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Environmental condition and values of Manukau Harbour

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Environmental condition and values of Manukau Harbour

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Prepared for
Auckland Regional Council by Coast and Catchment Ltd

Contents

1 Executive Summary

Manukau Harbour contains a variety of habitats and associated species assemblages that vary according to substrate type, sediment texture, exposure, tidal height and currents. Habitat forming biota such as coastal plants and structurally complex benthic fauna also contribute to habitat diversity. The harbour is largely intertidal, with highly productive sand and mudflats. These contain benthic communities, which mediate physico-chemical processes, sustain bird and fish populations, and provide important food resources for people living in the Auckland Region. The sandy, intertidal areas of the central harbour are inhabited by diverse communities with a high proportion of large, environmentally sensitive species. Subtidal channels provide habitat for sedentary subtidal invertebrates and a low tide refuge for mobile species such as fish. Highly valued areas of coastal vegetation are distributed throughout the harbour and include: seagrass beds, saltmarsh, vegetation sequences (e.g. mangrove to lowland forest), and mangrove forests. These areas are important for their vegetation and landscape values, and as habitats for coastal and marine fauna. Reef and boulder habitats are also scattered around the margins of the harbour and support a variety of mobile and sessile reef species. Tidal inlets are more sheltered and muddier than the central body, and therefore contain a different mix of species. These areas are important for juvenile fish, mangroves and saltmarsh. The harbour is especially significant for native and migratory wading birds. It is estimated to support more than 20% of the total New Zealand wader population, and is recognised as a national “hotspot” for coastal bird diversity and endangered bird species. Wader numbers in the harbour have been increasing since the 1960s.

Published information clearly shows that Manukau Harbour has been impacted by human activities. Side-branches of the harbour trap sediments, and associated stormwater contaminants, and are becoming muddier and more infilled. Mangrove expansion is also a significant issue in tidal inlets. The concentrations of key stormwater contaminants (copper, lead and zinc) are relatively low, except in Mangere Inlet and Oruarangi Creek, but concentrations are predicted to increase above sediment quality guidelines in a number of other areas over the next 18-100 years. Side-branches with urban catchments tend to have degraded benthic communities, but these continue to provide a range of ecological functions and services.

The central body of the harbour is less susceptible to sediment and contaminant accumulation. However, long term sediment texture data suggest that transitory sediment deposits occur at Clarks Beach, and modelling indicates that a significant proportion of sediment derived from south-eastern catchments is exported to the main body of the harbour. Consequently, the potential for suspended sediments and transitory sediment deposits to affect benthic communities in the main body of the harbour cannot be ruled out.

Invasive species, such as Pacific oysters, have impacted on the human and ecological values of the harbour. Pacific oyster beds restrict human access in many parts of the harbour and have modified the natural upper-tidal ecosystem. The effects of fishing are unknown, but are also likely to be significant. Less than 2% of West Coast snapper are estimated to originate from Manukau Harbour, compared with 98% from Kaipara Harbour, which has many similar characteristics. The reasons for this discrepancy are unknown, but environmental degradation cannot be ruled out as a contributing factor.

The Mangere Wastewater Treatment Plant (MWWTP) has also had a major influence on water quality in the harbour since 1960. The treatment of industrial and domestic wastewater by the MWWTP improved environmental quality in Mangere Inlet, but discharges from the plant have negatively affected overall water quality. However, water quality has improved significantly since 1987, which is largely due to improvements to the treatment plant.

The effects of stormwater discharges should take into account the environmental values and quality of the immediate receiving environment, and the potential for cumulative, broad scale impacts. Broad scale impacts could occur through the widespread dispersal of sediment and stormwater contaminants, or by degrading receiving environments that have an ecological role, which extends beyond the area directly affected by stormwater discharges. Examples of the latter include receiving environments that provide habitat for rare or migratory bird species, or nursery habitat for juvenile fish.

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 (Swales et al 2007). The other effects of sedimentation are less noticeable, but equally significant (see Gibbs and Hewitt 2004). Thick, catastrophic deposits of sediment (>2 cm) usually kill almost all bottom-dwelling organisms (Norkko et al 2002, Cummings et al 2003, Thrush et al 2003). 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 (Berkenbusch et al 2001). The deposition of fine sediment can alter the characteristics of benthic habitats, by reducing ambient grain size (Cummings 2007). 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 (e.g. de Boer 2007). It also affects the physiological condition of filter feeders by reducing feeding efficiency (e.g. Hewitt et al 2001) and potentially inhibits the feeding activity of other species such as visual predators (Morrison et al 2009).

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 (i.e. natural or synthetic carbon based compounds) contaminants may also be present in stormwater runoff, 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 2009).

The effects of wastewater discharges relate mainly to issues associated with human health, organic matter, nutrients and gross pollutants. Microbiological contaminants (i.e. 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 Manukau Harbour. Integrated catchment management plans (ICMPs) being prepared by Waitakere, Auckland and Manukau City Councils, and Papakura and Franklin District Councils are required to identify the best practicable option (BPO) for managing stormwater contaminants discharged into the harbour. 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 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 (e.g. reef, mud, sand etc.); scale (i.e. the size of the system or habitat); geography (e.g. location in relation to other habitats, latitude, east or west coast etc.); geomorphology (e.g. 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 community affects another species or community (e.g. mangrove expansion leads to the loss of mud-flat or sand-flat habitat).

In order to assess ecological sensitivity to the 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,

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

and monitoring and research data was therefore carried out to summarise information of the environmental values and quality of Manukau Harbour. 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 ARCs 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.

3 General Description

The Manukau Harbour is New Zealand's second largest harbour with an area of about 365 km^2, a shore length of approximately 460 km, spring tide volume of around 221.5 million m^3 and a total catchment area of approximately 895 km^2 (NIWA 2007). It was formed by the development a Quaternary[2] dune barrier (Awhitu Peninsula) that enclosed a large bay between Port Waikato and the Waitakere Ranges (Mara et al 2006). Today, Awhitu Peninsula extends along the south western boundary of the harbour, separating it from the west coast. The northern catchment is narrow, relative to the southern catchment, which extends around 13 – 17 km inland. The western catchment consists of a 4 to 7 km strip along Awhitu Peninsula, while a key feature of the eastern catchment is the Papakura Stream valley, which protrudes around 15 km inland (Figure 1). The narrow harbour entrance, with a width of 2.3 km, is located in the north-western corner of the harbour. Tidal flows through the entrance and littoral drift have created an extensive ebb-tide delta that extends ca. 5 km offshore and has an estimated sand volume of 1,250 x 10^6 m^3 (Hicks and Hume 1996).

The Waitakere Ranges are mainly volcanic in origin, so their geology differs markedly from that of Awhitu Peninsula. The area between the Waitakere Ranges and Auckland volcanic field is comprised of mixed formations of volcanic and marine sedimentary origins. The Auckland volcanic field is a significant geological feature in the northeastern catchment of the harbour, and is comprised of mixed formations of basalt lava, scoria and pyroclastics (ash, lapilli and lithic tuff). Smaller, patchy volcanic fields occur in northern parts of the eastern shore, centred on the Mangere, Ihumatao, Papatoetoe, and Puhinui areas. These features are scattered within the underlying Puketoka Formation, which is comprised of alluvial sediments containing pumiceous mud, sand and gravel, with muddy peat and lignite. The Puketoka Formation extends from Mangere around the eastern and southern shores to Waiuku. Beyond it is the uplifted Waipapa Group of the Hunua Ranges in the east, and South Auckland volcanic field in the south (Institute of Geological and Nuclear Sciences Ltd, 2001).

Manukau Harbour is a Category F estuary according to the Estuary Environment Classification of Hume et al (2007). Category F estuaries are characterised by shallow basins with narrow mouths that are usually formed by a spit or sand barrier. Where littoral drift occurs, ebb and flood tide deltas (i.e. sand bars) form at their mouths. Their tidal prisms comprise a large proportion of the total tidal volume, but contributions from river inputs are generally minor. Hydrodynamic processes are dominated by tides rather than wind driven circulation, and intertidal areas, cut by deep channels, form a high proportion of their total area. They have complex shorelines with many side-branches extending off the main body of the estuary. Substrates tend to be sandy in the main body and muddy in their side branches.

Accordingly, the harbour is a relatively shallow basin with a spring tide range of 2.8 m and average depth of 6.1 m (NIWA 2007). The harbour contains a constricted, relatively deep (< 50 m) entrance channel that splits into four "main" channels in the central harbour: Wairopa and Purakau Channels in the north of the harbour leading to Mangere Inlet in the northeast; Waiuku Channel leading to Waiuku River in the south; and, Papakura Channel leading to Pahurehure Inlet in the southeast (Figure 2 and Figure 3). Overall, approximately 62% (226 km^2) of the harbour is intertidal (NIWA 2007). Consequently, extensive intertidal sand banks are a dominant, and ecologically important, feature (Figure 2).

[2] < 2.6 million years before present

Figure 1: Manukau harbour catchments and associated stream systems.

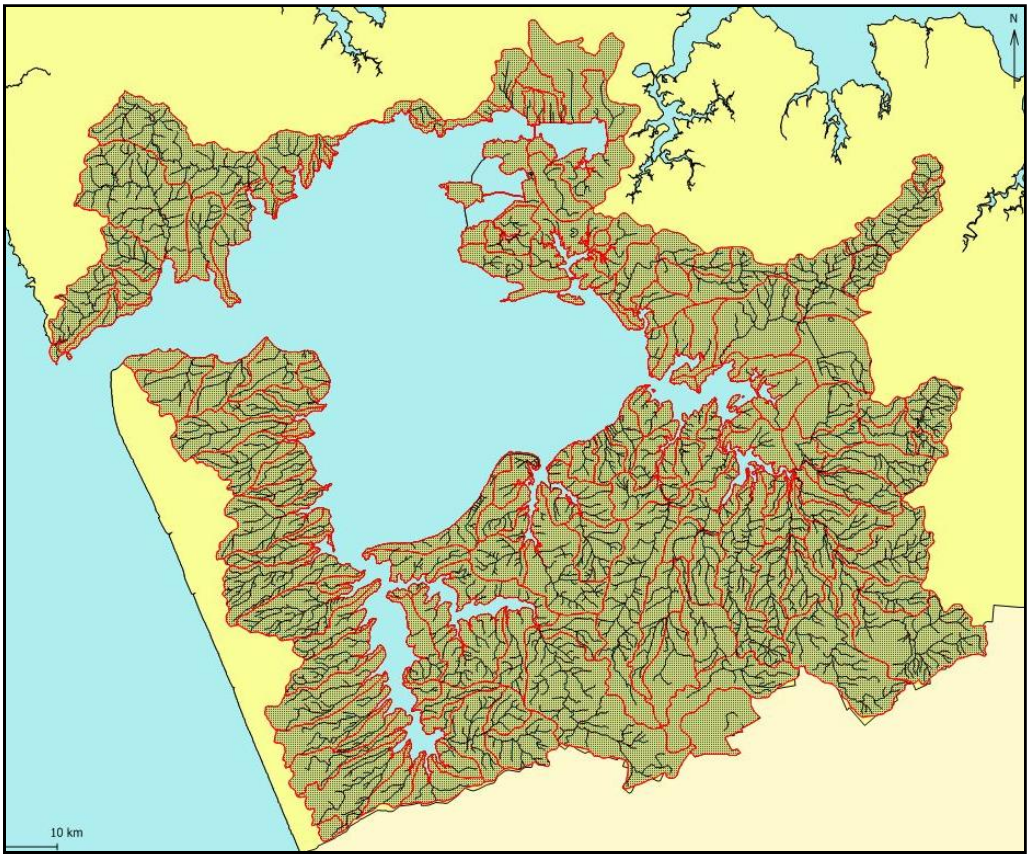


Figure 2: Major channels, inlets and intertidal sand and mud banks in Manukau Harbour.

