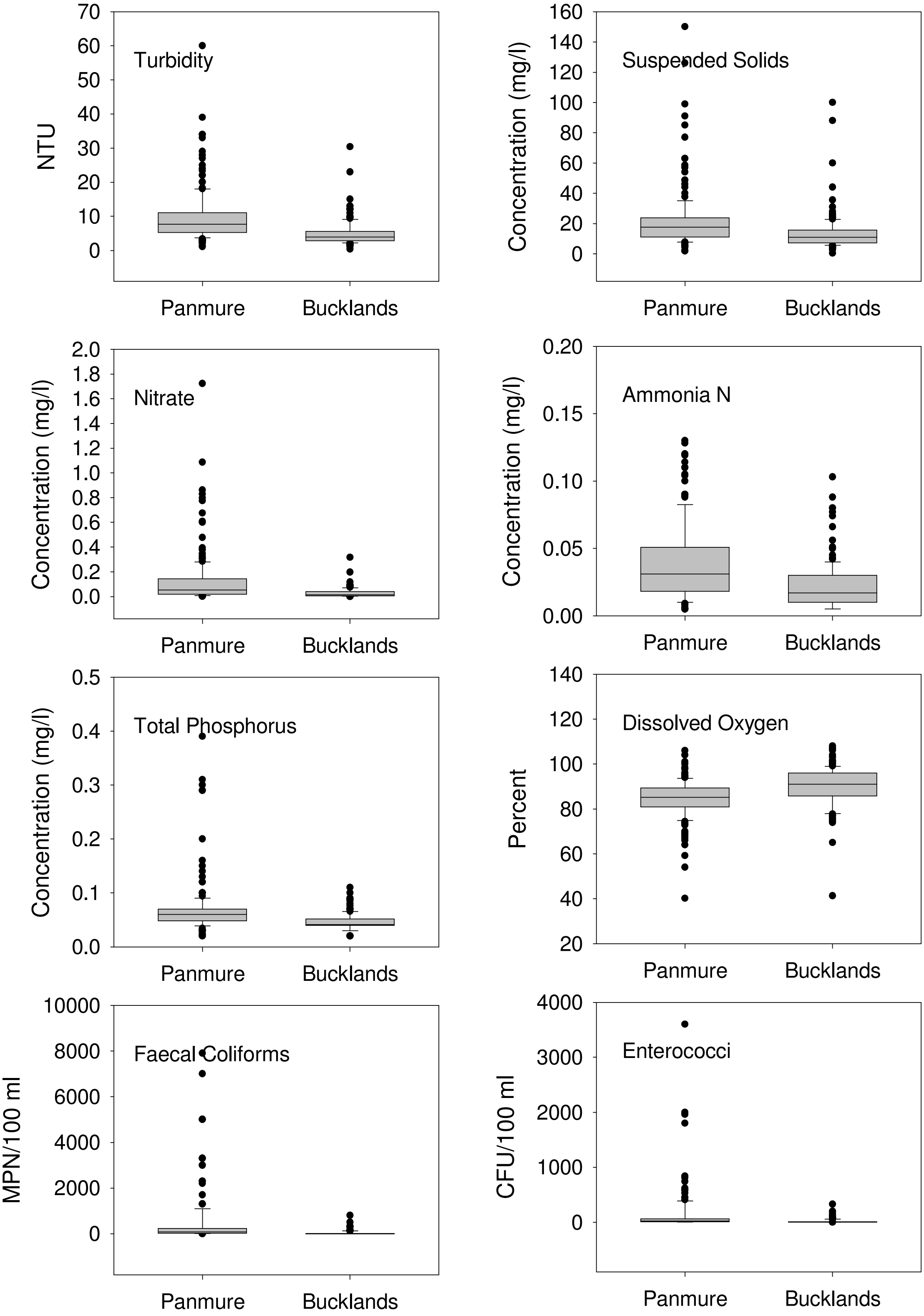


Figure 17

Boxplots of pooled 1991-2007 water quality from the Panmure Bridge and the main channel at Buckland's Beach (channel buoy 7) in the Tamaki Estuary. Boxes indicate median, 25th percentiles and 75th percentiles. Stems indicate 10th and 90th percentiles, while outliers are plotted individually.



3.6 Ecology

3.6.1 Benthic invertebrates

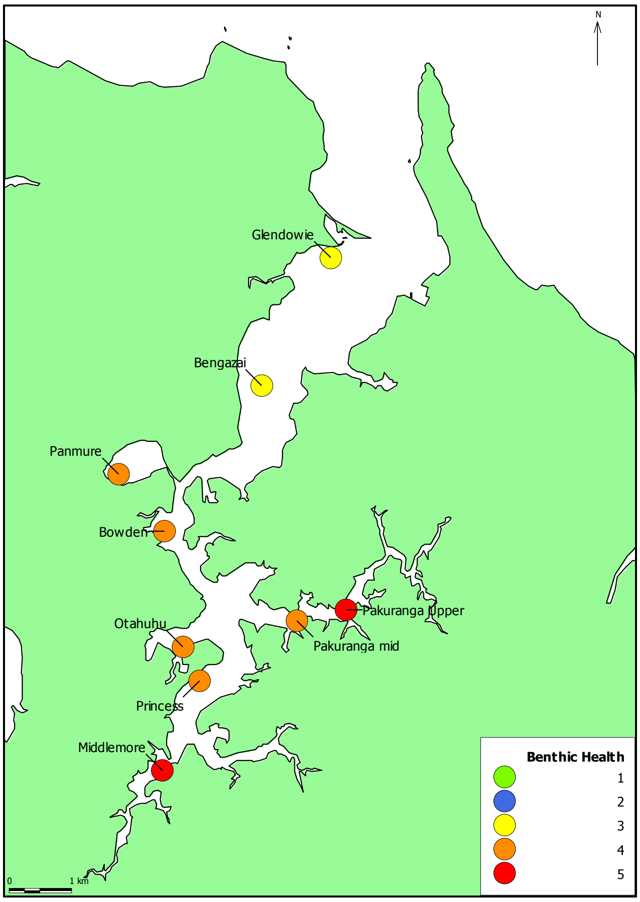
Benthic invertebrates in the Tamaki Estuary are sampled as part of the ARC's stormwater contaminant monitoring programme (Kelly 2007b), and for the development of the ARC's benthic health model (Anderson *et al.* 2006). Ecological samples were collected from nine sites in Tamaki Estuary: Benghazi; Bowden Rd; Glendowie; Middlemore; Otahuhu; Pakuranga upper; Pakuranga mid; Panmure; and, Princess St. The size of the sampling plot varied depending on the space available on the intertidal flats: ranging from 1000 m^2 (20 m x 50 m) to 10,000 m^2 (100 m x 100 m). Ten core samples (13 cm diameter x 15 cm deep) were collected from stratified random positions in each site. Stratification was used to avoid clumping of random samples. Ecological samples were sieved through a 0.5 mm mesh and preserved in isopropanol (70 per cent v/v). Sample sorting and taxonomic identification was carried out by NIWA Hamilton or the Leigh Marine Laboratory, with taxa being identified and enumerated to the lowest taxonomic level practical.

Ecological effects are assessed against a regional index of ecological condition (relative to stormwater contamination), which was derived from a study of the ecology, contaminant concentrations and physical characteristics of 84 sites spread throughout the Auckland region (Anderson *et al.* 2006). This index ranks the health of benthic communities from 1 (= healthy) to 5 (= degraded).

The ecological condition of benthic communities reflected the gradient in the concentration of copper and zinc concentrations down Tamaki Estuary (Figure 18). Benthic communities in the uppermost estuary sites, Middlemore and upper Pakuranga had the worst condition (health rank 5). The condition of benthic communities improves down the estuary, with mid-zone sites of the upper estuary having a health rank of 4, and sites in the outer estuary having a health rank of 3.

Figure 18

Ecological condition of benthic communities in the Tamaki Estuary. Health is ranked from 1 (green = healthy) to 5 (red = degraded).



The most recent data obtained for the benthic health model and stormwater contaminant monitoring were reanalysed to examine benthic biodiversity, total abundance, and the distribution patterns of a number of individual species. Benthic biodiversity generally decreased from the outer to inner Tamaki. The exception was the mid-Pakuranga site, were a relatively high number of species was obtained (n = 29). This is similar to the two outer Tamaki sites, Benghazi and Glendowie, which had 30 and 34 species respectively. By comparison, Middlemore and the upper Pakuranga had only 14 to 17 species.

The combined, total abundance of all species was relatively low throughout the Tamaki Estuary (c.f. other locations such as Mangere Inlet), with highest numbers occurring at Glendowie. This site had exceptionally large numbers of cockles and the nut shell *Nucula hartvigiana* (Figure 20a and b). The high numbers of these two species is reflected in the low value of Pielou's evenness index for the site (Figure 19c). Pielou's evenness index is a measure of how even (ie similar) the abundances of individual species are in a sample/site. Low index values indicate that the site is dominated by a single, or a few, species which occur in high abundance(s). The remaining species occur in relatively low abundances. In contrast, high index values indicate that the abundances of all species are fairly similar.

Sheltered, muddy sites with elevated contaminant levels tended to have disproportionately high numbers of tolerant species, which is also reflected in relatively low Pielou's evenness index values (Figure 19). Dominant species at each of these sites are listed below:

- Middlemore: nereidae (highly mobile, 30 to 60 mm predatory polychaete worms) and phoxocephalids (amphipods) (Figure 20d & f).
- Otahuhu: phoxocephalids (Figure 20f).
- Pakuranga Upper: nereidae (Figure 20d).
- Panmure and Bowden: *Cossura consimilis* (sedentary, 5 to 10 mm deposit feeding polychaete worm) (Figure 20e).

The mid-Pakuranga site also had relatively high numbers of nereidae and polydorids (sedentary, 10 to 30 mm tube-dwelling polychaete worms) (Figure 20c), which also tend to be tolerant of degraded habitats. The Middlemore site was somewhat unusual in that it was also the only site sampled in the Tamaki where pipis, *Paphies australis*, were recorded. Pipis are a sensitive species usually associated with good quality sites.

Figure 19

Number of species (a), total abundance (b), Margalef's index of species richness (c) and Pielou's evenness index (d) of benthic dwelling macroinvertebrates in Tamaki Estuary.

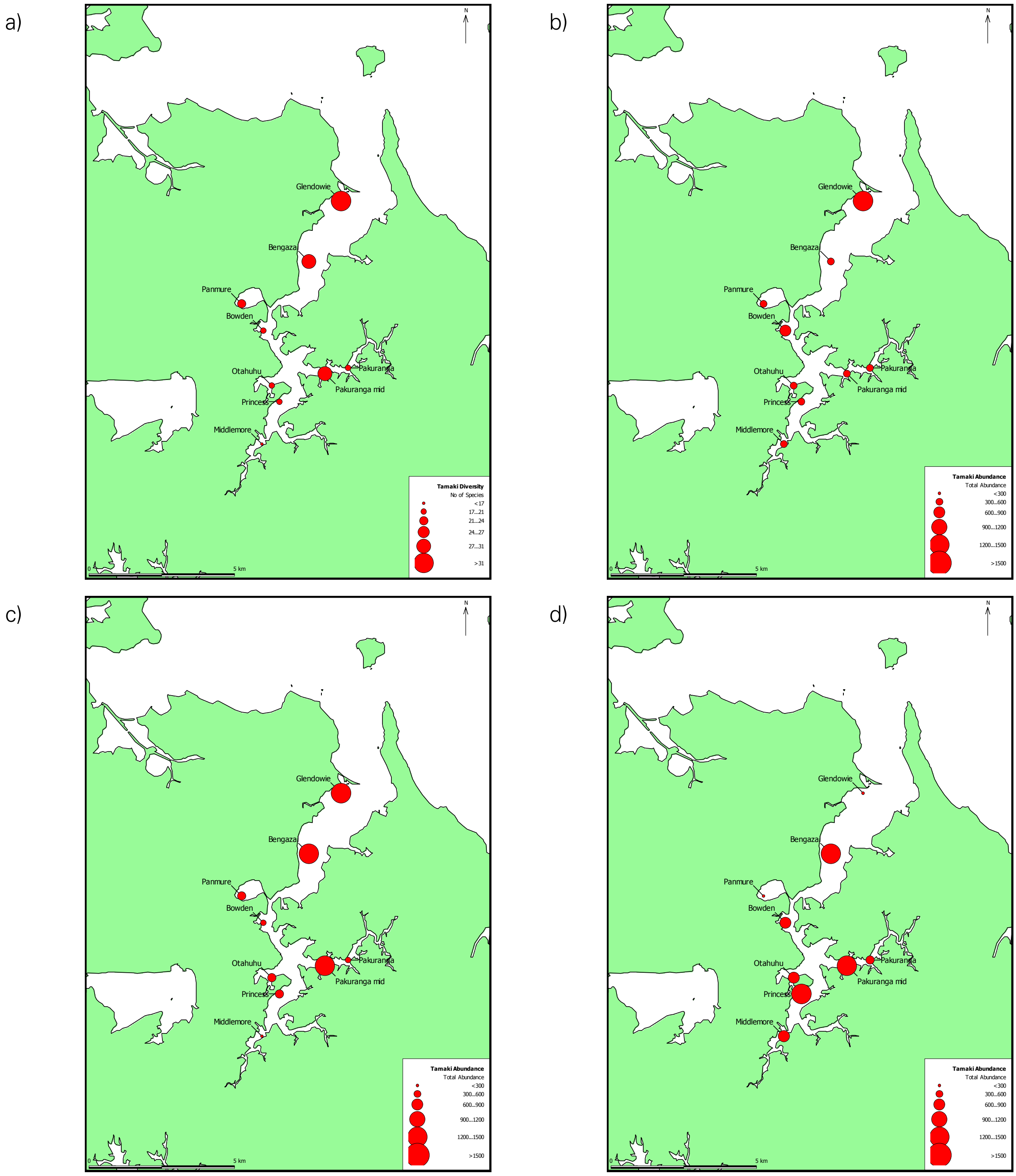
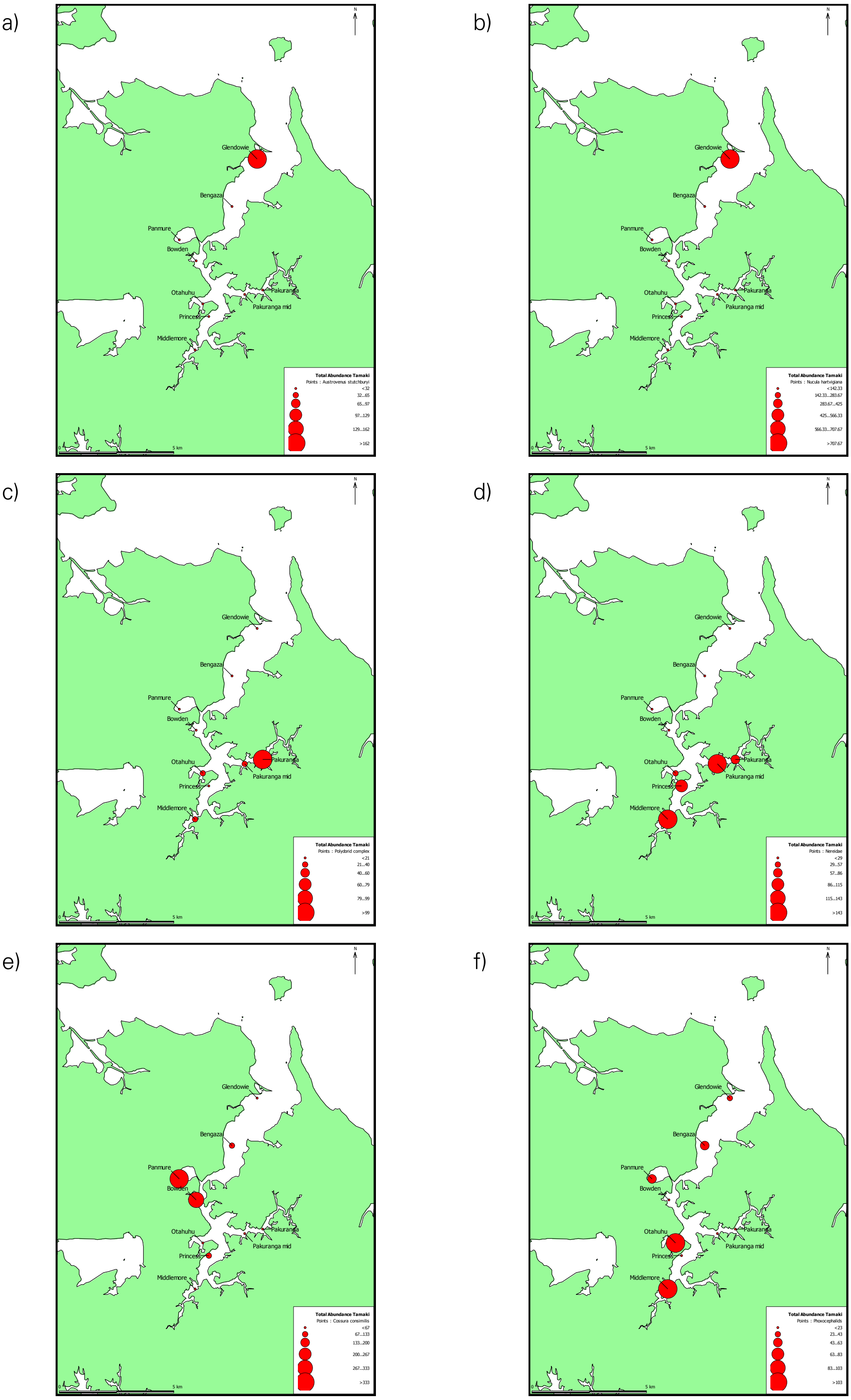


Figure 20

Total abundance of a) cockles *Austrovenus stutchburyi*, b) nut shells *Nucula hartvigiana*, c) Polydorids, d) Nereidae, e) *Cossura consimilis*, and f) Phoxocephalids.



A characterisation of benthic macrofaunal associations in the upper Tamaki was carried out as part of an assessment of five potential locations for a combined cycle power station in the 1980s (Grange 1982). The locations being considered were: Mangere Inlet; Puketutu; Pahurehure Inlet; Whau Creek; and upper Tamaki Inlet. The upper Tamaki survey included sites from Panmure Bridge to Seaside Park at the southern entrance to Otahuhu Creek. Five species associations were identified, with a distinct change in the occurrence of these assemblages up the estuary (Figure 21). This change was most apparent near the entrance to Pakuranga Creek. The five associations identified by Grange (1982) were:

1. *Boccardia* / *Pectinaria* (both polychaetes).
2. *Anthopleura* (chiton) / *Amphibola* (gastropod).
3. *Theora* / *Mactra* (both bivalves).
4. *Helice* (crab) / *Lepidonotus* (polychaete).
5. *Macrophthalmus* (crab) / *Nicon* (polychaete).

The change in benthic assemblages up the estuary and the marked transition around Pakuranga Creek are consistent with the findings of more recent sampling (see Figure 20). Re-sampling of Grange's sites would be useful to examine the changes that have occurred in benthic communities since 1982 in more detail.

Habitat surveys of Tamaki Estuary were also carried out by Hayward and Morley (2005) who identified three biologically distinct zones: 1) the outer estuary with a breakpoint at Tahuna Torea; 2) the middle estuary between Panmure and Tahuna Torea; and, 3) the upper estuary above Panmure. Some species were found throughout the estuary, including the Pacific oyster Cassostrea gigas, acorn barnacle Austrominius modestus, half crab Petrolisthes elongates, and leathery slug Onchidella nigricans. However, biotic distributions generally reflected changes in water "quality" up the estuary, changes from sandy to muddy substrate, and changes in habitat diversity, particularly the availability of hard, rocky substrate.

Overall, species diversity was highest in the outer estuary where water quality is strongly influenced by coastal processes, and there is a relatively high degree of habitat diversity. Diversity declined up the estuary as reef habitat became scarce, water more turbid and sediments muddier. Sponge, ascidian, anemone, barnacle, shrimp, gastropod, bivalve, nudibranch, and chiton faunas were all more diverse in the outer estuary. Most echinoderms were also limited to the outer estuary, with occasional observations of the starfish, Coscinasterias muricata and cushion star, Patiriella regularis between Tahuna Torea and Panmure Bridge. Concomitant changes in species assemblages within these groups were also recorded, such as the loss of gastropods adapted to reef and sandy habitats and greater prevalence of gastropods adapted to muddy environments up the estuary.

A number of introduced species were also recorded during the surveys (Table 2). These ranged from well established, widely distributed species such as Pacific oysters, to very recently introduced species (eg the swimming crab *Charybdis japonica* and sea squirt *Styela clava*), and species whose distribution in New Zealand is limited to the Tamaki Estuary (eg the tube worm *Ficopomatus enigmaticus*).

Figure 21

Species associations that Grange (1982) identified to characterise the benthic communities present in the upper Tamaki Estuary. The assemblages are: *Anthopleura* / *Amphibola* purple diamonds; *Boccardia / Pectinaria* yellow circles; *Helice / Lepidonotus* blue downward pointing triangles; and, *Macrophthalmus* / *Nicon* green upward pointing triangles; *Theora* / *Mactra* light blue squares. The spatial distribution of these assemblages illustrates the changes in the benthic community that occur up the estuary. Actual locations were taken from maps presented in the original report and are therefore approximate.

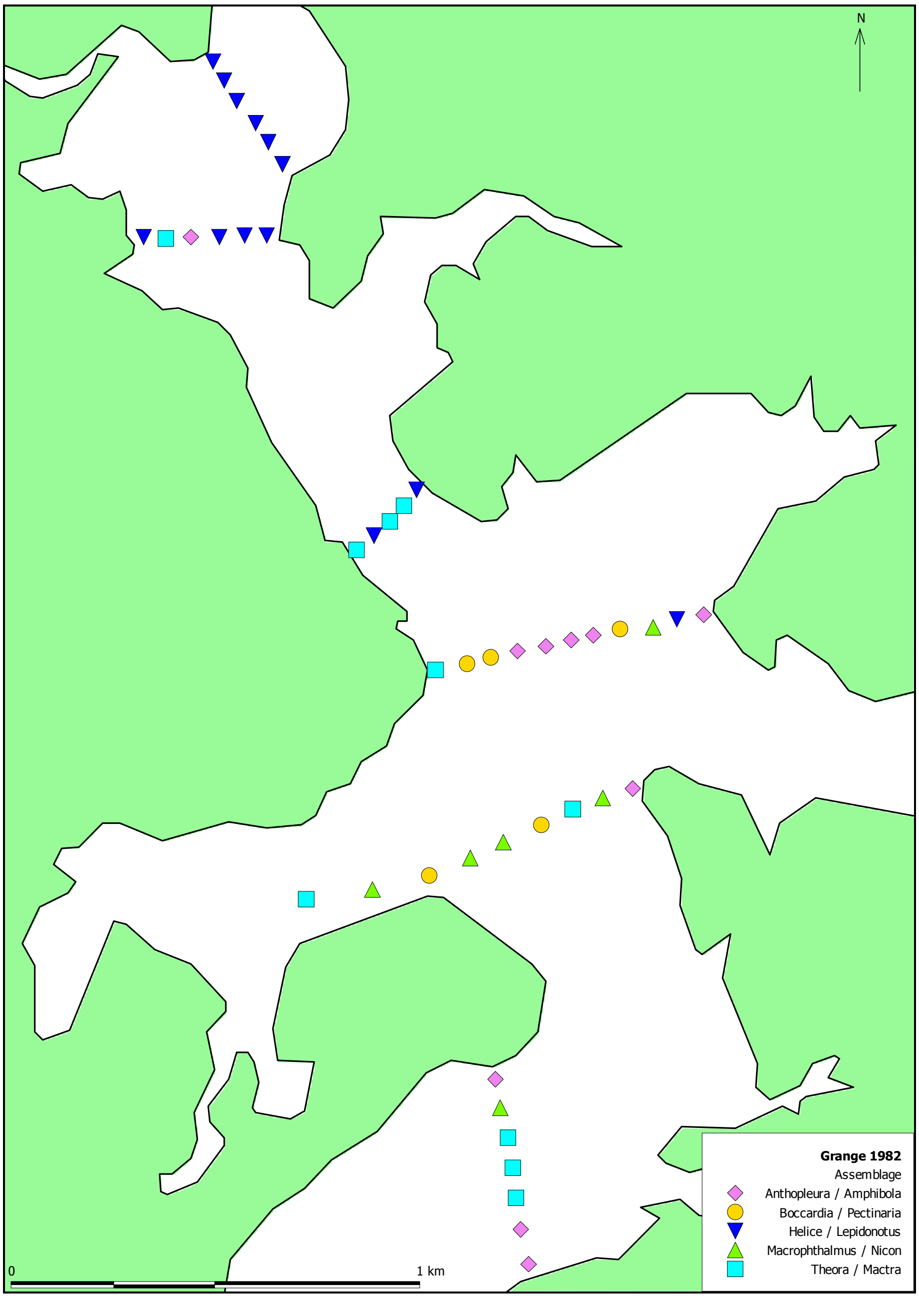


Table 2

Introduced species recorded from the Tamaki Estuary by Hayward and Morley (2005).

Species	Description	Locations
Crassostrea gigas	Pacific oysters	Widespread.
Musculista senhousia	Asian date mussel	Widespread patches.
Limaria orientalis	File shell	Pt England and Buckland Beach.
Theora lubrica	Bivalve	Central and outer parts of the estuary.
Charybdis japonica	Swimming crab	Entrance, Musick Pt. Tahuna Torea to Karaka Bay.
Balanus Amphitrite	Barnacle	Otara Lake weir.
Chaetopterus sp.	Parchment worm	Entrance to Tahuna Torea.
Ficopomatus enigmaticus	Calcareous tube worm	Otara Lake.
Watersipora sp.	Bryozoa	Outside the entrance at Achilles Pt.
Styela clava	Sea squirt	Entrance to Tahuna Torea.
Codium fragile ssp.	Seaweed	Entrance to Panmure Bridge.
Colpomenia durvillaei	Seaweed	Bucklands Beach around Musick Pt to Eastern Beach.
Hydroclathrus clathratus	Seaweed	Low tidal reefs near Karaka Bay and Bucklands Beach.
Arenigobius bifrenatus	Bridled goby (fish)	Widespread.

Foraminiferal[2] records obtained from sediment core samples have also been used to reconstruct the ecological history of Panmure Basin in relation to human activity in the adjoining catchment (Hayward *et al.* 2004). Significant changes have occurred in the composition of foraminiferal communities (from predominantly calcareous to predominantly agglutinated forms). These changes appeared to be associated with declining water salinity within the lagoon, which was attributed to increases in freshwater run-off as the catchment was deforested and impervious surfaces increased during urban development.

Morrisey *et al.* (2003) examined changes in benthic communities subject to urban stormwater run-off and included Pakuranga Creek as an impact site. The faunas of the two urbanised estuaries studied (Pakuranga and Hellyers) were similar to each other, but different to the non-urban sites (Paremoremo and Te Matuku). The authors concluded that this was consistent with an impact of contaminants derived from urban stormwater run-off. However, they noted that differences in faunas between the urban and non-urban estuaries were not clear-cut and the relationships between environmental variables and benthic fauna were not consistent through time.

3.6.2 Birds

Maps produced from Ornithological Society surveys indicate that the Manukau Harbour, southern Waitemata Harbour and Tamaki Estuary are national "hotspots" of bird diversity in coastal habitats (Robertson *et al.* 2007). The northern Manukau is also a "hotspot" for nationally critical endangered bird taxa (threat code 1), and the northern Manukau, southern Waitemata and Tamaki Estuary are hotspots for nationally vulnerable (threat code 3)

---

[2] Foraminifera are marine, single celled protozoa that secrete intricate calcareous or agglutinated shells.

endangered bird taxa. All three areas contain extensive sand and mudflats, which are a rich food resource for shore birds. An approximately three-hour tidal difference and the narrow distances between the Manukau Harbour and the Waitemata and Tamaki Estuary, also allow waders to extend their feeding times by easily moving between east and west coasts.

The Tamaki is utilised by a range of New Zealand resident and migratory shore birds, with the mid-to-lower reaches being particularly important due to the availability of roosting and feeding areas. The value of these areas is recognised through the designation of coastal protection areas and areas of significant conservation value (Figure 3 and Table 1). The Atlas of Bird Distribution in New Zealand (Robertson *et al.* 2007) indicates that up to 31 coastal bird species frequent the Tamaki and/or adjoining area (Appendix 4). Of these, 11 species have been classified as threatened (Hitchmough *et al.* 2007), with five species having threat codes 2 or 3[3] (ie grey duck (2), New Zealand dotterel (3), Caspian tern (3), reef heron (3) and wrybill (3)).

The outlet to Panmure Basin is also notable for its large, pied shag colony. Little and black shags, white-faced herons, gulls and kingfishers also frequent that area (Cameron *et al.* 1997). Tahuna Torea is a particularly high value "natural" area, with scrub, wetland, saltmarsh, estuary, shellbank, and sandflat habitats. Accordingly, the area is used by a variety of coastal and wetland birds. Barfoot (2007) provides the following list of 25 "shore and water" birds specifically from Tahuna Torea (compiled by M. Taylor, Ornithological Society July 2007). This list includes:

Banded dotterel
Bar-tailed godwit
Black-backed gull
Caspian tern
Gannet
Grey duck
Knot
Little black shag
Little shag
Mallard
Masked (spur-wing) plover
New Zealand dotterel
New Zealand kingfisher
Paradise shelduck
Pied oystercatcher
Pied shag
Pied stilt
Pukeko
Red-billed gull
Reef heron
Royal spoonbill
Variable oystercatcher
White-faced heron
White-fronted tern
Wrybill

The most common waders are the pied oystercatcher in autumn and winter (Figure 22), and godwit in summer. Together with pied stilts and knots, these can be seen seasonally on the coastal fringe and spit during high tide or feeding on the mudflats during low tide (Cameron *et al.* 1997). Hayward and Morley (2005) also list 15 species of bird observed during ecological surveys of Tamaki Estuary, of which 13 could be considered coastal or wetland species. Bird diversity tended to be greater in the mid-to-outer estuary, but mallard duck, white-faced heron, reef heron, pied oystercatcher, kingfisher, black-backed gull and red-billed gull were recorded in the Otara Lake area.

Dowding and Moore (2006) noted that the large upper Manukau flock of wrybill has an important feeding site in the upper Tamaki River (which is often used by 1000 birds or more); and concluded that it is a critical site for the species, but since it is not a roost site it does not feature in the usual lists of important sites.

---

[3] Threat code 1 equates to nationally critical, 2 nationally endangered, and 3 nationally vulnerable.

Figure 22
Black-backed gulls and South Island pied oystercatchers on the tip of Tahuna Torea spit during high tide.

3.6.3 Fish

Fish data from Tamaki Estuary is relatively limited. Barfoot (2007) lists five marine species from Tahuna Torea (from Conway 2005) which include: flounder (species not specified), yellow-eyed mullet, kahawai, Australian oyster blenny, and parore. Hayward and Morley (2005) list 16 species recorded during their surveys, or collected by Larcombe (1973), Auckland Museum and Kingett Mitchell and Associates (1996) (Table 3). Species recorded by Kingett Mitchell and Associates (1996) are of note, because data was obtained from upper reaches of the estuary and grey mullet are unusual on the east coast.

Based on information from nearby east coast areas (Francis *et al.* 2005), it would also be reasonable to expect to find species like speckled sole, sand flounder, snapper, estuarine stargazer, anchovy, sand goby, and estuarine triplefin. In Tamaki Estuary, speckled sole and sand flounder would be expected to be more common in the muddier, mid-to-upper estuary, whereas others such as snapper and estuarine stargazer would be expected to be more common in the outer estuary.

Table 3
Fish recorded from Tamaki Estuary in Hayward and Morley (2005). Sources are: H&M – Hayward and Morley (2005); L – Larcombe (1973); Auckland Museum – AK; and, Kingett Mitchell and Associates (1996) – KM.

Species	**Common name**	**Source**
Acanthoclinus fusus	Olive rockfish	H&M
Aldrichetta forsteri	Yellow-eyed mullet	KM
Arenigobius bifrenatus	Australian bridled goby	AK
Forsterygion lapillum	Common triplefin	H&M
Forsterygion nigripenne	Cockabully	L
Forsterygion varium	Variable triplefin	H&M
Galaxias maculates	Inanga	KM
Girella tricuspidata	Parore	AK
Gobiomorphus cotidianus	Common bully	KM
Gobiomorphus gobioides	Giant bully	KM
Gonorynchus gonorynchus	Sandfish	AK
Lissocampus filum	Pipefish	AK
Mugil cephalus	Grey mullet	KM
Notolabrus celidotus	Spotty	KM
Retropinna retropinna	Smelt	KM
Rhombosolea leporine	Yellow-belly flounder	KM

3.6.4 Vegetation

The most widely distributed and abundant coastal plant in Tamaki Estuary is the mangrove *Avicennia marina*. The distribution of mangroves was plotted using GIS and 2006 aerial photographs (Figure 23). The total area covered by mangrove forest in the Tamaki Estuary is approximately 186 ha. Mangroves are most prevalent in the upper estuary (ie above Panmure Bridge), and most abundant in the sheltered, muddy tributaries. Around 80 per cent of mangrove cover occurs within Pakuranga Creek, Otahuhu Creek, Otara Creek and Middlemore (west of the motorway bridge), with approximate areas of:

- Pakuranga Creek – 67 ha;
- Otahuhu Creek – 18 ha;
- Otara Creek – 33 ha; and
- Middlemore – 32 ha.

Smaller areas of mangrove occur in the Tahuna Torea lagoon and in small embayments on the eastern shore.

Forests are typically denser, and trees larger on the channel margins, with large areas of smaller, less dense trees behind. Mangrove forests also become patchier and less dense toward the mouth of the estuary. Lichens such as old man's beard *Usnea* and *Ramalina* commonly grow on tree trunks and branches, and patches of the dark, red algae *Catenella nipae* grow on lower trunks and pneumatophores of mangroves (Hayward and Morley 2005).

The Tahuna Torea area contains significant areas of regenerating forest, scrub, swamp and saltmarsh. Accordingly, it has a relatively wide variety of coastal plants, which include trees, shrubs, grasses, sedges, and rushes (see Barfoot 2007 for species lists). Haywood and Morley (in press) also identify areas of salt marsh between Curlew Bay and Tahuna Torea, and indicate that the best developed area of higher tidal salt meadow is in a small area on the northern, landward side of Tahuna Torea. This area contains patches of white flowering sea primrose, saltwort and yellow flowering Bachelor’s button. Two small patches of the invasive coastal cord grass, *Spartina* spp. were also recorded near high tide level between Curlew Bay and Seaside Park.

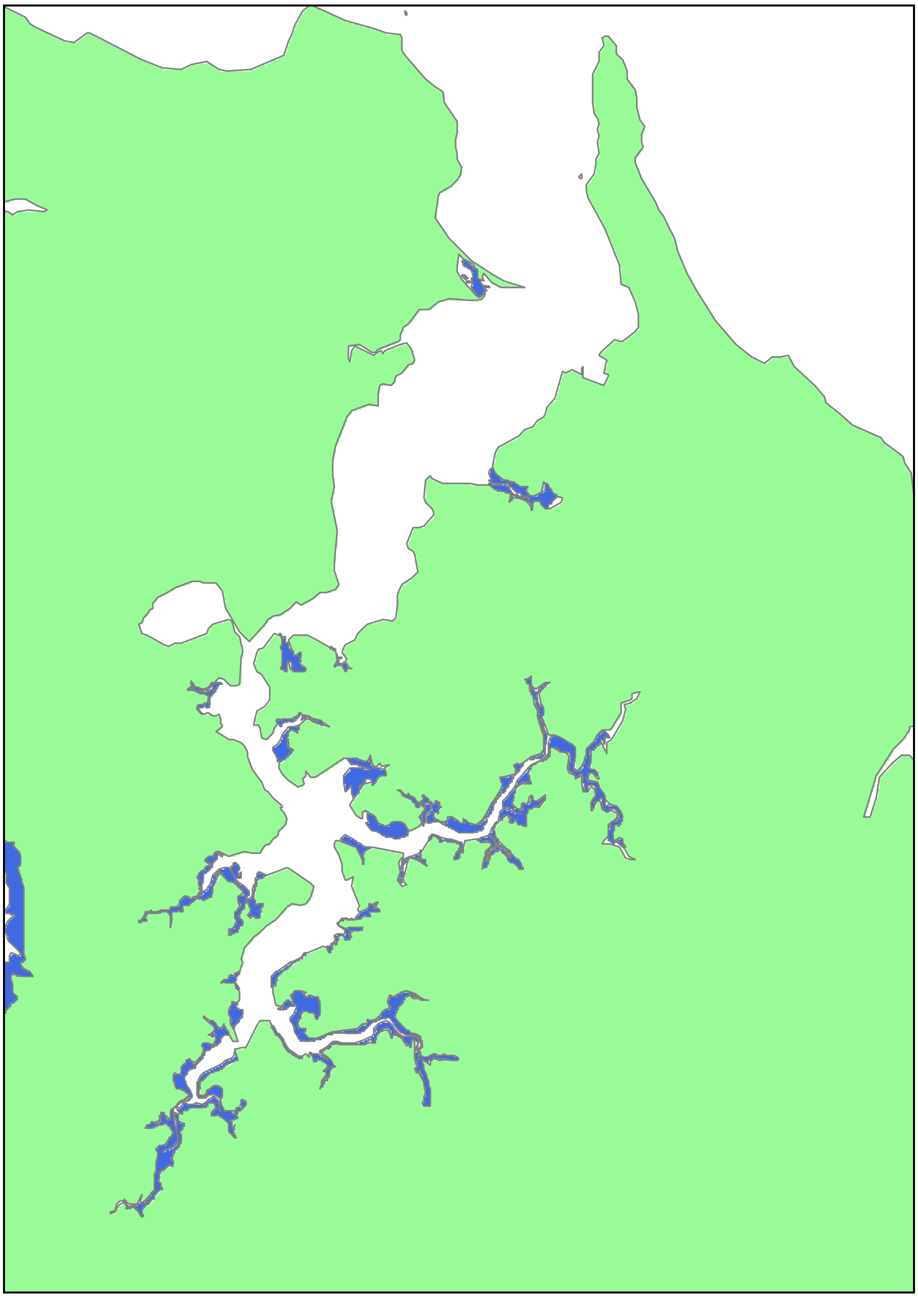
Salt marsh also occurs in the upper reaches of Wakaaranga Creek, which is dominated by mixed rushes, oioi *Leptocarpus similis*, wiwi *Juncus maritimus*, and giant umbrella sedge *Cyperus ustulatus* (Haywood and Morley in press). Ribbonwood, pohuehue and associated lichens also occur on higher ground.