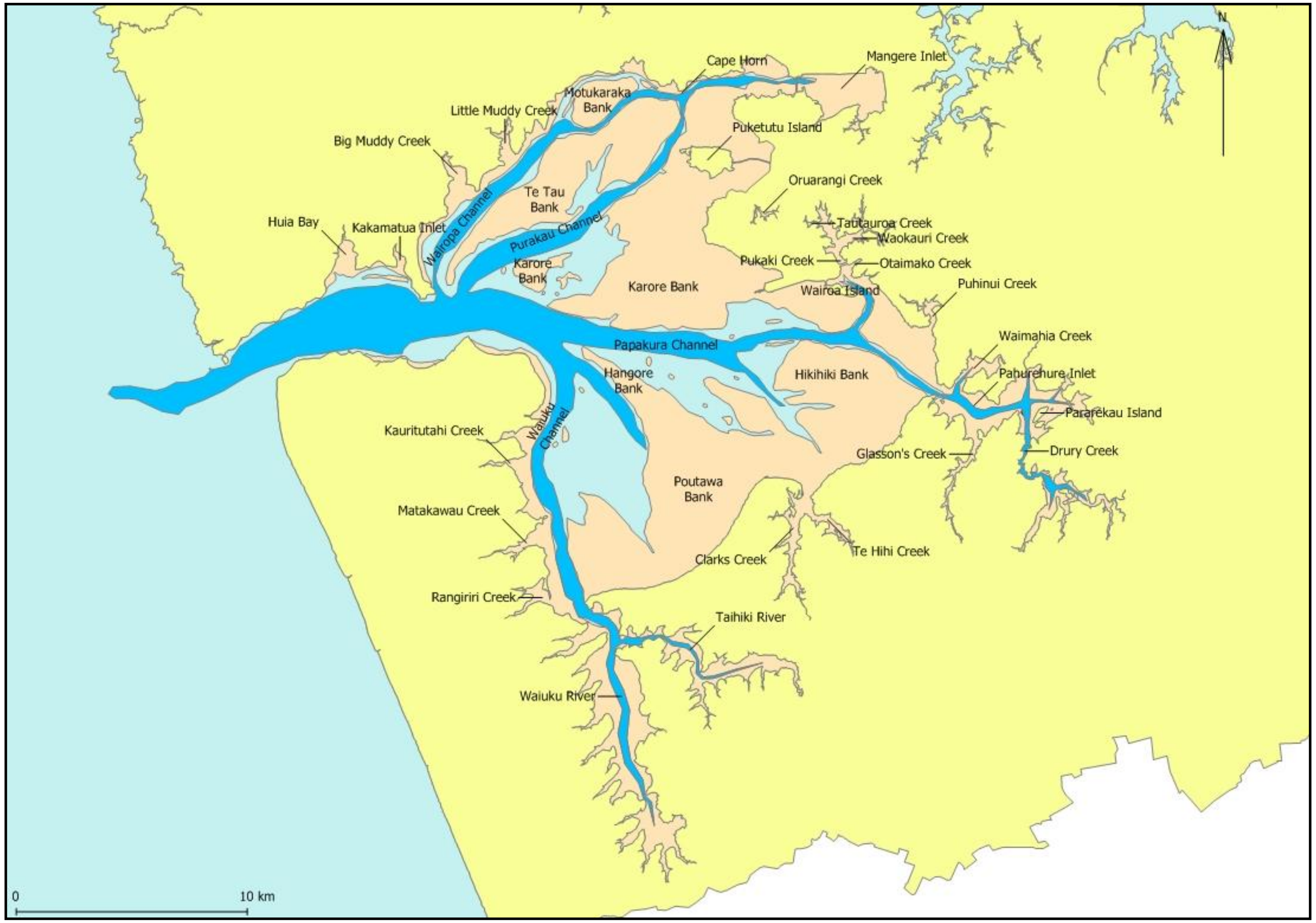


Figure 3: Towns, bays and beaches in and around Manukau Harbour.

Apart from the coastal structures at rural settlements, the western and southern shores of the main body of the harbour are relatively unmodified. Coastal structures are more common on the northern shoreline, west of Cape Horn, leading to a greater, albeit relatively low, level of shoreline modification. However, east of Cape Horn the number of coastal activities and degree of shoreline modification increases significantly. Mangere Inlet in the northeastern 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 (Figure 5). Ann's creek remains in the northeast 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 1960's, 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 landuse beyond (Figure 4). Likewise, fringing landuse along the northern and south-eastern shores is predominantly industrial-commercial.

South of Mangere Inlet is the Mangere Wastewater Treatment Plant (MWWTP). Prior to the building the plant, 25 million litres of trade wastes and 675,000 litres of untreated sewage were discharged daily into the Manukau (Watercare 2002). When the treatment plant opened in 1960 it processed household and industrial wastes that were previously discharged into the Manukau and Waitemata Harbours. At that time, the plant contained the world's largest oxidation ponds in full-time service. The opening of the MWWTP led to a dramatic improvement in environmental quality of Mangere Inlet, and the broader Manukau and Waitemata Harbours (Fitzmaurice unpublished). However, this improvement was not entirely without other (albeit more localised) environmental, cultural and social costs. The environmental costs included: the modification and loss of approximately 500 ha of intertidal flats and coastline between Puketutu Island and the Mangere coastline; blocking off of Oruarangi Creek; habitat loss with Mangere Lagoon; and, the creation of a substantial midge problem. These impacts were partially remedied when the plant was upgraded as part of the Wastewater 2000 project, which was completed in 2003. The upgrades included: the progressive removal of the oxidation ponds and their replacement with nine BNR (biological nitrogen removal) activated-sludge reactor clarifiers; the reopening of Oruarangi Creek and Mangere Lagoon to the sea; and the restoration of beaches south of Oruarangi Creek. The upgrade also resulted in further, significant, improvements to harbour water quality (see. Section 7). However, residual midge, nuisance algae and contaminated sediment problems remain, as do the Puketutu Island causeway and its associated discharge canal and holding pond.

Another prominent feature on the eastern shore of the harbour is the Auckland International Airport (which lies approximately 6km along the coast from the wastewater treatment plant). The airport runway was built on "reclaimed" land, which covers around 66 ha of the historic coastal marine area. The airport began operation in 1965 and currently services around 100 international flights and 300 domestic flights daily (159,600 aircraft movements per annum). Auckland International Airport Ltd owns approximately 1,500 hectares of freehold land and is developing a new northern runway, together with a variety of commercial and community facilities. These developments will largely occur on land that is currently, or has recently, been used for agricultural purposes. The new runway (due for completion to its full permitted length of 2,150 m by 2025), together with the existing runway will enable around 225,000 aircraft movements per annum (see www.aucklandairport.co.nz).

Other artificial structures in this area include

- A constructed bird roost situated in the coastal marine area between the MWWTP and the airport, which was originally built to attract birds away from the airport flight path. This feature now contains the outfall structure for the groundwater discharge from Ihumatao Quarry.
- The LPG terminal in Papakura Channel. LPG from ships is unloaded at the terminal and conveyed via a pipeline to an onshore depot.

3.1 Major Inlets

Side branches of the harbour are muddier than the main body, and generally consist of intertidal mudflats drained by a network of shallow channels. The largest of these side branches are Waiuku River and Pahurehure Inlet in the south and Mangere Inlet in the north (Figure 2). Waiuku River is an 11.5 km tributary that runs from Clarks Beach to Waiuku. This inlet is considered to be an ancient discharge point for the Waikato River, which was cut off by lava flows from the South Auckland volcanic field around 3 million years ago (Balance 1965, Ballance 1968, Murray-North Ltd 1988). Taihiki River is a major offshoot of Waiuku River, which extends eastward from a junction between Clarks and Glenbrook Beaches. Waiuku Estuary receives fresh water inputs from eight surrounding catchments (Tonkin and Taylor Ltd 2006). Landuse in the Waiuku and Taihiki river catchments is predominantly rural, but several rural townships also occur. These include Waiuku, Clarks Beach, Patamahoe, and Glenbrook. Rural activities in the catchment include diary and dry stock farming, horticulture and market gardening. Waiuku River is also notable for the presence of the BHP New Zealand Steel, steel mill on its eastern shore. This is among the largest heavy industrial sites in the Auckland Region.

The main body of Pahurehure Inlet extends 7.7 km from Weymouth to Papakura townships. Waimahia Creek and Papakura Stream feed into the northern shore of Pahurehure Inlet, while two narrow tributaries: Glassons Creek and Drury Creek extend approximately 4.5 km and 8.5 km respectively, inland from the southern shore. Drury Creek passes Hingaia settlement and terminates at Drury township. Landuse on the northern catchment of Pahurehure Inlet changed from rural, with small residential and commercial centres at Papakura and Manurewa in 1945, to predominantly urban by 1987 (Parshotam et al 2008). The current landuse in this area contains a mix of residential, commercial and light industrial activity, with small patches of rural landuse (predominantly pasture) in upper parts of the northern catchment. The proportion of rural landuse increases to the east and south, such that southern catchment of Pahurehure Inlet is predominantly rural. Pasture (dairy, dry stock and horses) and to a lesser extent market gardening comprise the major rural landuses (Parshotam et al 2008). The construction of the southern motorway in the 1960s also created barriers across the headwaters of Pahurehure Inlet. This confined tidal flows to narrow culverts under the motorway at Takanini and Papakura.

Mangere Inlet 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 profiles obtained from core samples (Matthews et al 2005). 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.

Mangere Inlet and its catchment have 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. The latter feature made Mangere Inlet strategically important in pre and early European times. It was utilised as a portage by both Maori and early Europeans, as its low elevation and short distance eased the transport 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 4).

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-1800’s. 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). 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) (Figure 5).

Figure 4: Westfield railway yards bordering the eastern margin of Mangere Inlet.

Figure 5: Changes in the northern shoreline of Mangere Inlet between 1940 (shaded) and 2006.

3.2 Minor Inlets

Many other small creeks and inlets radiate off the main body of the harbour and the major side branches. The largest of the minor inlets is Pukaki Creek, whose entrance occurs along the eastern boundary of the Auckland International Airport. Wairoa Island, which is part of the Auckland International Airport and connected to the mainland by a narrow causeway, is also located at the entrance to Pukaki Creek. The island is currently used for a variety of Airport related activities, and includes a bird roost which was developed by Auckland International Airport Ltd. The sandflats adjoining Wairoa Island have also been used in a number of research investigations. Landuse in the northern part of the Pukaki Creek catchment is largely residential. Google Earth indicates that the amount of residential and commercial-industrial development increased markedly between 2002 and 2009 on the north-western shore of Pukaki Creek. Despite this, a significant proportion of the Pukaki Creek (including its tributaries) catchment remains rural, with a mix of pasture and market gardening. Pukaki Creek is also designated a Tangata Whenua Management Area (see Section 3.4).

Oruarangi Creek is notable because it was blocked off from the main body of the harbour by a bund that was installed when the Mangere wastewater treatment ponds were constructed around 1959. Following this, seawater was prevented from entering the creek and the freshwater stream flows had to be pumped across the bund. The inlet remained disconnected from the harbour for over four decades and rapidly changed from a highly regarded tidal inlet with harvestable seafood resources and significant cultural values, to a highly impacted freshwater channel (Figure 6). In the early 2000's the creek had low dissolved oxygen levels, high summer temperatures and low summer flows, high turbidity levels and coliform counts, and had become infested with introduced weeds (Mills 2004). Furthermore, a strong gradient of sediment contamination was apparent from the upper to lower reaches of the creek.

Oruarangi Creek was subsequently reconnected with the sea in March 2005, following the removal of the Mangere wastewater treatment ponds and bund at the entrance of the inlet. As a consequence the creek is reverting back to a tidal inlet with associated intertidal flats, which have been rapidly colonised by marine fauna (Bioresearches 2007).

Huia Bay, located on the northern side of the harbour entrance, is the first estuarine embayment inside Manukau Heads and is protected from ocean swells by the Manukau Bar. The surrounding catchment has an area of ca. 24 km^2 and largely consists of steep formations of Waitakere Group rocks rising to 200 – 300 m above sea level. Landuse in the Huia catchment is dominated by rugged bush terrain, with native forest and scrubland covering all areas except the small residential settlement on the shores of Huia Bay. The catchment contains the upper and lower Huia dams, with storage capacities of 2.22×10^6 and 6.42×10^6 m^3 respectively. The upper and lower Huia dams receive runoff from 33% and 92% of the catchment respectively, which has a major influence on total catchment runoff. It is estimated that the Lower Huia dam reduces peak flood outflows by about 28% to 33% (for the 5 and 50 year return periods respectively) (from Ward 2005, citing Tonkin and Taylor 2001).

Figure 6: Aerial photos of Oruarangi Creek taken in 1959, 2001 and 2006.

The photos show the change from estuary, to stream and pasture, then back to estuary, due to the blocking and subsequent re-opening of the estuary mouth.

1959

2001

2006

3.3 Coastal Protection Areas

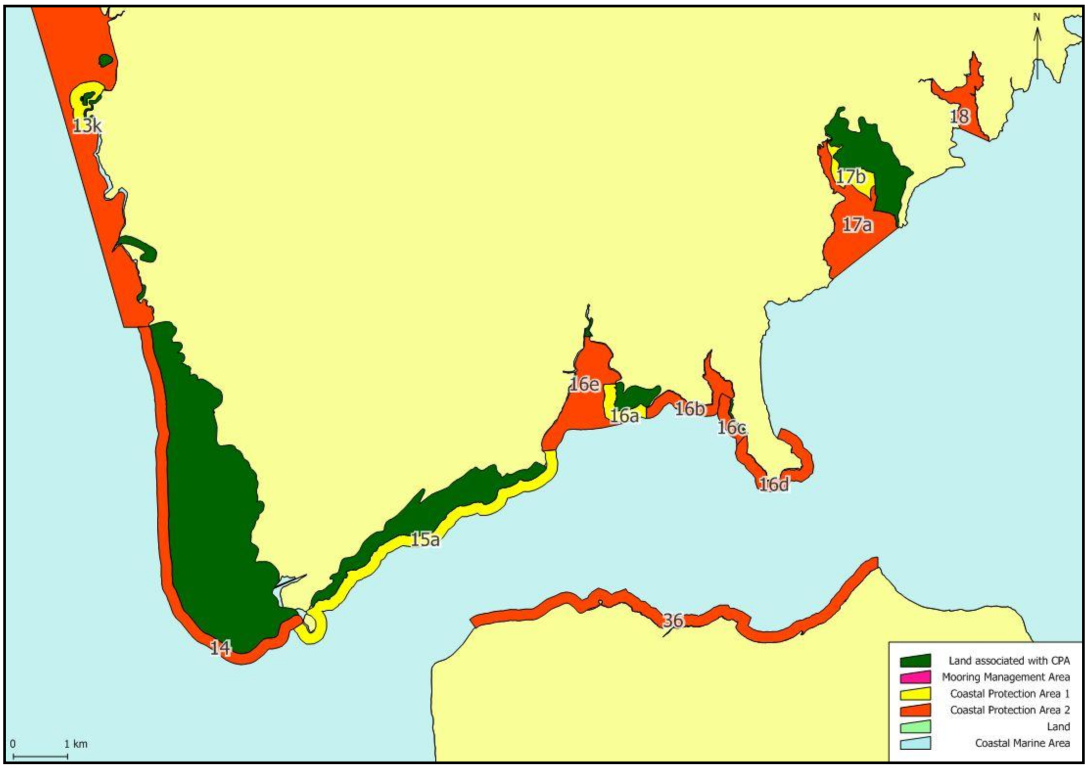
The environmental values of Manukau Harbour are reflected in the number of coastal protection areas within the harbour. Manukau Harbour contains 23 coastal protection areas (CPAs 14 - 36), which cover approximately 150 km^2 of the harbour (Figure 7 and Table 1). Ten of these CPAs are further divided into smaller sub-areas. The primary reasons for the CPA designations are:

- Geology and landforms: CPAs 14, 15, 16, 19, 20, 23, 25, 26, 28 and 33.
- Mangroves: CPAs 17, 18, 21, 27, 29, 30 and 31.
- Shrublands, saltmarsh and saline vegetation: CPAs 14 , 15, 17, 21, 22, 26, 27, 29, 30, 31 , 34 and 35.
- Vegetation sequences: CPAs 15, 16, 17, 18, 19, 21 and 27.
- Wetlands: CPA 15.
- Birds: CPAs 16, 17, 19, 23, 24, 25, 26, 27, 30, 32, 34 and 35.
- Intertidal mud or sandflats and associated biota: CPAs 22, 24, 26, 27, 29, 30 and 31.
- Variety of marine habitats and fauna: CPAs 15, 16, 17, 18, 27, 29, 30, 35 and 36.
- Fish: CPAs 26, 29 and 31.

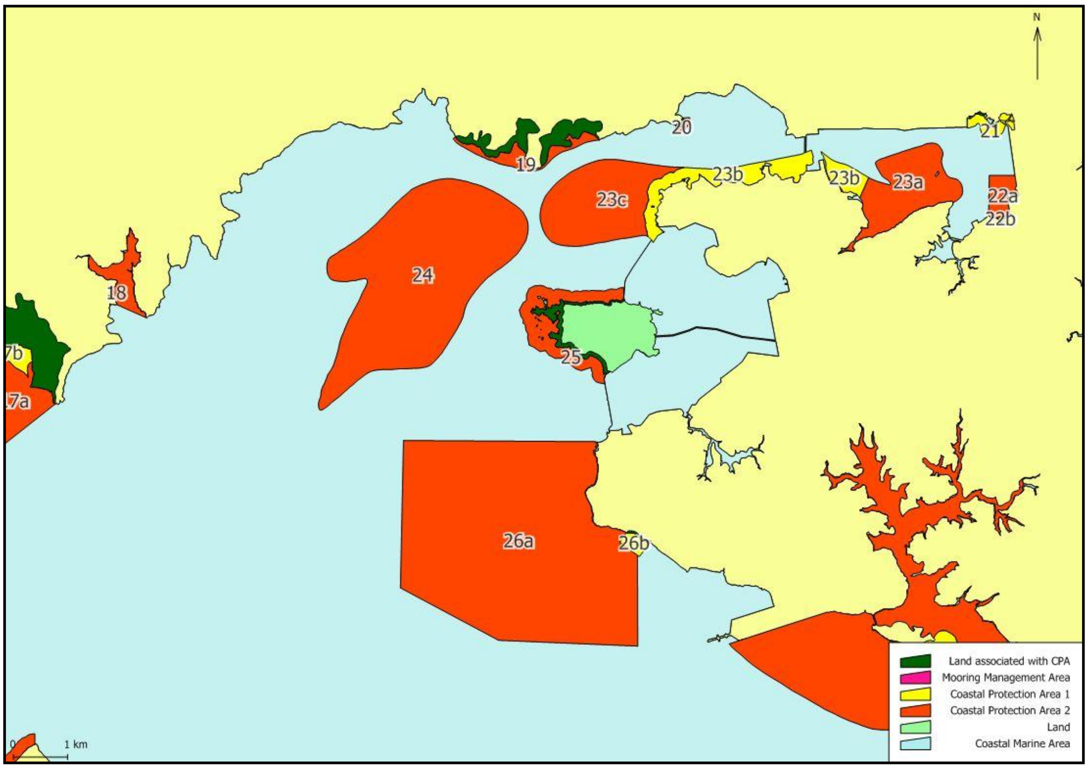
The harbour also contains 13 sites with cultural preservation or protection status. The location and a description of these sites is provided in Appendix 1.

Figure 7: Coastal protection areas (CPAs) in the: a) north-west corner; b) north-east corner; c) main body; d) Waiuku Creek; and, e) Pahurehure Inlet of Manukau Harbour.