A large patch of seagrass, *Zostera muelleri* covers most of the low tide sandflats along a 1km stretch of Karaka Bay, at the entrance to Tamaki Estuary. Smaller patches also occur off Tahuna Torea and in sandy areas between reefs outside the entrance of the estuary (Hayward and Morley 2005).

A relatively diverse range of intertidal and subtidal macroalgae (seaweeds) also occurs in rocky areas of the outer Tamaki. Hayward and Morley (2005) recorded 15 to 22 algal species at sites north of Tahuna Torea. Algal diversity was lower at sites between Panmure and Tahuna Torea (5-17 species) and lowest at sites above Panmure (six or fewer species).

Figure 23

Mangrove distribution (blue shading) in the Tamaki Estuary obtained from 2006 aerial photographs.



4 Mangere Inlet

4.1 General description

Manukau Harbour is New Zealand's second largest harbour with a total area of c. 370 km^2 at mean high water spring (MHWS) and catchment area of c. 870 km^2 (Vant and Williams 1992). The harbour is a well flushed, meso-tidal, coastal lagoon, with extensive areas of intertidal sand and mud flats. The surface area of the harbour is reduced by c. 60 per cent at low spring tide, with the exposure of broad, low-gradient tidal flats and banks covering 145 km^2 (Bell *et al.* 1998).

Mangere Inlet in the north-eastern corner of the harbour has an area of 6.6 km^2 and a catchment of 34.5 km^2 (Hume 1979). The northern shore of the inlet is highly modified due to port activities, roading and coastal "reclamation". This has led to the loss of three embayments at the inlets to historic streams, and also the loss of tidal inundation to the Hopua volcanic crater forming Onehunga Basin. Ann's Creek remains in the north-east corner of the inlet, although it is highly modified with only a short section of open stream remaining. Extensive "reclamation" along the eastern shore of Mangere Inlet was also carried out in the 1960s, in relation to the development of the Westfield rail yards (Matthews *et al.* 2005). The southern shore is less modified, with inlets to Harania and Tararata Creeks still largely intact, although the upper reaches of both creeks are dissected by high volume roads. Both creeks are heavily forested with mangroves. The eastern shore is immediately bordered by the Westfield railway yards, with industrial-commercial land use beyond (Figure 24). Likewise, fringing land use along the northern and south-eastern shores is predominantly industrial-commercial.

The inner inlet (above Mangere Bridge) is dominated by extensive areas of intertidal mudflats. A small island, Ngarango Otainui, is located at the eastern end. West of this is a shelly shoal that extends southeast-northwest on the eastern edge of the large, central mudflat. This shoal appears on the 1853 marine chart (Drury *et al.* 1853), indicating that it has persisted for 150+ years. Similarly, in 1853 the substrate was described as "soft black mud" suggesting that sediments within the inlet have always been muddy. This observation is consistent with sediment textures in core samples (Matthews *et al.* 2005). An extensive mangrove fringe extends along the eastern and southern shores of the inner inlet, and parts of the northern shore. They are less common beyond Mangere Bridge.

Outer parts of the inlet (west of Mangere Bridge) are more energetic, but are still relatively muddy. The northern shoreline of outer Mangere Inlet has been modified by the construction of Onehunga Wharf and the south-western motorway (State Highway 20). The southern shore is relatively unmodified, except in the area of Mangere Bridge and the reclamation forming the foreshore reserve in the vicinity of the Claresholm St boat ramp.

Figure 24
Westfield railway yards bordering the eastern margin of Mangere Inlet.

The inlet and its catchment has a long history of human use and development, due to the fertile volcanic soils, abundant marine life and the narrow corridor of land that separates it from the east coast. Mangere Inlet was strategically important because of the narrow corridor of land that separates it from the upper reaches of Otahuhu Creek on the east coast. This feature was utilised by both Maori and early Europeans, as its low elevation and short distance eased the portage of canoes and boats between the east and west coasts and, together with the Waiuku portage, also provided a critical link to the Waikato River. The short extent of the portage was highlighted by an early British trader, Walter Brodie, who claimed to have dragged a whale across it in forty minutes (Stone 2001). The western end of the portage is now occupied by the Westfield railway yards (Figure 24).

In pre-European times the Auckland isthmus, including the north-eastern Manukau, was home to many thousands of Maori. Forests were cleared by Maori colonisers for horticulture and to promote the growth of fern bracken. Kumara, yams, taro, and gourds were grown in extensive gardens during extended periods of peace. These periods were interspersed with times of warfare, where the population declined and gardens became overgrown with fern bracken and scrub (Stone 2001).

Intensive European settlement of the Mangere area began in the mid-1800s. Matthews *et al.* (2005) summarise the key development phases that have occurred since European settlement. Early Europeans established a settlement at Onehunga in the 1840s, and by the 1850s the area around Mangere Inlet was Auckland's agricultural centre. In the 1860s the Maori Land Wars lead to the establishment and growth of Otahuhu, where troops were stationed. In the 1870s numerous small industries were becoming established around the inlet including meat works, tanneries, and brickworks. The railway line was constructed along eastern foreshore by 1875. In the 1880s continuing industry growth was centred on Westfield shoreline where wastewater was directly discharged into the inlet. Urban and industrial development expanded during the 1900s, with ongoing discharges leading to the environmental degradation of the inlet. Gladsby *et al.* (1988) and Williamson *et al.* (1992) list the types and locations of direct industrial discharges. These included:

- three large meat works;
- an abattoir;
- three phosphate fertiliser works;
- two wool scours;
- fellmongeries;

- soap and candle works;
- a wood-pulp works;
- a battery works;
- a woollen mill;
- a tannery; and
- a glue works.

In addition, the inlet received inputs from: Middlemore Hospital; Otahuhu Borough Council's septic tank; leachate from various refuse tips; run-off from the Otahuhu railway workshops and later from the Pacific Steel plant at Otahuhu. During the 1950s, the decomposition of organic wastes stranded on the mud flats got so bad that it led to sulphate reduction under anaerobic conditions, which resulted in complaints about the smell of hydrogen sulphide and blackening of lead paint on houses in adjacent suburbs (Gladsby *et al.* 1988). In 1962, the Mangere Sewage Purification Works was opened and took the household and industrial wastes that were previously discharged into the inlet. This led to a significant improvement in environmental quality. From the 1970s to 1990s landfills on the northern coast of Mangere Inlet led to the "reclamation" and straightening of that shoreline (Matthews *et al.* 2005). In 2001, the Mangere Wastewater Treatment Plant was upgraded, and the areas previously occupied by oxidation ponds were returned to the harbour.

Eight primary coastal protection areas (CPAs 19 to 25) are either in, or in the immediate vicinity of, Mangere Inlet (Figure 25 and Table 4). Coastal protection area 22 is divided into two sub-areas, and CPA 3 is divided into three sub-areas. The primary reasons for the CPA designations are:

- Geology and landforms: CPA23b, CPA25.
- Wading birds: CPA23a-c, CPA24, CPA25.
- Mangroves: CPA21.
- Shrublands and saline vegetation: CPA21, CPA22a, CPA22b.
- Intertidal mud or sandflats: CPA22a, CPA23a-c, CPA24.

One sediment, and associated contaminant, settling zone was identified in ARC (2002a) and included in the Auckland Regional Plan: Coastal (Figure 25). The rationale for the determination of settling zones is provided in ARC (2002a and 2002b). At the time of writing, Auckland City Council and Metrowater were undertaking a technical review to determine whether these designations are appropriate (see Appendix 3: Depositional Zones Identified by Auckland City Council – Metrowater).

Figure 25

Coastal protection areas (CPAs) and areas of significant conservation value (ASCV) in Mangere Inlet. The sediment and contaminant settling zones identified in the Auckland Regional Plan: Coastal are also shown.

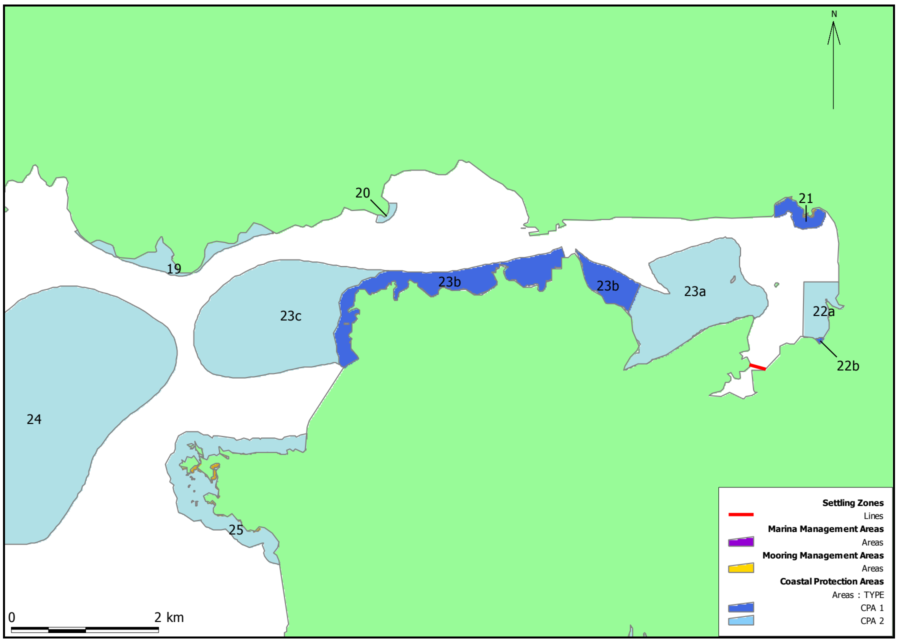


Table 4

Coastal protection areas (CPAs) and areas of significant conservation value (ASCV) in Mangere Inlet.

Protection type	**CPA / ASCV No.**	**Description**
Coastal Protection Area 2 & Area of Significant Conservation Value	19 / 7	**Cape Horn**: Important coastal forest remnants adjoin the coastal marine area along this stretch of coast. Firm papa reefs below the cliff grade quickly into a muddy intertidal flat near the channel edge. The bays also support a diversity of fauna. Waders and coastal birds feed throughout the area.
Coastal Protection Area 2 & Area of Significant Conservation Value	20 / 7	**White Bluff**: Geological exposure of complexly deformed Waitemata Group rocks showing faults and folds both below Mean High Water Springs and in the cliffs above. The site is one of the best examples of its type in the region and is considered to be regionally important.
Coastal Protection Area 1 & Area of Significant Conservation Value	21 / 7	**Ann's Creek**: Mangroves in the intertidal area form part of a unique gradient with the only significant remaining piece of native shrublands on lava flows in the Tamaki ecological district. The shrubland is the first ever collection site of the shrub, *Coprosma crassifolia*.
Coastal Protection Area 2 & Area of Significant Conservation Value	22a / 7	**South East Mangere** Inlet: Small upper intertidal area supporting a high diversity of native saline vegetation. To seawards is a diverse maritime marsh and small raised banks of clean sand supporting several species of plants characteristic of such areas. In the intertidal areas below the vegetated areas are extensive upper intertidal mudflats with dense populations of characteristic species.
Coastal Protection Area 1 & Area of Significant Conservation Value	22b / 7	**South East Mangere Inlet**: Small upper intertidal area supporting a high diversity of native saline vegetation. In the south-east corner (22b) is a 0.25 ha meadow of batchelor's button, *Cotula coronopifolia*.

Protection type	CPA / ASCV No.	Description
Coastal Protection Area 2 & Area of Significant Conservation Value	23a – c / 59 & 7	**Ambury**: This modified shoreline (23b) is used as a high tide roost by thousands of international migratory and New Zealand endemic wading birds including a number of threatened species. It is the most important winter roost on the Manukau Harbour for South Island Pied Oystercatchers. The associated intertidal banks (23a, 23c) are a feeding ground for these birds and a variety of other coastal bird species. The rocky area (23b) contains the best example of pahoehoe lava flows in New Zealand. These are located on the northern side of Kiwi Esplanade. For these reasons, this site has been selected by the Department of Conservation as an Area of Significant Conservation Value (ASCV).
Coastal Protection Area 2 & Area of Significant Conservation Value	24 / 7	**Te Tau Bank East**: This intertidal sandbank contains large numbers of shellfish, including edible species and species uncommon elsewhere in the Manukau Harbour. It is an important feeding area for wading birds.
Coastal Protection Area 2 & Area of Significant Conservation Value	25 / 7	**Puketutu Island**: A regionally important, isolated compound volcanic centre, with tuff ring remnants, scoria cones, and lava fields which enter the marine environment around the coast of the island. The island is used as a high tide roost by a variety of wading birds including several threatened species.

4.2 Hydrodynamics

Tidal ranges in Manukau Harbour are among the highest in New Zealand (Hume *et al.* 1992), and are amplified inside the harbour, from mean spring and neap heights of 2.7 m and 1.5 m respectively at the harbour entrance to 3.4 m and 2.0 m respectively at Onehunga Wharf in Mangere Inlet (Bell *et al.* 1998). Peak current velocities of up to 1.8 $m.s^{-1}$ can occur at the harbour entrance (Heath *et al.* 1977), but strong currents also occur at constrictions in other parts of the harbour. For instance, peak velocities at the neck of Mangere Inlet reach 1.0 $m\ s^{-1}$ during spring tides and 0.5 $m.s^{-1}$ during neap tides (Bell *et al.* 1998).

Peak current velocities, from the harbour entrance up to the mid-reaches of the main harbour channels, coincide with mid-tide during both the flood and ebb tidal phases (Bell *et al.* 1998). However, in the upper reaches of the harbour, peak currents occur closer to high water. For example, the peak-flood velocity at Onehunga Wharf occurs 1.75 h before high water and peak ebb occurs 2.5 h after high water (Bell *et al.* 1998).

Tidal-driven circulation dominates over wind-driven in most of Manukau Harbour except higher up in the intertidal areas. In those areas, wind-driven circulation is characterised by downwind flows over intertidal sand banks, with pressure-driven return flows in the deeper main channels (Bell *et al.* 1998).

The average annual residence time for water in the north-eastern Manukau Harbour (including Mangere Inlet) were estimated to be 12.6 days (Vant and Williams 1992). However, freshwater replacement times in summer can be half that in winter because net freshwater inflows can at times be negative ie losses to evaporation are greater than inputs from rainfall and inflows. Williamson *et al.* (1996) found that mass fluxes of suspended sediment in Mangere Inlet were greater during the flood than the ebb tide, and concluded that the inlet acted as a sediment and contaminant sink.

The hydrodynamics of Mangere Inlet were also modelled as part of the Coastal Receiving Environment Assessment (CREA) carried out by Auckland City Council and Metrowater

(Croucher *et al.* 2005a and 2005c). That work indicated that during large storm events, stormwater discharges increased flow velocities around consolidated outfalls located in the shallower parts of Mangere Inlet and Hillsborough Bay. Changes in flow velocities were not easily discernable at other locations or during small storm events.

4.3 Sediment characteristics, accumulation and contamination

4.3.1 ARC monitoring and investigations

Sediment samples are collected from three sites in Mangere Inlet at 2- to 5-year intervals (Figure 26). Samples are analysed for the concentrations of copper, lead and zinc in the fine (<63 μm) and total (<500 μm) sediment fractions (McHugh and Reed 2006, Kelly 2007b). Galai particle size analysis has also been carried out on sediments collected from these sites to monitor long-term changes in sediment characteristics (note that statistical analyses of sediment texture have not been carried out). A one-off analysis of tin, arsenic, cadmium, mercury, and antimony was also carried out at the two state of the environment (SoE) monitoring sites in Mangere Inlet in 2005 (Ann's Creek and the cemetery site). The concentrations of a range of organic compounds are also determined periodically at these sites (Reed and Webster 2004, McHugh and Reed 2006). The organic compounds include PAHs, PCBs, DDT, chlordane, lindane, dieldrin, methoxychlor, endosulfan, hexachlorobenzene.

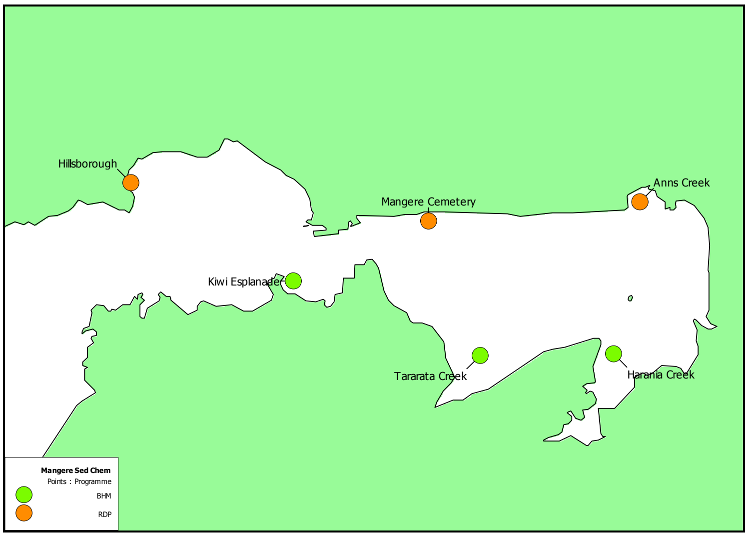
A one-off analysis of copper, lead and zinc concentrations in samples from three additional sites on the southern shore of the inlet was also carried out on 2006 (Harania and Tararata Creeks, and Kiwi Esplanade). This data was used in the development of the benthic health model (see Anderson *et al.* 2006).

Wet sieved, sediment grain size data has also been collected from all six sites in Mangere Inlet. This data is used to assist in the interpretation of ecological responses to stormwater contamination (Anderson *et al.* 2006, Kelly 2007b). Sediment texture is presented as percentage weight in: gravel (>2mm), coarse sand (2mm to 500 μm), medium sand (500 μm to 250 μm), fine sand (250 μm to 63 μm) and silt and clay (<63 μm).

Raw data from the above programmes were obtained for Mangere Inlet, re-plotted and summarised below.

Figure 26

Auckland Regional Council sediment monitoring and investigation sites in Mangere Inlet. Orange sites are stormwater contaminant monitoring sites (ie RDP sites, which include two state of the environment (SoE) sediment contaminant monitoring sites, namely Cemetery and Ann's Creek). Green sites were additional sites used in the development of the benthic health model (Anderson *et al.* 2006).



Principle co-ordinate analysis (Figure 27) and plots of raw Galai data (ie volume of sediment) (Figure 29) indicate that the Hillsborough site has markedly different sediment characteristics compared with the Mangere Cemetery and Ann's Creek sites. Sediments at the Hillsborough site have a high proportion of material in the 125 to 500 μm size fraction (by volume), whereas sediments at the other two sites are dominated by material in the <125 μm sediment fraction. Galai data also differentiated the Ann's Creek and Mangere Cemetery sites, by the amount of material in the <32 μm fraction, with Ann's Creek having a greater proportion of sediment in this size class. The results obtained from wet sieved sediments showed a similar gradient of an increasing proportion of fine sediments from outer to inner Mangere Inlet (Figure 28 and Figure 29).

Figure 27

Principal co-ordinate analysis of the volume of sediment in each of eight particle size classes (2.0 to 3.9 μm, 3.9 to 7.8 μm, 7.8 to 15.6 μm, 15.6 to 31.3 μm, 31.3 to 62.5 μm, 62.5 to 125 μm, 125 to 250 μm, and 250 to 500 μm) from three sites from Mangere Inlet: Hillsborough, Ann's Creek and Mangere Cemetery.. Sediment texture is similar for sites that are close together in the plots and dissimilar for sites that are widely separated. The overlying vector diagram indicates the influence (in terms of direction and strength) of each particle size class on the observed distribution. Sediment volumes were estimated using Galai particle size analysis.

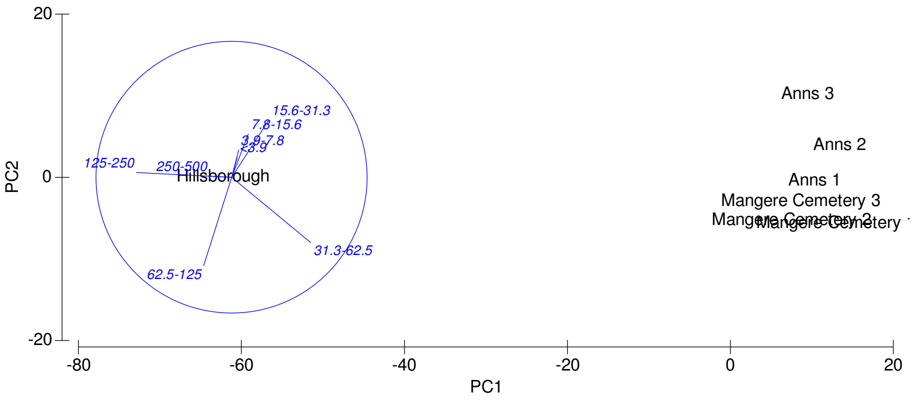


Figure 28

Principal co-ordinate analysis of sediment weight (as a per cent of total weight) in each of four particle size classes (<63 µm, 63 to 125 µm, 125 to 500 µm, and >500 µm) obtained by wet sieving samples from sites in the Mangere Inlet. Samples were collected for ecological monitoring and the associated development of ARC's benthic health model (Anderson *et al.* 2006). Sediment texture is similar for sites that are close together in the plot and dissimilar for sites that are widely separated. The overlying vector diagram indicates the influence (in terms of direction and strength) of each particle size class on the observed distribution.

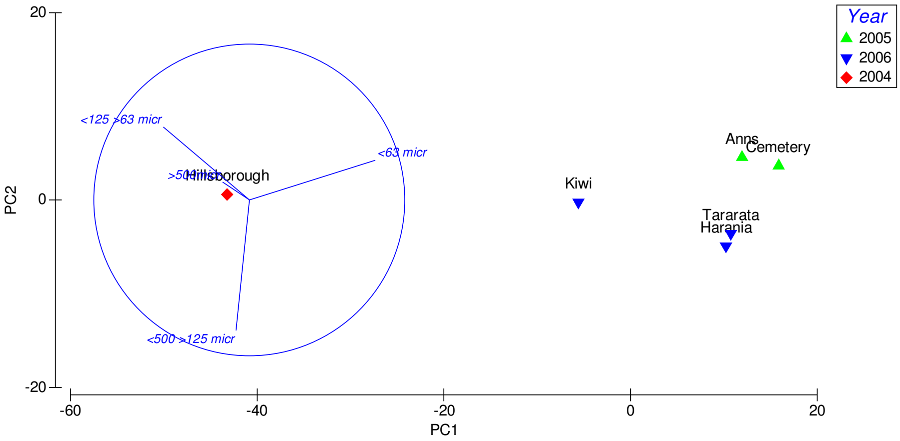
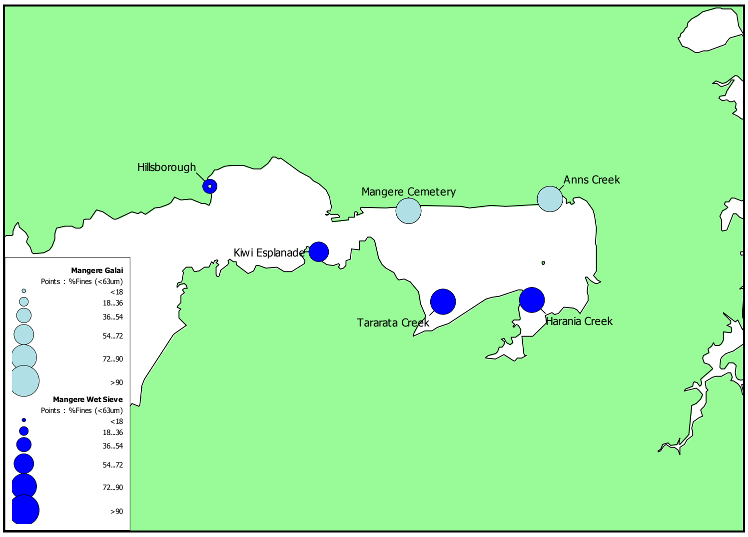


Figure 29

Distribution of fine sediment (<63 µm) in Mangere Inlet. The size of the circle is proportional to the percentage of fines. Dark circles represent percent weight values obtained from wet sieved sediments, and light circles represent sediment volume obtained from Galai analysis.

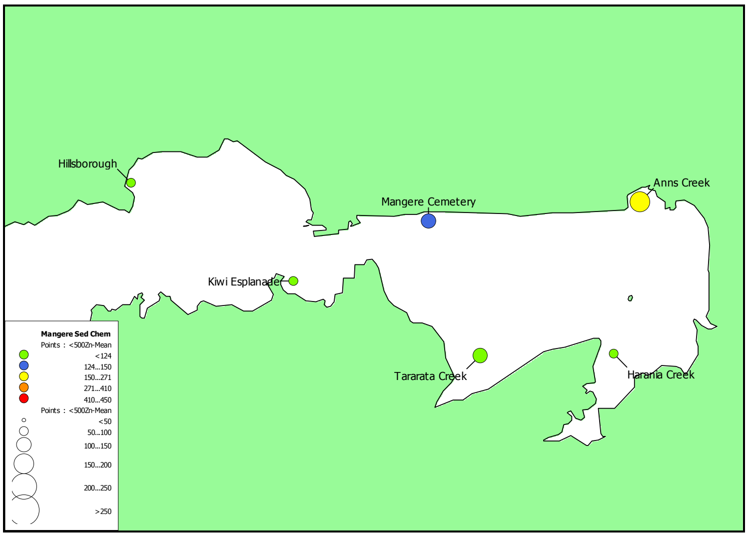


The sediment-contaminant monitoring and investigations carried out by the ARC since 1998 have been using comparable methods of sample collection and contaminant analysis. These programmes provide a robust set of sediment quality data for the estuary. Data on copper, lead and zinc concentrations were pooled from three ARC datasets: SoE monitoring, stormwater contaminants monitoring, and the benthic health model (Appendix 1). Contaminant concentrations are compared against a number of sediment quality guidelines, which are described in Section 3.3.

Plots of the metals data indicate that highest concentrations of zinc, copper and lead occur in the inner, northern, Mangere Inlet sites, ie Ann's Creek and Mangere Cemetery (Figure 30 to Figure 32). Total zinc concentrations exceeded ERL sediment quality guideline values at Ann's Creek and exceed TEL values at Mangere Cemetery[4]. Total copper concentrations also exceeded TEL sediment quality guideline values (ie amber ERC values) at these two sites and lead concentrations exceeded TEL values at Ann's Creek. The total concentrations of all three metals were below sediment quality guideline values at the three sites on the southern shore of Mangere Inlet, and at the entrance to the inlet (ie at Hillsborough).

Figure 30

Map showing relative sediment concentrations of total zinc (mg/kg) in Mangere Inlet (see Appendix 1 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is <TEL, blue TEL – ERL, yellow ERL to PEL, orange PEL to ERM and red is > ERM). See Section 3.3 for a description of sediment quality guidelines.



---

[4] TELs are equivalent to the ARC's "amber" environmental response criteria (ERC), and ERLs are equivalent to the ARC's "red" ERCs - see Section 3.3 and Appendix 2: Sediment Quality Guidelines.

Figure 31

Map showing relative sediment concentrations of total copper (mg/kg) in Mangere Inlet (see Appendix 1 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is <TEL, blue TEL – ERL, yellow ERL to PEL, orange PEL to ERM and red is > ERM). See Section 3.3 for a description of sediment quality guidelines.

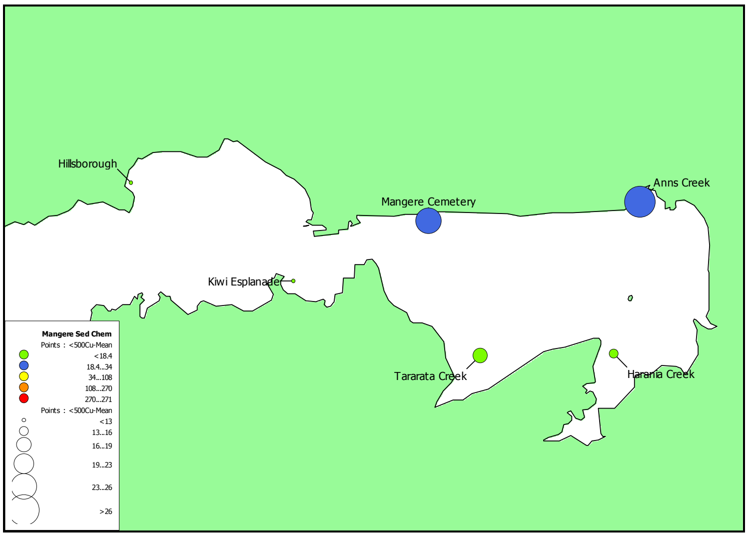
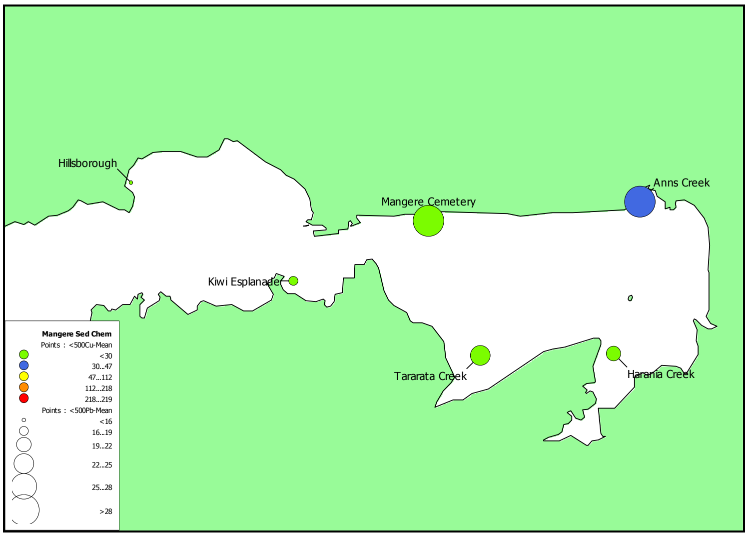


Figure 32

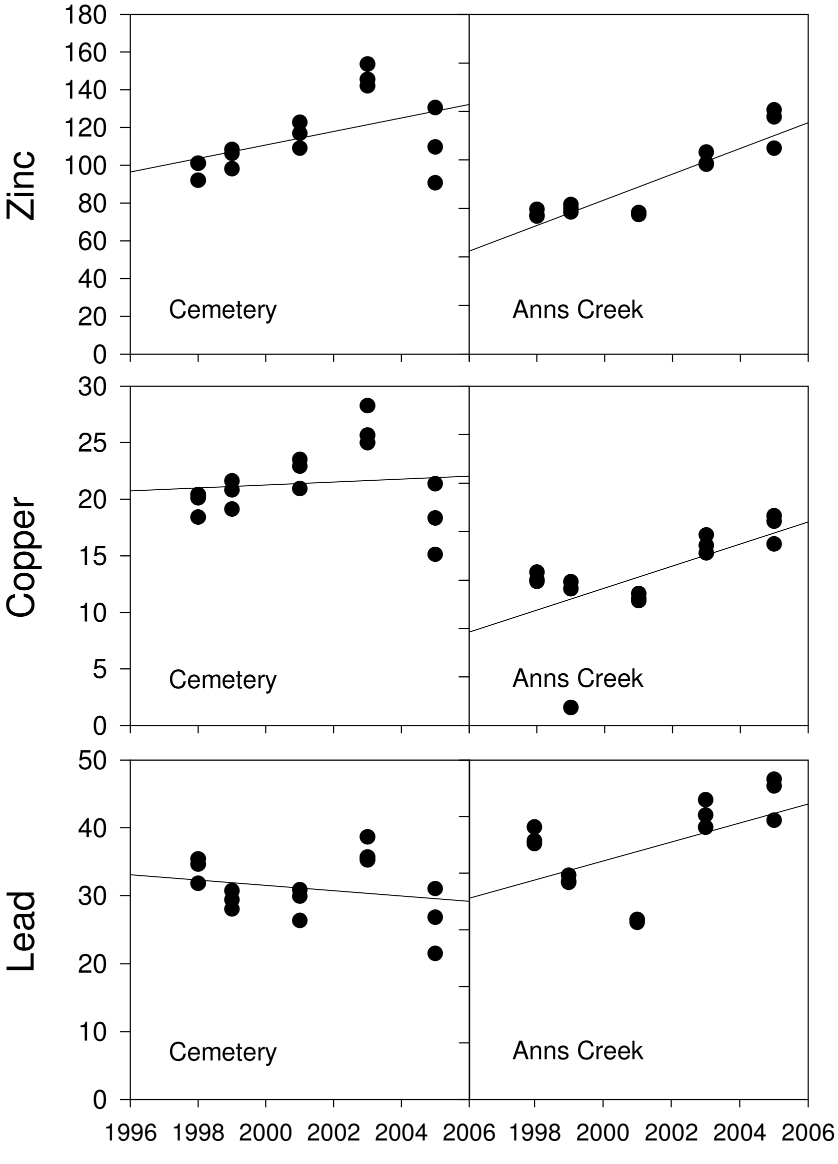
Map showing relative sediment concentrations of total lead (mg/kg) in Mangere Inlet (see Appendix 1 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is <TEL, blue TEL – ERL, yellow ERL to PEL, orange PEL to ERM and red is > ERM). See Section 3.3 for a description of sediment quality guidelines.



Repeated sampling of the Ann's Creek and Mangere Cemetery sites between 1998 and 2005 has allowed trends in the concentrations of copper, lead and zinc in the fine sediment fraction to be determined (McHugh and Reed 2006, Kelly 2007b). Linear regression indicates that, over that period, statistically significant increases have occurred in the concentration of copper, lead and zinc at the Ann's Creek site. Over that period, copper, lead and zinc concentrations in the fine sediment fraction of Ann's Creek have increased by 2.3, 1.7 and 13.2 mg/kg per year, respectively. Changes in the concentration of copper and zinc between 1998 and 2005 were not statistically significant at the Mangere Cemetery site, due to a concentration dip in 2005 (see Figure 33).

Figure 33

Trends in the concentrations (mg/kg) of zinc, copper and lead in the <63 µm sediment fraction (extracted using weak acid digestion) at the Mangere Cemetery and Ann's Creek monitoring sites in Mangere Inlet.



State of the environment monitoring of Ann's Creek and Mangere Cemetery also suggests that the sediment concentrations of most other metal and organic contaminants that have been measured are low, relative to sediment quality guideline values (Reed and Webster 2004, McHugh and Reed 2006). The exceptions are:

- dieldrin, which exceeds the ARC's environmental response criteria guideline value at both sites; and

- arsenic, which exceeds ERL sediment quality guideline values.

Highest arsenic concentrations occur in some of the "cleanest" SoE monitoring sites (eg Big Muddy Estuary, Long Bay and Cheltenham) (McHugh and Reed 2006), suggesting that arsenic levels are naturally elevated in marine sediments in the Auckland region. The concentrations observed in Mangere Inlet are therefore likely to be within the natural range, so arsenic contamination is not considered to be a significant issue. Total DDT concentrations also exceeded ERL values and were close to exceeding TEL values (ie red ERC values) in 2003.

A number of other studies have examined sediments and sediment contamination in Mangere Inlet. Core sampling indicates that sediment texture has been muddy in Mangere Inlet since pre-human times, but some variation has occurred since the arrival of humans (Matthews *et al.* 2005). Matthews *et al.* (2005) found that human activities had not changed the sediment texture on a mud bank in the central inlet. However, changes had occurred closer to the shore. Sediments at the outlet to Ann's Creek, changed from "muddy-sand" to "mud" during the Polynesian (pre-European) period and have remained relatively stable ever since. In contrast, the percentage of sand in sediments in the south-eastern inlet (north of the outlet to Fairburn's Creek at Westfield) increased over the Polynesian and early European periods. During this period sediments changed from "sandy-mud" to "muddy-sand". In the recent, late European period, sand content declined and sediments reverted back to "sandy-mud".

A detailed investigation of heavy metal pollution in Manukau Harbour was carried out by Gladsby *et al.* (1998), and also reported by Williamson *et al.* (1992). These studies determined the concentration of copper, lead, zinc, nickel, iron, cobalt, chromium, cadmium and magnesium at 135 samples collected throughout the Manukau Harbour. Metals were extracted from the <20 μm sediment fraction using HNO_3/H_2SO_4 digestion. Highest concentrations of copper, lead and zinc were obtained from the inner Mangere Inlet, and concentrations declined toward the entrance of the harbour. Chromium concentrations were also elevated within Mangere Inlet and showed similar patterns of decline toward the harbour mouth. Williamson *et al.* (1996) estimated suspended sediment and metal fluxes from Mangere Inlet and found that mass fluxes were greater during the flood than the ebb tide. Consequently, mobilised contaminants were returned to the inlet. This led to the conclusion that the inlet acted as a sediment and contaminant sink.

Roper *et al.* (1995) used sediments from Mangere Inlet to examine the effects of sediment contamination on the burial, crawling and drifting behaviour of the wedge shell *Macomona liliana*. Sediments from two sites from Mangere Inlet ("Mangere Inlet" and Harania Creek), one site adjoining Mangere Inlet (Granny's Bay), and one site in Hobson Bay were compared with "reference" sediments from one sandy site in the SE Manukau (Wairoa Island) and a muddy site in Raglan Harbour. The same experiments were also conducted on sediments that were chemically dosed to produce a range of copper and zinc concentrations.

Burial was slowed in sediments from all contaminated sites, but the effect was not statistically significant amongst sediments from Granny's Bay, Harania and Raglan Harbour (which had clean, muddy sediments). Significant levels of drifting occurred on sediments from Raglan and from some of the contaminated sites (Mangere Inlet and Hobson Bay). Crawling was unaffected. The results from the dosing experiment were less ambiguous, with strong burial, crawling and drifting responses with increasing concentrations of copper and zinc.

Williamson *et al.* (1995) examined metal partitioning in sediments from Mangere Inlet and the potential for metals to become permanently immobilised by diagenetic processes associated with bioturbation. Their results indicated that bioturbation affected sediment chemistry and in particular acid volatile sulphide (AVS) concentrations, the ratio of adsorbed to dissolved Mn^{2+} and the depth of reactive metal phases. However, metal immobilisation did not occur in the top 26 cm of sediment, leading to the conclusion that permanent immobilisation in the bioturbated layer was unimportant.

Watercare monitor the effects of the Mangere Wastewater Treatment Plant on the coastal environment in the north-east Manukau. Their programme includes the analysis of metal and organic contaminants in sediments and shellfish, water quality parameters, benthic macrofauna and the distribution and abundance of benthic macroalgae (Bioresearches 2007). The sediment monitoring component includes one site in Mangere Inlet (Onehunga Bay). Sediment contaminant concentrations at this site are generally consistent with those obtained from the ARC surveys of sites in Mangere Inlet.

Croucher *et al.* (2005c) provide predictions of sediment and zinc accumulation in 17 "deposition zones" in the north-east Manukau, using a particle tracking model and estimates of catchment sediment and zinc run-off from 16 consolidated outfalls. Predicted sedimentation rates ranged from 0.01 mm/year to 0.54 mm/year, with highest accumulation rates occurring in Hillsborough Bay. Other sheltered areas with elevated sediment accumulation rates (0.09 to 0.22 mm/year) included Harania Creek, Onehunga Bay, Tararata Creek and the northern shore if the inner inlet. The remaining sites had accumulation rates of <0.06 mm/year.

150-year predictions of zinc accumulation in the silt fraction were also provided for each of the deposition zones. Since 2005, Auckland City Council and Metrowater have collected more detailed land use information and are revising the zinc loads used in the CREA models. This information will be used to update predictions of zinc accumulation in Mangere Inlet, and may lead to substantial changes in the results. The following summary should therefore be treated with an appropriate degree of caution.

Highest accumulation rates and ultimate concentrations of zinc were predicted for Hillsborough Bay. Furthermore, zinc concentrations at this site did not reach an equilibrium during the simulation period. Ann's Creek and Harania Creek also had relatively high rates of increase and did not reach an equilibrium during the simulation period. However, the zinc concentrations at the end of the simulation period were substantially lower at these sites, compared with concentrations in Hillsborough Bay. Most other sites within the inner Mangere Inlet increased steadily over the simulation, to reach maximum concentrations slightly above or below ERM sediment quality guideline values. The other outer inlet sites generally stayed below ERM concentrations (see Section 3.3 for a description of sediment quality guidelines).

Reducing zinc loads by 35 per cent led to substantial reductions in ultimate zinc concentrations in Hillsborough Bay, but even 85 per cent reductions could not prevent ERM guideline values being exceeded. Zinc loads had to be reduced by 35 per cent and 75 per cent respectively to prevent ERM values being exceeded at Mangere Cemetery and Ann's Creek respectively.

4.4 Biological contamination

The ARC analyses metal and organic contaminant concentrations in mussels and oysters from the Mangere area as part of its Shellfish Contaminant state of the environment Monitoring Programme. The oyster monitoring component has been running almost continuously since 1987, whereas mussel monitoring only began in 1999. Data from the oyster programme (Kelly 2007a) are therefore presented here (note that Figure 14 contains data on organic contaminant concentrations in Mangere mussels).

The Manukau Oyster Monitoring Programme was initiated as part of the Manukau Harbour Action Plan (Auckland Regional Water Board 1987), following concerns over the environmental condition of the harbour. Initially 11 sites were monitored, however, following an assessment of 5 years data, the number of sites was reduced to four in 1992: Granny's Bay (at the entrance to Mangere Inlet), Cornwallis, Pahurehure, and Hingaia Inlets. The catchments adjoining these sites were selected to represent different land uses ranging from highly urbanised to those dominated by rural activity and/or bush.

Two groups of contaminants are assessed: key metals and organic contaminants (PAHs, DDT, dieldrin, chlordane, lindane and PCBs). Metal concentrations in Manukau oysters tend to be highly variable and do not provide much differentiation among sites. Consequently, sediment-metal concentrations are the preferred method of examining spatial and temporal trends in metals (see Section 4.3).

PAH concentrations in Granny's Bay oysters are similar to those in oysters from Pahurehure and Hingaia in the south-eastern Manukau Harbour, and have been reasonably variable since 1995 (ie since a consistent set of PAH congeners has been monitored – see Kelly (2007a)). No consistent temporal trends are apparent in PAH concentrations.

Highest levels of DDT have been recorded at Granny's Bay (c.f. other Manukau sites) in 13 of the 18 years that monitoring has occurred (Figure 34). A relatively large increase in DDT concentrations in Granny's Bay oysters occurred between 2000 and 2003, coincident with the decommissioning of the oxidation ponds at the Mangere Sewage Treatment Plant. However, concentrations have since dropped, and 2005 concentrations were the lowest recorded since 2001.

Concentrations of chlordane in Granny's Bay oysters have dropped exponentially since monitoring began in 1987, due to the phasing out, and eventual deregistration, of this group of compounds (Kelly 2007a) (Figure 34). The relatively large drop in the chlordane concentrations in oyster tissues between 1995 and 1996 is consistent with the longer term pattern of decline. However, concentrations increased slightly around the time when the Mangere wastewater treatment ponds were decommissioned, matching the rise in DDT concentrations at this site. Since 2003, chlordane concentrations in Granny's Bay oysters have returned to pre-2000 levels.

Levels of lindane and dieldrin have declined at all sites since 1987. Low concentrations of these contaminants have remained in oysters since then, with little differentiation between sites.

PCB concentrations declined in Granny's Bay oysters between 1995 and 1997, but rose again between 1998 and 2002 (Figure 34). Concentrations have subsequently declined, and in 2005 were the lowest recorded at this site. However, they are still significantly greater than the concentrations in oysters from other ARC monitoring sites in the Manukau Harbour.

Oyster metal concentrations are highly variable, but copper and zinc concentrations in oysters from the Granny's Bay, Pahurehure and Hingaia sites are greater than in oysters from the clean reference site at Cornwallis. There is some suggestion that interannual variability in the oyster concentration of zinc and copper is driven by cyclical climate patterns (ie the southern oscillation index) rather than stormwater run-off (Kelly 2007a).

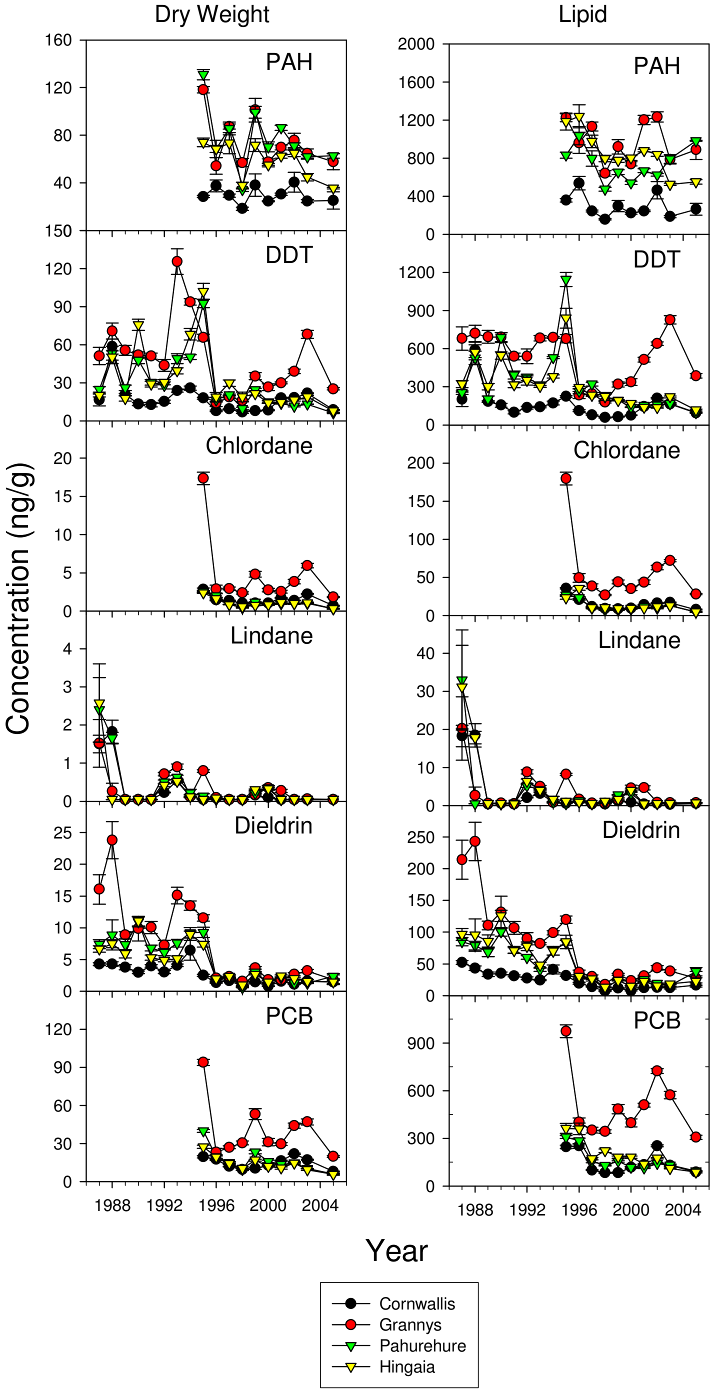
The results from the oyster monitoring programme are consistent with those of the mussel monitoring programme. Although the mussel programme has not been running as long as the oyster programme, it does include four east coast sites which allows broader geographical contrasts to be made (Kelly 2007a). Those data (see Figure 14) indicate that mussels in Mangere Inlet have:

- intermediate concentrations of PAH;
- consistently, the highest concentrations of chlordane and DDT;
- relatively high concentrations of dieldrin and PCBs; and
- low concentrations of lindane, which are similar to those of other sites.

Diggles *et al.* (2000) also found that the concentrations of organic contaminants were elevated in the livers and bile of yellow-bellied flounder caught around Onehunga. That investigation is covered in greater detail in Section 4.6.3.

Figure 34

Concentrations of organic contaminants in oysters collected from Cornwallis, Granny's Bay, Pahurehure, and Hingaia between 1987 and 2005. Data in plots on the left are expressed as ng/g oyster dry weight (± s.e.) and those on the left are expressed as ng/g lipid. Data below detection limits (DL) are presented as 0.5 x DL (from Kelly 2007a).



4.5 Water quality

The Auckland Regional Council has been continuously monitoring water quality in the Manukau Harbour since 1989. Monthly samples are collected by helicopter from six sites within the harbour. Samples are analysed for: temperature; salinity; turbidity; suspended solids; nitrate; nitrite; ammonia N; total and soluble phosphorus; faecal coliforms; enterococci; and, chlorophyll *a*. Information from two sites is relevant to Mangere Inlet: Mangere and Puketutu Island. A review of water quality data was being carried out at the time of writing, so recent statistical analyses were not available. The data was therefore plotted and visually assessed for temporal trends and other patterns, compared with other sites in the region (Kelly *et al.* 2006) and where available, compared against ANZECC (2000) water quality guidelines.

Water quality in Mangere Inlet is strongly influenced by the discharge from the Mangere Wastewater treatment plant. Consequently, the concentrations of nitrate, nitrite, ammonia-N, total phosphorus and dissolved reactive phosphorus at the Mangere and Puketutu sites are amongst the highest in the region (Kelly *et al.* 2006). A significant improvement in concentrations of ammonia-N has occurred since the commissioning of the Mangere Wastewater treatment plant upgrades, but nitrate and total phosphorus concentrations have become more variable, with a trend towards higher peak concentrations (Figure 35). ANZECC (2000) water quality guidelines recommend a nitrate low reliability trigger value of 0.7 mg/l and moderate reliability trigger value for ammonia-N of 0.91 mg/l at pH 8.0 (see ANZECC (2000) Section 8.3.7.2). Ammonia-N concentrations frequently exceeded this trigger level prior to the 2001 upgrade of the Mangere Wastewater Treatment Plant. Since 2001, ammonia-N concentrations have remained well below the trigger value. However, nitrate concentrations have gone from occasionally exceeding their trigger value to regularly exceeding it.

The values of most other parameters, including faecal coliforms and enterococci, tend to be within the ranges found at other harbour and estuarine sites in the Auckland region. The exceptions are suspended solid concentrations and turbidity at the Mangere Inlet site, which are generally high. Suspended solid concentrations and turbidity at the Puketutu site are lower than those at Mangere (Figure 35 and Figure 36), but are similar to sites in the Waitemata Harbour.

Historically, water quality at the Mangere site has been slightly poorer than at the Puketutu site (eg generally higher concentrations of suspended solids, nitrate, total phosphorus and lower dissolved oxygen concentrations (Figure 36)). However, the recent changes in the concentrations of nitrate and phosphorus mean that, apart from suspended solids, water quality is now generally better at the Mangere site.

Figure 35

Long-term trends in water quality in Mangere Inlet and Puketutu Island.

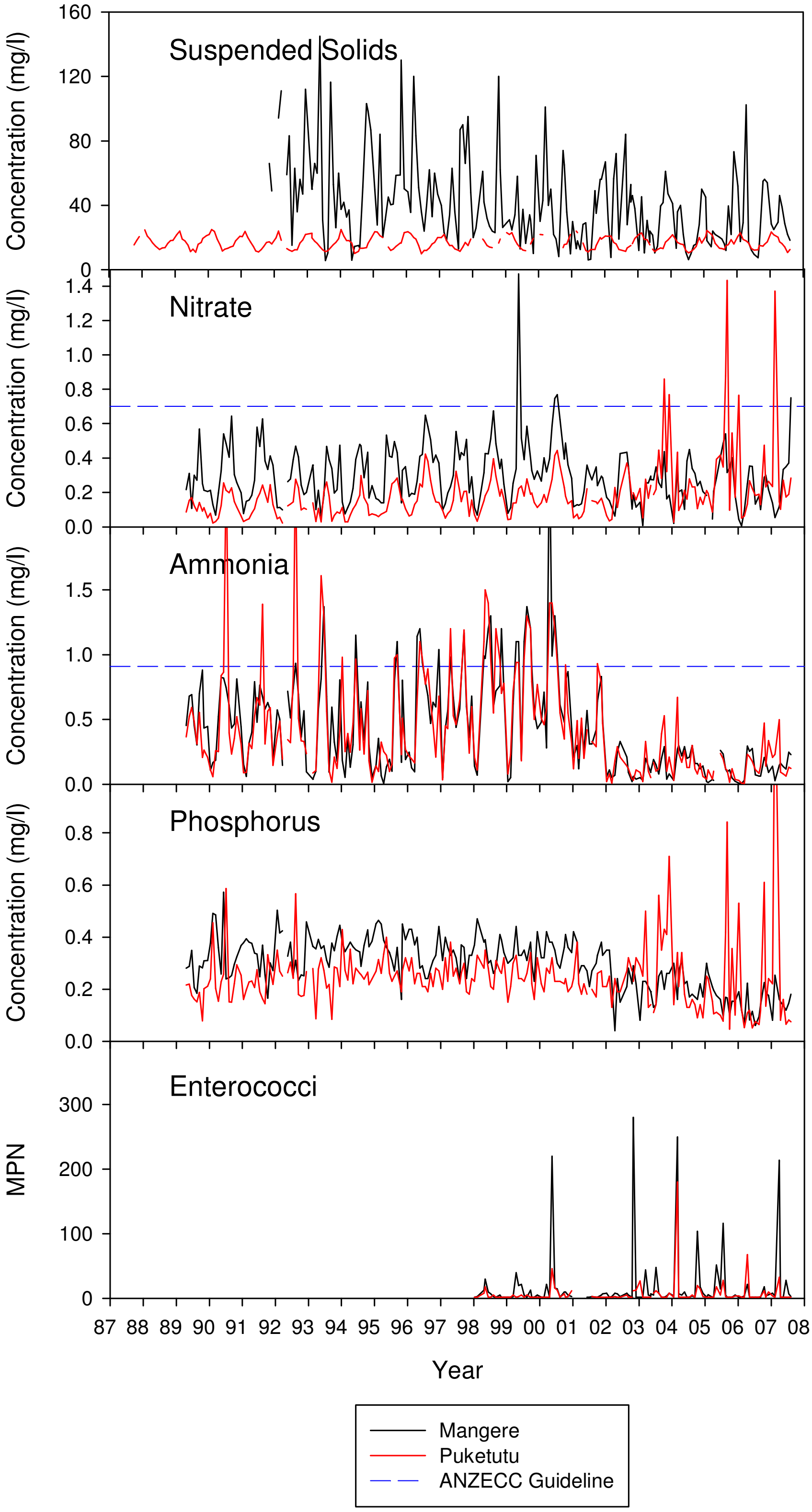
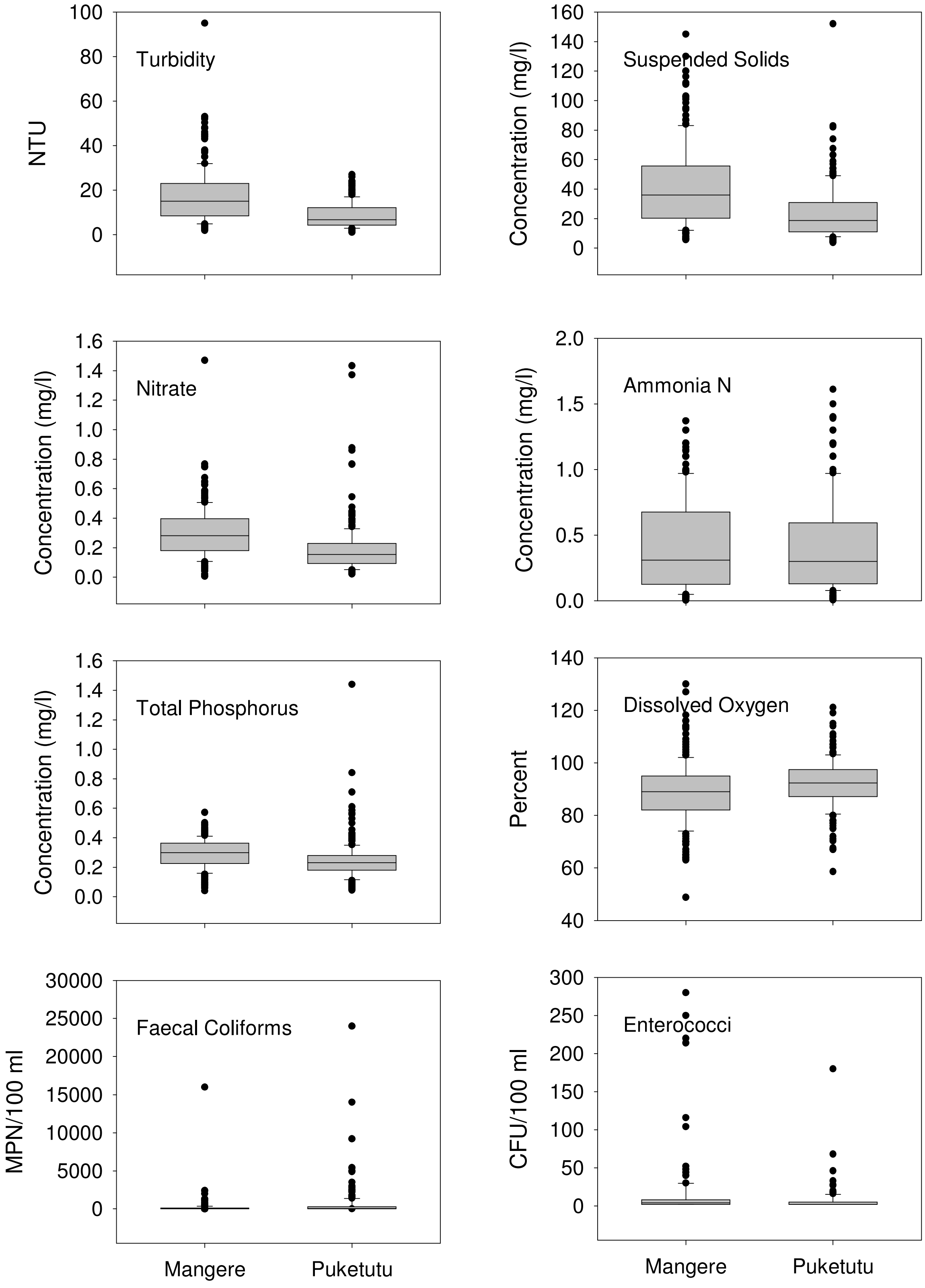


Figure 36

Boxplots of pooled 1989 – 2007 water quality from Mangere Inlet and Puketutu Island. The exception is Enterococci, which were measured from 1998. Boxes indicate median, 25th percentiles and 75th percentiles. Stems indicate 10th and 90th percentiles, while outliers are plotted individually.



4.6 Ecology

4.6.1 Benthic invertebrates

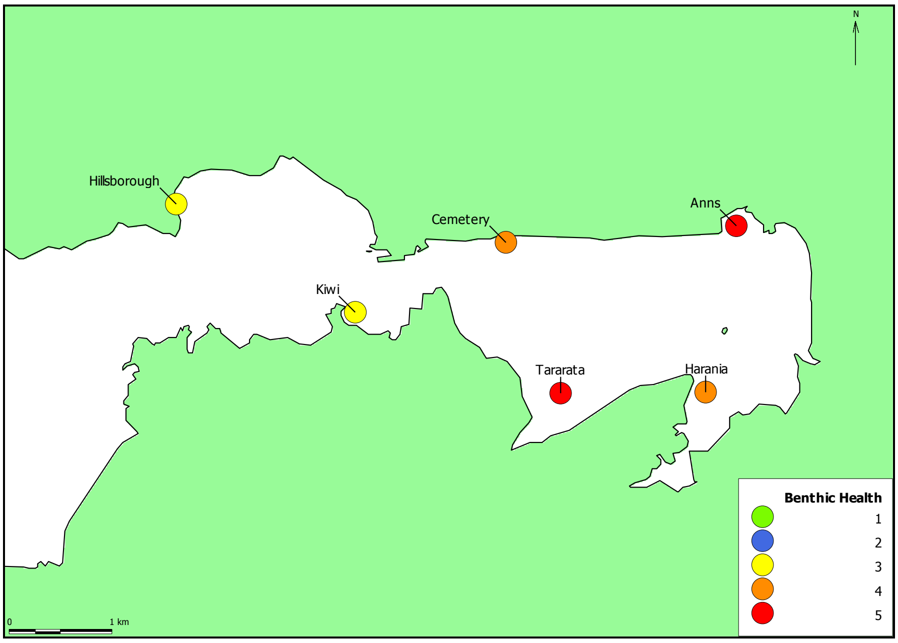
Benthic invertebrates in Mangere Inlet were sampled as part of the ARC's stormwater contaminant monitoring programme (Kelly 2007b), and for the development of the ARC's benthic health model (Anderson *et al.* 2006). Ecological samples were collected from six sites in Mangere Inlet: Ann's Creek; Mangere Cemetery; Hillsborough; Kiwi Esplanade; Tararata Creek; and, Harania Creek. The size of the sampling plot varied depending on the space available on the intertidal flats: ranging from 1000 m^2 (20 m x 50 m) to 10,000 m^2 (100 m x 100 m). Ten core samples (13 cm diameter x 15 cm deep) were collected from stratified random positions in each site. Stratification was used to avoid clumping of random samples. Ecological samples were sieved through a 0.5 mm mesh and preserved in isopropanol (70 per cent v/v). Sample sorting and taxonomic identification was carried out by NIWA Hamilton or the Leigh Marine Laboratory, with taxa being identified and enumerated to the lowest taxonomic level practical.

Ecological effects are assessed against a regional index of ecological condition (relative to stormwater contamination), which was derived from a study of the ecology, contaminant concentrations and physical characteristics of 84 sites spread throughout the Auckland region (Anderson *et al.* 2006). This index ranks the health of benthic communities from 1 (= healthy) to 5 (= degraded).

The ecological condition of benthic communities was degraded at all sites, but was worse at sites east of Mangere Bridge (Figure 37). Benthic communities at Ann's Creek and Tararata Creek had the worst condition (health rank 5), while the ecological condition of the Mangere Cemetery and Harania Creek sites was slightly better (health rank 4). The Kiwi Esplanade and Hillsborough sites had the best health rank of 3.

Figure 37

Ecological condition of benthic communities in Mangere Inlet. Health is ranked from 1 (green = healthy) to 5 (red = degraded).



The most recent data obtained for the benthic health model and stormwater contaminant monitoring were reanalysed to examine benthic biodiversity, total abundance, and the distribution patterns of a number of individual species. Benthic biodiversity (and species richness) was greatest at the Hillsborough site (26 species), and sites on the southern shore of Mangere Inlet (22 to 25 species) (Figure 38). The northern sites had low levels of diversity with Mangere Cemetery having 20 species and Ann's Creek, 13 species.

The combined, total abundance of all species was relatively high in Mangere Inlet. Greatest abundances occurred at Tararata, Ann's Creek and Mangere Cemetery, with counts of 1935, 1811, and 1757 respectively. These high counts were primarily due to the 10 to 30 mm, deposit feeding polychaete worm, *Heteromastus filiformis* (Figure 39c), which had total counts of 1682, 1349, and 1591 respectively. This species is relatively tolerant of degraded environmental conditions, and also dominated counts at the Harania and Kiwi Esplanade sites. The dominance of this species is reflected in the low value of Pielou's evenness index for these three sites (Figure 38d). Pielou's evenness index is a measure of how even (ie similar) the abundances of individual species are in a sample/site. Low index values indicate that the site is dominated by a single, or a few, species which occur in high abundance(s). The remaining species occur in relatively low abundances. In contrast, high index values indicate that the abundances of all species are fairly similar.

A number of other tolerant species were also associated with the inner Mangere sites. Relatively high numbers of neridae (highly mobile, 30 to 60 mm predatory polychaete worms) (Figure 39d), *Artritica bifurcata* (sedentary, 2 to 5 mm deposit feeding bivalves) (Figure 39e) and phoxocephalids (amphipods) (Figure 39f) occurred at one or more of these sites.

In contrast, relatively few *H. filiformis* were obtained from the Hillsborough site (total n = 49). This site had comparatively high numbers of cockles and wedge shells (Figure 39a & b), which are relatively sensitive to environmental degradation (total n = 67). Kiwi Esplanade was also noteworthy for the relatively high number of cockles.

Figure 38

Number of species (a), total abundance (b), Margalef's index of species richness (c) and Pielou's evenness index (d) of benthic dwelling macroinvertebrates in Tamaki Estuary.

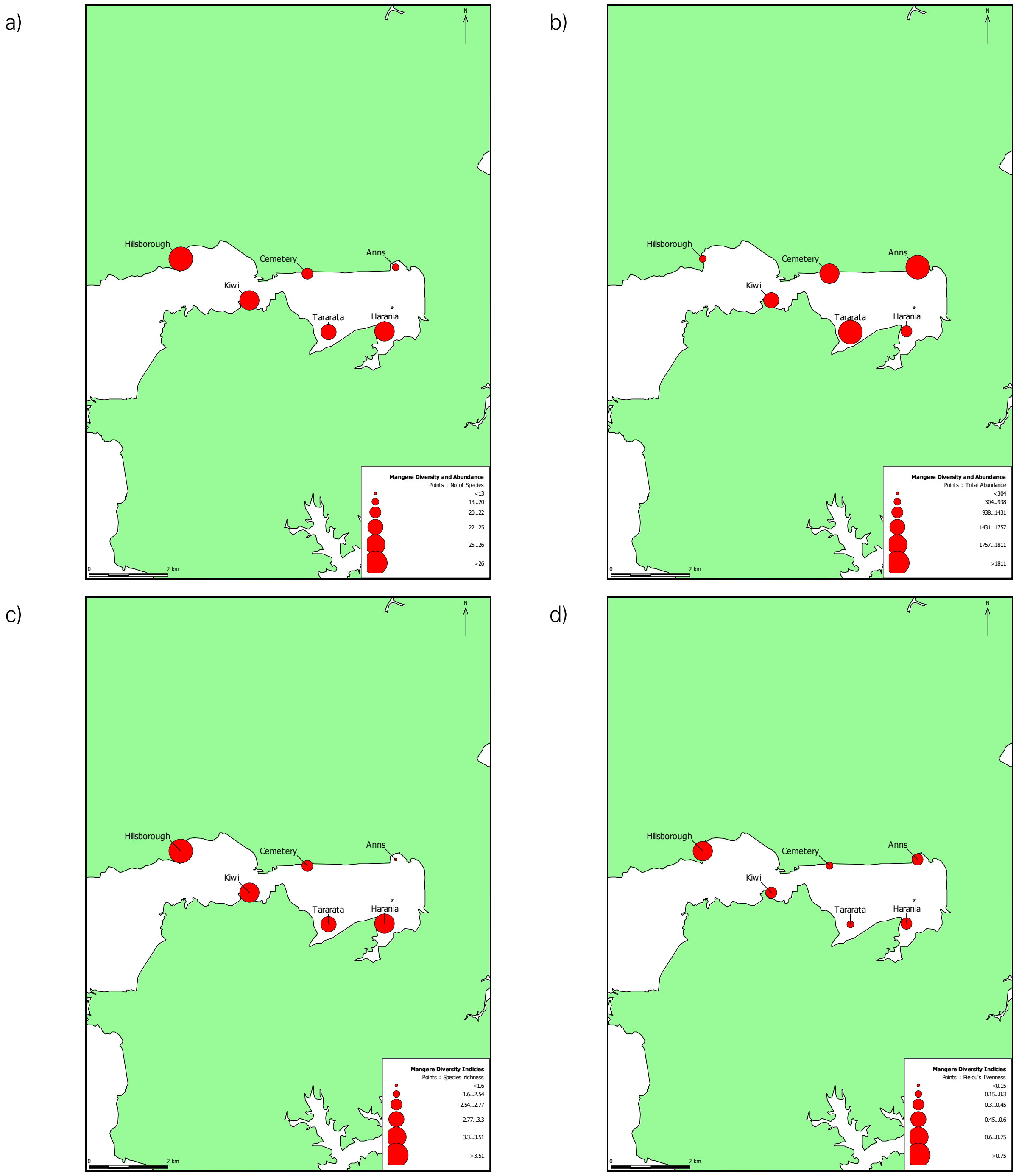
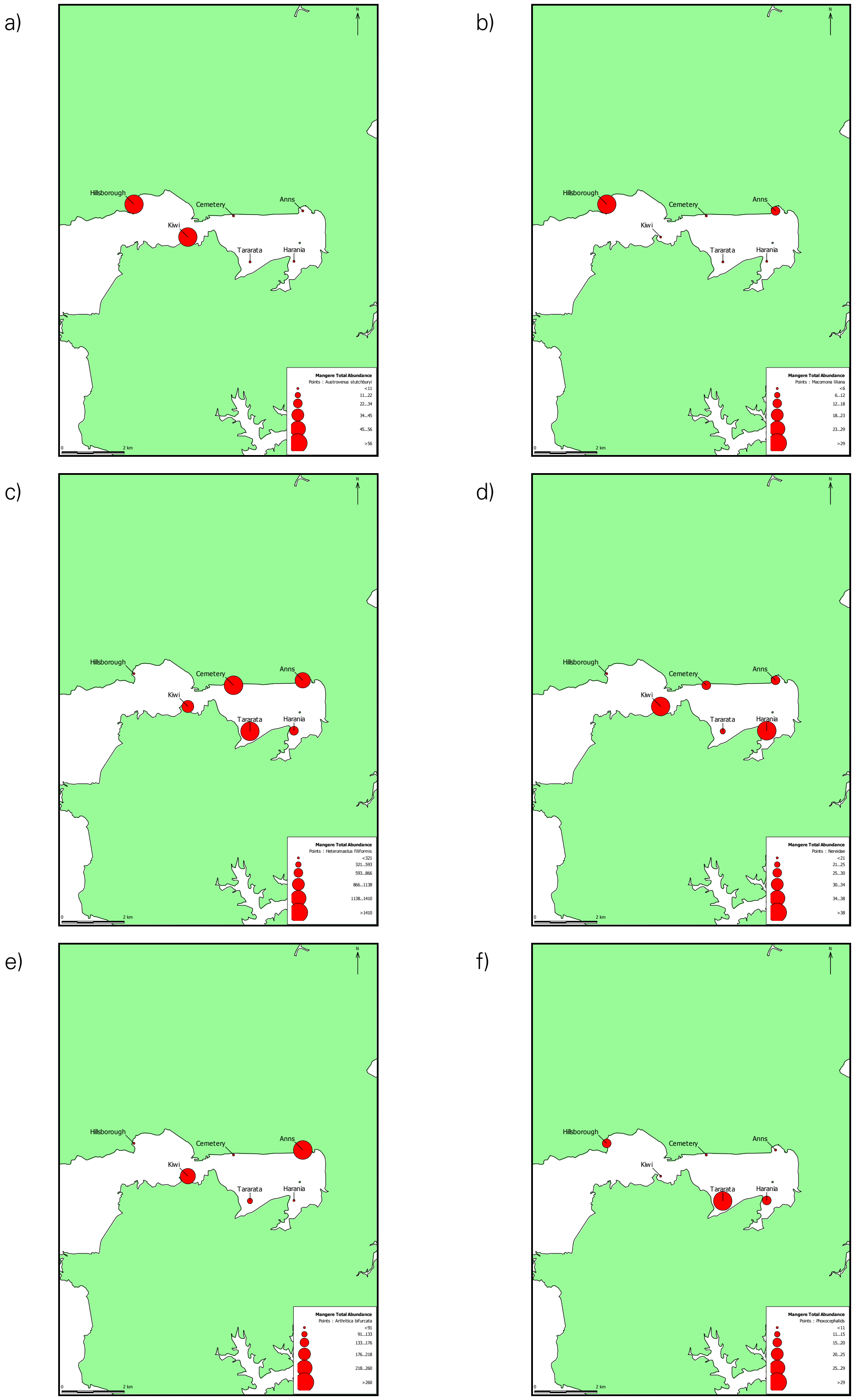


Figure 39

Total abundance of a) cockles *Austrovenus stutchburyi*, b) wedge shells *Macomona liliana*, c) *Heteromastus filiformis*, d) Nereidae, e) *Arthritica bifurcata*, and f) Phoxocephalids.

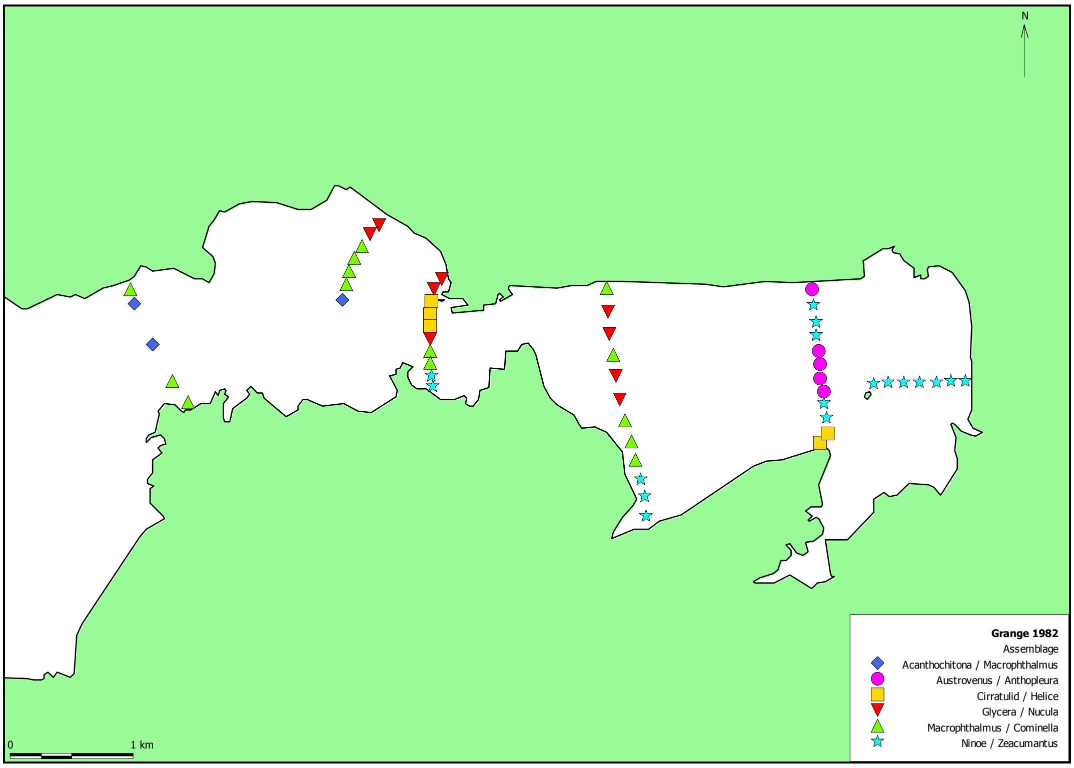


A characterisation of benthic macrofaunal associations in Mangere Inlet was carried out in the 1980s as part of an assessment of five potential locations for a combined cycle power station (Grange 1982). The locations being considered were: Mangere Inlet; Puketutu; Pahurehure Inlet; Whau Creek; and upper Tamaki Inlet. Six species associations were identified in Mangere Inlet, all with low numbers of species and individuals, and consequently low species-richness and species-diversity index values. Clear patterns were apparent in the spatial distribution of these species assemblages (Figure 40). Notable features included: a cockle (*Austrovenus*) and anemone dominated association in the east-central part of the inner inlet; a mud snail (*Zeacumantus*) and polychaete dominated association at the eastern end of the inner inlet and at creek outlets; and a crab (*Macrophthalmus*) and whelk (*Cominella adspersa*) dominated association, which was relatively widespread in outer parts of the inlet. Recent sampling indicates that cockles are still relatively common in many parts of Mangere Inlet, but they tend to be most abundant west of the Mangere Bridge (see Figure 39). Overall, the six species associations identified by Grange were:

1. Cirratulid / *Helice* association; off Onehunga wharf and southern point at entrance to Harania Creek.
2. *Austrovenus* (formally *Chione*) / *Anthopleura* association; eastern-central parts of inner inlet.
3. *Glycera* / *Nucula* association; western-central parts of inner inlet and outer inlet.
4. *Macrophthalmus* / *Cominella adspersa* association; western-central parts of inner inlet and outer inlet.
5. *Acanthochitona* / *Macrophthalmus* association: western-outer inlet.
6. *Ninoe* / *Zeacumantus* association: eastern shore of inner Inlet, Tararata Creek and Kiwi Esplanade.