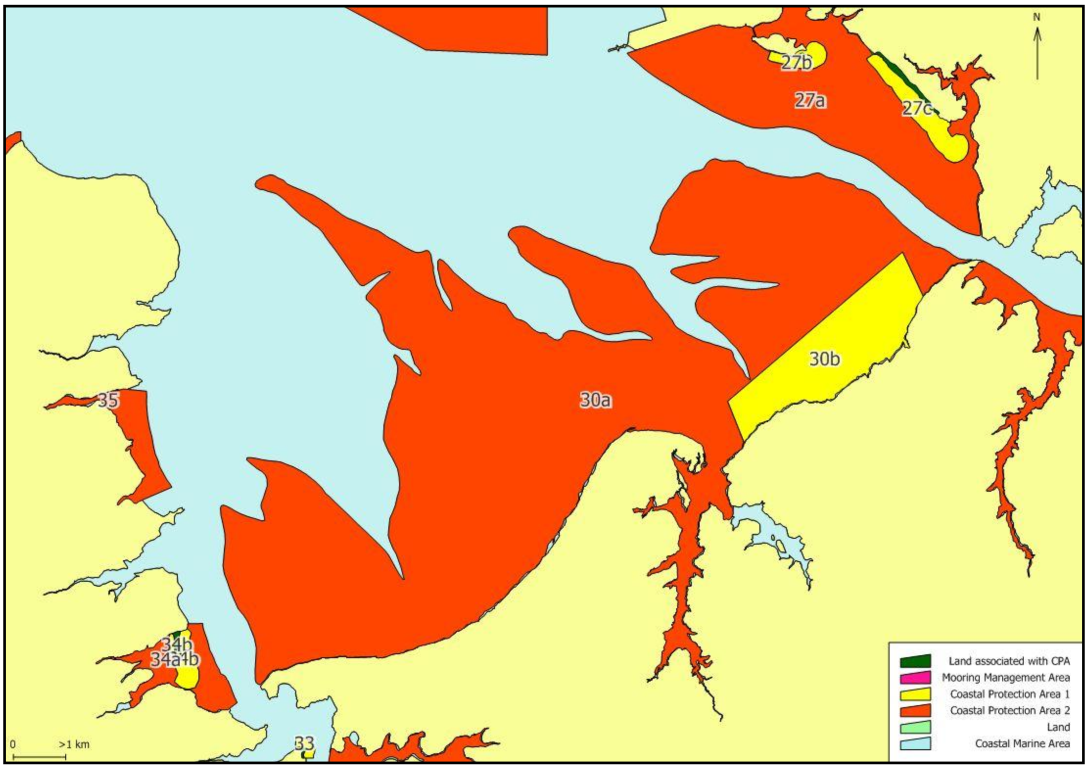
a)



b)


N
19
20
21
23b
23b
23a
22a
22b
23c
24
18
7b
7a
25
26a
26b
Land associated with CPA
Mooring Management Area
Coastal Protection Area 1
Coastal Protection Area 2
Land
Coastal Marine Area
0
1 km

c)


N
27b
27a
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30b
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34h
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33
Land associated with CPA
Mooring Management Area
Coastal Protection Area 1
Coastal Protection Area 2
Land
Coastal Marine Area
0
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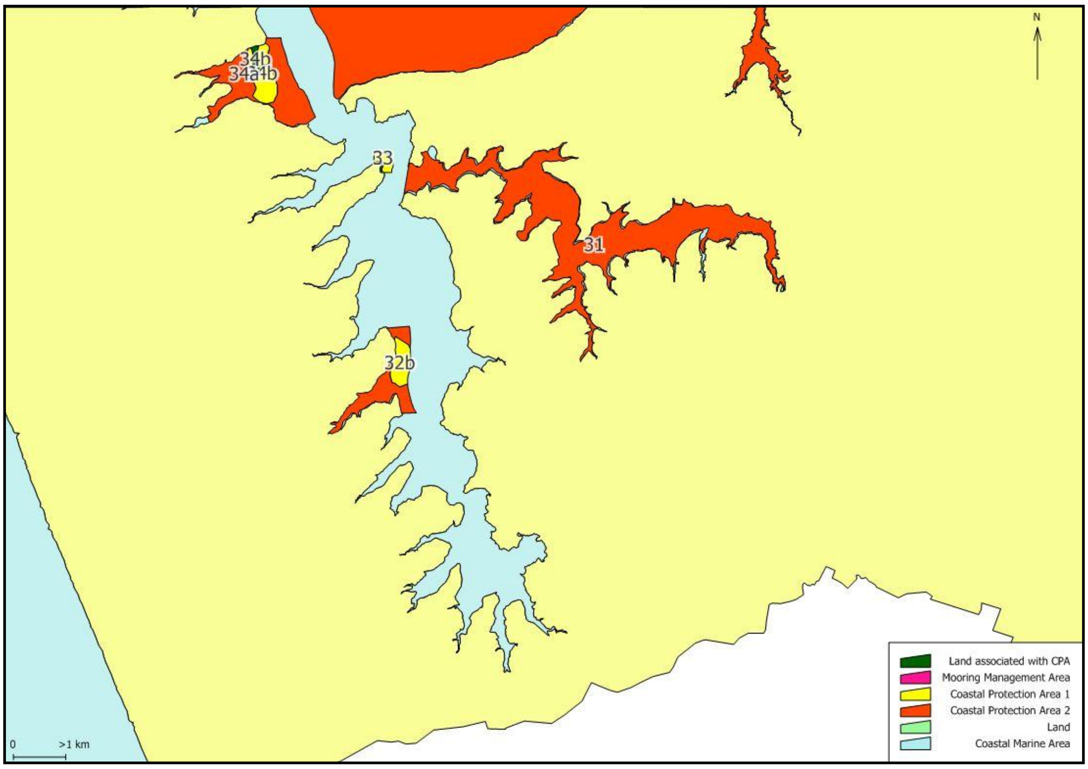
d)



34b
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Land associated with CPA
Mooring Management Area
Coastal Protection Area 1
Coastal Protection Area 2
Land
Coastal Marine Area
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>1 km

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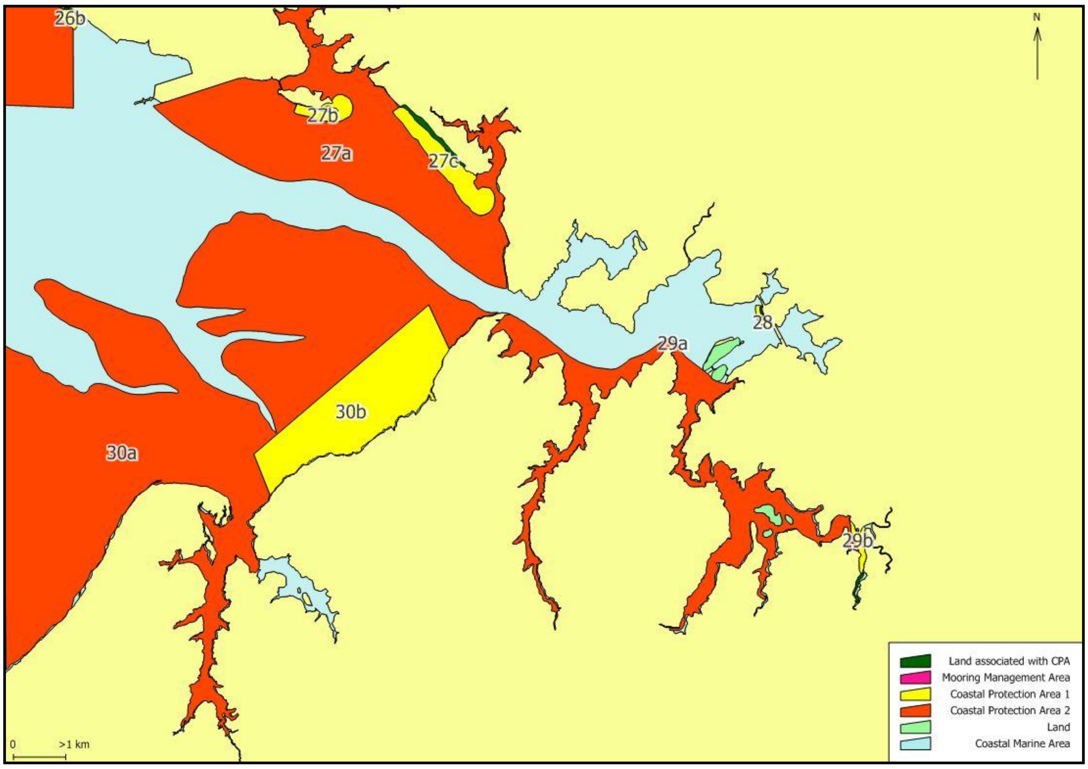

26b
27b
27a
27c
28
29a
30b
30a
29b
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Land associated with CPA
Mooring Management Area
Coastal Protection Area 1
Coastal Protection Area 2
Land
Coastal Marine Area
0
>1 km

Table 1: Coastal protection areas (CPAs) in Manukau Harbour (from the Auckland Regional Plan: Coastal).

Protection Type	CPA N°.	Description
Coastal Protection Area 2. Area of Significant Conservation Value	14	**Whatipu:** A large area of mobile dunes which is the best example of recent (mostly 1900 to 1930) coastal progradation in New Zealand, leaving many sea caves stranded in the hills behind. It is considered to be a nationally important landform and is also an important and complex habitat for a variety of animal and plant communities. Relatively high numbers of threatened and bird species roost in the mobile sand areas and feed in the surrounding waters and intertidal areas. Some species breed in the area; this is an important nesting area for white-fronted terns. In most places, the marine ecosystem grades into areas of natural coastal vegetation, including natural pingao and spinifex communities in the more mobile, freshwater wetland vegetation in the damp depressions and around the lakes, flaxlands at the base of the cliffs and forests on the cliffs themselves. Much of this vegetation is considered to be amongst the best in the Waitakere ecological district and much of it is habitat for a range of threatened plants. Secretive and threatened coastal fringe birds use the freshwater habitats, as do a variety of coastal bird species.
Coastal Protection Area 1 (a and b). Area of Significant Conservation Value	15a-b	**Omanawanui:** Because of the combination of strong, cool lateral currents and erosion-resistant rocks, this stretch of coast (15a) supports a diverse and rich marine fauna which shows open coast, harbour, and southern affinities. The encrusting fauna – sponges, bryozoans, ascidians, and hydroids – is uncommon elsewhere on the west coast of the North Island and, in fact, some species have not been found anywhere else in New Zealand. In most places, the marine ecosystem grades into areas of natural coastal vegetation, some of which is considered to be amongst the best in the Waitakere ecological district. Steep vegetated hillslopes rise approximately 200 metres above the harbour and show a gradient from coastal fringe to slope to ridgetop vegetation. This area is an integral part of the Manukau Harbour, which is an internationally important wetland selected in its entirety by the Department of Conservation as an Area of Significant Conservation Value (ASCV). The Paratutae Wave Cut Notch (15b) is the best example of a wave cut notch on the west coast of the Region.
Coastal Protection Area 1 (a)and 2 (b-e). Area of Significant Conservation Value	16a-e	**Huia to Cornwallis:** A combination of marine habitats is found in this area. The western area (16a, 16b) is comparable to the Omanawanui area having rich and diverse fauna which reflects the similarly strong, cool lateral currents and erosion-resistant rocks. At the eastern end (16c, 16d) the direction and strength of the current changes and boulder beaches become important. Close to Huia (16a), the marine ecosystem grades into an area of natural coastal forest on the cliffs and gumland vegetation higher up. Both of these are considered to be the best in the Waitakere ecological district. The cliffs and intertidal rocks on the Cornwallis Peninsula (16c) are considered to be

		geologically important because of the exposure of a sequence of volcanic-rich flysch beds that accumulated close to the contemporaneous late Miocene Waitakere volcanoes. The intertidal area of Hui Bay (16e) is an important bird feeding area.
Coastal Protection Area 1 (b) and 2 (a). Area of Significant Conservation Value	17a-b	**Big Muddy Creek:** Within and surrounding this small estuarine inlet there are a variety of habitats with notable gradients and links between them. The lower intertidal flats (17a) support dense populations of soft shore fauna and Zostera beds. These grade into dense algal beds in the mid-tidal zone, which in turn grade into extensive mangrove areas in the upper intertidal area. There are also important links between the marine and terrestrial environments. Coastal forest adjoins the mangroves in the more sheltered areas (17b) and shoreline rock shelves and shelly beaches in the more exposed areas. The direct connections between terrestrial and saline vegetation benefit the threatened secretive coastal fringe bird species which are found in this inlet which feed in the intertidal areas and nest and roost under the continuous cover on the land.
Coastal Protection Area 2. Area of Significant Conservation Value	18	**Little Muddy Creek**: Similar to Big Muddy Creek, this small estuarine inlet contains a variety of intertidal habitats ranging from mudflats to rocky reefs. There is an uninterrupted sequence from algal beds in the mid-tidal area, to an extensive mangrove marsh in the upper tidal areas into good stands of coastal forest.
Coastal Protection Area 2. Area of Significant Conservation Value	19	**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	**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	**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 1 (b) and 2 (a). Area of Significant Conservation Value	22a-b	**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. Small upper intertidal area supporting a high diversity of native saline vegetation. In the southeast corner (22b) is a 0.25 ha meadow of batchelor's button, Cotula coronopifolia.
Coastal Protection Area 2. Area of Significant	23a – c	**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

Conservation Value		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	**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	**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.
Coastal Protection Area 1 (b) and 2 (a). Area of Significant Conservation Value	26 a-b	**Ihumatao:** The Karore intertidal sandbank (26a) is a particularly rich area which provides a variety of sand flat habitats between high tide and low spring tide marks. On it grows the most extensive area of seagrass (Zostera) remaining in the Manukau Harbour. Large numbers of fish and wading birds feed on the Karore Bank, with particularly high densities of some common waders feeding in and around the remaining seagrass beds. Waterfowl, such as black swans and ducks, feed on the seagrass itself. There is also an artificial bird roost within this area. On the southernmost part of the coast in this area is a fossil forest (26b), buried in excess of 50,000 years ago by tuff from Maungataketake volcano and subsequently exhumed by coastal erosion. The fossil forest lies both below Mean High Water Springs and on land within the coastal environment. The site is an excellent example of its type and is considered to be nationally important. The Department of Conservation has selected the fossil forest as an Area of Significant Conservation Value (ASCV).
Coastal Protection Area 1 (b-c) and 2 (a). Area of Significant Conservation Value	27a-c	**Puhinui:** Area of intertidal banks and shellbanks forming a complex habitat for a variety of animal and plant communities. The extensive gently-graded sand flats (27a) support dense populations of intertidal sand flat organisms and are an excellent feeding ground for thousands of international migratory and New Zealand endemic wading birds including a number of threatened species. The associated shellbanks at Puhinui (27c) are used as a high tide roost by many of these waders as well as a variety of coastal birds. An artificial roost has been constructed at Wiroa Island (27b) and this is widely used by coastal birds. Waders also use this roost, which is the major roost on the Manukau Harbour for the threatened wrybill. Impounded behind the shellbanks is one of the biggest, best and least disturbed areas of saltmarsh remaining in the Manukau Harbour. The vegetation grades from the shellbank vegetation, into the saltmarsh, and then into kanuka forest with small native trees including kahikatea and rimu above Mean High Water Springs at Puhinui (27c). The saltmarsh, as well as being a habitat for a number of uncommon or

		threatened plants, is an important habitat for a variety of threatened secretive coastal fringe birds. Its habitat quality is enhanced by the adjoining terrestrial vegetation which provides shelter for the birds and offers potential nesting sites. In the shelter of the Puhinui, Pukaki, and Waokauri Creeks are significant areas of mangroves. Those in the Puhinui Creek are some of the oldest mangroves in the harbour and have batchelor's button meadows on the fringe in places. The Department of Conservation has selected the roosts and saltmarsh at Puhinui along with closely adjacent intertidal banks as an Area of Significant Conservation Value (ASCV).
Coastal Protection Area 1. Area of Significant Conservation Value	28	**Takanini:** Pumicite geological exposure of primary tephra from the Taupo Volcanic Zone. The exposure itself is above Mean High Water Springs, but would be affected by activities within the coastal marine area. The site is the purest in the Manukau Harbour and was not extensively modified by estuarine processes during deposition and is therefore considered to be nationally important. It has been selected by the Department of Conservation as an Area of Significant Conservation Value (ASCV).
Coastal Protection Area 1 (b) and 2 (a). Area of Significant Conservation Value	29a-b	**Drury:** This area is comprised of a variety of intertidal habitats (29a) ranging from sandy mud intertidal flats, to current-exposed rocky reefs and a variety of saline vegetation. Healthy and often expanding areas of mangroves grow in the shelter of the Pahurehure Inlet, Whangamaire Stream, and Drury and Whangapouri Creeks and in the southern half of the Whangapouri Creek are notable seagrass (Zostera) beds. Within the upper tidal reaches of Drury Creek (29b) there are a variety of marshes, grading from mangroves through to extensive areas of jointed rush-dominated saltmarsh, to freshwater vegetation in response to salinity changes. This same area (29b) is a migration pathway between marine and freshwater habitats for a number of different species of native freshwater fishes.
Coastal Protection Area 1 (b) and 2 (a). Area of Significant Conservation Value	30a-b	**Clarks Beach to Karaka Point:** Area of intertidal banks and shellbanks forming a complex habitat for a variety of animal and plant communities. The extensive gently-graded predominantly fine sand flats (30a) support the greatest diversity and abundance of intertidal sand flat organisms in the Manukau Harbour. They are an excellent feeding ground for many thousands of international migratory and New Zealand endemic wading birds including a number of threatened species. Several shellbanks have developed just offshore at Karaka (30b) since the early to mid 1980's and are now numerically the most important roost on the Manukau Harbour, most notably for waders, but also for a variety of coastal birds. There are a number of other roosts along the shore, most notably near Seagrove, the second most important roosting site on the harbour. These are used during most high tides, but during high spring tides at Seagrove, the birds move onto adjacent pasture. There is a variety of saline vegetation within this area. The intertidal flats between Clarks Beach and Seagrove were the site of very extensive beds of seagrass. Seagrass beds declined sharply, but have been reappearing around the region in recent years. Along the shores there are fringes of

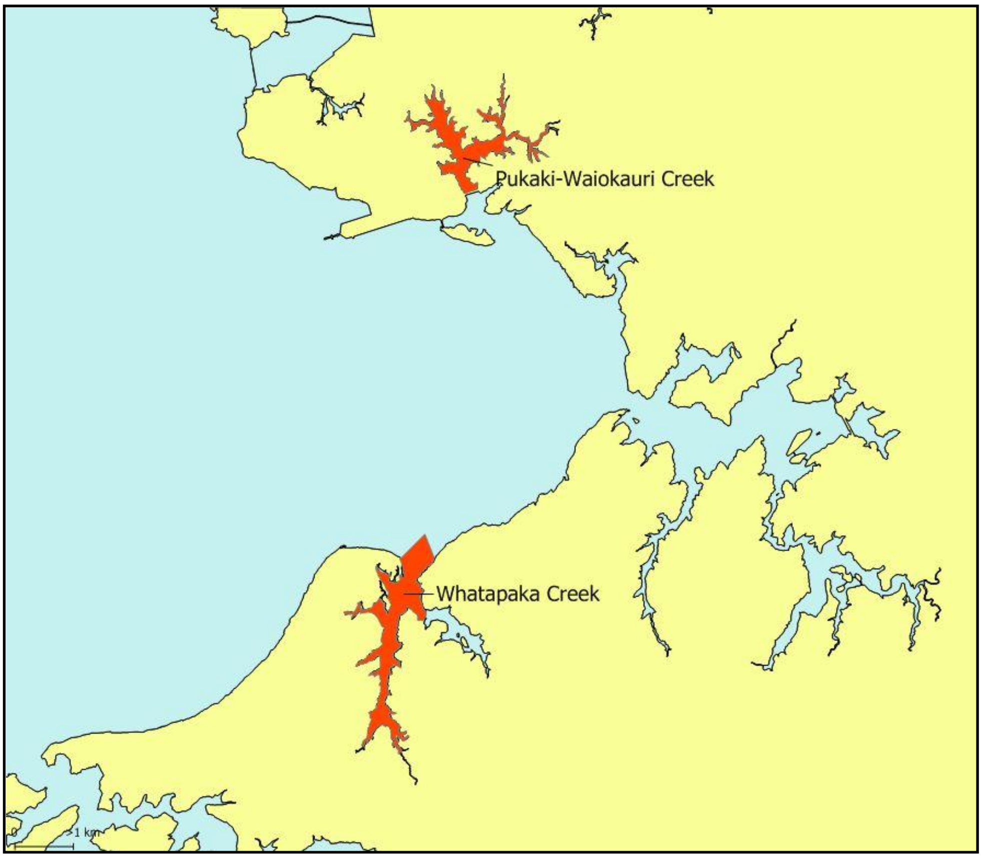
		saltmarsh, which reach their greatest extent and best condition along the northern shore of Seagrove Peninsula. Within the creek itself, at Seagrove, there are areas of healthy mangroves which are expanding rapidly. The Department of Conservation has selected the roosts and closely adjacent intertidal banks as an Area of Significant Conservation Value (ASCV).
Coastal Protection Area 2. Area of Significant Conservation Value	31	**Taihiki River:** This inlet is comprised of a diversity of sheltered harbour habitats ranging from predominantly sandy intertidal flats, to mangroves and to pockets of saltmarsh. It is considered to be an important nursery area for young flounder and grey mullet. This remains one of the least impacted of harbour habitats in the Manukau because of the lack of major inputs of sediment from the catchment and vegetated shoreline.
Coastal Protection Area 1. Area of Significant Conservation Value	32	**Waipipi:** Shell and sand banks at the entrance to Waipipi Creek (32b) which are isolated from the shore at high tide are used as a high tide roost by a variety of coastal birds and several hundred to a few thousand international migratory and New Zealand endemic wading birds including a number of threatened species. Waders congregate on the adjacent intertidal flats (32a) before moving onto the roost. This is one of the smaller of the major high tide wader roosts on the Manukau Harbour. The Department of Conservation has selected the roosts and closely adjacent intertidal banks as an Area of Significant Conservation Value (ASCV).
Coastal Protection Area 1. Area of Significant Conservation Value	33	**Te Toro Quaternary Sands**: Geological exposure of sands which predates the eruptions of Taranaki and Taupo volcanic centres and the subsequent current transport of black sands northwards along the coast. The exposure is both below Mean High Water Springs and in the cliffs above. The site is considered to be regionally important.
Coastal Protection Area 1 (b) and 2 (a). Area of Significant Conservation Value	34	**Pollok:** Spit Sand bank formed into a spit (34b) is a high tide roost used by a variety of coastal birds and thousands of international migratory and New Zealand endemic wading birds including a number of threatened species. Waders congregate on the adjacent intertidal flats (34a) before moving onto the roost. Saltmarsh habitats join the spit with fairly extensive intertidal mangrove areas in Rangiriri Creek. The Department of Conservation has selected the roosts and closely adjacent intertidal banks as an Area of Significant Conservation Value (ASCV).
Coastal Protection Area 2. Area of Significant Conservation Value	35	**Awhitu:** A range of shoreline habitats in microcosm are found along the shores of Awhitu Regional Park and in the Kauritahi Stream. These support a large range of wading and coastal birds in addition to a number of threatened coastal fringe birds that dwell in the saline vegetation. The area is an integral part of the Manukau Harbour, an internationally important wetland selected by the Department of Conservation as an Area of Significant Conservation Value (ASCV).
Coastal Protection Area 2. Area of Significant Conservation Value	36	**South Head west of Mako Point:** This area is subjected to strong, cool lateral currents similar to those at Omanawanui on the opposite side of the harbour mouth. Consequently, this stretch of coast also supports a diverse and rich marine fauna which shows open coast, harbour, and southern

affinities. The south head contrasts with the north because of the softer rocks and platform reefs which mean that the biota differs and is less diverse and abundant.