Re-sampling of Grange's sites would be useful to examine the changes that have occurred in benthic communities since 1982 in more detail.

Figure 40
Species assemblages in Mangere Inlet identified by Grange (1982). The assemblages are: *Cirratulid / Helice* yellow squares; *Austrovenus / Anthopleura* purple circles; *Glycera / Nucula* red downward pointing triangles; and, *Macrophthalmus / Cominella* green upward pointing triangles; *Ninoe / Zeacumantus* light blue stars; and, *Acanthochitona / Macrophthalmus* blue diamonds. Actual locations were taken from maps presented in the original report and are therefore approximate.



Thrush and Roper (1988) and Roper *et al.* (1988) compared benthic communities and the settlement of benthic macrofauna at five sites (including Mangere Inlet) covering a contaminant gradient in Manukau Harbour. The only obvious relationship between benthic communities and contamination were low densities, or the absence of species, at the Mangere Inlet site (Roper *et al.* 1988). This site also had the lowest median number of species and individuals settling on trays (Thrush and Roper 1988), leading Roper *et al.* (1988) to conclude that "the level of pollution, almost certainly from run-off, has had a severe effect on the community structure at this station".

Roper *et al.* (1995) found that burial of juvenile *Macomona liliana* was slowed in sediments from contaminated sites (although not always significantly so), including Mangere Inlet (see Section 4.3). Significant levels of drifting also occurred on sediments from Raglan, Mangere Inlet and Hobson Bay, but crawling was unaffected.

Foraminiferal[5] records obtained from sediment core samples have also been used to reconstruct a contaminant-related ecological history of the inlet (Matthews *et al.* 2005). The foraminiferal communities apparent in the sediment record reflect different periods of human presence and activity:

1. **Pre -Polynesian and Polynesian period**: forest clearance and cultivation, and subsequent sediment erosion had no measurable effect on foraminiferal community composition.

---

[5] Foraminifera are marine, single celled protozoa that secrete intricate calcareous or agglutinated shells.

2. **Early European to 1960s**: Foraminiferal communities do not change substantially in the outer parts of Mangere Inlet, but marked changes occur at sites close to industrial (eg meat works and tanneries) outfalls in inner parts of the inlet. In the latter half of this period, foraminifera disappear altogether, or are vary sparse, in a core located next to the discharge from the Southdown meatworks, probably due to excessively high organic loadings leading to acidic conditions.
3. **~ 1960s**: Widespread faunal changes due to the closure of industrial outfalls and nutrient and sediment discharges from the Mangere Wastewater Treatment Plant.
4. **1960s – Present day**: patterns of *in situ* faunal composition move back toward those obtained from the pre-human period.

4.6.2 Birds

Maps produced from Ornithological Society surveys indicate that the Manukau Harbour, southern Waitemata Harbour and Tamaki Estuary are national "hotspots" of bird diversity in coastal habitats (Robertson *et al.* 2007). The northern Manukau is also a "hotspot" for nationally critical endangered bird taxa (threat code 1), and the northern Manukau, southern Waitemata and Tamaki Estuary are hotspots for nationally vulnerable (threat code 3) endangered bird taxa. All three areas contain extensive sand and mudflats, which are a rich food resource for shore birds. An approximately three-hour tidal difference and the narrow distances between the Manukau Harbour and the Waitemata and Tamaki Estuary also allow waders to extend their feeding times by easily moving between the west and east coasts.

Mangere Inlet, in the north-eastern Manukau Harbour is used by a range of New Zealand resident and migratory shore birds. The value of these areas is recognised through the designation of coastal protection areas and areas of significant conservation value (Figure 25 and Table 4), designed to protect bird roosting and foraging areas. The Atlas of Bird Distribution in New Zealand (Robertson *et al.* 2007) indicates that up to 48 coastal bird species frequent Mangere Inlet and/or the adjoining area (Appendix 3). Of these, 15 species have been classified as threatened (Hitchmough *et al.* 2007), with seven species having threat codes 1, 2 or 3[6] (ie black stilt (1), brown teal (2), grey duck (2), New Zealand dotterel (3), Caspian tern (3), reef heron (3) and wrybill (3)).

Bird counts were also included in the assessment of environmental effects for the SH20 Manukau Harbour Crossing Project (Larcombe 2006) at Mangere. Birds within or adjacent to the footprint of the duplicate bridge and reclamation area included: pied shag; black shag; little shag; black-backed gull; red-billed gull; pied stilt; South Island pied oystercatcher; white-faced heron; kingfisher; white-fronted tern; mallard duck; pukeko; and, spur-winged plover.

Sagar *et al.* (1999) present data on the distribution of waders throughout New Zealand between 1984 and 1994, and Veitch and Habraken (1999) present data on changes in wader numbers in the Firth of Thames and Manukau Harbour between 1960 and 1998. The results from these papers that are relevant to the Manukau Harbour are summarised below.

Pied oystercatchers were widely distributed, and numbers increased markedly following the ban on shore bird shooting in 1940. In winter around 65 per cent of pied oystercatchers in New Zealand were counted at three sites: Manukau Harbour, Kaipara Harbour and the Firth of

---

[6] Threat code 1 equates to nationally critical, 2 nationally endangered, and 3 nationally vulnerable.

Thames. Of these the highest counts were obtained in the Manukau Harbour. The numbers of pied oystercatchers in the Manukau declined in summer when the birds flew south to their breeding grounds in the southern North Island and South Island.

Pied stilts were also widespread throughout New Zealand, but the highest numbers were consistently counted in the Firth of Thames, Manukau and Kaipara Harbours. The numbers of pied stilts in the Manukau Harbour have been relatively stable between 1960 and 1998 (Veitch and Habraken 1999).

Banded dotterel breed primarily on gravel river beds on the east coast of the North and South Islands and migrate north to coastal areas in New Zealand and Australia around January. The numbers are relatively high in the Manukau Harbour during autumn and winter (Sagar *et al.* 1999), and they appear to have increased in number between 1960 and 1998 on the Manukau, but not in the Firth of Thames (Veitch and Habraken 1999).

Wrybills breed in Canterbury and Otago riverbeds in late August to January, and move to their wintering grounds in Northland, Auckland and South Auckland harbours from late December to early January. Wrybill populations declined in the early 1900s, and then slowly increased between 1940 and 1960. Between 1984 and 1994, greatest winter counts were obtained from the Firth of Thames and Manukau Harbour (Sagar *et al.* 1999), and numbers remained relatively stable in the Manukau Harbour between 1960 and 1999 (Veitch and Habraken 1999). Dowding and Moore (2006) note that Manukau Harbour and Firth of Thames wintering sites are critical to the survival of wrybill, and that any impacts at these sites could be catastrophic for the population.

The black stilt is an endangered endemic species with an estimated population size of 68 in 1994 (Sagar *et al.* 1999). Black stilts are normally sedentary near their central South Island breeding sites, but those mated with pied stilts and hybrid offspring tend to migrate to the coast and northwards at the end of the breeding season. Between 1984 and 1994, most of the migratory birds were observed in Manukau Harbour, Firth of Thames and Kaipara Harbour (Sagar *et al.* 1999).

Common Northern Hemisphere migrants to the Manukau Harbour included:

- High numbers of:
  - bar-tailed godwits;
  - lesser knots.
- Moderate numbers of:
  - turnstones.
- Low numbers of:
  - Pacific golden plovers;
  - eastern curlews;
  - red-necked stints;
  - sharp-tailed sandpipers;
  - whimbrels;
  - curlew sandpipers.

Thompson and Dowding (1999) analysed mercury, lead and cadmium concentrations in blood of South Island pied oystercatchers to determine whether metal concentrations are higher in birds sampled from central Auckland (Mangere Inlet) compared with those from a rural, control site (South Kaipara Harbour). Mercury concentrations were low at both sites and no significance was detected between the sites. However, lead concentrations were substantially, and significantly, higher in birds from Mangere Inlet. Some of the individuals sampled from Mangere Inlet exhibited blood lead concentrations above 200 ng.g^{-1} wet weight, which may lead to sub-clinical toxicological effects. Cadmium concentrations were similarly low at both sites.

4.6.3 Fish

The Manukau Harbour has always been an important source of fish for subsistence, commercial and recreational fishers. The main commercial fish species obtained from the Manukau Harbour are grey mullet, yellow-eyed mullet, rig and parore (Appendix 5: Manukau Commercial Fish Catches), with set nets comprising the primary fishing method.

A substantial amount of recreational fishing is carried out from boats, but shore based line fishing, netting and spear fishing are also popular. The old Mangere Bridge, in Mangere Inlet, is one of the most popular land-based fishing spots on the harbour, and regularly attracts large numbers of anglers (Figure 41).

Figure 41
Fishing from old Mangere Bridge in Mangere Inlet (May 2008).

Relatively detailed surveys of fish use of intertidal to low tide sand and mudflats were carried out in the Manukau Harbour in February 2001 by NIWA (Morrison & Francis, unpublished data (for further details, refer to Morrison *et al.* 2002 and Francis *et al.* 2005)). Original fish count data, which was collected using beach seine tows (assumed to fish a width of 9 m), were obtained from Mark Morrison (NIWA), and raw fish diversity data was plotted without correcting for tow length (Figure 42). Species count data were then corrected for tow length (count/metre towed) and plotted to illustrate the distribution of individual fish species within Mangere Inlet, relative to the broader Manukau Harbour (Figure 43).

Eight sites were located in, and around, Mangere Inlet. They had an average of 4.1 (± 2.0 S.D.) fish species (uncorrected tows data), with the greatest number of species obtained at the outlet to Tararata Creek, within the inner Mangere Inlet (7 species), and the sites off Kiwi Esplanade and White Bluff (6 species each) (Figure 42). Uncorrected data indicated that southern side-branches of the Manukau tended to have more fish species per site than central or northern parts of the harbour.

The Tararata site had the highest corrected counts of yellow-eyed mullet of any site in the Manukau harbour, while the Kiwi Esplanade site had the highest corrected counts of sand flounder (Figure 43). Relatively high numbers of mottled triplefins were also obtained from the Tararata site. Conversely, numbers of anchovy, exquisite goby, smelt, speckled sole and yellow-belly flounder were relatively low at the Mangere sites, while garfish, grey mullet, estuarine triplefin, and red gurnard were absent.

Figure 42

Number of fish species obtained in 9 m wide beach seine nets in February 2001 (Morrison and Francis unpublished data). Note that these data have not been corrected for tow length.

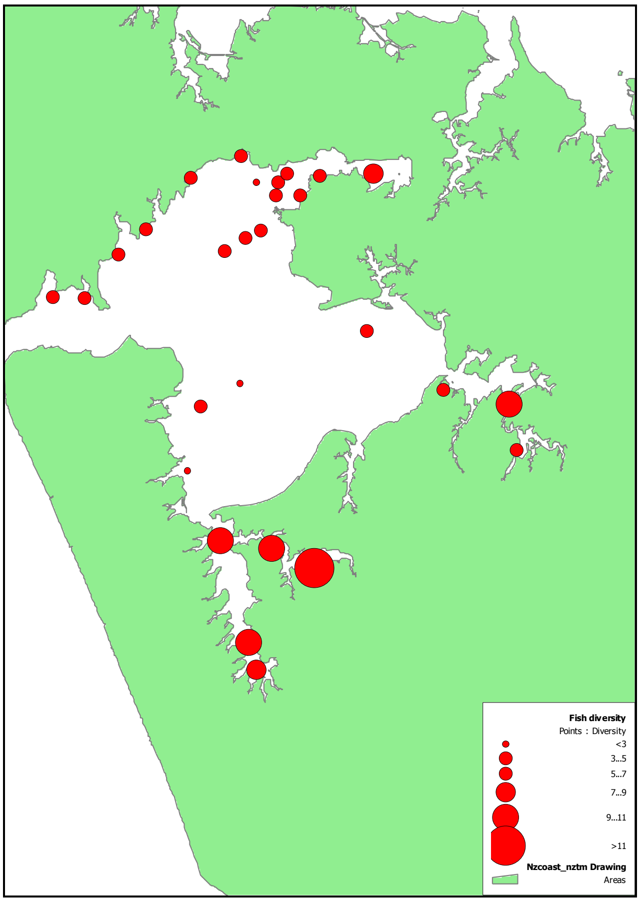
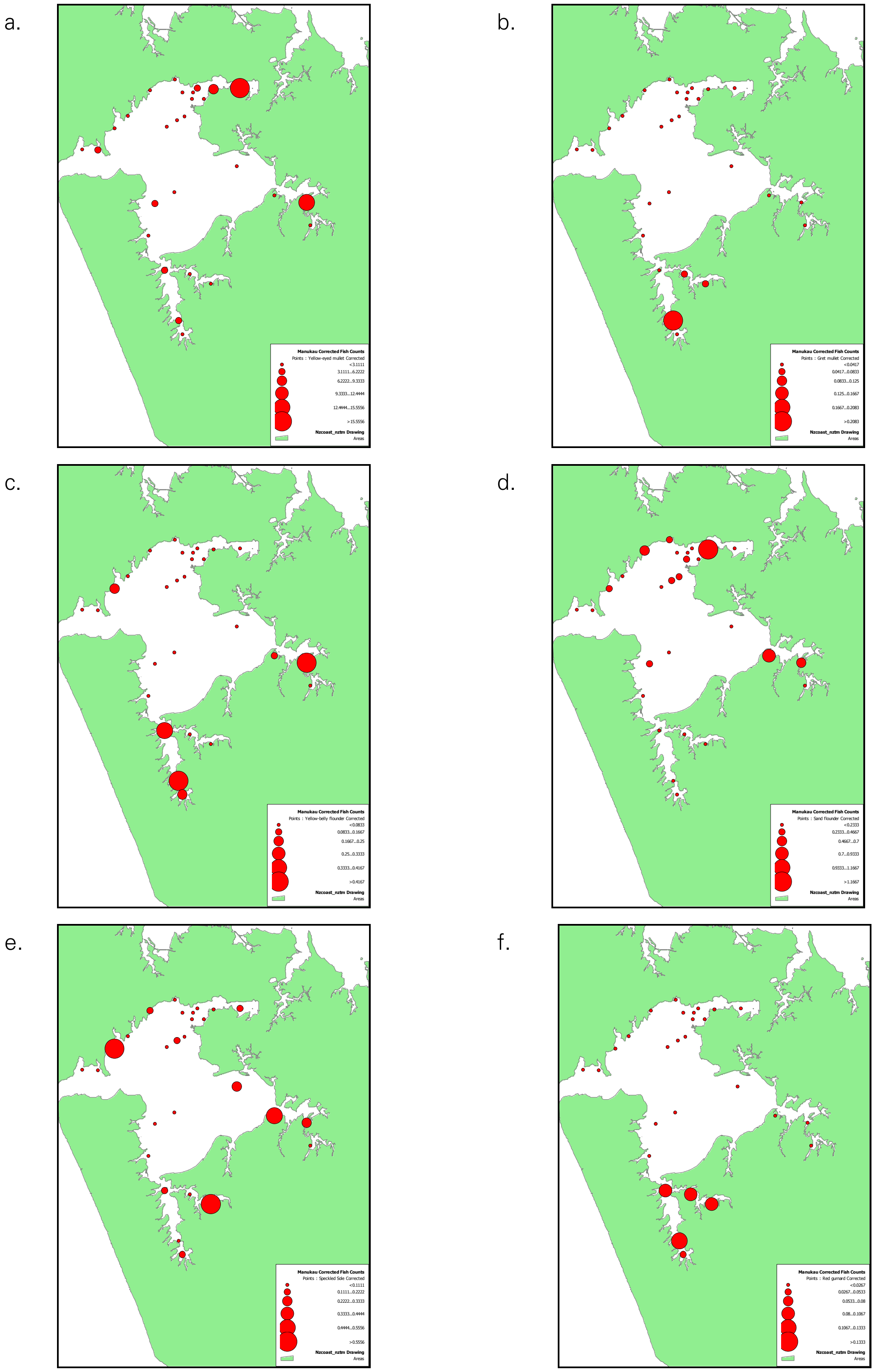
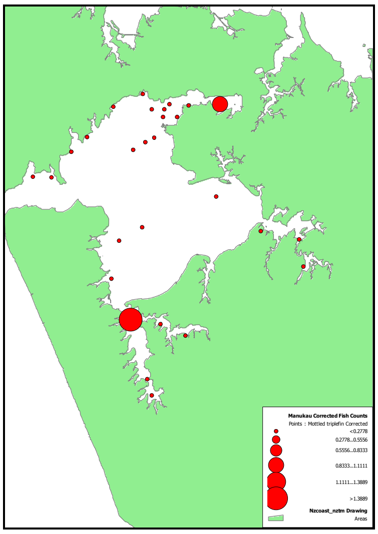


Figure 43

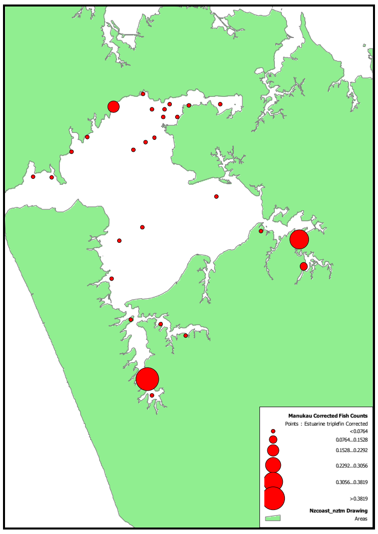
Distribution of a) yellow-eyed mullet, b) grey mullet, c) yellow-bellied flounder, d) sand flounder, e) speckled sole, f) red gurnard, g) mottled triplefin, h) estuarine triplefin, i) exquisite goby, j) anchovy k) smelt, and l) garfish in Manukau Harbour (Morrison and Francis unpublished data).



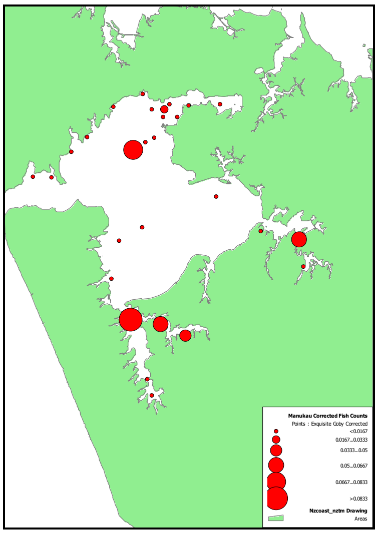
g.



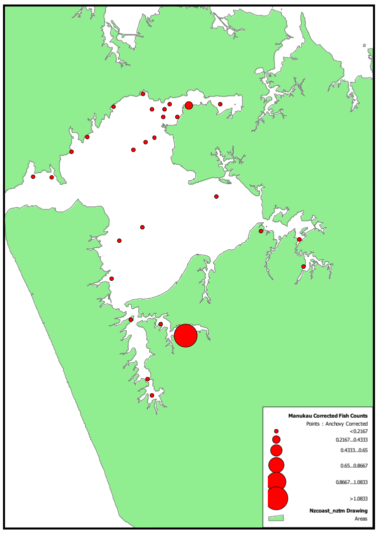
h.



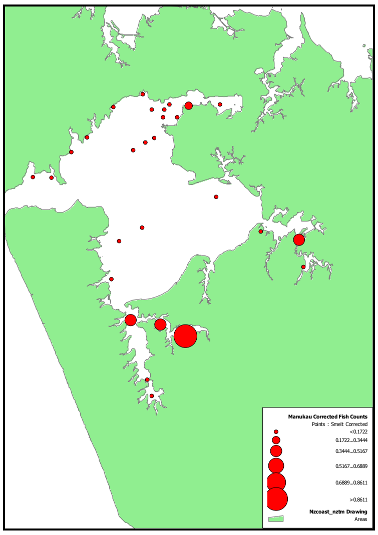
i.



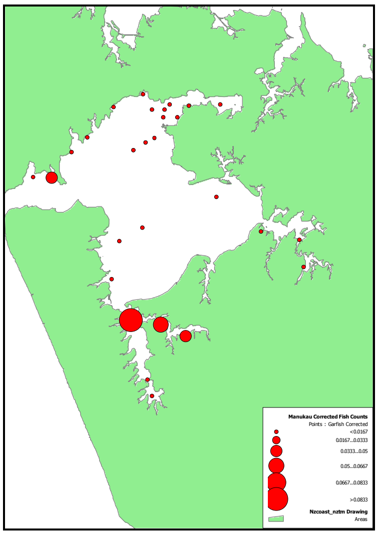
j.



k.



l.



Yellow-belly flounder *Rhombosolia leporina* (and, to a lesser extent, sand flounder) from Manukau were used to examine the relationship between contamination and the prevalence of parasites and pathological lesions (Diggles *et al.* 2000). Flounder were collected over a two-year period from three sites along a pollution gradient in the Manukau Harbour: Rangirere (least contaminated), Weymouth and Onehunga-Mangere Inlet (most contaminated). Cornwallis was also sampled on two occasions, but low catch rates at the start of the study meant this site was dropped. In the second year, flounder from the Manukau were also compared with those caught from Tauhoa River in Kaipara Harbour and Mahurangi Estuary.

The study involved the analysis of fish movement, blood cell abnormalities and parasites in all fish, and liver pathology in a sub-sample of fish. A sub-sample of fish from Rangirere, Weymouth and Onehunga were also analysed for EROD enzyme (an indicator of proteins that catalyse aromatic and chlorinated hydrocarbons), organochlorine pesticides (DDT, chlordane, lindane and dieldrin) and PCBs in liver tissues, and PAHs in bile.

The results of the study were somewhat equivocal, with only a few of the potential indicators showing trends that were consistent with the contaminant gradient. Most fish displayed a high degree of site fidelity over the study period, but some individuals were highly mobile. This suggested that yellow-bellied flounder are probably suitable for detecting acute and sub-acute effects of contamination, but are not suitable for detecting long-term chronic effects. Contaminant and EROD tissue concentrations showed a clear increasing trend from the least to most contaminated Manukau Harbour sites. The concentrations of dieldrin, chlordane, PCBs, DDT, PAH and EROD increased along the contaminant gradient and were highest in flounder collected from Onehunga.

Flounder from Onehunga (ie the most contaminated site) also had a higher prevalence of pre-neoplastic (ie pre-tumorous) liver lesions, which are known to be associated with contaminant exposure, and a greater abundance of an ectoparasitic isopod (*Nerocila obigyna*). However, the prevalence and/or abundance of other parasites, such as the myxosporean bile parasite *Ceratomyxa* sp. and an ectoparasitic leech, were lower at Onehunga.

Pre-neoplastic liaisons are considered to be useful early indicators of contaminant-related tissue damage, but Diggles *et al.* (2000) cautioned that other factors could also be involved in their production. Furthermore, they do not provide a definitive indication of reduced organism or environmental health.

4.6.4 Vegetation

The most widely distributed and abundant coastal plant in Mangere Inlet is the mangrove *Avicennia marina*. The present distribution of mangroves was plotted using GIS and a combination of 2001 and 2006 aerial photographs (Figure 44). The total area covered by mangrove forest in Mangere Inlet was approximately 110 ha in 2001/2006. Mangroves are most prevalent at the eastern end of the inlet, and in Harania, Tararata and Ann's Creeks.

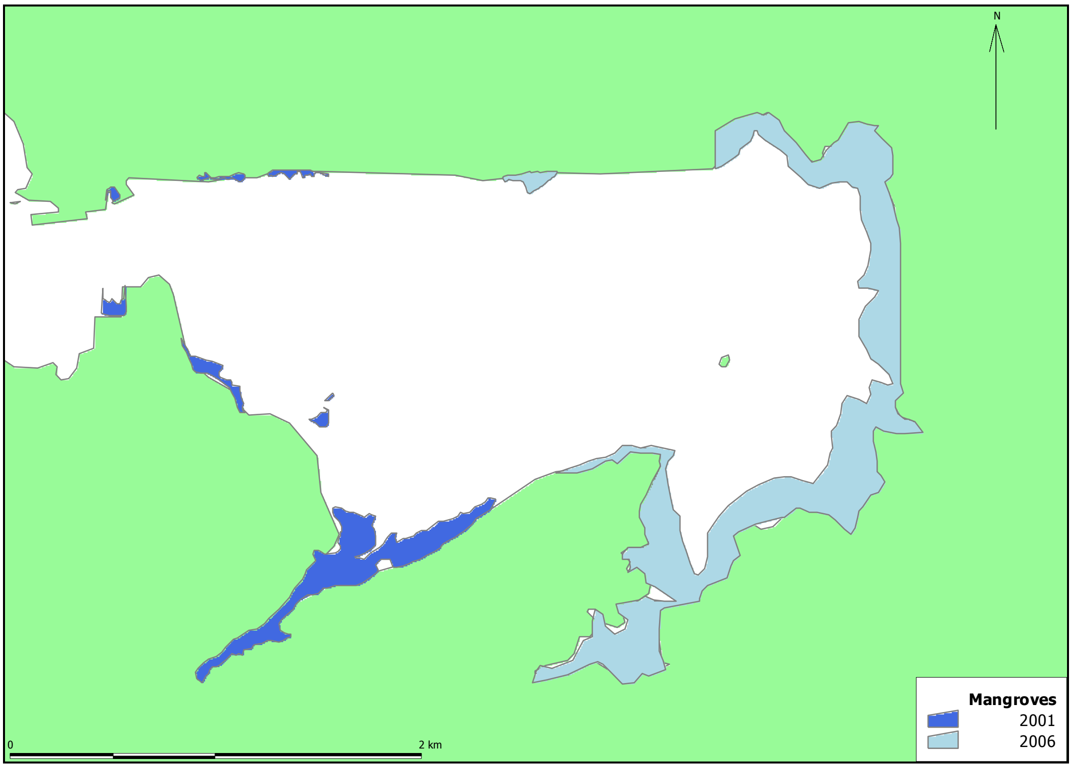
Aerial photos indicate that mangroves were absent, or limited to an occasional scattered tree in 1959. Henriques (1977) estimated that by the mid-1970s Ann's Creek contained ca. 1 ha of mangroves, and Harania and Tararata Creeks contained ca. 4 ha of mangroves each. This indicates that the expansion of mangrove forests in Mangere Inlet has therefore occurred since 1959, with most of the growth happening since the mid-1970s.

Henriques (1977) also estimated that 10 ha of native salt marsh occurred in the north-east and south east corners of Mangere inlet in the mid-1970s. The Auckland Regional Plan: Coastal also notes a small, upper-intertidal area with a diverse mix of native saline vegetation in the south-eastern corner of the inlet. The area also contains maritime marsh and a 0.25 ha meadow of batchelor's button, *Cotula coronopifolia*. The area is a Coastal Protection Area due to its coastal vegetation values (CPA 22a and 22b).

Ann's Creek also contains the only significant piece of native shrublands growing on lava flows in the Tamaki Ecological District. Consequently, this area is also a Coastal Protection Area (CPA 21). This area is also notable because the it is the type locality for the shrub, *Coprosma crassifolia*, which still grows naturally on nearby Hamlins Hill.

Figure 44

Mangrove distribution in Mangere Inlet plotted from a combination of 2001 and 2006 aerial photographs.



5 Whau Estuary

5.1 General description

The Whau Estuary is a ca. 5.5 km long tidal creek on the southern shore of the Waitemata Harbour, which forms the boundary between Auckland and Waitakere Cities. The eastern shore is formed by Rosebank Peninsula, which separates Whau Estuary from Waterview Inlet. Much of the inner estuary consists of a single channel, flanked by mud flats and mangrove forest. The Northwestern Motorway crosses the sand and shellbanks at the tip of Rosebank Peninsula, and passes over the outer Whau Estuary. A mooring management area in the outer estuary nominally contains 68 swing and 101 pole moorings, with a total capacity for 316 moorings (Auckland Regional Plan: Coastal).

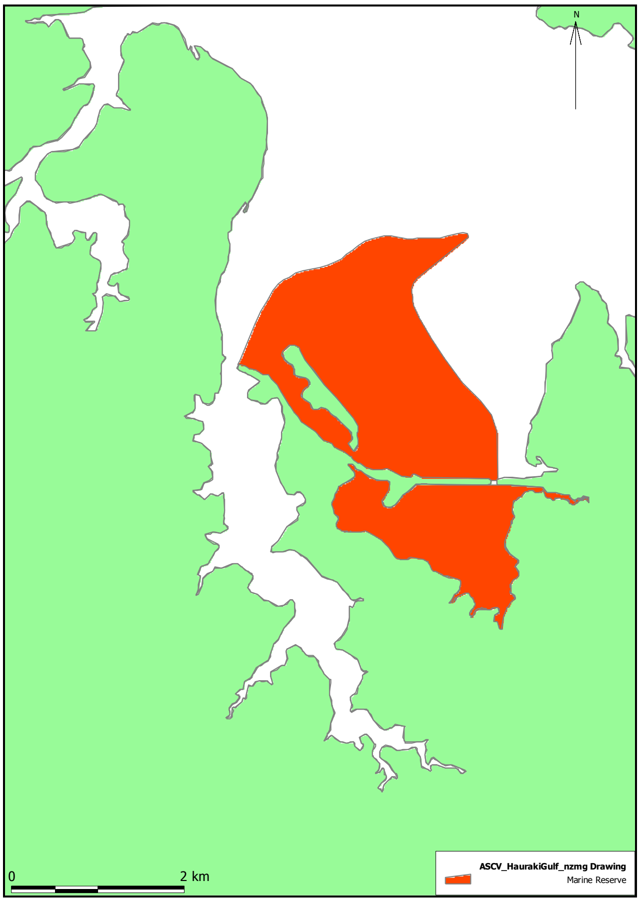
Motu Manawa (Pollen Island) Marine Reserve is located on the south-eastern shore at the entrance to Whau Estuary (Figure 45). The marine reserve contains mangroves, saltmarsh, shellbanks and intertidal mudflats and sandflats that are utilised by a variety of New Zealand and migratory wading and non-wading bird species.

Three relatively large (Rewarewa, Wairau and Glendene) and four minor tributaries drain into the western shore of Whau Estuary. Rewarewa enters in the headwaters, close to Whau Stream. The proximity of the headwaters to the Manukau Harbour meant that the Whau was an important link between the east and west coast for both Maori and early Europeans. Canoes, boats and materials were conveyed across the narrow strip of land separating the two coasts via the Whau portage between Avondale Stream and Green Bay (Stone 2001). For several decades, plans for a canal between Whau Estuary and Manukau Harbour were mooted, but these never eventuated.

The Whau has a long history of commercial and industrial development, with untreated industrial waste being discharged into it for around a century (MacKay 2001). In the second half of the 1800s it became an important centre for the brickworks industry, with the first of several brickworks established near the foot of Rata Street in 1861. In the 1860s New Lynn was a busy trade centre with five public wharves, and materials and goods were transported by boats using the Whau Estuary, up until 1948. A tannery was established next to Avondale Stream (a tributary of Whau stream) in 1888, and a gelatine and glue factory were set up nearby.

Today the Whau catchment contains a mix of land uses, dominated by residential development. However, a significant amount of light industrial and commercial development is also present in the Rosebank, Glendene, Henderson South, Avondale and New Lynn areas.

Figure 45
Motu Manawa (Pollen Island) marine reserve (red) at the entrance to Whau Estuary.



Three coastal protection areas (CPAs 53, 54 and 55b) are either in or in the immediate vicinity of Whau Estuary (Figure 46 and Table 5). The primary reasons for the CPA designations are:

- wading birds: CPA53, CPA54 and CPA55b;
- mangroves: CPA53, CPA54 and CPA55b;
- saline vegetation: CPA53, CPA54 and CPA55b;
- shellbanks and intertidal sandflats: CPA53, CPA55; and
- landforms: CPA53.

Two sediment, and associated contaminant, settling zones were identified in ARC (2002) and included in the Auckland Regional Plan: Coastal (Figure 46). The rationale for the determination of settling zones is provided in ARC (2002a and 2002b). At the time of writing, Auckland City Council and Metrowater were undertaking a technical review to determine whether these designations are appropriate (see Appendix 3: Depositional Zones Identified by Auckland City Council – Metrowater).

Figure 46

Coastal protection areas (CPAs) in Whau Estuary. The sediment and contaminant settling zones identified in the Auckland Regional Plan: Coastal are also shown.

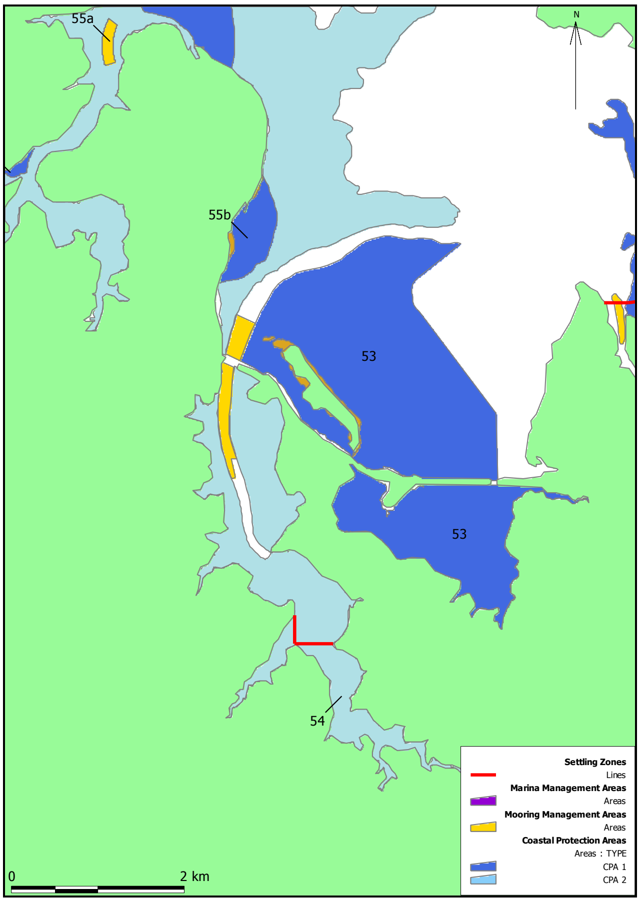


Table 5

Coastal protection areas (CPAs) and areas of significant conservation value (ASCV) in Whau Estuary.

Protection type	**CPA / ASCV**	**Description**
Coastal Protection Area 1 & Area of Significant Conservation Value	53 / 30 & 111	**Pollen Island**: This is an area of saltmarsh, mangroves, shellbanks, and estuarine and harbour mud flats. It is the best remaining largely unmodified area of its type in the Waitemata Harbour and is considered to be a nationally important landform. It is also a complex habitat for a variety of animal and plant communities. Pollen and Traherne Islands and the surrounding shellbanks are the major high tide roost on the Waitemata Harbour for thousands of international migratory and New Zealand endemic wading birds as well as a variety of coastal birds. This includes a number of threatened species. They are also an important breeding and flocking area for the threatened New Zealand Dotterel on the Waitemata Harbour. The surrounding intertidal banks and waters are a feeding ground for all of these birds.
Coastal Protection Area 2 & Area of Significant Conservation Value	54 / 30	**Whau Estuary**: The Whau Estuary contains substantial quantities of saline vegetation. There are around 40 hectares of mangroves with the taller trees growing in the lower intertidal areas and mangroves of smaller stature growing in the firmer high intertidal regions. These in turn grade into a fringe of saltmarsh lining the coast. The saline vegetation is an important habitat for threatened secretive

Protection type	CPA / ASCV	Description
		coastal fringe birds particularly where it abuts terrestrial vegetation which provides roosts for the birds at high tide and potential nesting sites.
Coastal Protection Area 1 & Area of Significant Conservation Value	55b / 30	**Te Atatu east (Entrance to Whau Estuary)**: Extensive clean high-tidal sandflats and a prominent shellbank offer a high tide roost for some of these wading birds and a variety of coastal birds. Large and significant areas of saline vegetation grow in the shelter of these shellbanks. The extensive shell barriers protect high level mangroves with a healthy sedge, rush and glasswort saltmarsh.

5.2 Hydrodynamics

The hydrodynamics of Whau Estuary were modelled as part of the Coastal Receiving Environment Assessment (CREA) carried out by Auckland City Council and Metrowater (Croucher *et al.* 2005a and 2005d). Modelling indicated that current velocities in Whau Estuary are typically less than 1 $m.s^{-1}$ even at maximum incoming tide. Highest current velocities occur through the entrance to the estuary. At low tide, most of the estuary is dry, and water is confined to the main channel. Conversely, at high tide, most of the estuary is underwater.

Modelling indicated that in the lower parts of the estuary, the effect of large storms on the water velocities tended to be limited to the areas immediately adjacent to consolidated stormwater outfalls. In the upper Whau, the volume of the main channel is relatively small and the added volume entering during large storms has a greater influence. For instance, during the modelled storm, the main channel velocities in the very upper estuary (near Avondale) were approximately two-to-three times higher than fair-weather flows. Furthermore, the flow overtopped the main channel, which reduced the extent of the mudflat boundary.

5.3 Sediment characteristics, accumulation and contamination

5.3.1 ARC monitoring and investigations

Sediment samples are collected from four stormwater contaminant monitoring (ie RDP) sites in Whau Estuary at 2- to 5-year intervals (Figure 47). Three of these are also state of the environment (SoE) monitoring sites (upper Whau, lower Whau, and Wairau). Samples are analysed for the concentrations of copper, lead and zinc in the fine (<63 μm) and total (<500 μm) sediment fractions (McHugh and Reed 2006, Kelly 2007b). Galai particle size analysis has also been carried out on sediments collected from these sites to monitor long-term changes in sediment characteristics (note that statistical analyses of sediment texture have not been carried out). A one-off analysis of tin, arsenic, cadmium, mercury, and antimony was also carried out at the three Whau Estuary SoE monitoring sites in 2005. The concentrations of a range of organic compounds are also determined periodically at these three sites (Reed and Webster 2004, McHugh and Reed 2006). The organic compounds include PAHs, PCBs, DDT, chlordane, lindane, dieldrin, methoxychlor, endosulfan, hexachlorobenzene.

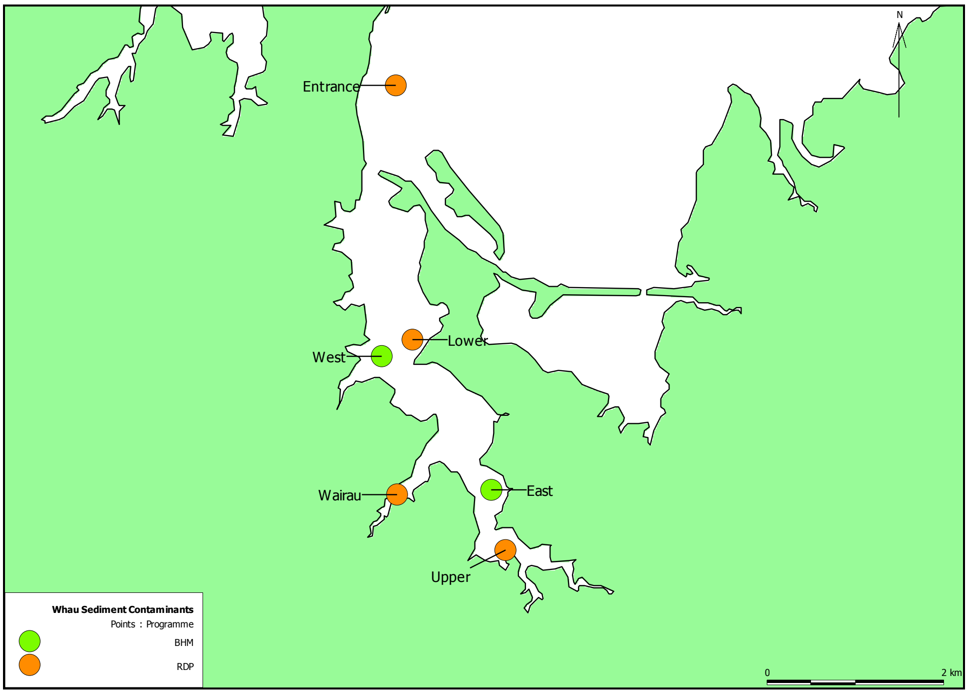
A one-off analysis of copper, lead and zinc concentrations in samples from two additional sites was also carried out in 2006 (Whau east and Whau west). This data was used in the development of the benthic health model (see Anderson *et al.* 2006).

Wet sieved, sediment grain size data has also been collected from all six sites in Whau Estuary. This data is used to assist in the interpretation of ecological responses to stormwater contamination (Anderson *et al.* 2006, Kelly 2007b). Sediment texture is presented as percentage weight in: gravel (>2mm), coarse sand (2mm to 500 µm), medium sand (500 µm to 250 µm), fine sand (250 µm to 63 µm) and silt and clay (<63 µm).

Raw data from the above programmes were obtained for Whau Estuary, re-plotted and is summarised below.

Figure 47

Auckland Regional Council sediment monitoring and investigation sites in Whau Estuary. Orange sites are stormwater contaminant monitoring sites (ie RDP sites) (ie which include state of the environment (SoE) sediment contaminant monitoring sites). Green sites are validation sites used in the development of the benthic health model (Anderson *et al.* 2006).



Principle co-ordinate analysis (Figure 48) and plots of raw Galai data (ie volume of sediment) (Figure 50) indicate that there is a gradient in sediment texture from the outer Whau north of the Northwestern Motorway bridge to upper Whau Estuary. Sediments at the entrance site had a relatively high proportion of material in the 125 to 250 µm size fraction (by volume). The proportion of sediments in the <63 µm fraction increased up the river, with the Whau lower and Wairau sites having similar, intermediate, proportions of sediments in this fraction, and Whau upper having a high proportion of sediments in this size fraction. The results obtained from wet sieved sediments were not entirely consistent with the Galai data, but the entrance was clearly differentiated by the high proportion of sediments in the 63 to 125 µm size fraction, compared with the other sites with a high proportion of sediments in the <63 µm size fraction (Figure 49 and Figure 50).

Figure 48

Principal co-ordinate analysis of the volume of sediment in each of eight particle size classes (2.0 to 3.9 µm, 3.9 to 7.8 µm, 7.8 to 15.6 µm, 15.6 to 31.3 µm, 31.3 to 62.5 µm, 62.5 to 125 µm, 125 to 250 µm, and 250 to 500 µm) from four sites in Whau Estuary. Sediment texture is similar for sites that are close together in the plots and dissimilar for sites that are widely separated. The overlying vector diagram indicates the influence (in terms of direction and strength) of each particle size class on the observed distribution. Sediment volumes were estimated using Galai particle size analysis.

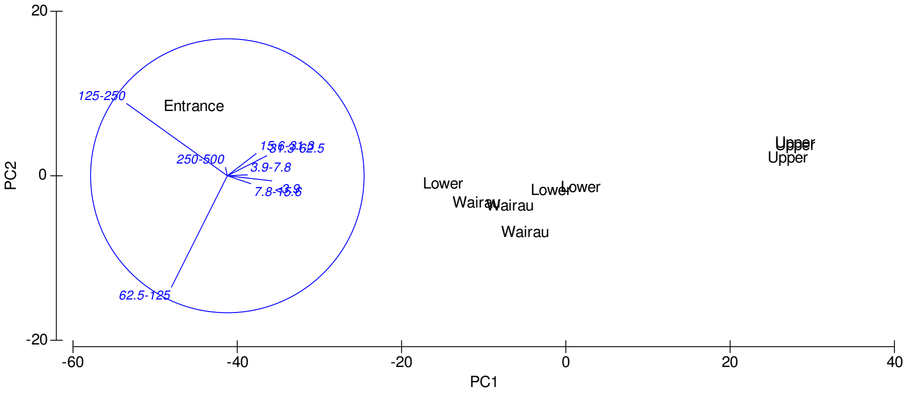


Figure 49

Principal co-ordinate analysis of sediment weight (as a per cent of total weight) in each of four particle size classes (<63 µm, 63 to 125 µm, 125 to 500 µm, and >500 µm) obtained by wet sieving samples from sites in the Whau Estuary. Samples were collected for ecological monitoring and the associated development of ARC's benthic health model (Anderson *et al.* 2006). Sediment texture is similar for sites that are close together in the plot and dissimilar for sites that are widely separated. The overlying vector diagram indicates the influence (in terms of direction and strength) of each particle size class on the observed distribution.

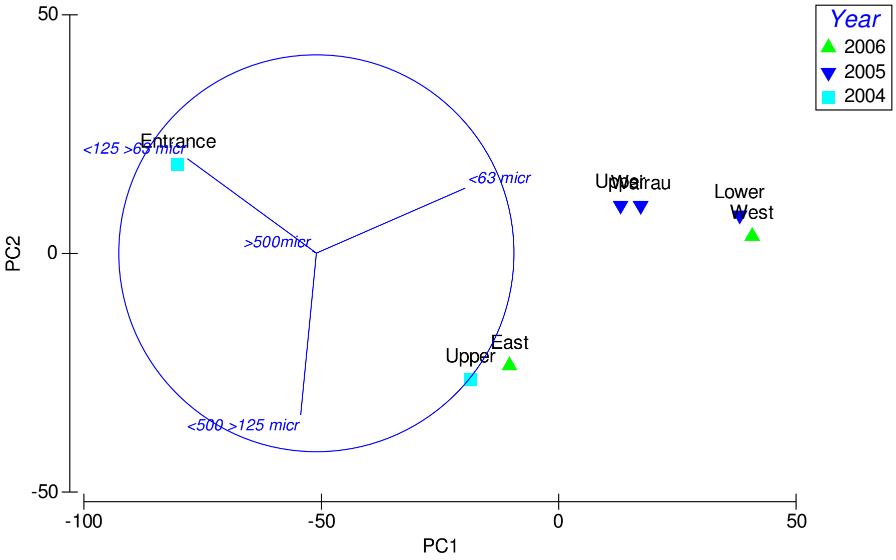
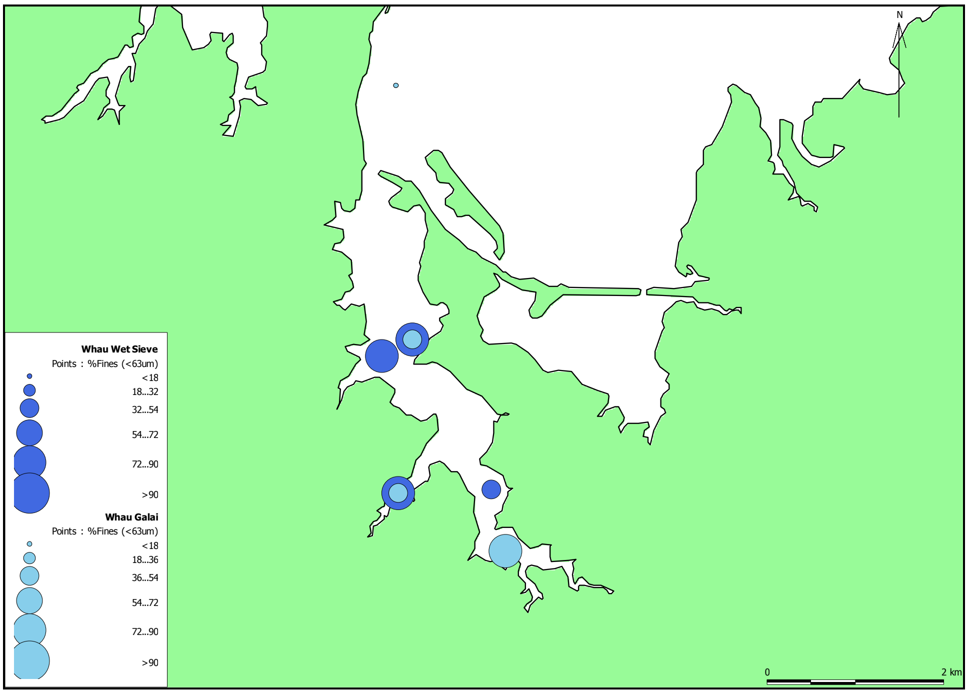


Figure 50

Distribution of fine sediment (<63 µm) in Whau Estuary. The size of the circle is proportional to the percentage of fines. Dark circles represent percent weight values obtained from wet sieved sediments, and light circles represent sediment volume obtained from Galai analysis.



The sediment-contaminant monitoring and investigations carried out by the ARC since 1998 have been using comparable methods of sample collection and contaminant analysis. These programmes provide a robust set of sediment quality data for the estuary. Data on copper, lead and zinc concentrations were pooled from three ARC datasets: SoE monitoring, stormwater contaminants monitoring, and the benthic health model (see Appendix 1). Contaminant concentrations are compared against a number of sediment quality guidelines, which are described in Section 3.3.

Plots of the metals data indicate that highest concentrations of zinc, copper and lead occur in the most sheltered upper areas of Whau Estuary, ie Whau upper and Wairau (Figure 51 to Figure 53). Total zinc concentrations exceeded ERL sediment quality guideline values at all five inner Whau sites south of the Northwestern Motorway bridge. Total copper concentrations also exceeded ERL sediment quality guideline values in the upper Whau and Wairau sites, and total lead concentrations exceeded ERL values in the upper Whau, Whau east and Wairau sites. Copper and lead also exceeded TEL sediment quality guideline values (ie amber ERC values) at the Whau east, Whau west and Whau lower sites. The total concentrations of all three metals were below sediment quality guideline values at the entrance to Whau Estuary (ie north of the motorway bridge).

Figure 51

Map showing relative sediment concentrations of total zinc (mg/kg) in Whau Estuary (see Appendix 1 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is <TEL, blue TEL – ERL, yellow ERL to PEL, orange PEL to ERM and red is > ERM). See Section 3.3 for a description of sediment quality guidelines.

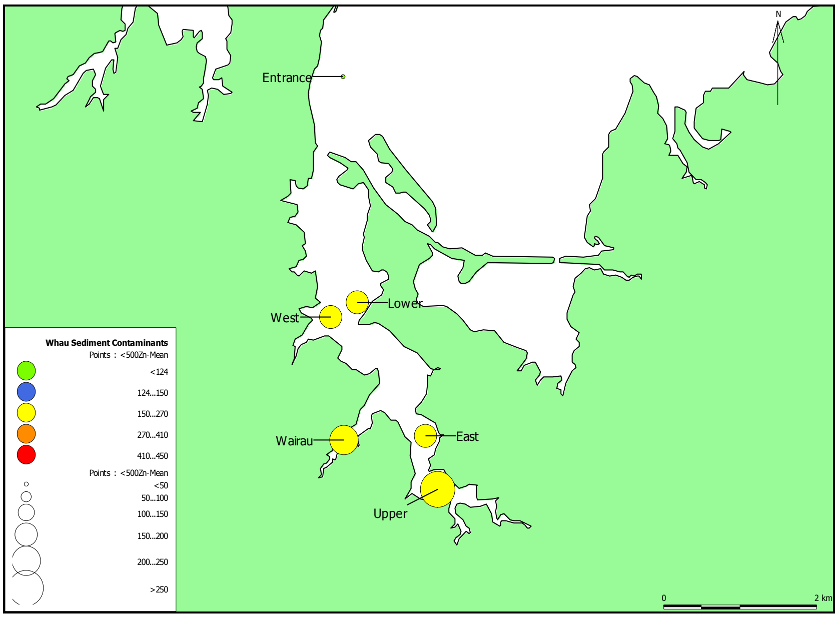


Figure 52

Map showing relative sediment concentrations of total copper (mg/kg) in Whau Estuary (see Appendix 1 for the actual data and sampling year) (see Appendix 1 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is <TEL, blue TEL – ERL, yellow ERL to PEL, orange PEL to ERM and red is > ERM). See Section 3.3 for a description of sediment quality guidelines.

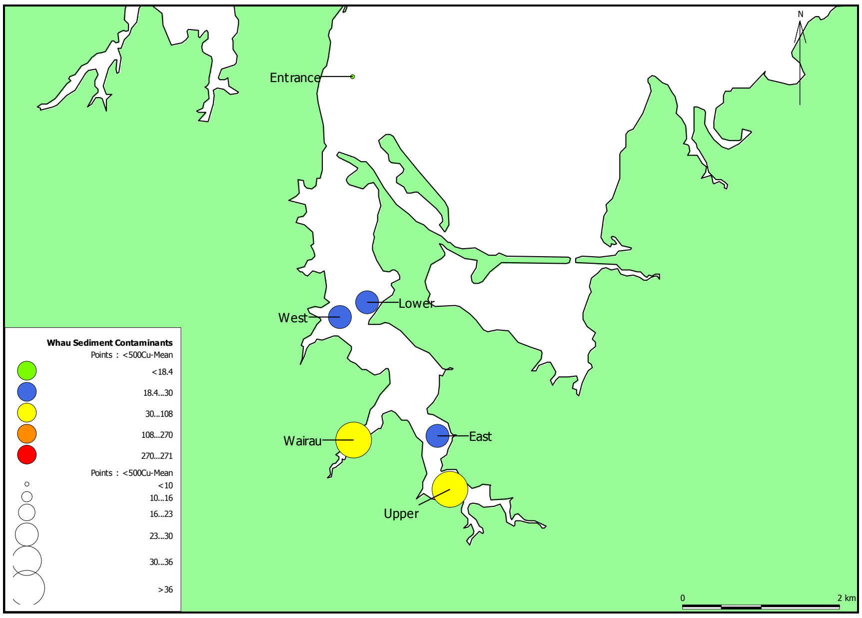
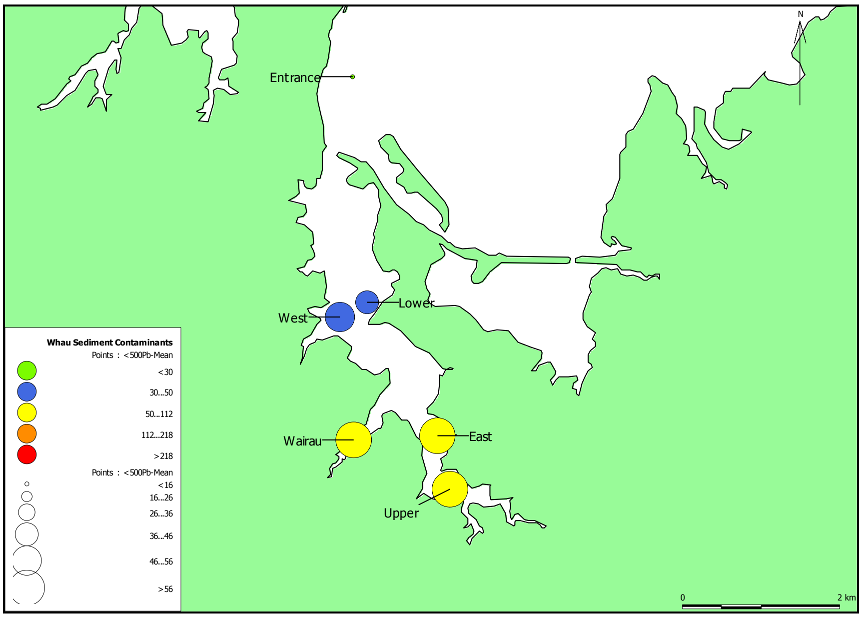


Figure 53

Map showing relative sediment concentrations of total lead (mg/kg) in Whau Estuary (see Appendix 1 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is <TEL, blue TEL – ERL, yellow ERL to PEL, orange PEL to ERM and red is > ERM). See Section 3.3 for a description of sediment quality guidelines.

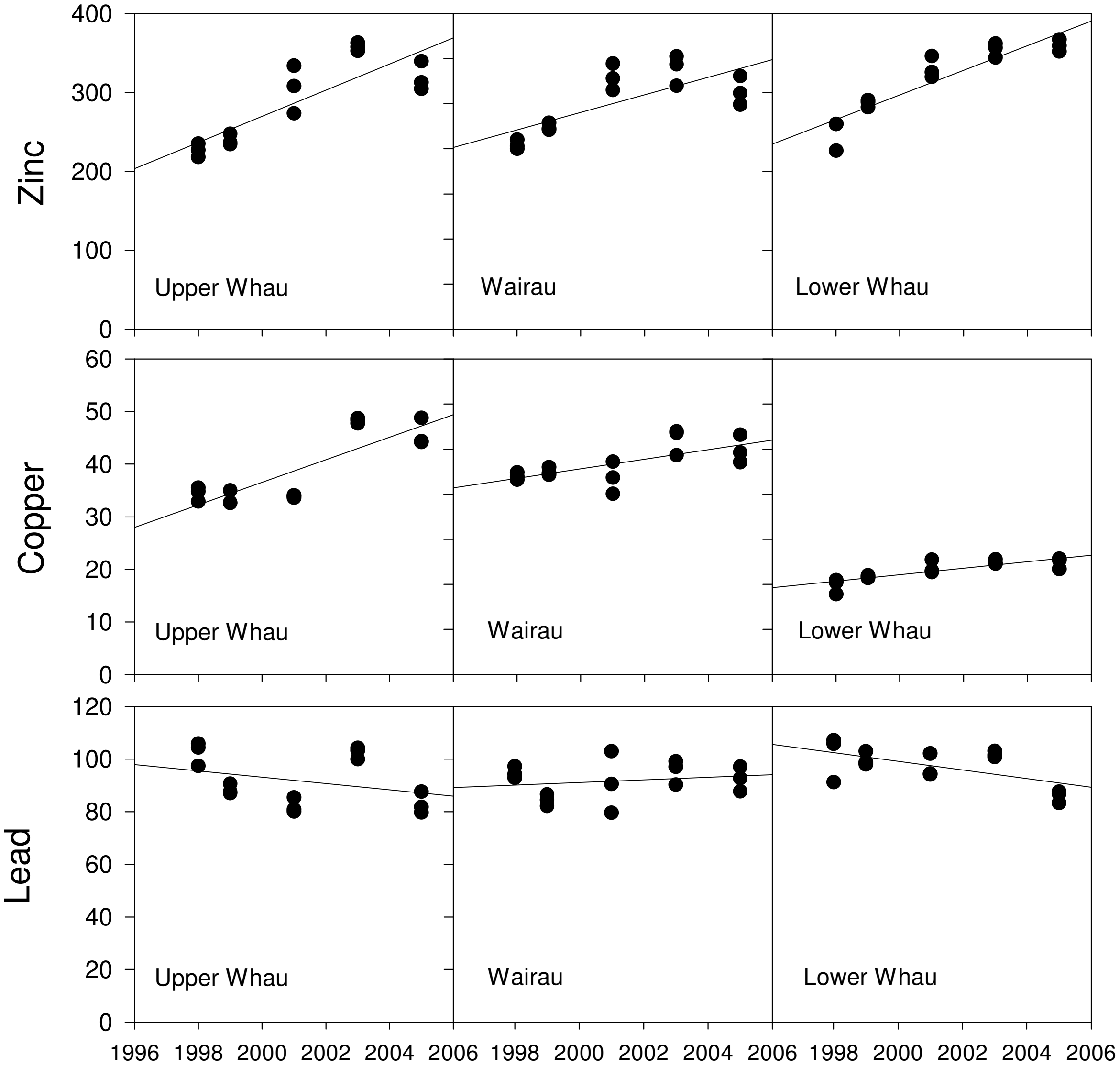


Repeated sampling of the upper and lower Whau and Wairau sites between 1998 and 2005 has allowed trends in the concentrations of copper, lead and zinc in the fine sediment fraction to be determined (McHugh and Reed 2006, Kelly 2007b) (Figure 54). Linear regression analysis indicates that, over this period, statistically significant increases have occurred in the concentration of copper and zinc at all three sites. Copper concentrations increased by 0.7, 2.1, and 1.1 mg/kg per year at the lower, upper and Wairau sites respectively. Zinc concentrations increased by 7.8, 16.5 and 9.7 mg/kg per year at the lower, upper and Wairau sites respectively. Consequently, average copper concentrations increased by 13 per cent to 40 per cent in the 7-year period between 1998 and 2005, and average zinc concentrations increased by 29 per cent to 44 per cent.

In contrast, lead concentrations at the lower Whau site declined significantly between 1998 and 2005, and remained relatively stable at the other two SoE sites.

Figure 54

Trends in the concentrations (mg/kg) of zinc, copper and lead in the <63 µm sediment fraction (extracted using weak acid digestion) at the Wairau and upper and lower monitoring sites in Whau Estuary.



ARC monitoring indicates that the sediment concentrations of some other metal and organic contaminants also exceed sediment quality guideline values at the upper Whau, Wairau and lower Whau sites (Reed and Webster 2004, McHugh and Reed 2006). These include:

- mercury, which exceeded ERL sediment concentrations at all three sites;
- arsenic, which exceeded ERL concentrations in sediments at all three sites; and
- high molecular weight PAHs, which exceeded TEL (ie amber ERC) concentrations at the Whau lower and Wairau sites, and ERL (ie red ERC) concentrations at the Whau upper site.

Highest arsenic concentrations occur in some of the “cleanest” SoE monitoring sites (eg Big Muddy Estuary, Long Bay and Cheltenham) (McHugh and Reed 2006), suggesting that arsenic levels are naturally elevated in marine sediments in the Auckland region. The concentrations observed in Whau Estuary are therefore likely to be within the natural range, so arsenic contamination is not considered to be a significant issue.

Mercury concentrations also tend to be elevated at urban sites which are subject to urban stormwater run-off. Consequently, there is a relatively strong relationship between mercury concentrations and other urban stormwater contaminants, such as zinc (see Figure 12).

Croucher *et al.* (2005d) estimated sediment and zinc accumulation in 10 “deposition zones” in Whau Estuary, using a particle tracking model and estimates of catchment sediment and zinc run-off from 10 consolidated outfalls. 150-year predictions of zinc accumulation in the silt fraction were provided for each of the deposition zones. Since 2005, Auckland City and Metrowater have collected more detailed land use information and are revising the zinc loads used in the CREA models. This information will be used to update predictions of zinc accumulation in Whau Estuary, and may lead to substantial changes in the results. The following summary should therefore be treated with an appropriate degree of caution.

Predicted zinc accumulation rates and ultimate concentrations of were highest in the upper Whau, and declined with distance down the Whau. Zinc concentrations reached equilibrium concentrations at the upper-most site during the simulation period, but not at the other sites. Zinc concentrations at the two outer Whau sites, and the outer-most of the inner Whau site did not exceed ERM sediment quality guideline values during the simulation period. All other sites exceeded ERM values between 2006 and ca. 2050. Reducing zinc loads at these sites by 35 per cent led to substantial reductions in ultimate zinc concentrations, but 75 per cent reductions were generally required to prevent ERM guideline values being exceeded, or slightly exceeded.

5.4 Biological contamination

Little information is available on shellfish contamination in Whau Estuary, with only one published study identified by literature search. Copper, lead zinc and cadmium concentrations were measured in barnacles, *Elminius modestus*, collected from Whau Estuary and 16 other east coast and Manukau Harbour sites (Zauke *et al.* 1992). Concentrations of all four metals were highly variable in barnacles from Whau River, but lead and copper concentrations were still significantly higher than most other sites.

5.5 Water quality

The Auckland Regional Council has been continuously monitoring water quality in Whau channel since 1998. Monthly samples are collected by helicopter and analysed for: temperature; salinity; turbidity; suspended solids; nitrate; nitrite; ammonia-N; total and soluble phosphorus; faecal coliforms; enterococci; and, chlorophyll *a*. A review of water quality data was being carried out at the time of writing, so recent statistical analyses were not available. The data was therefore plotted and visually assessed for temporal trends and other patterns, and compared with other sites in the region. Nitrate and ammonia-N were also compared with ANZECC (2000) water quality guidelines.

Plots suggest that suspended solids concentrations declined in Whau channel between 1998 and 2007 (Figure 55). Peak nitrate concentrations appear to have increased between 2000 and 2001, but have subsequently declined (Figure 55). Ammonia-N concentrations are generally low and relatively stable, and both nitrate and ammonia-N concentrations are consistently well below ANZECC (2000) water quality trigger values. Phosphorus concentrations also tend to be relatively low, but occasional spikes do occur. Similarly, enterococci levels are generally low, but occasional spikes occur.

Pooled data 1998/2007 data from all Waitemata Harbour sites indicates that water quality in Whau Channel is similar to that at the Chelsea, Henderson and Hobsonville sites, and better than sites in the upper Waitemata (Figure 56), which have higher nutrient concentrations, slightly lower dissolved oxygen levels, and larger and more frequent spikes in microbiological indicators.

Figure 55

Long-term water quality trends in Whau channel.

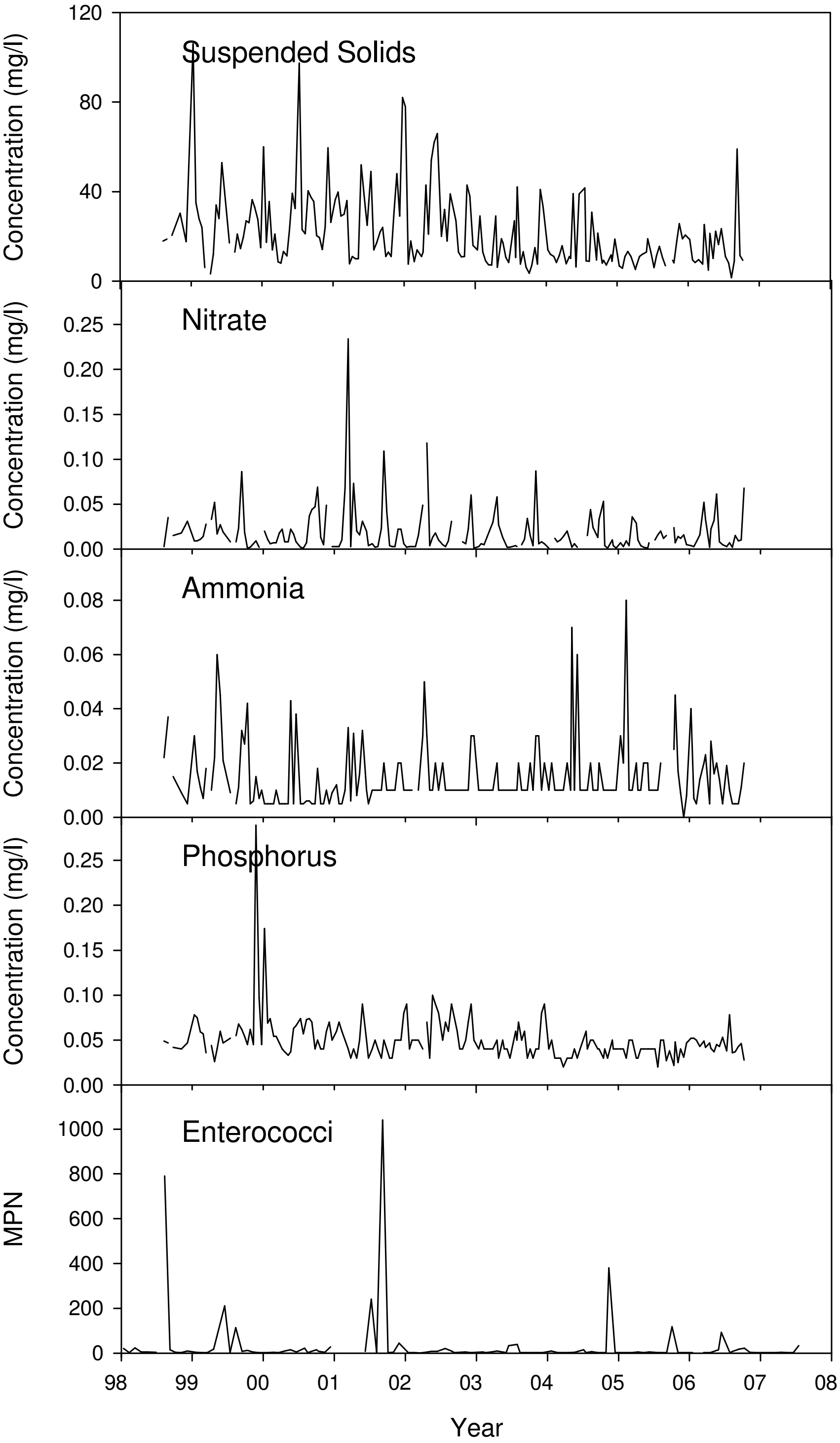
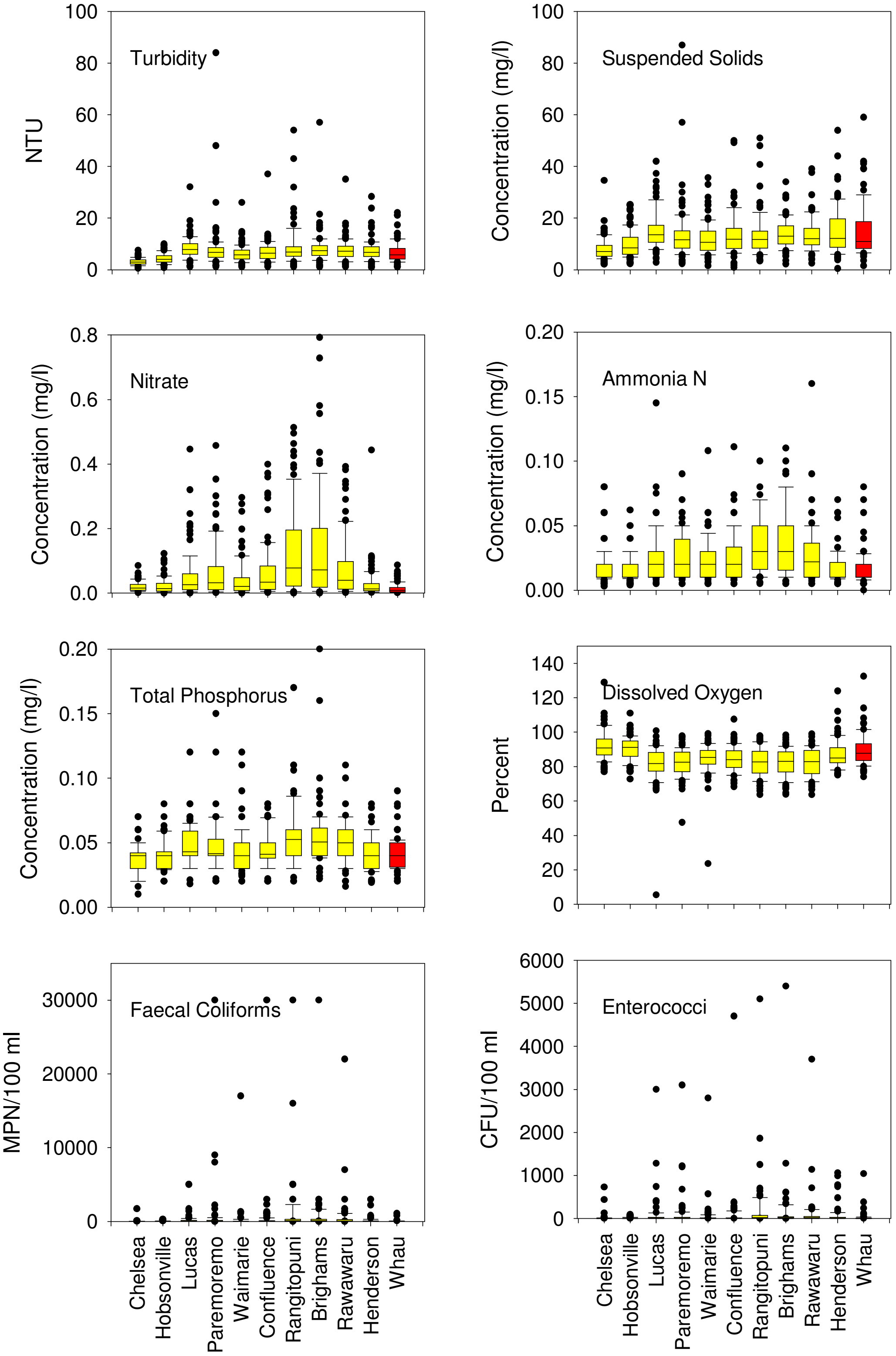


Figure 56

Boxplots of pooled 1998-2007 water quality data from sites in the Waitemata Harbour. The Whau Channel site is on the extreme right of each plot and highlighted in red. Boxes indicate median, 25th percentiles and 75th percentiles. Stems indicate 10th and 90th percentiles, while outliers are plotted individually.



5.6 Ecology

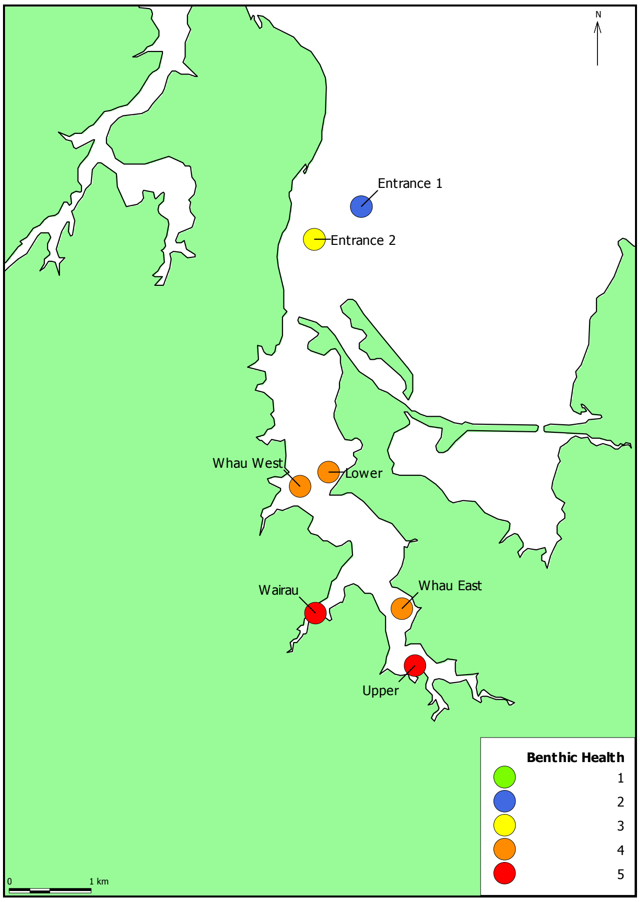
5.6.1 Benthic invertebrates

Benthic invertebrates in Whau Estuary were sampled as part of the ARC's stormwater contaminant monitoring programme (Kelly 2007b), and for the development of the ARC's benthic health model (Anderson *et al.* 2006). Ecological samples were collected from seven sites: Whau Entrance 1, Whau Entrance 2, Whau Lower, Whau West, Whau East, Whau Upper, and Wairau. The size of the sampling plot varied depending on the space available on the intertidal flats: ranging from 1000 m^2 (20 m x 50 m) to 10,000 m^2 (100 m x 100 m). Ten core samples (13 cm diameter x 15 cm deep) were collected from stratified random positions in each site. Stratification was used to avoid clumping of random samples. Ecological samples were sieved through a 0.5 mm mesh and preserved in isopropanol (70 per cent v/v). Sample sorting and taxonomic identification was carried out by NIWA Hamilton or the Leigh Marine Laboratory, with taxa being identified and enumerated to the lowest taxonomic level practical.