3.4 Tangata Whenua Management Areas

Two areas in the Manukau Harbour have been specifically identified as Tangata Whenua Management Areas in the Auckland Regional Plan: Coastal: Whatapaka Creek and Pukaki-Waiokauri Creek (Figure 8). The Auckland Regional Plan: Coastal states that the Waitangi Tribunal recommended that Whatapaka Creek be reserved for the exclusive use of the Hapu of Whatapaka in 1985. An application to the Maori Land Court by Whatapaka Marae resulted in the establishment in 1992 of Whatapaka Creek as a Maori Reservation under the Maori Affairs Act 1953, (now Te Ture Whenua Maori Act 1993) for the purpose, *inter alia* of a place of significance for the common use and benefit of Whatapaka Marae. The Waitangi Tribunal also recommended that Pukaki-Waiokauri Creek be reserved for the exclusive use of the Pukaki Marae. As with Whatapaka Creek, the creek was the subject of a Waitangi Tribunal recommendation and an application to the Maori Land Court resulted in the establishment in 1992 of Pukaki-Waiokauri Creek as a Maori Reservation for the purpose, *inter alia* of a place of significance for the common use and benefit of the Hapu of Te Akitai and Te Ahiwaru o Waiohua. The local Tangata Whenua are Kaitiaki of the lands in question, and have maintained the natural and ecological values over several centuries, despite significant development pressures over the last century. The Tangata Whenua Management Areas recognise this, and the customary rights, responsibilities, and relationships of the Tangata Whenua with their ancestral taonga.

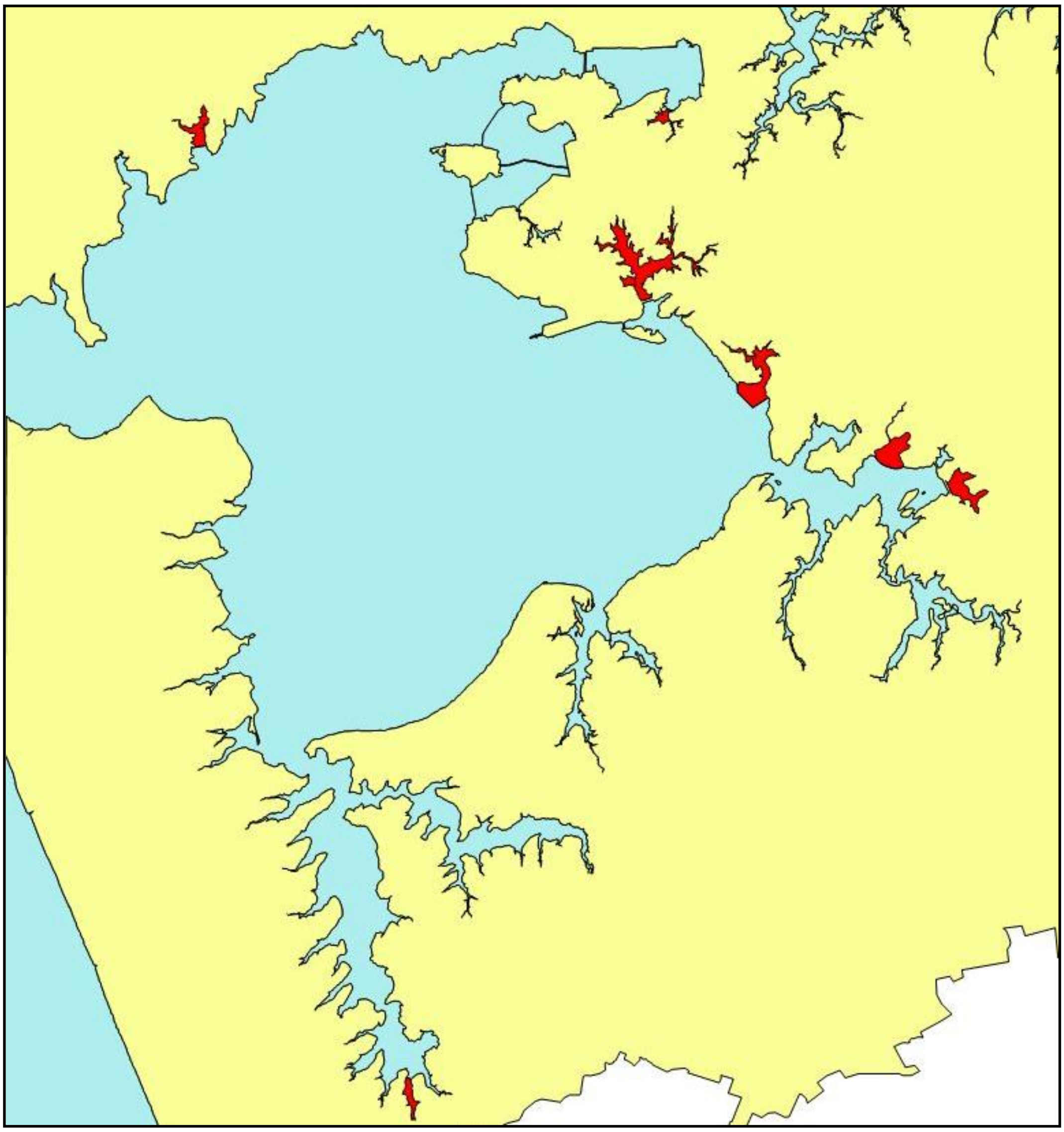
Figure 8: Whatapaka Creek and Pukaki-Waiokauri Creek Tangata Whenua Management Areas.



3.5 Contaminant Settling Zones

Eight sediment, and associated contaminant, settling zones were identified in ARC (2002a) and included in the Auckland Regional Plan Coastal (Figure 9). 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 and have proposed an alternative zone for Mangere Inlet (see Appendix 2).

Figure 9: Contaminant settling zones (red) identified in the Auckland Regional Plan: Coastal. Note that two adjoining settling zones are located in Pukaki-Waiokauri Creek.



4 Hydrodynamics

Tidal ranges in Manukau Harbour are among the highest in New Zealand (Hume et al 1992). Tides 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 (Bell et al 1998), and 4.5 m and 1.6 m in Pahurehure Inlet (Pritchard et al 2008). The 9-km-long entrance channel has the most complex velocity patterns in the harbour due to the confluence of the major inner-harbour channels; the constriction imposed by the Puponga Point headland; and the flood-tide delta (Huia Banks), which forms a major obstacle to the flow. The flow convergence around the Puponga Point and Huia Banks appears to limit the exchange of water between the northern and southern channels of the inner harbour (Bell et al 1998). The volume of water in the entrance channel at low tide is approximately equal to the tidal compartment of the inner harbour (Heath et al 1977). Accordingly, the volume of the entrance channel is large enough at low water to accommodate the entire tidal prism of the inner harbour (Bell et al 1998).

No large-scale eddy patterns are evident in the inner-harbour because of the relatively narrow, incised, channels (Bell et al 1998). Currents are predominantly tidally driven, with peak velocities of up to 1.8 m s^{-1} occurring at the harbour entrance (Heath et al 1977). 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). Spring tide velocities also exceeded 1.0 m s^{-1} at the entrance to Pahurehure Inlet and 1.5 m s^{-1} in narrow parts of the Drury Creek channel (i.e. near Hingaia) (Pritchard et al 2008).

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).

Salinity based estimates of water residence time indicate that average, harbour-wide exchange rates are between 11 (Vant and Williams 1992) and 22 days (Heath et al 1977). However, water residence times vary from one area to another, and seasonally (in response to freshwater inflows) (Vant and Williams 1992). For instance, in the northeastern Manukau the average residence time of freshwater inflows was estimated to be 12.6 days. However, replacement times in summer can be half those in winter because net freshwater inflows can at times be negative i.e. losses to evaporation are greater than inputs from rainfall and inflows (Vant and Williams 1992).

Tidal-driven circulation dominates over wind-driven in most of Manukau Harbour, except the upper intertidal, where wind-driven circulation is characterised by downwind flows, with pressure-driven return flows via the deeper main channels. Tide and wind-generated currents, together with locally generated wind waves, suspend and advect fine sediments from exposed intertidal banks, which contributes to high turbidity levels in the harbour (Bell et al 1998). Wave development across the harbour is influenced by wind, fetch and tidal changes in depth (Smith et al 2001). In the Manukau Harbour fetch varies widely, depending on the state of the tide. Fetch becomes severely limited as the tide falls and sandbanks emerge, which reduces wave height. Largest waves occur when strong winds coincide with greatest fetch i.e. during high, spring tides.

The intertidal nature of the harbour also means that wave development is duration limited. Water depth changes as waves propagate (i.e. travel) across the harbour, and wave development is shut down every tidal cycle by the emergence of intertidal flats. Smith et al (2001) found that the time required for the fastest wave to propagate across the harbour is of the order of two hours. Tidal changes in water depth during this time result in a "non-stationary" situation. Consequently, non-stationary modelling using shallow water spectral wave models, such as SWAN, is necessary to fully understand wave development. Variations in surface roughness, associated with the catchment topography and landcover, also cause wind speeds to vary around the harbour, which significantly affects wave generation.

Dolphin et al (1995) found that during spring tides, flood currents were strong enough to entrain bed sediments on the mid-low tide sandflats out from Wairoa Island, but upper sandflat and ebb tide currents were not. However, orbital currents and turbulence associated with breaking and shoaling wind-waves cause bed disturbances, which mobilise and rework the sediments (Bell et al 1997). The surf and shoaling wave zones move across the intertidal flats as the tide advances and retreats. Microscale ripples are formed during small to moderate wave activity, whereas ridges and runnels are formed and reworked by high intensity, episodic storm events (Dolphin et al 1995). Dolphin et al (1995) identified three types of sediment mixing and associated processes on the sandflats of Wairoa Island (Table 2). Bell et al (1997) subsequently summarised these as:

1. ripple movements caused by small waves (< 0.3 m high) mix sediments to 0.2 to 2 cm depth at intervals of days to weeks;
2. surficial sediment disturbance and larger ripple movements caused by larger waves coinciding with high water, spring tides and strong southwest winds, mix sediments to 2-3 cm depths at a time scale of months; and,
3. episodic storm events sporadically mix sediments to depths of 8 cm or more by reworking ridges and runnels at time scales of months to decades.

Table 2: Summary of sediment mixing processes on the sandflats of Wairoa Island (from Dolphin et al 1995).