Ecological effects are assessed against a regional index of ecological condition (relative to stormwater contamination), which was derived from a study of the ecology, contaminant concentrations and physical characteristics of 84 sites spread throughout the Auckland region (Anderson *et al.* 2006). This index ranks the health of benthic communities from 1 (= healthy) to 5 (= degraded).

A gradient in the ecological condition of benthic communities was apparent, with condition declining up the Whau Estuary. Consequently, benthic communities at the upper Whau and Wairau sites had the worst condition (health rank 5). The ecological condition of the Whau East, West and Lower sites was slightly better (health rank 4), and the condition of the benthic communities at the entrance to Whau Estuary were the best of the five sites and were ranked as moderately degraded to good (health ranks 3 & 2 respectively).

Figure 57
Ecological condition of benthic communities in the Whau Estuary. Health is ranked from 1 (green = healthy) to 5 (red = degraded).



The most recent data obtained for the benthic health model and stormwater contaminant monitoring were reanalysed to examine benthic biodiversity, total abundance, and the distribution patterns of a number of individual species.

Benthic biodiversity (and species richness) was greatest at the Whau East site (30 species), and the two sites at the entrance to Whau Estuary (26 to 27 species) (Figure 58). The upper-most and west site had the lowest diversity (10 to 15 species) (ie Wairau, Whau Upper and Whau West). The entrance sites also had the greatest total counts of macroinvertebrates with 1255 and 1157 individuals at the Entrance 2 and Entrance 1 sites respectively (Figure 58b). These sites were dominated by the nut shell *Nucula hartvigiana*, and cockle *Austrovenus stutchburyi* (Figure 59a & b). The dominance of these species is reflected in the low value of Pielou's evenness index for these two sites (Figure 58d). Pielou's evenness index is a measure of how even (ie similar) the abundances of individual species are in a sample/site. Low index values indicate that the site is dominated by a single, or a few, species which occur in high abundance(s). The remaining species occur in relatively low abundances. In contrast, high index values indicate that the abundances of all species are fairly similar. The wedge shell *Macomona liliana*, was found only at the two entrance sites (Figure 59c). *Macomona liliana* and *Austrovenus stutchburyi* are both sensitive to habitat degradation.

The eastern Whau Estuary sites (ie Whau East and Whau Lower) had a relatively even mix of species, but the total abundance of macroinvertebrates was moderate-to-low. The most abundant species at the Whau east site were tolerant of degraded environmental quality, ie polydorids (sedentary, 10 to 30 mm tube-dwelling polychaete worms) and *Cossura consimilis* (a sedentary, 5 to 10 mm deposit feeding polychaete worm). The Whau Lower site has highest counts of phoxocephalids (amphipods), neridae (highly mobile, 30 to 60 mm predatory polychaete worms), and the 10 to 30 mm, deposit feeding polychaete worm, *Heteromastus filiformis*. All three species are tolerant of degraded environmental quality.

The Whau West, Whau Upper and Wairau sites also had low diversity, low total counts of macroinvertebrates, and were dominated by species tolerant of environmental degradation. Whau West was dominated by mud crabs, *Helice* sp., and polydorids (sedentary, 10 to 30 mm tube-dwelling polychaete worms) (Figure 59e). Wairau was dominated by phoxocephalids (Figure 59f), and Whau Upper was dominated by neridae (Figure 59d).

Figure 58

Number of species (a), total abundance (b), Margalef's index of species richness (c) and Pielou's evenness index (d) of benthic dwelling macroinvertebrates in Whau Estuary.

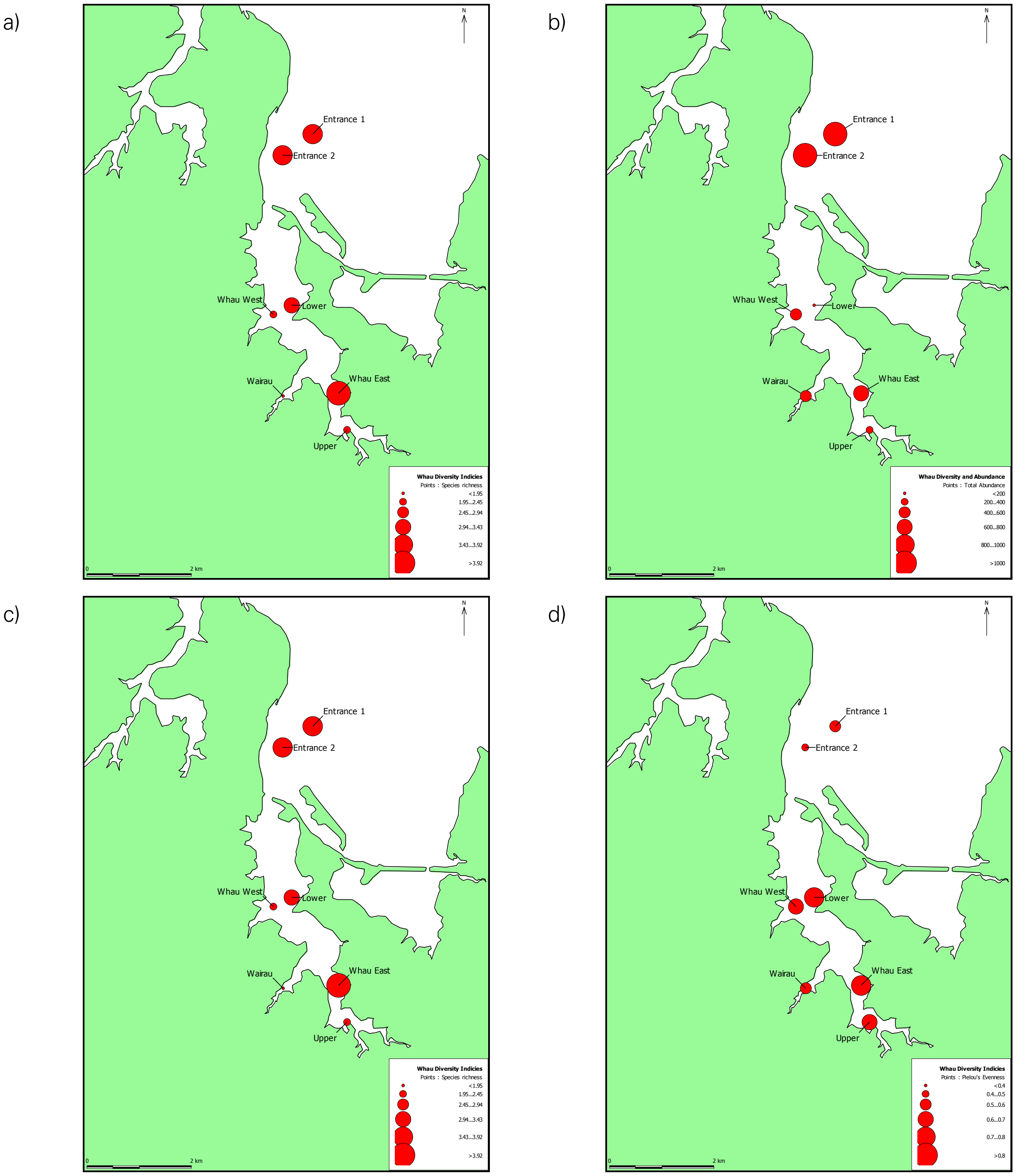
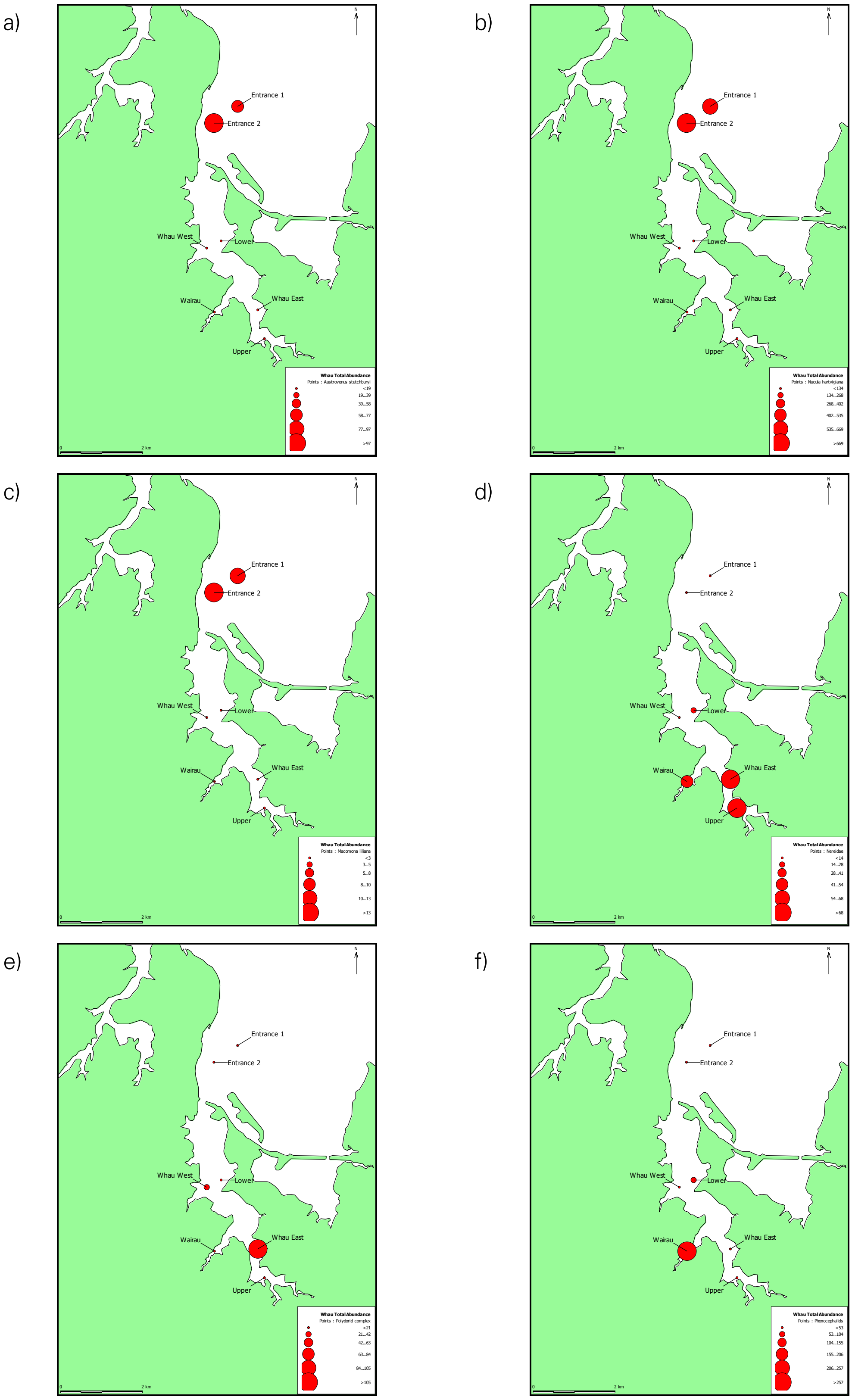


Figure 59

Total abundance of a) cockles *Austrovenus stutchburyi*, b) nut shells *Nucula hartvigiana*, c) wedge shells, *Macomona liliana*, d) Nereidae, e) Polydorids, and f) Phoxocephalids.



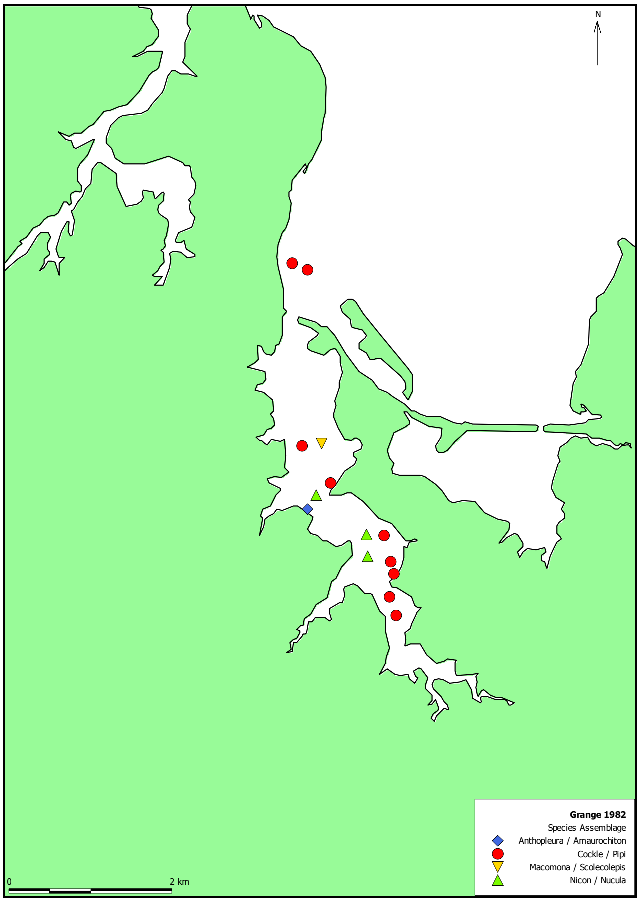
A limited number of other studies have examined benthic macrofauna in Whau Estuary. The characterisation of benthic macrofaunal associations in Whau Estuary was carried out in the 1980s as part of an assessment of five potential locations for a combined cycle power station (Grange 1982). The locations considered were: Mangere Inlet; Puketutu; Pahurehure Inlet; Whau Creek; and the Upper Tamaki. Six species groups were identified in, and adjacent to, Whau Estuary. However, only four of these occurred above the motorway bridge (Figure 60). These were the *Austrovenus / Paphies* (cockles and pipis); *Nicon* / *Nucula*; *Macomona* (ie *Tellina*) / *Scolecolepis*; and, *Anthopleura* / *Amaurochiton* associations.

Comparison of the distributions reported by Grange (1982) with recent ARC data (Figure 59), suggests that significant changes have occurred to the benthic ecosystem of Whau Estuary over the past 25 years. Grange (1982) found that assemblages dominated by cockles and pipis were widespread throughout the entire area, including the upper Whau. Similarly, assemblages dominated by the polychaete, *Nicon aestuariensis* and the small nutshell, *Nucula hartvigiana*, were scattered throughout the more sheltered intertidal parts of the inner Whau, and the distribution of an assemblage dominated by wedge shells *Macomona lilliana* and the polychaete *Scolecolepis* sp. also extended to the lower Whau. This contrasts strongly with the recent ARC surveys, which indicated that the cockles, wedge shells and nut shells occur in relatively high numbers north of the motorway bridge, but are absent from the inner Whau, or occurred in very limited numbers. Re-sampling of Grange's sites would be useful, to examine the changes that have occurred in benthic communities since 1982 in more detail.

Sivaguru and Grace (2002) also reported dense cockle-beds and relatively high numbers of nut shells, small limpets (*Notoacmea helmsi*) and sea anemones (*Anthopleura aureoradiata*), on the banks of Whau River, north of the motorway bridge. Their survey indicated that this area was characterised by one of the most diverse a species associations in the Pollen Island Marine Reserve (49 taxa) and it also had the highest counts of macrofauna. Their survey did not extend into the inner Whau.

Figure 60

Distribution of species assemblages in Whau Estuary, as identified by Grange (1982). The assemblages are: *Anthopleura* / *Amaurochiton* blue diamonds; *Austrovenus / Paphies* (cockles and pipis) red circles; *Macomona* / *Scolecolepis* yellow downward pointing triangles; and, *Nicon* / *Nucula* green upward pointing triangles. Actual locations were taken from maps presented in the original report and are therefore approximate.



5.6.2 Birds

Maps produced from Ornithological Society surveys indicate that the Manukau Harbour, southern Waitemata Harbour and Tamaki Estuary are national "hotspots" of bird diversity in coastal habitats, and hotspots for nationally vulnerable (threat code 3) endangered bird taxa (Robertson *et al.* 2007). All three areas contain extensive sand and mudflats, which are a rich food resource for shore birds. An approximately three-hour tidal difference and the narrow distances between the Manukau Harbour and the Waitemata and Tamaki Estuary also allow waders to extend their feeding times by easily moving between the west and east coasts.

Whau Estuary and the adjoining coast is used by a range of New Zealand and migratory shore birds. The value of these areas is recognised through the designation of coastal protection areas and areas of significant conservation value, which are intended to protect bird roosting and foraging areas (Figure 46 and Table 5). The Atlas of Bird Distribution in New Zealand (Robertson *et al.* 2007) indicates that up to 26 coastal bird species frequent the area (Appendix 3). Of these, 10 species have been classified as threatened (Hitchmough *et al.* 2007), with five species having threat codes 2 or 3[7] (ie grey duck (2), New Zealand dotterel (3), Caspian tern (3), reef heron (3) and wrybill (3)).

Historically, the Whau portage, between the Waitemata and Manukau Harbours, was a favourite place for Maori to catch birds (such as godwit) in flight, as they changed harbours on the rising tide (Simmons 1987). Low flying birds were apparently "swept" from the sky using forked branches. Early reports from the Ornithological Society of New Zealand also record the highly endangered black stilt in Whau Estuary eg Sibson and Prickett (1960).

Pollen and Traherne Islands and the surrounding shellbanks are particularly important high tide roosts for international migratory and endemic New Zealand wading birds, and a variety of other coastal birds. The islands are breeding and flocking areas for the threatened New Zealand Dotterel (Auckland Regional Plan: Coastal). Fernbird and banded rail also breed on the higher parts of the islands. The surrounding intertidal banks and waters are feeding grounds for a variety of waders and shore birds such as godwit, knot, pied oystercatcher and wrybill (Cameron *et al.* 1997). Consequently, the number of birds using these areas can be relatively high. For example, Jowett (1989) reported 2500 bar-tailed godwits and 4000 lesser knots at Pollen Island. Vagrant individuals of less-frequent migrants, such as Pacific golden plover and American golden plover, have also been seen in the area (eg Jowett 1989).

5.6.3 Fish

Relatively detailed surveys of fish use of intertidal to low tide sand and mudflats were carried out in the Waitemata Harbour in February 2001, by NIWA (Morrison & Francis, unpublished data (for further details, refer to Morrison *et al.* 2002 and Francis *et al.* 2005)). Original fish count data, which was collected using beach seine tows (assumed to fish a width of 9 m), were obtained from Mark Morrison (NIWA), and raw fish diversity data was plotted without correcting for tow length (Figure 61). Species count data were then corrected for tow length (count/metre towed) and plotted to illustrate the distribution of individual fish species within the Whau Channel, relative to the broader Waitemata Harbour (Figure 62).

Five of the 31 Waitemata sites surveyed were located along Whau Channel. Of these, one was located on the southern side of the Northwestern Motorway bridge, but the remaining four were adjacent to the lower channel, north of the motorway bridge (numbered one to five from the innermost to outermost site). An average of 5.4 (1.82 S.D.) fish species was obtained from the Whau Channel sites (uncorrected tows data), with the greatest number of species obtained at Site 1, south of the motorway bridge (eight species) (Figure 61). Uncorrected data indicated that fish diversity at this site was relatively high (the maximum number of species obtained from any site in Waitemata Harbour was nine), and similar to other side-branches of the harbour. Fish diversity tended to be lower in central parts of the harbour. As such, fewer species were obtained from the other Whau Channel sites (three to six species).

Whau Site 1, south of the motorway bridge had the highest corrected counts of yellow-belly flounder, specked sole and exquisite goby among all 31 Waitemata Harbour sites (Figure 62c, e & i). However, fish abundance was relatively low in the other, outer Whau Channel sites. The three most abundant species at Site 1 were speckled sole, yellow-bellied flounder and exquisite goby in that order (Figure 63). In contrast, Sites 2 to 4 had very few yellow-bellied flounder and exquisite gobies, but relatively high counts of yellow-eyed mullet. The abundances of all fish species were relatively low at the outermost site (Site 5).

---

[7] Threat code 1 equates to nationally critical, 2 nationally endangered, and 3 nationally vulnerable.

The occurrence and abundance of a number of fish species were very patchy throughout the entire Waitemata Harbour. For example, four species occurred at less than 30 per cent of the Waitemata sites: sand goby, mottled triplefin, snapper and spotty. None of these species were caught in Whau Channel.

Figure 61

Number of fish species obtained in 9 m wide beach seines in February 2001 (Morrison and Francis unpublished data). Note that these data have not been corrected for tow length.

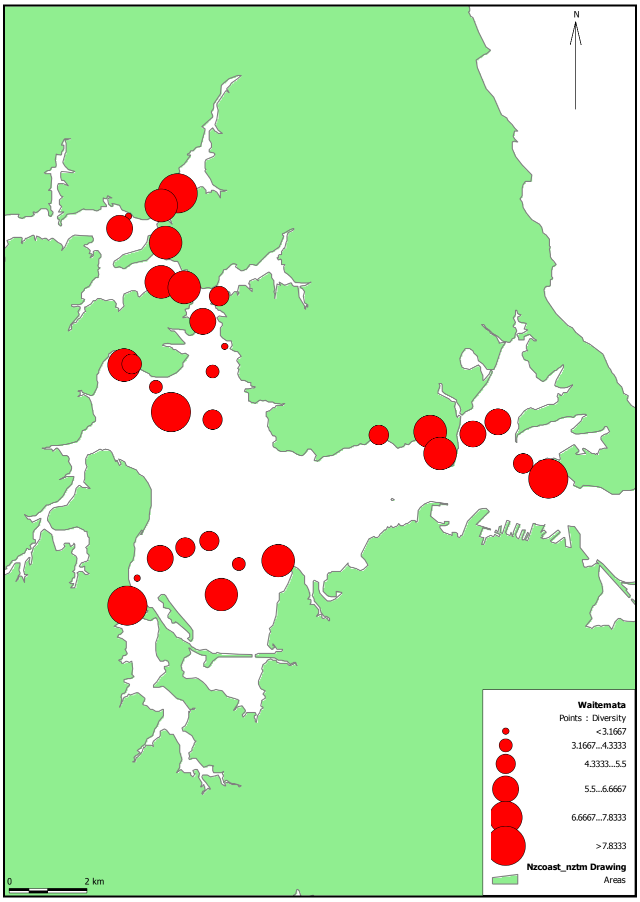
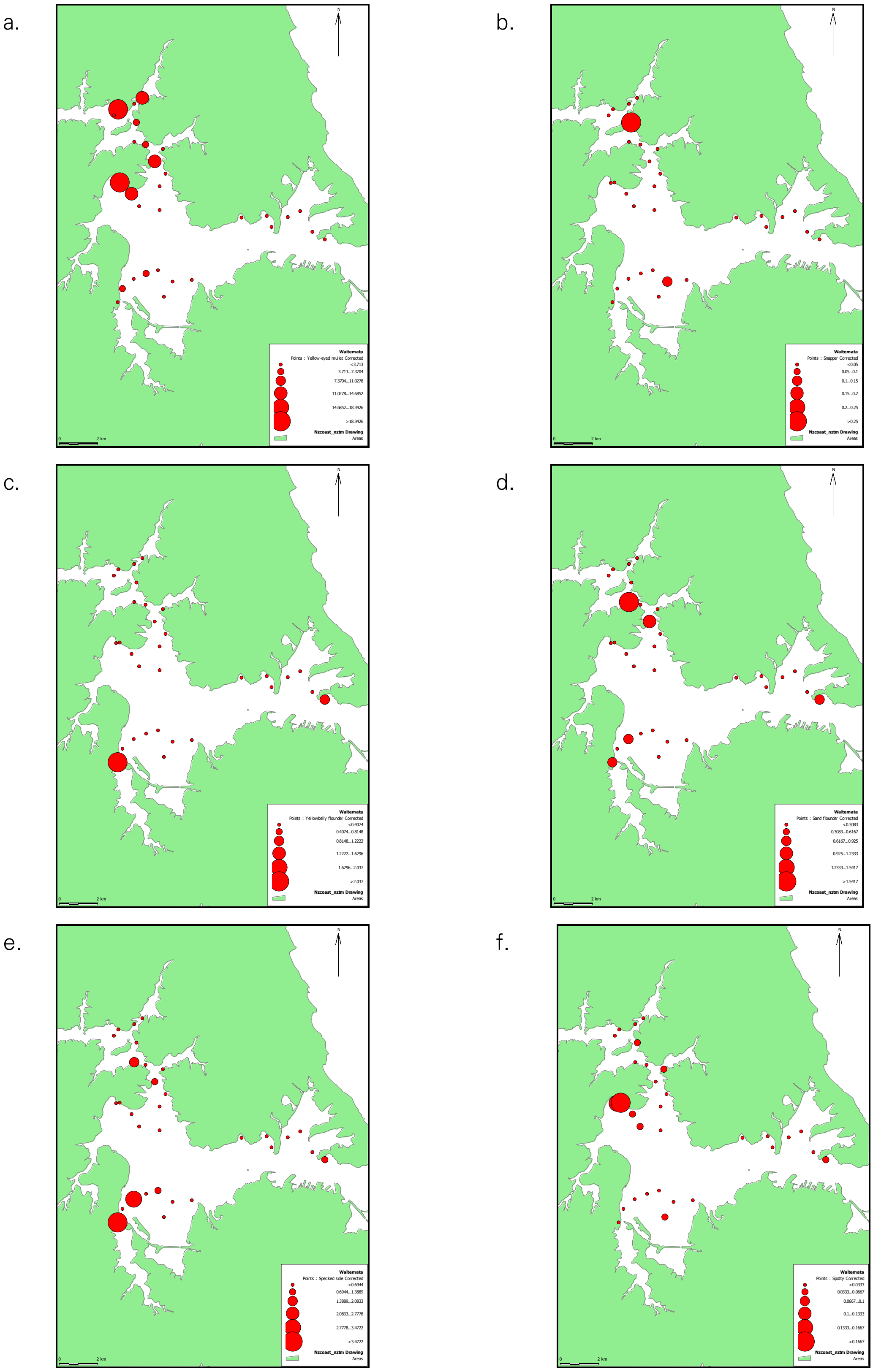
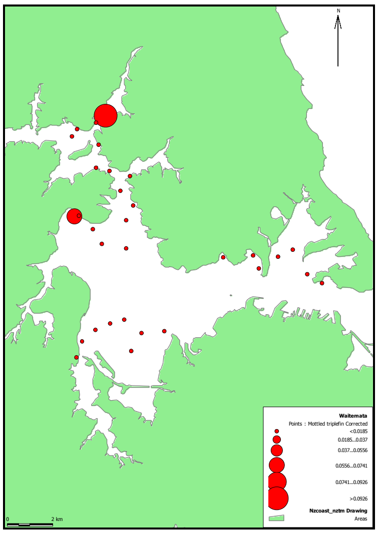


Figure 62

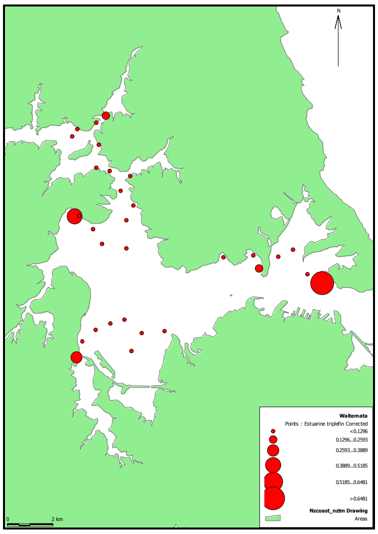
Distribution of a) yellow-eyed mullet, b) snapper, c) yellow-bellied flounder, d) sand flounder, e) speckled sole, f) spotty, g) mottled triplefin, h) estuarine triplefin, i) exquisite goby, j) anchovy k) smelt, and, l) sand goby in Waitemata Harbour (Morrison and Francis unpublished data). Note that the smallest represent zero counts.



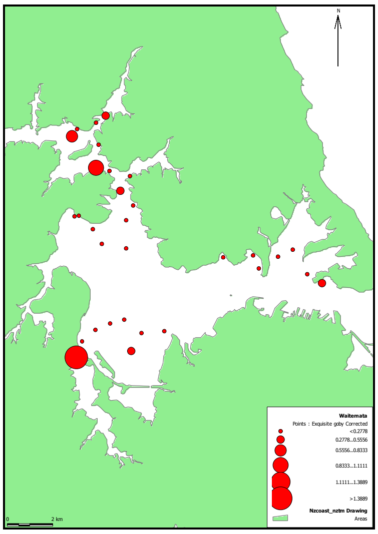
g.


N
Waitemata
Points : Mottled triplefin Corrected
<0.0185
0.0185...0.037
0.037...0.0556
0.0556...0.0741
0.0741...0.0926
>0.0926
Nzcoast_nztm Drawing
Areas
0
2 km

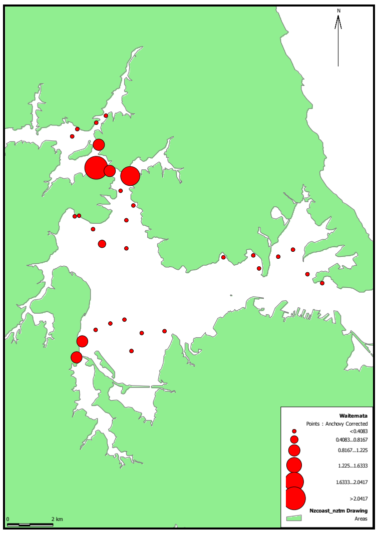
h.


N
Waitemata
Points : Estuarine triplefin Corrected
<0.1296
0.1296...0.2593
0.2593...0.3889
0.3889...0.5185
0.5185...0.6481
>0.6481
Nzcoast_nztm Drawing
Areas
0
2 km

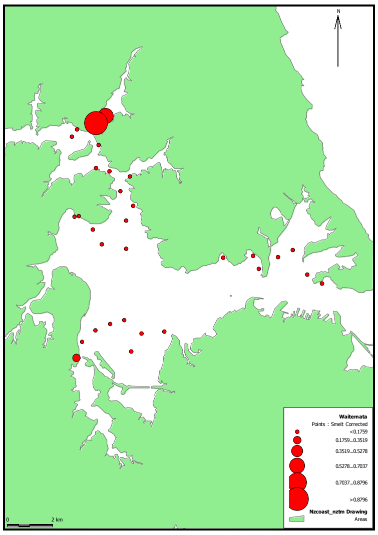
i.


N
Waitemata
Points : Exquisite goby Corrected
<0.2778
0.2778...0.5556
0.5556...0.8333
0.8333...1.1111
1.1111...1.3889
>1.3889
Nzcoast_nztm Drawing
Areas
0
2 km

j.


N
Waitemata
Points : Anchovy Corrected
<0.4083
0.4083...0.8167
0.8167...1.225
1.225...1.6333
1.6333...2.0417
>2.0417
Nzcoast_nztm Drawing
Areas
0
2 km

k.


N
Waitemata
Points : Smelt Corrected
<0.1759
0.1759...0.3519
0.3519...0.5278
0.5278...0.7037
0.7037...0.8796
>0.8796
Nzcoast_nztm Drawing
Areas
0
2 km

l.

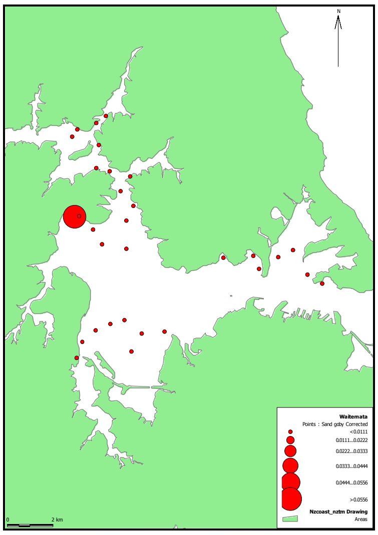
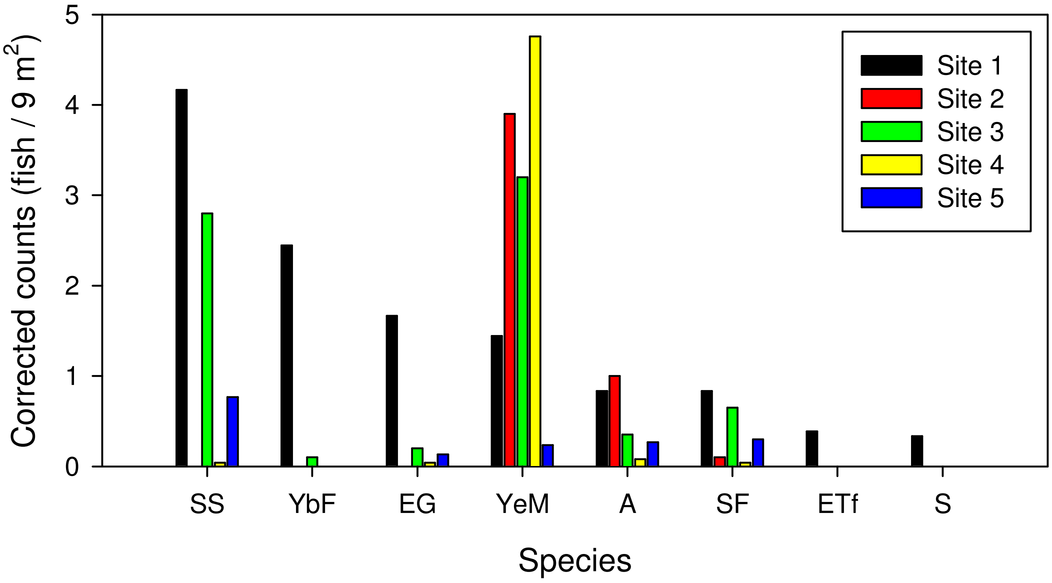

N
Waitemata
Points : Sand goby Corrected
<0.0111
0.0111...0.0222
0.0222...0.0333
0.0333...0.0444
0.0444...0.0556
>0.0556
Nzcoast_nztm Drawing
Areas
0
2 km

Figure 63

Corrected fish counts in the innermost (Site 1) to outermost (Site 5) Whau Channel sites. Fish species are: yellow-belly flounder – YbF; exquisite goby – EG; yellow-eyed mullet – YeM; anchovy – A; sand flounder – SF; estuarine triplefin – EtF; smelt – S.



5.6.4 Vegetation

The most widely distributed and abundant coastal plant in Whau Estuary is the mangrove *Avicennia marina*. The distribution of mangroves was plotted using GIS and 2006 aerial photographs (Figure 64) and with reference to Google Earth, but these were not ground truthed. The total area covered by mangrove forest in the Whau Estuary is approximately 204 ha. Relatively extensive areas occur on the eastern and western banks below Wairau Inlet. Aerial photographs suggest that areas in the outer parts of the estuary tend to consist of a fringe of large, dense mangroves close to the channel, with extensive areas of smaller, low-density mangroves behind. The area of mangrove narrows above Wairau Inlet, but forests appear to be denser than those in the lower reaches, and have a more uniform, large, tree size. Comparison of aerial photos taken from the outer Whau in 1940 and 2006 indicate that only slight marginal expansion of the mangrove forest has occurred in the lower estuary over that period (Figure 66).

Pollen Island and the adjacent area on the eastern side of Whau River contain the largest remaining areas of saltmarsh and salt meadow in Waitemata Harbour (Figure 64 and Figure 65, Hayward *et al.* 1999). Small patches or fringing ribbons of rush dominated salt marsh also occur adjacent to mangrove forest up Whau Estuary. This consists of a variety of rushes and sedges, which are inundated during peak high tides.

Figure 64
Mangrove (blue) and salt marsh (orange) distribution in the Whau Estuary. Salt marsh distribution was mapped using aerial photographs and the habitat map contained in Hayward *et al.* (1999).

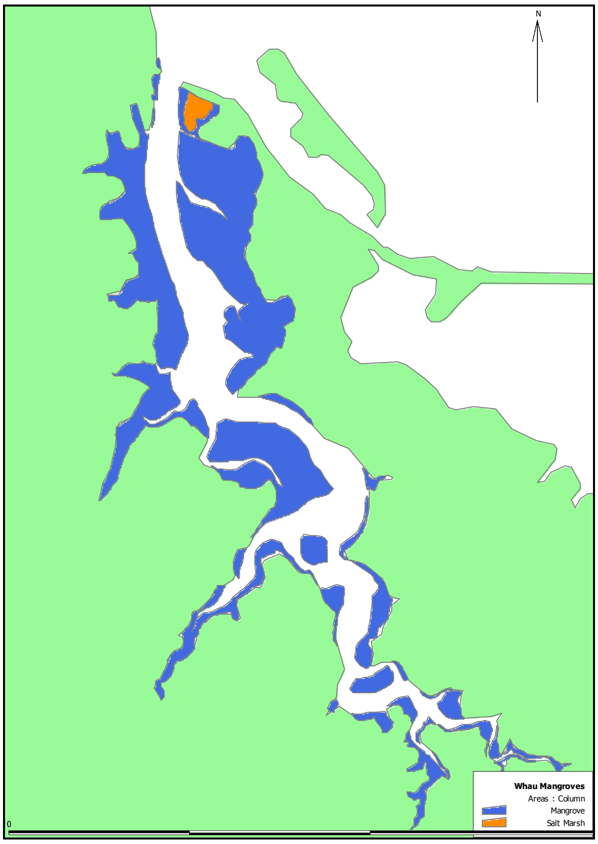
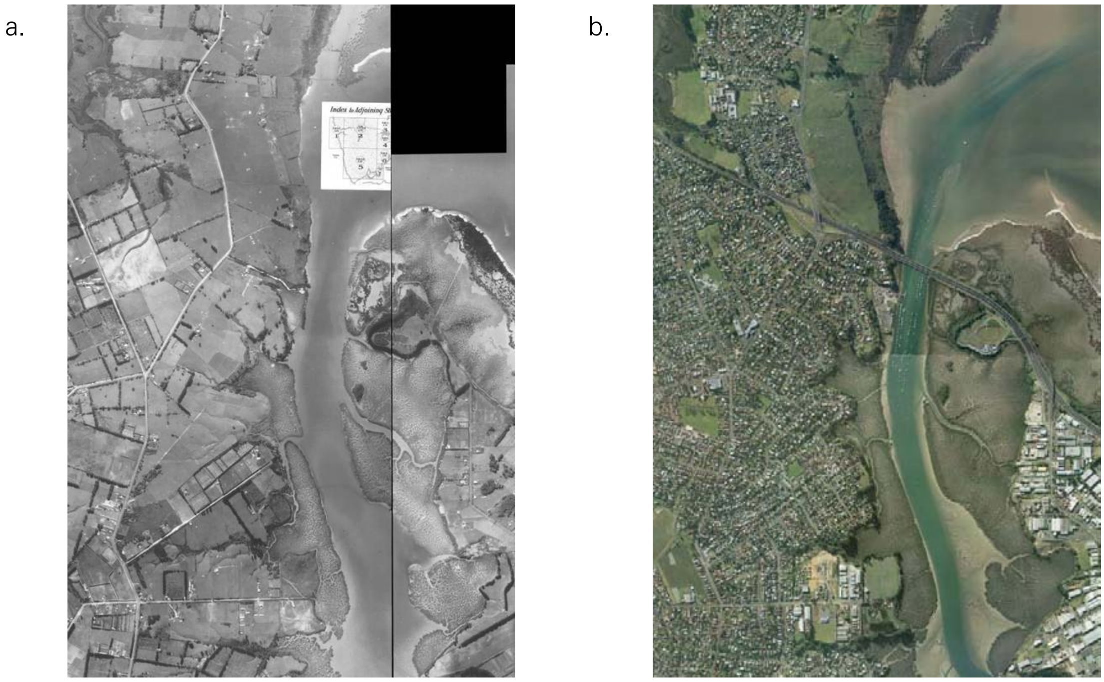


Figure 65
Saltmarsh on the eastern shore, at the entrance to Whau Estuary (see Figure 64 for the location).

Figure 66

Aerial photos of the outer Whau showing the extent of mangrove forest (and urban development) in 1940 and 2006. Also note the addition of the Northwestern Motorway in the 2006 photograph.



6 Conclusions

6.1 Tamaki Estuary

Tamaki Estuary covers a biophyiscal gradient, which extends from sheltered, muddy tidal creeks to a sheltered, open-coastal system with a mix of reef and soft sediment habitats. The high diversity of species in the estuary reflects the variety and quality of available habitats. Environmental quality and habitat diversity are greatest in the lower Tamaki, where exposed reef and sand habitats between Tahuna Torea and the entrance of the estuary add significantly to benthic diversity. Tahuna Torea is an important feature, which also enhances the coastal vegetation and bird values of the lower estuary.

Habitat diversity is lower in the mid-Tamaki between Tahuna Torea and Panmure Bridge, and this is reflected in a reduction of species diversity. However, sediment quality remains relatively good in this area and the intertidal sand and mud flats still contain a relatively high diversity and abundance of species, particularly between Tahuna Torea and Point England. The productivity and scale of the broad intertidal sand and mud flats between Tahuna Torea and Panmure Bridge is reflected in their importance as foraging areas for a variety of wading birds, including several endangered species. Salt marsh and salt meadow in Wakaaranga Creek are also important features of the mid-Tamaki. Unfortunately, the environmental values of this area have been, and are probably continuing to be, slowly degraded. For instance, water quality at Panmure Bridge is notably worse than at Bucklands Beach and organic contaminant concentrations in mussels set at Panmure Bridge are among the highest in the Auckland region. Analysis of benthic health suggests that contaminants have affected the composition of benthic communities in this area.

A distinct environmental break-point occurs in the vicinity of Panmure Bridge, with the estuary narrowing and becoming more sheltered above the bridge. Catchment areas are also larger, relative to the area of estuary in this part of the Tamaki. Sediments become muddier and more contaminated above Panmure Bridge, and extensive mangrove forests occur in side branches and upper reaches of the estuary. Zinc and copper concentrations are worst in the upper Pakuranga and Middlemore areas, and concentrations of these two metals are continuing to increase rapidly. A number of other metal and organic contaminants also exceed low-level sediment quality guideline values in these areas. These changes are reflected in the composition of the ecological community. Benthic community health is substantially degraded at all sites above Panmure Bridge, with sites in the upper Pakuranga and Middlemore areas having the worst ecological condition. The benthic community mainly consists of mud and contaminant tolerant species, but local anomalies do occur. For instance, pipis, which are regarded as being sensitive to environmental quality, were recorded at the Middlemore site. Despite its degraded state, the upper Tamaki still contains functioning benthic communities that continue to provide a range of functions and services (eg contributing to food-web and geochemical processes). It is also used by a range of bird and fish species. For instance, Pakuranga Creek contains an important bird roost which is used by hundreds of waders that feed in the estuary. Fish data from the Tamaki is limited, but upper estuarine areas commonly have high levels of fish diversity, and it is likely that a variety of fish utilise these areas in the Tamaki.

6.2 Mangere Inlet

Mangere Inlet has an unenviable history of environmental management. The coastline has been highly modified by "reclamation" and the estuary has been affected by the direct discharge of industrial waste for around a century. The commissioning of the Mangere Wastewater Treatment Plant significantly improved the condition of the inlet, but the discharge from the plant also has an effect on water quality. The 2001 upgrade to the plant has reduced its impact on water quality, but the effects of the discharge are still distinguishable. The ongoing effects of stormwater contaminants and unauthorized discharges from industrial sites are also problematic.

The inlet contains extensive areas of intertidal mudflats, with a central shell bank towards the eastern end. Mangroves fringe the margins of the inner inlet, with greatest mangrove cover on the eastern and southern shores. Sediments are muddy, and the northern shore is moderately contaminated with copper and zinc. Sites on the southern shore and outer inlet appear to have relatively good sediment quality. Isolated hot spots of contamination occur within the inlet, due to unauthorized discharges of wastewater and/or stormwater. Mussels, oysters and flounder collected from Mangere Inlet also tend to have relatively high concentrations of organic contaminants in their tissues, and lead concentrations in the blood of South Island pied oystercatchers have also been found to be high.

Benthic community health has been significantly degraded in the inner parts of Mangere Inlet, but it is only moderately impacted in outer parts. Despite this, the inlet still contains functioning benthic communities that continue to provide a range of functions and services (eg contributing to food-web and geochemical processes). It is also utilised by a range of fish and bird species. The north-eastern Manukau, including Mangere Inlet, is a national hotspot for coastal bird diversity and is utilised by a number of endangered species. Old Mangere Bridge is a very popular recreational fishing spot and fish diversity within the inlet is relatively high. The bridge also provides a haul-out area that is occasionally used by juvenile seals (pers. obs.).

6.3 Whau Estuary

Whau Estuary has two distinct zones: the outer Whau channel, north of the motorway bridge; and, the inner Whau, south of the bridge. The inner Whau consists of a sheltered inlet with relatively broad, mangrove-fringed mudflats that drain into a narrow central channel. The outer channel is an exposed open tributary of the central Waitemata Harbour, which drains extensive and highly productive intertidal sandflats. Pollen Island Marine Reserve adjoins the southern bank of the outer Whau channel.

Whau Estuary has a long history of industrial use and development, which dates back to the early period of European settlement. Current land use in the Whau catchment is predominantly residential with substantial pockets of industrial/commercial development in the Rosebank, New Lynn and Glendene areas. The Whau is heavily affected by diffuse urban stormwater run-off. Isolated hot spots of contamination also occur within the inlet, due to unauthorized discharges of wastewater and/or stormwater.

The inner Whau is one of the most contaminated coastal waterways in the Auckland region, with particularly high concentrations of zinc in estuarine sediments. Copper, lead, mercury and PAH concentrations are also elevated. Sediment quality monitoring indicates the zinc and copper concentrations are continuing to increase rapidly, and modelling suggests that this trend will continue for the foreseeable future. In contrast, sediment contaminant concentrations are low, and water quality is relatively good, in the outer Whau.

Differences in habitat characteristics and quality between the inner and outer Whau are reflected in the ecological characteristics of benthic communities. Benthic community health varies from good in the outer Whau to highly degraded in the upper Whau. Comparisons between samples collected in 1982 (Grange 1982) and those collected in 2004-2007 suggests that benthic communities in the inner Whau were significantly degraded over that period, which probably coincides with major increases in the concentration of sediment contaminants. Notable changes appear to have been the loss of communities dominated by cockles, pipis and wedge shells from the inner Whau. Despite this, the inner Whau still contains functioning benthic communities that continue to provide a range of functions and services (eg contributing to food-web and geochemical processes).

The outer Whau has very high ecological values due to the diversity and abundance of species, which includes extensive and dense shellfish beds. The area is therefore used by large numbers of waders and other shore birds, including a number of endangered species. Less is known about bird use of the inner Whau, but historical records indicate that the area has been used by endangered species such as the black stilt. A survey of the Waitemata Harbour indicated that fish diversity and abundance were relatively high immediately south on the Northwestern Motorway bridge, but declined down the channel north of the bridge. Speckled sole, yellow-bellied founder and exquisite goby were particularly prevalent, and numbers at this site were the highest recorded of the 31 Waitemata sites surveyed.

7 Acknowledgements

Mark Morrison (NIWA) kindly provided data from fish surveys of the Manukau and Waitemata Harbours. Michael Lindgreen assisted with the provision of reports, shape files and other information from Metrowater and Auckland City Council. Library resources from the University of Auckland were also used for this review.

8 References

ABRAHIM G.M.S., 2005. *Holocene sediments of Tamaki Estuary: characterisation and impact of recent human activity on an urban estuary in Auckland, New Zealand.* PhD, University of Auckland

ABRAHIM G., PARKER R., 2002. Heavy-metal contaminants in Tamaki Estuary: impact of city development and growth, Auckland, New Zealand. *Environmental Geolology* 42:883-890

ANDERSON M.J., HEWITT J.E., FORD R.B., THRUSH S.F., 2006. *Regional models of benthic ecosystem health: predicting pollution gradients from biological data TP317,* Auckland Regional Council, Auckland

ANZECC (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality,* Australian and New Zealand Environment & Conservation Council, and Agriculture and Resource Management Councils of Australia & New Zealand, Canberra, Australia.

ARC, 1992. *Tamaki catchment and estuary: Review of water quality.* Technical Publication TP20, Auckland Regional Council, Auckland

ARC, 2002a. *Regional maps of settling zones and outer zones.* ARC Technical Publication TP170, Auckland Regional Council, Auckland

ARC, 2002b. *Environmental targets for the urban coastal marine area.* ARC Technical Publication TP169, Auckland Regional Council, Auckland

AUCKLAND REGIONAL WATER BOARD, 1987. *Manukau Harbour Action Plan*, Auckland Regional Water Board, Auckland

BARFOOT, C., 2007. *Tahuna Torea: tip-site to nature reserve.* Tamaki Estuary Protection Society, Auckland

BELL, R.G., DUMNOV, S.V., WILLIAMS, B.L., GREIG, M.J.N., 1998. Hydrodynamics of Manukau Harbour, New Zealand. *New Zealand Journal of Marine & Freshwater Research* 32:81-100

Bioresearches, 2007. *Harbour environment monitoring programme 2006 - 2007,* Watercare Services Limited, Auckland

CAMERON, E., HAYWARD, B., MURDOCH, G., 1997. *A field guide to Auckland; exploring the region's natural and historic heritage.* Godwit Publishing, Auckland

CONWAY, P., 2005. Tidal variation of chlorophyll-containing pigments in a temperate tidal salt-marsh lagoon. Master of Applied Science, Auckland University of Technology

CROUCHER A.E., BOGLE, M.G.V., O'SULLIVAN, M.J., 2005A. *Coastal Receiving Environment Assessment (CREA), Report 1: Modelling framework,* Uniservices, Auckland

CROUCHER, A.E., M.G.V. B., O'SULLIVAN, M.J., 2005b. *Coastal Receiving Environment Assessment (CREA) report III: Tamaki Estuary*, Uniservices (University of Auckland), Auckland

CROUCHER, A.E., M.G.V. B., O'SULLIVAN M.J., 2005c. *Coastal Receiving Environment Assessment (CREA) report VI: Manukau Harbour*, Uniservices (University of Auckland), Auckland

CROUCHER, A.E., M.G.V. B., O'SULLIVAN, M.J., 2005d. *Coastal Receiving Environment Assessment (CREA) report II: Whau Estuary*, Uniservices (University of Auckland), Auckland

DEPREE, C., AHRENS, M. (in press). *Polycyclic aromatic hydrocarbons in Auckland's aquatic environment: sources, concentrations and potential environmental risks.* Technical Publication, Auckland Regional Council, Auckland

DIGGLES, B.K., SMITH, M., MORRISON, M., MILLS, G., HINE, P.M., BULL, B., 2000. *Final report on parasites and pathological lesions of yellow-belly flounder Rhombosolia leporina and their relationship with contamination in Manukau Harbour.* ARC Technical Publication TP140, Auckland Regional Council, Auckland

DOWDING, J.E., MOORE, S.J. , 2006. *Habitat networks of indigenous shorebirds in New Zealand 261*, Department of Conservation, Wellington

DRURY, B., KERR, H., OKE, P., 1853. *Manukau Harbour.* British Admiralty, London.

FRANCIS, M.P., MORRISON, M.A., LEATHWICK, J., WALSH, C., MIDDLETON, C., 2005. Predictive models of small fish presence and abundance in northern New Zealand harbours. *Estuarine, Coastal and Shelf Science* 64:419-435

GIBBS, M., HEWITT, J., 2004. *Effects of sedimentation on macrofaunal communities: a synthesis of research studies for ARC.* ARC Technical Publication TP264, Auckland Regional Council, Auckland

GLASBY, G.P., STOFFERS, P., WALTER, P., DAVIS, K.R., RENNER, R.M., 1988. Heavy-metal pollution in Manukau and Waitemata Harbours, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 22:595-611

GRANGE, K.R., 1982. Macrobenthic communities at possible combined cycle power station sites in Manukau and Waitemata Harbours, Auckland. *Oceanographic Summary 19*, New Zealand Oceanographic Institute

HAYWARD, B.W., GRENFELL, H.R., NICHOLSON, K., PARKER, R., WILMHURST, J., HORROCKS, M., SWALES, A., SABAA, A.T., 2004. Foraminiferal record of human impact on intertidal estuarine environments in New Zealand's largest city. *Mar* Micropaleontol 53:37-66

HAYWARD, B.W., MORLEY, M.S., 2005. *Intertidal life of the Tamaki Estuary and its entrance, Auckland.* ARC Technical Publication, TP373, Auckland Regional Council, Auckland

HAYWARD, B.W., MORLEY, M.S., STEPHENSON, B.A., BLOM, W.M., GRENFELL, H.R., PRASAD, R., ROGAN, D., THOMPSON, F., CHEETHAM, J., WEBB, M., 1999. *Intertidal and subtidal biota and habitats of the central Waitemata Harbour.* ARC Technical Publication TP127, Auckland Regional Council, Auckland

HEATH, R.A., GREIG, M.J.N., SHAKESPEARE, B.S., 1977. Circulation and hydrology of Manukau Harbor. *New Zealand Journal of Marine & Freshwater Research* 11:589-608

HENRIQUES, P.R., 1977. *Selected ecological aspects of the Manukau Harbour.* PhD Thesis, University of Auckland

HITCHMOUGH, R,; BULL, L,; CROMARTY, P. (compilers), 2007. *New Zealand threat classification system lists 2005.* Wellington, Department of Conservation. 194 p.

HUME, T.M., 1979. *Aspects of the hydrology of the Mangere Inlet-Wairopa Channel area, north-east Manukau Harbour, Auckland.* Water and Soil Division, Ministry of Works and Development, Auckland

JOWETT, C., 1989. *Birdwatching in the north OSNZ News*, p 7-8.

KELLY, S., 2007a. *Contaminant monitoring in shellfish: Results of the 2005 shellfish contaminant monitoring programme.* ARC Technical Publication TP 332, Auckland Regional Council, Auckland

KELLY, S., 2007b. *Marine Receiving Environment Stormwater Contaminants: Status Report 2007.* ARC Technical Publication TP333, Auckland Regional Council, Auckland

KELLY, S., BARNES, G., MCMURTRY, M., YEE, J., KUMAR, N., 2006. *State of the environment monitoring: stream, lake and coastal water quality January - December 2004.* ARC Technical Publication TP266, Auckland Regional Council, Auckland

KINGETT MITCHELL AND ASSOCIATES, 1996. *Assessment of biological resources of the upper Tamaki Estuary and Otara Lake*, Kingett Mitchell and Associates

LARCOMBE, M.F., 1973. *Waitemata Harbour Study, Ecology*, Auckland Harbour Board and Auckland Regional Authority

LARCOMBE, M., 2006. *Coastal marine ecology and water quality assessment. In: Sinclair K (ed) SH20 Manukau Harbour Crossing Project: Assessment of environmental effects, Vol 2.* Transit NZ

LONG, E.R., MORGAN, L.G., 1990. *The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program NOAA Technical Memorandum*, NOS OMA 52, National Oceanic and Atmospheric Administration, Seattle, Washington

MACDONALD,D.D., CARR, R.S., CALDER, F.D., LONG, E.R., INGERSOLL, C.G., 1996. Development and evaluation of sediment quality guidelines for Florida coastal waters. *Ecotoxicology* 5:253-278

MACKAY, J., 2001. *The Whau: our streams, our river, our backyards.* Waitakere City Council, Auckland

MATTHEWS, A., GRENFELL, H.R., HAYWARD, B.W., HORROCKS, M., 2005. *Foraminiferal record of sewage outfall impacts on the inner Manukau Harbour, Auckland, New Zealand.* New Zealand Journal of Marine and Freshwater Research 39:193-215

MCHUGH, M., REED, J., 2006. *Marine sediment monitoring programme: 2005 results* TP316, Auckland Regional Council, Auckland

MILLS, G.N., 1994. *Organic contaminants in Tamaki Estuary shellfish. Consultancy Report for the ARC ARC319*, NIWA, Hamilton

MILLS, G.N., FAHEY, L.S., 1995. *Organic contaminants in Waitemata and Tamaki mussels: Summer 1994 deployment data*. Consultancy Report for Auckland Regional Council ARC236/3, NIWA, Hamilton

MORRISEY, D.J., TURNER, S.J., MILLS, G.N., WILLIAMSON, R.B., WISE, B.E., 2003. Factors affecting the distribution of bentic macrofauna in estuaries contaminated by urban run-off. *Marine environmental research* 55:113-136

MORRISEY, D.J., WILLIAMSON, R.B., VAN DAM, L., LEE, D.J., 2000. Stormwater contamination of urban estuaries. 2. Testing a predictive model of the build-up of heavy metals in sediments. *Estuaries* 23:67-79

MORRISON, M.A., FRANCIS, M.P., HARTILL, B.W., PARKINSON, D.M., 2002. Diurnal and tidal variation in the abundance of the fish fauna of a temperate tidal mudflat. *Estuarine, Coastal and Shelf Science* 54:793–807

REED, J., WEBSTER, K., 2004. *Marine Sediment Monitoring Programme - 2003 Results* TP246, Auckland Regional Council, Auckland

ROBERTSON, C.J.R., ROBERTSON, C.J.R., BULL, P.C., ORNITHOLOGICAL SOCIETY OF NEW ZEALAND., 2007. *Atlas of bird distribution in New Zealand 1999-2004*. Ornithological Society of New Zealand, Wellington, N.Z.

ROPER, D.S., NIPPER, M.G., HICKEY, C.W., MARTIN, M.L., WEATHERHEAD, M.A., 1995. Burial, crawling and drifting behaviour of the bivalve Macomona liliana in response to common sediment contaminants. *Marine Pollution Bulletin* 31:471-478

ROPER, D.S., THRUSH, S.F., SMITH, D.G., 1988. The influence of run-off on intertidal mudflat benthic communities. *Mar Environ Res* 26:1-18

SAGAR, P.M., SHANKAR, U., BROWN, S., 1999. Distribution and numbers of waders in New Zealand, 1983-1994. *Notornis* 46:1-43

SIBSON, R.B., PRICKETT, J., 1960. Classified summarised notes. *Notornis* 9:77

SIMMONS, D., 1987. *Maori Auckland,* Bush Press Communications, Auckland

SIVAGURU, K., GRACE, R., 2002. *Benthos and sediments of Motu Manawa (Pollen Island) Marine Reserve*. Conservancy Report, Department of Conservation, Auckland

STEWART, M.J., 2005. *Ecological effects associated with urban development on populations of the New Zealand cockle (Austrovenus stutchburyi).* PhD Thesis, University of Auckland

STONE, R.C.J., 2001. *From Tamaki-Makau-Rau to Auckland.* Auckland University Press, Auckland

SWALES, A., WILLIAMSON, R.B., VAN DAM, L.F., STROUD, M.J., MCGLONE, M.S., 2002. Reconstruction of urban stormwater contamination of an estuary using catchment history and sediment profile dating. *Estuaries* 25:43-56

THOMPSON, D.R., DOWDING, J.E., 1999. Site-specific heavy metal concentrations in blood of South Island pied oystercatchers *Haematopus ostralegus finschi* from the Auckland region, New Zealand. *Marine Pollution Bulletin* 38:202–206

THRUSH, S.F., ROPER, D.S., 1988. Merits of macrofaunal colonization of intertidal mudflats for pollution monitoring preliminary study. *Journal of Experimental Marine Biology & Ecology* 116:219-234

Williamson, R.B., Blom, A., Hume, T.M., Glasby, G.P., Larcombe, M., 1992. Heavy metals in Manukau Harbour sediments. *Water Quality Centre Publication* 23, DSIR, Hamilton

WILLIAMSON, R.B., MOL-KRIJNEN, J., VAN DAM, L., 1995. Trace metal partitioning in bioturbated, contaminated, surficial sediments from Mangere Inlet, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29:117-130

WILLIAMSON, R.B., MORRISEY, D.J., 2000. Stormwater contamination of urban estuaries 1: Predicting the build-up of heavy metals in sediments. *Estuaries* 23:56-66

WILLIAMSON, R.B., MORRISEY, D.J., SWALES, A., MILLS, G.N., 1998. *Distribution of contaminants in urbanised estuaries: prediction and observation*. Technical Publication TP139, Auckland Regional Council

WILLIAMSON, R.B., VAN DAM, L.F., BELL, R.G., GREEN, M.O., KIM, J.P., 1996. Heavy metal and suspended sediment fluxes from a contaminated, intertidal inlet (Manukau Harbour, New Zealand). *Marine Pollution Bulletin* 32:812-822

VANT, W.N., WILLIAMS, B.L., 1992. Residence times of Manukau Harbour, New Zealand. *New Zealand Journal of Marine & Freshwater Research* 26:393-404

VEITCH, C.R., HABRAKEN, A.M., 1999. Waders of the Manukau Harbour and Firth of Thames. *Notornis* 46:45-70

ZAUKE, G.P., HARMS, J., FOSTER B.A., 1992. Cadmium, lead, copper, and zinc in Elminius modestus Darwin (Crustacea, Cirripedia) from Waitemata and Manukau Harbours, Auckland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 26:405-415

9 Bibliography

9.1 Contaminants

ABRAHIM, G., PARKER, R., 2002. Heavy-metal contaminants in Tamaki Estuary: impact of city development and growth, Auckland, New Zealand. *Environ Geol* 42:883-890

ABRAHIM, G.M.S., PARKER, R.J., NICHOL, S.L., 2007. Distribution and assessment of sediment toxicity in Tamaki Estuary, Auckland, New Zealand. *Environ Geol* 52:1315-1323

BIORESEARCHES, 2007. *Harbour environment monitoring programme 2006 – 2007.* Watercare Services Limited, Auckland

BIORESEARCHES, 2005. *Watercare Services Ltd project Manukau pond recovery monitoring programme 2004-2005.* Client report for Watercare Services Ltd., Bioresearches, Auckland

BULL, D.C., WILLIAMSON, R.B., 2001. Prediction of principal metal-binding solid phases in estuarine sediments from color image analysis. *Environ Sci Technol* 35:1658-1662

CROUCHER, A.E., BOGLE, M.G.V., O'SULLIVAN, M.J., 2005a. *Coastal Receiving Environment Assessment (CREA), Report 1: Modelling framework.* Uniservices, Auckland

CROUCHER, A.E., M.G.V. B., O'SULLIVAN, M.J., 2005b. *Coastal Receiving Environment Assessment (CREA) report II: Whau Estuary.* Uniservices (University of Auckland), Auckland

CROUCHER, A.E., M.G.V. B., O'SULLIVAN, M.J., 2005c. *Coastal Receiving Environment Assessment (CREA) report III: Tamaki Estuary.* Uniservices (University of Auckland), Auckland

CROUCHER, A.E., M.G.V. B., O'SULLIVAN, M.J., 2005d. *Coastal Receiving Environment Assessment (CREA) report VI: Manukau Harbour.* Uniservices (University of Auckland), Auckland

DEMEKE, G., 1986. Chemical speciation of Manukau Harbour sediments. MSc Thesis, University of Auckland.

DEPREE, C., AHRENS, M. (In Press) Polycyclic aromatic hydrocarbons in Auckland's aquatic environment: sources, concentrations and potential environmental risks, Auckland Regional Council, Auckland

DIFFUSE-SOURCES LIMITED, 2004. Regional Discharges Project Sediment Quality Data Analysis. ARC Technical Publication TP245, Auckland Regional Council, Auckland

DIGGLES, B.K., SMITH, M., MORRISON, M., MILLS, G., HINE, P.M., BULL, B., 2000. *Final report on parasites and pathological lesions of yellow-belly flounder Rhombosolia leporina and their relationship with contamination in Manukau Harbour. ARC Technical Publication TP140.* Auckland Regional Council, Auckland

EVANS, C.W., WILSON D.A., MILLS G.N., 2001. Quantitative competitive (qc) RT-PCR as a tool in biomarker analysis. *Biomarkers* 6:7-14

FERGUSON, L.R., GREGORY, T.J., PEARSON, A.E., HAY, J.E., LEWIS, G.D., 1996. Mutagenicity tests as a monitoring tool for potential mutagens and carcinogens in shellfish gathering areas of New Zealand. *New Zealand Journal of Marine & Freshwater* Research 30:413-421

GLASBY, G.P., STOFFERS, P., WALTER, P., DAVIS, K.R., RENNER, R.M., 1988. Heavy-metal pollution in Manukau and Waitemata Harbours, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 22:595-611

GRIFFITHS, G., TIMPERLEY, M., 2005. *Auckland City stormwater - A summary of NIWA and other relevant studies.* NIWA Client Report AKL2005-007, NIWA, Auckland

HAYWARD, B.W., GRENFELL, H.R., NICHOLSON, K., PARKER, R., WILMHURST, J., HORROCKS, M., SWALES, A., SABAA, A.T., 2004. Foraminiferal record of human impact on intertidal estuarine environments in New Zealand's largest city. *Mar Micropaleontol* 53:37-66

HAYWARD, B.W., GRENFELL, H.R., SABAA, A.T., MORLEY, M.S., HORROCKS, M., 2006. Effect and Timing of Increased Freshwater Run-off into Sheltered Harbor Environments Around Auckland City, New Zealand. *Estuaries Coasts* 29:165-182

HICKEY, C.W., ROPER, D.S., HOLLAND, P.T., TROWER, T.M., 1995. Accumulation of organic contaminants in two sediment-dwelling shellfish with contrasting feeding modes: Deposit - (*Macomona liliana*) and filter-feeding (*Austrovenus stutchburyi*). *Archives of Environmental Contamination & Toxicology* 29:221-231

HOLLAND, P.T., HICKEY, C.W., ROPER, D.S., TROWER, T.M., 1993. Variability of organic contaminants in inter-tidal sandflat sediments from Manukau Harbour, New Zealand. *Archives of Environmental Contamination & Toxicology* 25:456-463

KELLY, S., 2007a. *Contaminant monitoring in shellfish: Results of the 2005 shellfish contaminant monitoring programme.* ARC Technical Publication TP 332, Auckland Regional Council, Auckland

KELLY, S., 2007b. *Marine Receiving Environment Stormwater Contaminants: Status Report 2007.* ARC Technical Publication TP333, Auckland Regional Council, Auckland

MATTHEWS, A., 2004. *Human impact in the Mangere Inlet, Manukau Harbour; with emphasis on the foraminiferal record.* MSc Thesis, University of Auckland

MATTHEWS, A., GRENFELL, H.R., HAYWARD, B.W., HORROCKS, M., 2005. Foraminiferal record of sewage outfall impacts on the inner Manukau Harbour, Auckland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 39:193-215

MAXWELL, G.S., 1987a. *The chemical flush into Auckland's Tamaki Estuary, following a major fire, on 21 December 1984, at ICI Mt. Wellington site: an ecological assessment*, ICI? Auckland, N.Z.

MAXWELL, G.S., 1987b. *The ecological recovery of the Tamaki Estuary: a report on the Post ICI Fire Ecological Monitoring Programme, April 1985 to November 1986,* ICI? Auckland, N.Z.

MCHUGH, M., REED, J., 2006. *Marine sediment monitoring programme: 2005 results.* TP316, Auckland Regional Council, Auckland

MILLS, G.N., 1994. *Organic contaminants in Tamaki Estuary shellfish.* Consultancy Report for Auckland Regional Council ARC319, NIWA, Hamilton

MILLS, G.N., 1997. *Polychlorinated biphenyls, PCBs) in Pacific Steel samples*. NIWA Client Report ARC80227, NIWA, Hamilton

MILLS, G.N., FAHEY L.S., 1995. *Organic contaminants in Waitemata and Tamaki mussels: Summer 1994 deployment data.* Consultancy Report for Auckland Regional Council ARC236/3, NIWA, Hamilton

MORRISEY, D.J., DEWITT, T.H., ROPER, D.S., WILLIAMSON, R.B., 1999. Variation in the depth and morphology of burrows of the mud crab Helice crassa among different types of intertidal sediment in Zew Zealand. *Marine Ecology Progress Series* 182:231-242

MORRISEY, D.J., TURNER, S.J., MILLS, G.N., WILLIAMSON, R.B., WISE, B.E., 2003. Factors affecting the distribution of bentic macrofauna in estuaries contaminated by urban run-off. *Marine environmental research* 55:113-136

MORRISEY, D.J., WILLIAMSON, R.B., VAN DAM, L., LEE, D.J., 2000. Stormwater contamination of urban estuaries. 2. Testing a predictive model of the build-up of heavy metals in sediments. *Estuaries* 23:67-79

PRIDMORE, R.D., ROPER, D.S., HEWITT, J.E., 1990. Variation in composition and condition of the pacific oyster *Crassostrea gigas* along a pollution gradient in Manukau Harbour New Zealand. *Marine Environmental Research* 30:163-178

REED, J., WEBSTER, K., 2004. *Marine Sediment Monitoring Programme - 2003 Results TP246,* Auckland Regional Council, Auckland

ROPER, D.S., NIPPER, M.G., HICKEY, C.W., MARTIN, M.L., WEATHERHEAD, M.A., 1995. Burial, crawling and drifting behaviour of the bivalve Macomona liliana in response to common sediment contaminants. *Marine Pollution Bulletin* 31:471-478

ROPER, D.S., PRIDMORE, R.D., CUMMINGS, V.J., HEWITT, J.E., 1991. Pollution-related differences in the condition cycles of pacific oysters *Crassostrea gigas* from Manukau Harbour New Zealand. *Marine Environmental Research* 31:197-214

ROPER, D.S., THRUSH, S.F., SMITH, D.G., 1988. The influence of run-off on intertidal mudflat benthic communities. *Marine Environmental Research* 26:1-18

SHAW, A.T., 1996. *The mudcrab (Helice crassa) as a potential indicator of stormwater impacts in estuarine environments.* MSc Thesis, University of Auckland.

SIMPSON, J.D., 1978. *Analysis of copper and lead in the Waitemata and Manukau Harbours.* MSc Thesis, University of Auckland

STEWART, C., DE MORA, S.J., JONES, M.R.L., MILLER, M.C., 1992. Imposex in New Zealand neogastropods. *Marine Pollution Bulletin* 24:204-209

SWALES, A., WILLIAMSON, R.B., VAN DAM, L.F., STROUD, M.J., MCGLONE, M.S., 2002. Reconstruction of urban stormwater contamination of an estuary using catchment history and sediment profile dating. *Estuaries* 25:43-56

SYMMANS, W.J., 2000. *Ecological risk assessment of the Tamaki Estuary, Auckland. MSc,* School of Environmental and Marine Sciences

THOMPSON, D.R., DOWDING, J.E., 1999. Site-specific heavy metal concentrations in blood of South Island pied oystercatchers *Haematopus ostralegus finschi* from the Auckland region, New Zealand. *Marine Pollution Bulletin* 38:202–206

THRUSH, S.F., ROPER, D.S., 1988. Merits of macrofaunal colonization of intertidal mudflats for pollution monitoring preliminary study. *Journal of Experimental Marine Biology & Ecology* 116:219-234

TIMPERLEY, M., MATHIESON, T., 2002. *Marine Sediment Monitoring Programme 1998 - 2001: Review of Results and Procedures.* TP193, Auckland Regional Council, Auckland

VAN ROON, M., 1999. *Availability, toxicity and uptake of heavy metals by marine invertebrates: a review with reference to the Manukau Harbour, New Zealand..* Dept. of Planning, University of Auckland, Auckland

VAN ROON, M., 2000. An update on heavy metal pollution in the Manukau Harbour, Dept. of Planning, University of Auckland, Auckland, N.Z.

VANT, W.N., GIBBS, M.M., SAFI, K.A., THRUSH, S.F., 1998. Fluxes of organic carbon in Manukau Harbour, New Zealand. Estuaries 21:560-570

WILCOCK, R.J., NORTHCOTT, G.L., 1995. Polycyclic aromatic hydrocarbons in deep cores from Mangere Inlet, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29:107-116

WILLIAMSON, R.B., BLOM, A., HUME T.M., GLASBY G.P., LARCOMBE M., 1992. Heavy metals in Manukau Harbour sediments. *Water Quality Centre Publication* 23, DSIR, Hamilton

WILLIAMSON, R.B., HUME T.M., MOL-KRIJNEN J., 1994. A comparison of the early diagenetic environment in intertidal sands and muds of the Manukau Harbour, New Zealand. *Environ Geol* 24:254-266

WILLIAMSON, R.B., MOL-KRIJNEN, J., VAN DAM, L., 1995. Trace metal partitioning in bioturbated, contaminated, surficial sediments from Mangere Inlet, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29:117-130

WILLIAMSON, R.B., MORRISEY, D.J., 2000. Stormwater contamination of urban estuaries. 1. Predicting the build-up of heavy metals in sediments. *Estuaries* 23:56-66

WILLIAMSON, R.B., MORRISEY, D.J., SWALES, A., MILLS, G.N., 1998. *Distribution of contaminants in urbanised estuaries: prediction and observation.* Technical Publication TP139, Auckland Regional Council

WILLIAMSON, R.B., VAN DAM, L.F., BELL, R.G., GREEN, M.O., KIM, J.P., 1996. Heavy metal and suspended sediment fluxes from a contaminated, intertidal inlet (Manukau Harbour, New Zealand). *Marine Pollution Bulletin* 32:812-822

ZAUKE, G.P., HARMS, J., FOSTER, B.A., 1992. Cadmium, lead, copper, and zinc in Elminius modestus Darwin (Crustacea, Cirripedia) from Waitemata and Manukau Harbours, Auckland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 26:405-415

9.2 Ecology

BARFOOT, C., 2007. *Tahuna Torea: tip-site to nature reserve.* Tamaki Estuary Protection Society, Auckland [N.Z.]