Type of mixing	Movement of small wave ripples	Surficial sediment disturbance and movement of wave ripples	Movement-formation of ridges and runnels
Location	Entire sandflat		Upper sandflat
Frequency	Days - Weeks	Weeks - Months	Months - Decades
Net sediment transport	Nil	Yes	Yes
Depth of disturbance	1 – 1.5 cm	2 – 3 cm	~ 20 cm
Drivers of bedform change	Shallow water (<30 cm) Wavelets	High water Spring tides Strong SW winds Increased storm duration	High water > 4 m LAT Winds > 10 m/s Wind speed and direction maintained for around 2.5 hours around high tide Super elevated water levels.

The hydrodynamics of Mangere and Pahurehure Inlets have also been modelled as part of the Coastal Receiving Environment Assessment (CREA) carried out by Auckland City Council and Metrowater (Croucher et al 2005a and 2005b), and South-East Manukau Study carried by the ARC (Pritchard et al 2008). In both cases the modelling was carried out to provide inputs into stormwater contaminant models. The CREA model 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. However, changes in flow velocities were not easily discernable at other locations or during small storm events.

5 Sediment characteristics, accumulation and contamination

The characteristics of marine sediments has a major influence on marine habitats and benthic communities (Gibbs and Hewitt 2004, Hewitt et al 2009, Thrush et al 2008b). Consequently, the maintenance of diverse and healthy benthic communities depends on the preservation of sediment quality. Harbour and estuary sediments can be modified by elevated inputs of fine terrestrial sediments, organic matter and chemical contaminants such as nutrients, heavy metals and persistent organic compounds.

Sediment and contaminant effects can range from: localised, catastrophic impacts arising from major discharges of sediment or contaminants, which cause the rapid die-off of benthic biota in the affected area; through to slow, long term, and relatively large scale shifts in habitats and associated benthic communities (e.g. a change from sandy to muddy to mangrove habitat).

Strategies for managing sediment and contaminant impacts are likely to vary according to the nature of the catchment and receiving environment, ambient conditions, and trends in sediment accumulation and quality. Information on ambient sediment characteristics, contaminant levels, and sediment and contaminant accumulation is therefore required to develop options for stormwater management that prevents or minimises the effects of sediments and contaminants.

5.1 Sediment characteristics and accumulation

The dominant sources of sediments in Manukau Harbour are inputs from the West Coast, shoreline and cliff erosion, river sediment, and biogenic production (e.g. shells). Sediment derived from the open coast is predominantly deposited in the entrance channel, Huia Bank and near Puponga Point, and is not reworked into the inner harbour. A division between marine dominated and fluvial dominated sediments occurs near this point (Ward 2005).

Intertidal areas in the main body of Manukau Harbour are dominated by sandy sediments ranging from 63 μm – 2 mm in diameter, with <5% mud (<63 μm) (Murray-North Ltd 1988). Relatively large areas of muddy sand (10 - 50% mud) are also found between Hanore and Karore Banks, on Te Tau Bank and along the eastern margin of Awhitu Peninsula (Gregory et al 1994, Figure 10). Muddier sediments are also found in the lee of shell banks, in seagrass beds, along channel margins, and in more sheltered areas such as around Puketutu Island (Murray-North Ltd 1988). Murray-North Ltd (1988) identified two types of shellbank that were formed by wave action: migrating ripples of shells and large, relatively static high shell banks.

The mud content of sediments increases from the central harbour to the side branches: grading from sand to muddy sand, sandy mud and/or mud. Harbour channels have strong tidal flows and are pathways for transporting sediment. Most sediments are comprised of < 50% calcium carbonate, but isolated patches with > 50% calcium carbonate occur in a number of areas throughout the harbour. Large, gravelly-sand beds are found in the main channels, with smaller areas of gravel at the confluence of Papakura and Waiuku Channels and in the upper sections of Wairopa and Parakau Channels. Small gravel patches also occur in Mangere Inlet, at the entrance to Taihiki Creek, and out from Clarks Beach and Wairoa Island. Patchy shell banks tend to be more common on the southern shore of the harbour between Clarks Beach and Puhinui Inlet, but they are also found at the entrance to Mangere Inlet, south of Oruarangi Creek, in Huia Bay, and at the entrance to inlets on Awhitu Peninsula.

Recent surface and core samples of sediments collected from the southeast Manukau Harbour and Pahurehure Inlet show that the mud content of the surface sediments in that area was typically less than 10% by volume, with the muddiest sediments located close to the Papakura motorway causeway and the developed urban centres (Figure 11). Sediment accumulation rates inside Pahurehure Inlet were typical of other estuaries in the Auckland region, but sediments did not appear to accumulate on sand flats beyond the entrance to the inlet.

Particle size analysis of two sediment cores indicates that muddiness has increased at sites at the entrance to Glassons Creek and west of the Papakura motorway causeway. The data also suggests that intertidal flats at most sites within Pahurehure Inlet are long-term sinks for fine sediments (Reed et al 2008). 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".

Figure 10: Distribution of major sediment types in Manukau Harbour (based on Gregory et al 1994)

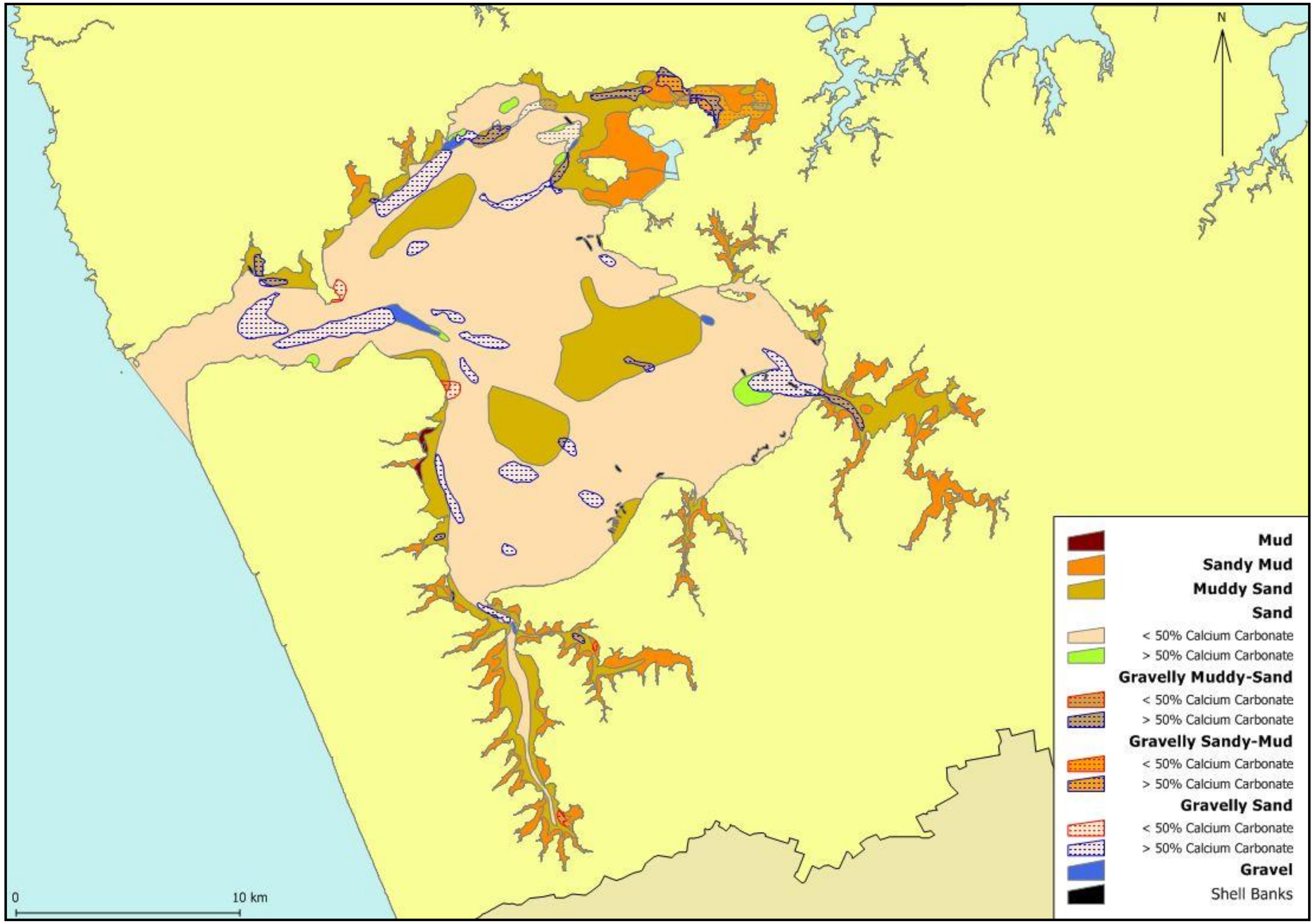
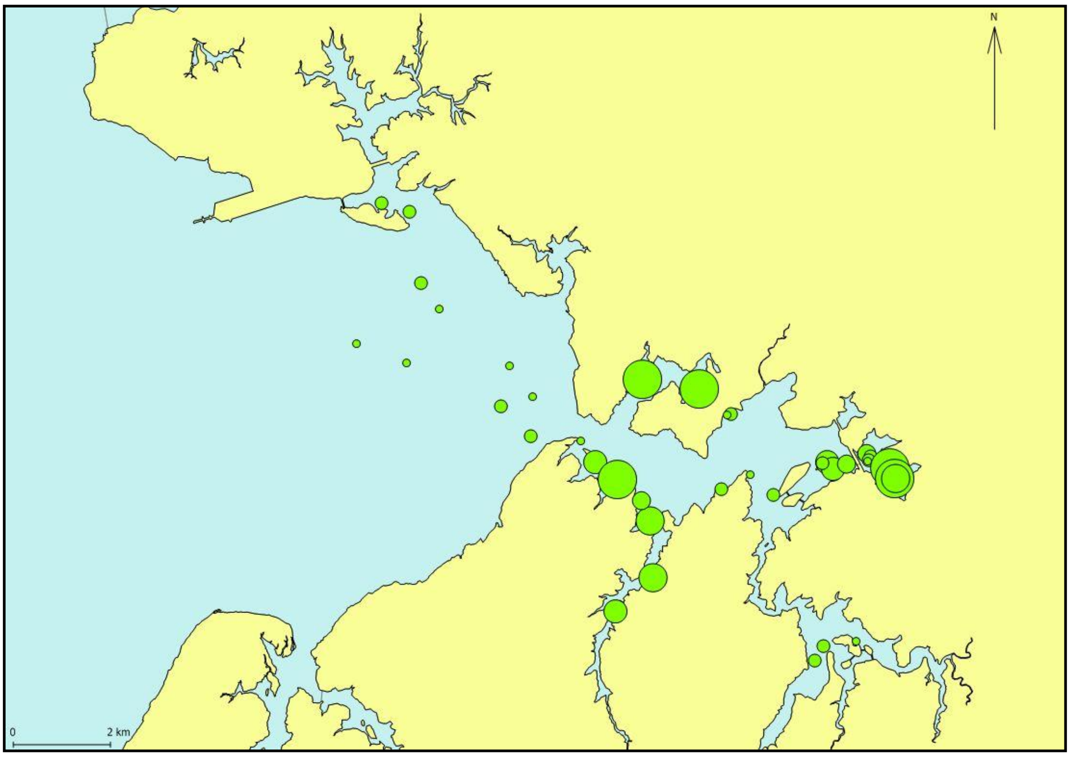


Figure 11: Relative proportion of sediments (by volume) that were < 63 μm in the Southeast Manukau (from Reed et al 2008). Dot size varies according to the percentage below < 63 μm.