BARR, N.G., REES T.A.V., 2003. Nitrogen status and metabolism in the green seaweed *Enteromorpha intestinalis*: An examination of three natural populations. *Marine Ecology Progress Series 249*:133-144

BIORESEARCHES, 2007. *Harbour environment monitoring programme 2006 – 2007.* Watercare Services Limited, Auckland

BIORESEARCHES, 2005. *Watercare Services Ltd project Manukau pond recovery monitoring programme 2004-2005.* Client report for Watercare Services Ltd. Bioresearches, Auckland

CAMERON, E., HAYWARD, B., MURDOCH, G., 1997. A field guide to Auckland. Exploring the region's natural and historic heritage., Godwit Publishing, Auckland

CLARKE, L.J., 1997. *A study of cockle (Austrovenus stutchburyi) populations in the Tamaki Estuary.* MSc, University of Auckland

CONWAY, P., 2005. *Tidal variation of chlorophyll-containing pigments in a temperate tidal salt-marsh lagoon.* Master of Applied Science, Auckland University of Technology

CREESE, R., HOOKER, S., DE LUCA, S., WHARTON, Y., 1997. Ecology and environmental impact of Musculista senhousia (Mollusca: Bivalvia: Mytilidae) in Tamaki Estuary, Auckland, New Zealand. *New Zealand Journal of Marine Freshwater Res* 31:225-236

DEWITT, T.H., HICKEY, C.W., MORRISEY, D.J., NIPPER, M.G., ROPER, D.S., WILLIAMSON, R.B., VAN DAM, L., WILLIAMS, E.K., 1999. Do amphipods have the same concentration-response to contaminated sediment in situ as in vitro? *Environ Toxicol Chem* 18:1026-1037

GAO, J., 1998. *A hybrid method toward accurate mapping of mangroves in a marginal habitat from SPOT multispectral data.* Int J Remote Sens 19:1887-1899

GRANGE, K.R., 1977. Littoral Benthos Sediment Relationships In Manukau Harbor New-Zealand. *New Zealand Journal of Marine & Freshwater Research* 11:111-124

GRANGE, K.R., 1979. Soft bottom macro benthic communities of Manukau Harbor New-Zealand. *New Zealand Journal of Marine & Freshwater Research* 13:315-330

GRANGE, K.R., 1982. Macrobenthic communities at possible combined cycle power station sites in Manukau and Waitemata Harbours, Auckland. *Oceanographic Summary* 19, New Zealand Oceanographic Institute

GRIFFITHS, G., TIMPERLEY, M., 2005. *Auckland City stormwater - A summary of NIWA and other relevant studies.* NIWA Client Report AKL2005-007, NIWA, Auckland

GUST, N., INGLIS, G.J., 2006. Adaptive multi-scale sampling to determine an invasive crab's habitat usage and range in New Zealand. *Biol Invasions* 8:339-353

HAYWARD, B.W., GRENFELL, H.R., NICHOLSON, K., PARKER, R., WILMHURST, J., HORROCKS, M., SWALES, A., SABAA, A.T., 2004. Foraminiferal record of human impact on intertidal estuarine environments in New Zealand's largest city. *Mar Micropaleontol* 53:37-66

HAYWARD, B.W., GRENFELL, H.R., SABAA, A.T., MORLEY, M.S., HORROCKS, M., 2006. Effect and Timing of Increased Freshwater Run-off into Sheltered Harbor Environments Around Auckland City, New Zealand. *Estuaries Coasts* 29:165-182

HAYWARD, B.W., MORLEY, M.S., 2005. *Intertidal life of the Tamaki Estuary and its entrance, Auckland.* ARC Technical Publication, TP373, Auckland Regional Council, Auckland

HAYWARD, B.W., MORLEY, M.S., STEPHENSON ,B.A., BLOM, W.M., GRENFELL, H.R., PRASAD, R., ROGAN, D., THOMPSON, F., CHEETHAM, J., WEBB, M., 1999. *Intertidal and subtidal biota and habitats of the central Waitemata Harbour.* ARC Technical Publication TP127, Auckland Regional Council, Auckland

HENRIQUES, P.R., 1976. *Manukau Harbour ecology: preliminary investigations: report to the Works Division,* Auckland Regional Authority, Drainage Dept of the Works Division Auckland Regional Authority, Auckland

HENRIQUES, P.R., 1977. *Selected ecological aspects of the Manukau Harbour.* PhD Thesis, University of Auckland

KINGETT MITCHELL & ASSOCIATES, 1996. A*ssessment of biological resources of the upper Tamaki Estuary and Otara Lake.* Kingett Mitchell & Associates, Auckland

LARCOMBE, M., 2006. *Coastal marine ecology and water quality assessment. In: Sinclair K (ed) SH20 Manukau Harbour Crossing Project: Assessment of environmental effects, Vol 2.* Transit NZ

MATTHEWS, A., 2004. *Human impact in the Mangere Inlet, Manukau Harbour; with emphasis on the foraminiferal record.* MSc Thesis, University of Auckland

MATTHEWS, A., GRENFELL, H.R., HAYWARD, B.W., HORROCKS, M., 2005. Foraminiferal record of sewage outfall impacts on the inner Manukau Harbour, Auckland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 39:193-215

MAXWELL, G.S., 1987a. *The chemical flush into Auckland's Tamaki Estuary, following a major fire, on 21 December 1984, at ICI Mt. Wellington site: an ecological assessment,* ICI? Auckland, N.Z.

MAXWELL, G.S., 1987b. *The ecological recovery of the Tamaki Estuary: a report on the Post ICI Fire Ecological Monitoring Programme, April 1985 to November 1986,* ICI? Auckland, N.Z.

MILLER, A., INGLIS, G.J., POULIN, R., 2006. Comparison of the ectosymbionts and parasites of an introduced crab, Charybdis japonica, with sympatric and allopatric populations of a native New Zealand crab, Ovalipes catharus (Brachyura: Portunidae). *New Zealand Journal of Marine and Freshwater Research* 40:369-378

MORRISEY, D.J., DEWITT, T.H., ROPER D.S., WILLIAMSON R.B., 1999. Variation in the depth and morphology of burrows of the mud crab Helice crassa among different types of intertidal sediment in Zew Zealand. *Marine Ecology Progress Series* 182:231-242

MORRISEY, D.J., TURNER ,S.J., MILLS, G.N., WILLIAMSON, R.B., WISE, B.E., 2003. Factors affecting the distribution of bentic macrofauna in estuaries contaminated by urban run-off. *Marine environmental research* 55:113-136

ROPER, D.S., NIPPER, M.G., HICKEY, C.W., MARTIN, M.L., WEATHERHEAD, M.A., 1995. Burial, crawling and drifting behaviour of the bivalve Macomona liliana in response to common sediment contaminants. *Marine Pollution Bulletin* 31:471-478

ROPER, D.S., THRUSH, S.F., SMITH, D.G., 1988. The influence of run-off on intertidal mudflat benthic communities. *Marine Environmental Research* 26:1-18

SAFI, K.A., VANT, W.N., HALL ,J.A., 2002. Growth and grazing within the microbial food web of a large coastal embayment. *Aquatic Microbial Ecology* 29:39-50

SIVAGURU, K., GRACE, R., 2002. *Benthos and sediments of Motu Manawa (Pollen Island) Marine Reserve. Conservancy Report.* Department of Conservation, Auckland

STEWART, M.J., 2005. *Ecological effects associated with urban development on populations of the New Zealand cockle* (*Austrovenus stutchburyi*). PhD Thesis, University of Auckland

SWALES, A., WILLIAMSON, R.B., VAN DAM, L.F., STROUD, M.J., MCGLONE, M.S., 2002. Reconstruction of urban stormwater contamination of an estuary using catchment history and sediment profile dating. *Estuaries* 25:43-56

SYMMANS, W.J., 2000. *Ecological risk assessment of the Tamaki Estuary, Auckland.* MSc, School of Environmental and Marine Sciences

THRUSH, S.F., HEWITT, J.E., PRIDMORE, R.D., 1989. Patterns in the spatial arrangements of polychaetes and bivalves in intertidal sandflats. *Marine Biology* 102:529-536

THRUSH, S.F., ROPER, D.S., 1988. Merits of macrofaunal colonization of intertidal mudflats for pollution monitoring preliminary study. *Journal of Experimental Marine Biology & Ecology* 116:219-234

WILKINSON, V.H., 1981. *Production ecology of microphytobenthic populations in the Manukau harbour.* MSc Thesis, University of Auckland.

9.3 Sedimentation and sediment texture

ABRAHIM, G., PARKER, R., 2002. Heavy-metal contaminants in Tamaki Estuary: impact of city development and growth, Auckland, New Zealand. *Environ Geol* 42:883-890

ABRAHIM, G.M.S., 2005. *Holocene sediments of Tamaki Estuary: characterisation and impact of recent human activity on an urban estuary in Auckland, New Zealand.* PhD, University of Auckland

BIORESEARCHES, 2007. *Harbour environment monitoring programme 2006 – 2007.* Watercare Services Limited, Auckland

BIORESEARCHES, 2005. *Watercare Services Ltd project Manukau pond recovery monitoring programme 2004-2005.* Client report for Watercare Services Ltd. Bioresearches, Auckland

GIBBS, M., HEWITT ,J., 2004. *Effects of sedimentation on macrofaunal communities: a synthesis of research studies for ARC.* ARC Technical Publication TP264, Auckland Regional Council, Auckland

GLASBY, G.P., STOFFERS, P., WALTER, P., DAVIS, K.R., RENNER, R.M., 1988. Heavy-metal pollution in Manukau and Waitemata Harbours, New Zealand. New Zealand Journal of Marine and Freshwater Research 22:595-611

GREGORY, M.R., 1994. *Manukau and Waitemata harbours sediments.* National Institute of Water & Atmospheric Research Ltd., Wellington

GRIFFITHS, G., TIMPERLEY, M., 2005. *Auckland City stormwater - A summary of NIWA and other relevant studies.* NIWA Client Report AKL2005-007, NIWA, Auckland

HAYWARD, B.W., GRENFELL, H.R., SABAA, A.T., MORLEY, M.S., HORROCKS M., 2006. Effect and Timing of Increased Freshwater Run-off into Sheltered Harbor Environments Around Auckland City, New Zealand. *Estuaries Coasts* 29:165-182

MATTHEW,S A., 2004. *Human impact in the Mangere Inlet, Manukau Harbour; with emphasis on the foraminiferal record.* MSc Thesis, University of Auckland

MATTHEWS, A., GRENFELL, H.R., HAYWARD, B.W., HORROCKS, M., 2005. Foraminiferal record of sewage outfall impacts on the inner Manukau Harbour, Auckland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 39:193-215

MCHUGH, M., REED, J., 2006. *Marine sediment monitoring programme: 2005 results.* TP316, Auckland Regional Council, Auckland

MORRISEY, D.J., WILLIAMSON, R.B., VAN DAM, L., LEE, D.J., 2000. Stormwater contamination of urban estuaries. 2. Testing a predictive model of the build-up of heavy metals in sediments. *Estuaries* 23:67-79

SIVAGURU, K., GRACE, R., 2002. *Benthos and sediments of Motu Manawa (Pollen Island) Marine Reserve.* Conservancy Report, Department of Conservation, Auckland

SWALES, A., WILLIAMSON, R.B., VAN DAM, L.F., STROUD, M.J., MCGLONE, M.S., 2002. Reconstruction of urban stormwater contamination of an estuary using catchment history and sediment profile dating. *Estuaries* 25:43-56

TIMPERLEY, M., MATHIESON, T., 2002. *Marine Sediment Monitoring Programme 1998 - 2001: Review of Results and Procedures.* TP193, Auckland Regional Council, Auckland

Wilcock, R.J., Northcott, G.L., 1995. Polycyclic aromatic hydrocarbons in deep cores from Mangere Inlet, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29:107-116

WILLIAMSON, R.B., BLOM, A., HUME, T.M., GLASBY, G.P., LARCOMBE, M., 1992. Heavy metals in Manukau Harbour sediments. *Water Quality Centre Publication* 23, DSIR, Hamilton

WILLIAMSON, R.B., HUME, T.M., MOL-KRIJNEN, J., 1994. A comparison of the early diagenetic environment in intertidal sands and muds of the Manukau Harbour. *New Zealand. Environ Geol* 24:254-266

WILLIAMSON, R.B., MOL-KRIJNEN, J., VAN DAM, L., 1995. Trace metal partitioning in bioturbated, contaminated, surficial sediments from Mangere Inlet, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29:117-130

WILLIAMSON, R.B., MORRISEY, D.J., 2000. Stormwater contamination of urban estuaries. 1. Predicting the build-up of heavy metals in sediments. *Estuaries* 23:56-66

WILLIAMSON, R.B., MORRISEY, D.J., SWALES, A., MILL,S G.N., 1998. *Distribution of contaminants in urbanised estuaries: prediction and observation.* Technical Publication TP139, Auckland Regional Council

WILLIAMSON, R.B., VAN DAM, L.F., BELL, R.G., GREEN, M.O., KIM, J.P., 1996. Heavy metal and suspended sediment fluxes from a contaminated, intertidal inlet, Manukau Harbour, New Zealand). *Marine Pollution Bulletin* 32:812-822

9.4 Vegetation

BARFOOT, C., 2007. *Tahuna Torea: tip-site to nature reserve,* Tamaki Estuary Protection Society, Auckland

CAHOON, L.B., SAFI, K.A., 2002. Distribution and biomass of benthic microalgae in Manukau Harbour, New Zealand. *New Zealand Journal of Marine & Freshwater Research* 36:257-266

CAMERON, E., HAYWARD, B., MURDOCH, G., 1997. *A field guide to Auckland: Exploring the region's natural and historic heritage.* Godwit Publishing, Auckland

CONWAY, P., 2005. *Tidal variation of chlorophyll-containing pigments in a temperate tidal salt-marsh lagoon.* Master of Applied Science, Auckland University of Technology

GAO, J., CHEN, H., ZHANG, Y., ZHA, Y., 2004. Knowledge-Based approaches to accurate mapping of mangroves from satellite data. *Photogramm Eng Remote Sensing* 70:1241-1247

HAYWARD, B.W., MORLEY, M.S., 2005. *Intertidal life of the Tamaki Estuary and its entrance, Auckland.* ARC Technical Publication, TP373, Auckland Regional Council, Auckland

HAYWARD, B.W., MORLEY, M.S., STEPHENSON, B.A., BLOM, W.M., GRENFELL, H.R., PRASAD, R., ROGAN, D., THOMPSON, F., CHEETHAM, J., WEBB, M., 1999. *Intertidal and subtidal biota and habitats of the central Waitemata Harbour.* ARC Technical Publication TP127, Auckland Regional Council, Auckland

HENRIQUES, P.R., 1976. *Manukau Harbour ecology: preliminary investigations: report to the Works Division,* Auckland Regional Authority, Drainage Dept of the Works Division Auckland Regional Authority, Auckland

HENRIQUES, P.R., 1977. *Selected ecological aspects of the Manukau Harbour.* PhD Thesis, University of Auckland

HENRIQUES, P.R., 1978. *The vegetated tidelands of the Manukau Harbour: report to the Manukau Harbour study.* Auckland Regional Authority, Auckland

SAFI, K.A., VANT, W.N., HALL, J.A., 2002. Growth and grazing within the microbial food web of a large coastal embayment. *Aquatic Microbial Ecology* 29:39-50

WILCOX, S.J., BARR, N., BROOM, J., FURNEAUX, R.H., NELSON, W.A., 2007. Using gigartinine to track the distribution of an alien species of *Gracilaria* in New Zealand. *Journal of Applied Phycology* 19:313-323

WILKINSON, V.H., 1981. *Production ecology of microphytobenthic populations in the Manukau harbour.* MSc Thesis, University of Auckland.

9.5 Modelling and hydrodynamics

AUCKLAND REGIONAL COUNCIL, 2002. *Regional maps of settling zones and outer zones.* ARC Technical Publication TP170, Auckland Regional Council, Auckland

BELL, R.G., DUMNOV, S.V., WILLIAMS, B.L., GREIG, M.J.N., 1998. *Hydrodynamics of Manukau Harbour, New Zealand.* New Zealand Journal of Marine & Freshwater Research 32:81-100

BLACK, K.P., 1996. *Numerical modelling in the upper Tamaki Estuary for the environmental assessment of the Otahuhu Power Station heated-cooling-water discharge.* Client report prepared for: Kingett Mitchell and Associates, NIWA, Hamilton

CROUCHER, A.E., BOGLE, M.G.V., O'SULLIVAN, M.J., 2005a. *Coastal Receiving Environment Assessment (CREA), Report 1: Modelling framework,* Uniservices, Auckland

CROUCHER, A.E., M.G.V. B., O'SULLIVAN, M.J., 2005b. *Coastal Receiving Environment Assessment (CREA) report II: Whau Estuary,* Uniservices (University of Auckland), Auckland

CROUCHER, A.E., M.G.V. B., O'SULLIVAN, M.J., 2005c. *Coastal Receiving Environment Assessment (CREA) report III: Tamaki Estuary,* Uniservices (University of Auckland), Auckland

CROUCHER, A.E., M.G.V. B., O'SULLIVAN, M.J., 2005d. *Coastal Receiving Environment Assessment (CREA) report VI: Manukau Harbour*, Uniservices (University of Auckland), Auckland

HEATH, R.A., GREIG, M.J.N., SHAKESPEARE, B.S., 1977. Circulation and hydrology of Manukau Harbor. *New Zealand Journal of Marine & Freshwater Research* 11:589-608

HUME, T.M., 1979. *Aspects of the hydrology of the Mangere Inlet-Wairopa Channel area, north-east Manukau Harbour, Auckland.* Water and Soil Division, Ministry of Works and Development, Auckland

MORRISEY, D.J., WILLIAMSON, R.B., VAN DAM, L., LEE, D.J., 2000. Stormwater contamination of urban estuaries. 2. Testing a predictive model of the build-up of heavy metals in sediments. *Estuaries* 23:67-79

VANT, W.N., WILLIAMS, B.L., 1992. Residence times of Manukau Harbour, New Zealand. *New Zealand Journal of Marine & Freshwater Research* 26:393-404

WILCOCK, R.J., NORTHCOTT, G.L., 1995. Polycyclic aromatic hydrocarbons in deep cores from Mangere Inlet, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 29:107-116

WILLIAMSON, R.B., MORRISEY, D.J., 2000. Stormwater contamination of urban estuaries. 1. Predicting the build-up of heavy metals in sediments. *Estuaries* 23:56-66

9.6 Fish and Birds

BARFOOT, C., 2007. *Tahuna Torea: tip-site to nature reserve,* Tamaki Estuary Protection Society, Auckland

BULL, P.C., GAZE, P.D., ROBERTSON, C.J.R., 1985. *The atlas of bird distribution in New Zealand,* Ornithological Society of New Zealand, Wellington

CAMERON, E., HAYWARD, B., MURDOCH, G., 1997. *A field guide to Auckland; Exploring the region's natural and historic heritage.* Godwit Publishing, Auckland

CONWAY, P., 2005. *Tidal variation of chlorophyll-containing pigments in a temperate tidal salt-marsh lagoon.* Master of Applied Science, Auckland University of Technology

DIGGLES, B.K., SMITH, M., MORRISON, M., MILLS, G., HINE, P.M., BULL, B., 2000. *Final report on parasites and pathological lesions of yellow-belly flounder Rhombosolia leporina and their relationship with contamination in Manukau Harbour.* ARC Technical Publication TP140, Auckland Regional Council, Auckland

DOWDING, J.E., 2001. *Numbers, distribution and movement patterns of shorebirds using the southern arm of the upper Waitemata Harbour.* Unpublished report to Auckland Conservancy, Department of Conservation.

DOWDING, J.E., MOORE, S.J., 2006. *Habitat networks of indigenous shorebirds in New Zealand 261*, Department of Conservation, Wellington

EVANS, C.W., WILSON, D.A., MILLS, G.N., 2001. Quantitative competitive (qc) RT-PCR as a tool in biomarker analysis. *Biomarkers* 6:7-14

FRANCIS, M.P., MORRISON, M.A., LEATHWICK, J., WALSH, C., MIDDLETON, C., 2005. Predictive models of small fish presence and abundance in northern New Zealand harbours. *Estuarine, Coastal and Shelf Science* 64:419-435

FRANCIS, M.P., WALSH, C., MORRISON, M.A., MIDDLETON, C., 2003. Invasion of the Asian goby, Acentrogobius pflaumii, into New Zealand, with new locality records of the introduced bridled goby, Arenigobius bifrenatus. *New Zealand Journal of Marine and Freshwater Research* 37:105-112

HAYWARD, B.W., MORLEY, M.S., 2005. *Intertidal life of the Tamaki Estuary and its entrance, Auckland.* ARC Technical Publication, TP373, Auckland Regional Council, Auckland

HITCHMOUGH, R,; BULL, L,; CROMARTY, P. (compilers), 2007. *New Zealand threat classification system lists 2005.* Wellington, Department of Conservation. 194 p.

JOWETT, C., 1989. *Birdwatching in the north OSNZ News*, p 7-8.

KINGETT MITCHELL & ASSOCIATES, 1996. *Assessment of biological resources of the upper Tamaki Estuary and Otara Lake,* Kingett Mitchell & Associates, Auckland

LARCOMBE, M., 2006. *Coastal marine ecology and water quality assessment. In: Sinclair K (ed) SH20 Manukau Harbour Crossing Project: Assessment of environmental effects, Vol 2.* Transit NZ

LAWRIE, D.A., 1978. *Planning for the preservation of birdlife in Manukau Harbour.* Dissertation (DipTP), University of Auckland

MORRISON, M.A., FRANCIS, M.P., HARTILL, B.W., PARKINSON, D.M., 2002. Diurnal and tidal variation in the abundance of the fish fauna of a temperate tidal mudflat. *Estuarine, Coastal and Shelf Science* 54:793–807

PARK, H.G.M., 1983. *Sea & shore birds of the Hauraki Gulf Maritime Park,* The Park, Auckland

Robertson C.J.R., Robertson C.J.R., Bull P.C., Ornithological Society of New Zealand. (2007) Atlas of bird distribution in New Zealand 1999-2004. Ornithological Society of New Zealand, Wellington, N.Z.

SAGAR, P.M., SHANKAR, U., BROWN, S., 1999. Distribution and numbers of waders in New Zealand, 1983-1994. *Notornis* 46:1-43

SIBSON, R.B., PRICKETT, J., 1960. Classified summarised notes. *Notornis* 9:77

THOMPSON, D.R., DOWDING, J.E., 1999. Site-specific heavy metal concentrations in blood of South Island pied oystercatchers *Haematopus ostralegus finschi* from the Auckland region, New Zealand. *Marine Pollution Bulletin* 38:202–206

VEITCH, C.R., 1978. Waders of the Manukau Harbour and Firth of Thames. *Notornis* 25:1-24

VEITCH, C.R., HABRAKEN A.M., 1999. Waders of the Manukau Harbour and Firth of Thames. *Notornis* 46:45-70

10 Appendix 1: Copper , Lead and Zinc Concentrations Obtained from ARC Monitoring and Investigations

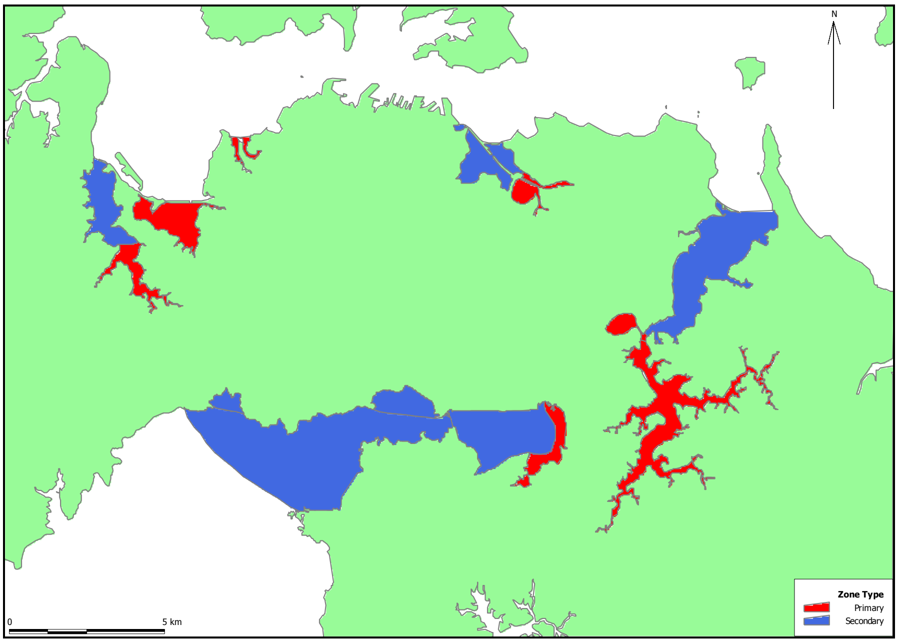
Location	Latest sample	Programme	Name	X_NZTM	Y_NZTM	<500Cu-Mean	<500Pb-Mean	<500Zn-Mean	<63Cu-Mean	<63Pb-Mean	<63Zn-Mean	Bethic health
Mangere	2005	RDP	Ann's Creek	1762214	5911375	29.1	31.5	154.0	40.9	53.7	235.8	5
Mangere	2005	RDP	Mangere Cemetery	1759965	5911179	25.1	28.3	136.0	18.3	26.5	110.3	4
Mangere	2006	BHM	Harania Creek	1761930	5909763	14	20.8	96	20.7	24	121	4
Mangere	2006	BHM	Kiwi Esplanade	1758529	5910536	12	16.5	76	18.7	20.6	104	3
Mangere	2006	BHM	Tararata Creek	1760514	5909744	16	22.9	103	22.2	26.1	129	5
Tamaki	2004	RDP	Point England	1766859	5916213	12.1	19.7	80.3	17.0	23.2	99.0	
Tamaki	2004	RDP	Benghazi	1766817	5915306	9.6	16.2	75.4	19.7	26.0	110.3	3
Tamaki	2002	RDP	Roberta Reserve	1768102	5918846				10.0	24.0	81.0	
Tamaki	2004	RDP	Panmure	1764512	5913867	22.8	33.2	150.0	23.7	34.5	145.0	4
Tamaki	2004	RDP	Bowden Rd	1765249	5912959	25.7	35.0	168.7	28.3	35.7	167.0	4
Tamaki	2005	RDP	Pakuranga Upper	1768173	5911686	34.4	36.4	236.0	45.4	56.0	307.0	
Tamaki	2004	RDP	Princess St	1765814	5910530	17.5	26.5	143.0	27.3	37.1	187.7	4
Tamaki	2004	RDP	Otahuhu Creek	1765554	5911076	24.9	33.8	151.3	24.7	35.4	156.0	4
Tamaki	2005	RDP	Middlemore	1765179	5909106	25.8	32.6	182.0	35.3	51.6	234.4	5
Tamaki	2005	SoE	Pakuranga Upper	1766741	5911708	20	25.4	149	28.38	36.71	167.64	
Tamaki	2006	BHM	Glendowie	1767936	5917369	18	23.8	100	3.5	5.03	32.5	3
Tamaki	2006	BHM	Pakuranga Mid	1767379	5911500	31	39.2	187	22.6	25.8	153	4
Whau	2004	RDP	Whau Entrance 2	1748081	5920323	3.1	6.3	24.9	17.7	26.5	103.3	3
Whau	2005	RDP	Whau Lower	1748262	5917476	24.2	41.3	161.0	24.8	42.9	179.7	4
Whau	2005	RDP	Whau Wairau	1748097	5915742	42.9	64.6	216.0	49.8	92.5	263.8	5
Whau	2005	RDP	Whau Upper	1749308	5915109	36.0	65.6	256.0	45.8	83.0	318.9	5
Whau	2006	BHM	Whau East	1749153	5915793	27	60.3	194	27.3	50.6	182	4

Location	Latest sample	Programme	Name	X_NZTM	Y_NZTM	<500Cu-Mean	<500Pb-Mean	<500Zn-Mean	<63Cu-Mean	<63Pb-Mean	<63Zn-Mean	Bethic health
Whau	2006	BHM	Whau West	1747915	5917294	23	46.8	154	48.9	47.4	172	4
Whau	2002	BHM	Whau Entrance 1	1748665	5920735	4.4	29.6	8.95	18	106	35	2

11 Appendix 2: Sediment Quality Guidelines

Source	**ARC**			**MacDonald *et al.* (1996)**		**Long and Morgan (1990)**	
Guideline	**Green**	**Amber**	**Red**	**TEL**	**PEL**	**ERL**	**ERM**
Copper	<18	18-34	>34	18.7	108.2	34	270
Lead	<30	30-50	>50	30.2	112.2	47	218
Zinc	<124	124-150	>150	124	271	150	410

12 Appendix 3: Depositional Zones Identified by Auckland City Council – Metrowater



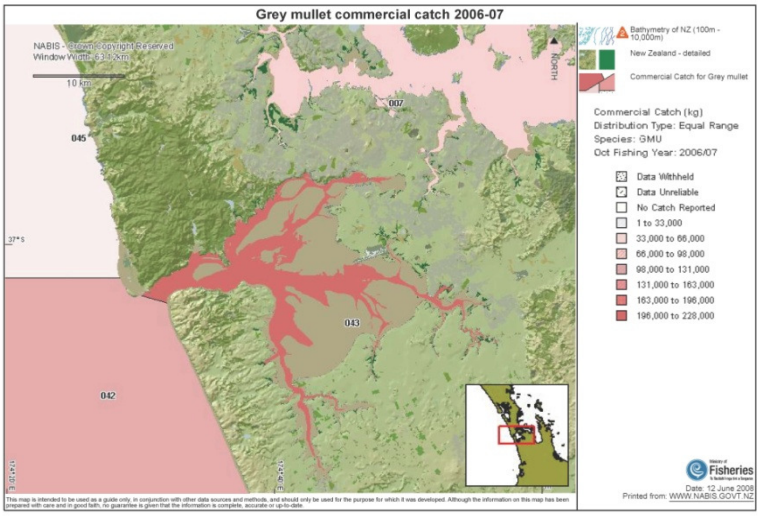
13 Appendix 4: Bird Species List for Tamaki Estuary, Mangere Inlet, and Whau Estuary and Adjoining Areas

Common name	**Latin name**	**Origin**	**Tamaki**	**Mangere**	**Whau**	**Threat status**
All black stilt & black x pied stilt	*Himantopus spp*	Endemic		√		1?
Asiatic black-tailed godwit	*Limosa limosa melanuroides*	Sraggler		√		
Australasian little grebe	*Tachybaptus novaehollandiae novaehollandiae*	Native		√		
Australasian pied stilt	*Himantopus himantopus leucocephalus*	Native	√	√	√	
Autralasian gannet	*Morus serrator*	Native	√	√	√	
Banded dotterel spp	*Charadrius bicinctus spp*	Endemic	√	√	√	5
Black-billed gull	*Larus bulleri*	Endemic	√	√		4
Black-fronted dotterel	*Charadrius melanops*	Native		√		
Black shag	*Phalacrocorax carbo novaehollandiae*	Native	√	√	√	6
Black stilt	*Himantopus novaezelandiae*	Endemic		√		1
Black swan	*Cygnus atratus*	Introduced	√	√	√	
Blue penguin spp	*Eudyptula minor spp*	Native	√			5
Brown teal	*Anas aucklandica chlorotis*	Endemic		√		2
Canada goose	*Branta canadensis maxima*	Introduced		√		
Caspian tern	*Sterna caspia*	Native	√	√	√	3
Cattel egret	*Bubulcus ibis coromandus*	Migrant		√		
Eastern bar-tailed godwit	*Limosa lapponica baueri*	Migrant	√	√	√	
Feral goose	*Anser anser*	Introduced		√		
Fluttering shearwater	*Puffinus gavial*	Endemic		√		
Grey duck	*Anas superciliosa superciliosa*	Native	√	√	√	2
Grey teal	*Anas gracilis*	Native				
Lesser knot	*Calidris canutus canutus*	Migrant	√	√	√	
Little black shag	*Phalacrocorax sulcirostris*	Native	√	√	√	7
Little shag	*Phalacrocorax melanoleucos brevirostris*	Endemic	√	√	√	
Mallard	*Anas platyrhynchos platyrhynchos*	Introduced	√	√	√	
New Zealand dabchick	*Poliocephalus rufopectus*	Endemic		√		6

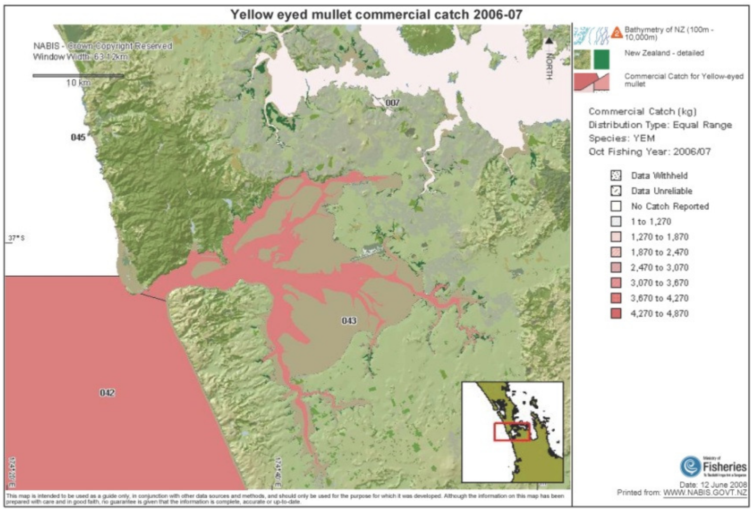
Common name	**Latin name**	**Origin**	**Tamaki**	**Mangere**	**Whau**	**Threat status**
New Zealand dotterel	*Charadrius obscurus*	Endemic	√	√	√	1
New Zealand kingfisher	*Halcyon sancta vagans*	Native	√	√	√	
New Zealand scaup	*Aythya novaeseelandiae*	Endemic		√		
New Zealand shoveler	*Anas rhynchotis variegata*	Endemic		√		
Pacific golden plover	*Pluvialis fulva*	Migrant		√		
Paradise shelduck	*Tadorna variegate*	Endemic	√	√	√	
Pectoral sandpiper	*Calidris melanotos*	Sraggler		√		
Pied shag	*Phalacrocorax varius varius*	Native	√	√	√	
Pukeko	*Porphyrio porphyrio melanotus*	Native	√	√	√	
Red-billed gull	*Larus novaeholladiae scopulinus*	Endemic	√	√	√	5
Red-necked stint	*Calidris ruficollis*	Migrant	√	√		
Reef heron	*gretta sacra sacra*	Native	√	√	√	3
Royal spoonbill	*Platalea regia*	Native	√	√		
Sharp-tailed sandpiper	*Calidris acuminate*	Migrant	√			
Siberian tattler	*Tringa brevipes*	Sraggler		√		
Sooty shearwater	*Puffinus griseus*	Native		√		
South Island pied oystercatcher	*Haematopus ostralegus finschi*	Endemic	√	√	√	
Southern black-backed Gull	*Larus dominicanus dominicanus*	Native	√	√	√	
Spotted shag spp	*Stictocarbo punctatus punctatus*	Endemic		√		
Spur-wing plover	*Vanellus miles novaehollandiae*	Native	√	√	√	
Turnstone	*Arenaria interpres*	Migrant		√		
Variable oystercatcher	*Haematopus unicolor*	Endemic	√	√	√	
White-faced heron	*Ardea novaehollandiae novaehollandiae*	Native	√	√	√	
White-fronted tern	*Sterna striata*	Native	√	√	√	5
Wrybill	*Anarhynchus frontalis*	Endemic	√	√	√	3

14 Appendix 5: Manukau Commercial Fish Catches

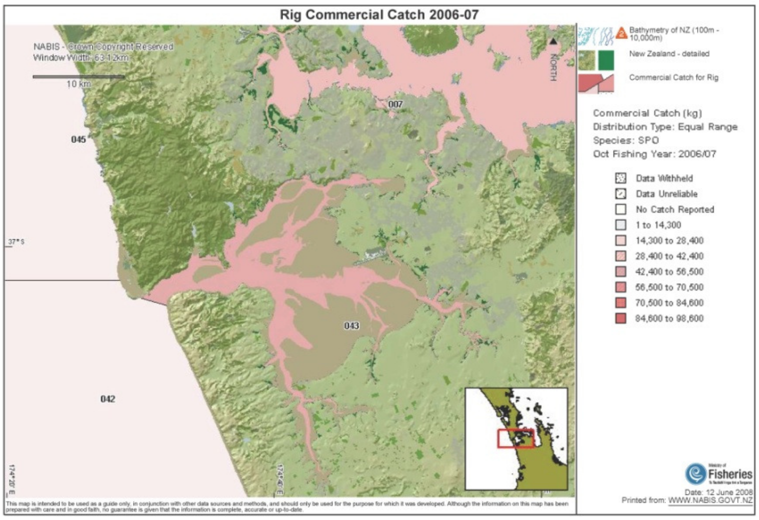
2006-07 commercial catch (kg) of: grey mullet; yellow-eyed mullet; rig; parore; and, snapper. Data obtained from Ministry of Fisheries NABIS website.

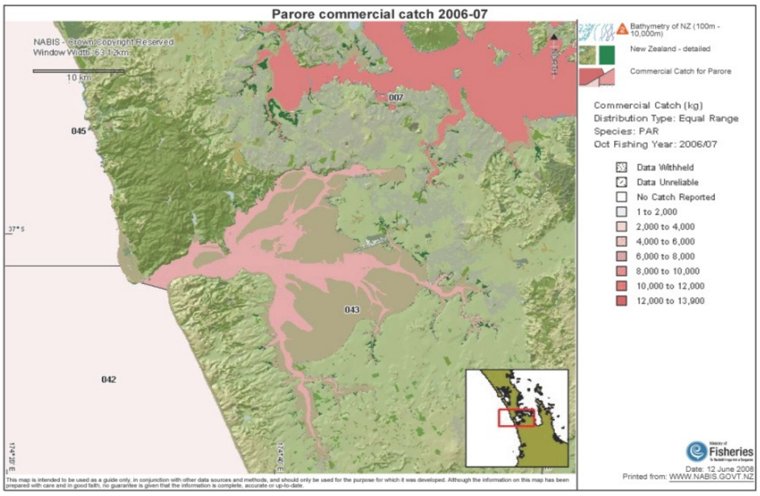


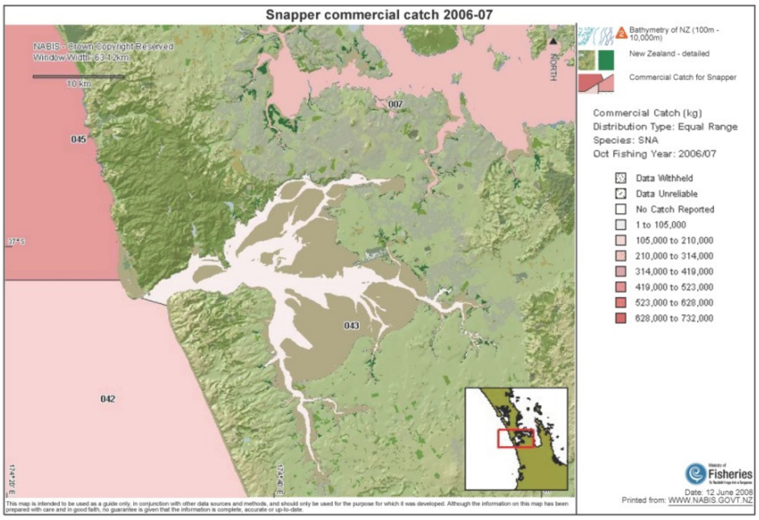
Grey mullet commercial catch 2006-07



Yellow eyed mullet commercial catch 2006-07


Rig Commercial Catch 2006-07


Parore commercial catch 2006-07


Snapper commercial catch 2006-07