Green (2008b) used the USC3 (urban stormwater contaminant model version 3) to model sediment accumulation in 23 sub-estuaries, which covered the area of harbour east of the Auckland Airport. The model indicated that the fate of sediments was largely dependent on circulation patterns in the harbour, but differences were apparent among the tidal creeks. Most sediment discharged into Clarks Creek was retained within it, whereas sediment discharged into Glassons Creek tended to be more mobile, with around 20% being retained, 30% deposited around the mouth of the creek and the remaining proportion being dispersed widely within Pahurehure Inlet and out to the central harbour. Drury Creek trapped a slightly greater proportion (about 25%) of sediment from its upper catchment, but less sediment was trapped from catchments closer to its mouth. Sediments escaping from Drury Creek were widely dispersed, but more tended to be deposited in the inner reaches of Pahurehure Inlet than in other areas. Conversely, Drury Creek also received and trapped sediments from remote catchments in the inner reaches of Pahurehure Inlet. For instance, 7%, 15%, 17% and 11% of the sediment from the Papakura, Takanini, Papakura Stream, and Bottle Top Bay catchments, respectively, ended up in Drury Creek.

A relatively large proportion of the sediment discharged from the Manurewa / Weymouth, Papakura, Takanini and Papakura Stream catchments was trapped close to the discharge points, but escaping sediments were widely dispersed. Puhinui Creek trapped around 30% of sediment deposited directly into it, with escaping sediments being widely dispersed in Manukau Harbour. Highest trapping rates were obtained for Pukaki Creek, which retained around 75% of direct sediment inputs. Like Puhinui, the sediment that escaped from Pukaki Creek was dispersed widely.

Overall, predicted sediment accumulation rates ranged from 5.57 mm yr^{-1} east of Glassons Creek entrance, to 0.03 mm yr^{-1} (or effectively zero) on Hikihiki Bank. More sediment tended to accumulate in the inner reaches of Pahurehure Inlet than in the outer reaches, and the study also indicated that tidal creeks draining into Pahurehure Inlet accumulate sediment at similar rates (to each other) (Green 2008b).

Huia Bay near the harbour entrance is also infilling, but this appears to be due to the onshore migration of sediment rather than sediment runoff from the adjoining catchment (Ward 2005). Average rates of sedimentation in Huia Bay are calculated to have increased from 0.22 mm yr^{-1} in the mid-late Holocene to an average rate of 2.49 mm yr^{-1} between the late Holocene and the present day.

The mud content of sediments at the ARC's ecological monitoring sites in the main body of the harbour have also varied since 1987. Hewitt and Hailes (2007) found that sediments from the ARC's Clarks Beach site had higher and more variable proportions of mud than sediments from the Cape Horn or Auckland Airport monitoring sites (see Section 8.1 for the location of these sites). At times, the mud content of sediments at Clarks Beach has exceeded 40%, but consistent temporal trends are not apparent at this, or any of the other monitoring sites. Similarly, organic carbon content was variable at all sites, no temporal trends were apparent. The mud content in sediments from the other southern Manukau sites (Elletts Beach and Karaka Point) tends to be similar to Clarks Beach, but it has never exceeded 5% in sediments from the Auckland Airport site.

5.2 Sediment Contamination

Sediment-contaminant monitoring carried out by the ARC since 1998 has used comparable methods of sample collection and contaminant analysis. The ARC's programmes therefore provide a robust set of sediment quality data for Manukau Harbour.

Sediment-contaminant concentrations are typically compared against sediment quality guidelines, which usually provide a set of low and high values. The low values are nominally indicative of contaminant concentrations where the onset of biological effects is expected to occur (e.g. 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 (e.g. 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 where biological effects were observed.

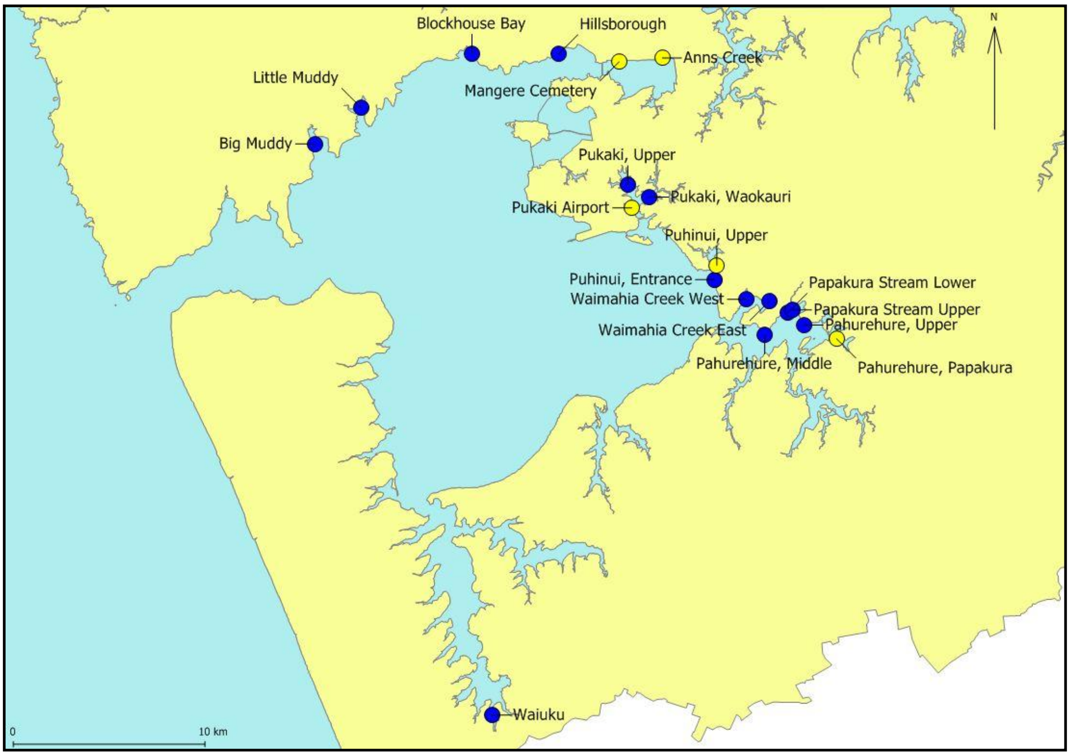
- Threshold Effect Levels (TEL) and Probable Effects Levels (PEL) developed by the Florida Department of Environmental Protection (MacDonald et al 1996). TEL and PEL values take into account studies that showed biological effects plus those that showed no effects (c.f. ERL's and ERM's which were derived from effects data only). TEL and PEL values tend to be more conservative (i.e. protective) than ERL and ERM values described above.

- The ARC's green, amber and red environmental response criteria (ERC's), 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 3.

Sediment contaminants from 18 sites are routinely analysed in Manukau Harbour at 2 to 5 year intervals as part of the State of the Environment (SoE) sediment chemistry monitoring and stormwater contaminants monitoring programmes (Figure 12). Samples are tested 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 state of the environment (SoE) monitoring sites in 2005 (Figure 12). The concentrations of a range of organic compounds are also determined periodically at these sites (Reed and Webster 2004, McHugh and Reed 2006, Reed and Gadd 2009). The organic compounds include PAHs, PCBs, DDT, chlordane, lindane, dieldrin, methoxychlor, endosulfan, hexachlorobenzene. Raw data from the above programmes were obtained, re-plotted and summarised below. Recent values for copper, lead and zinc concentrations are also presented in Appendix 4.

Figure 12: Auckland Regional Council sediment monitoring and investigation sites in Manukau Harbour. Blue sites are stormwater contaminant monitoring sites (i.e. RDP sites), yellow sites are state of the environment (SoE) sediment contaminant monitoring sites.



Plots of the 2007 metals data indicate that highest concentrations of zinc, copper and lead occur in the inner, northern, Mangere Inlet sites, i.e. Ann's Creek and Mangere Cemetery (Figure 13 to Figure 15). Total zinc concentrations exceeded ERL sediment quality guideline values at Ann's Creek and exceed TEL values at Mangere Cemetery[3]. Total copper concentrations also exceeded TEL sediment quality guideline values (i.e. amber ERC values) at these two sites. The total concentrations of these three metals were below sediment quality guideline values at all other monitoring sites in Manukau Harbour.

[3] TELs are equivalent to the ARC's "amber" environmental response criteria (ERC), and ERLs are equivalent to the ARC's "red" ERCs - see Section 5.2 and Appendix 3.

Figure 13: Map showing relative sediment concentrations of total zinc (mg/kg) in Manukau Harbour (from Kelly 2007b, and Reed and Gadd 2009 - see Appendix 4 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, orange TEL – ERL, and red is > ERL). See text for a description of sediment quality guidelines.

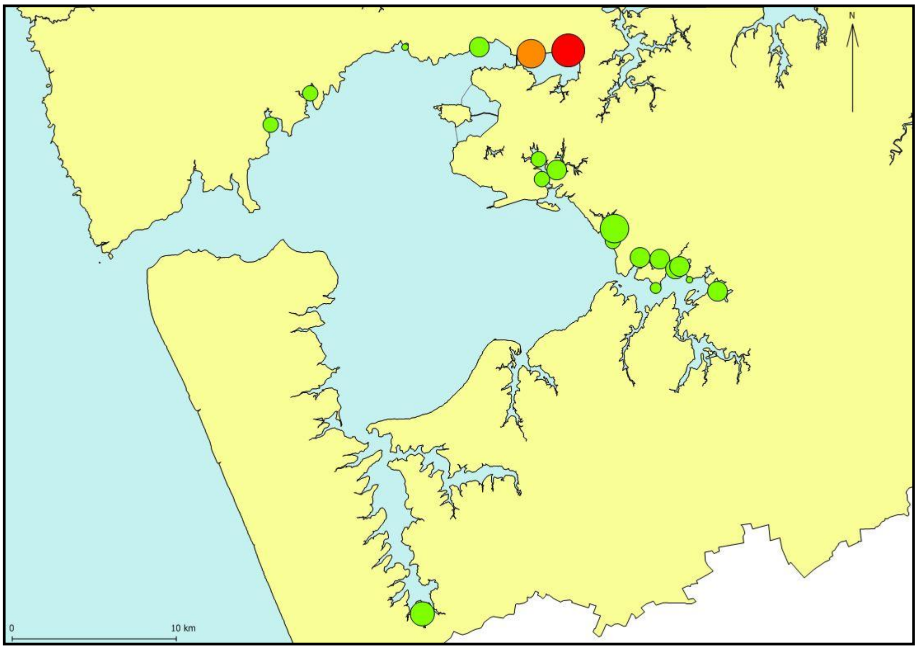


Figure 14: Map showing relative sediment concentrations of total copper (mg/kg) in Mangere Inlet (from Kelly 2007b, and Reed and Gadd 2009 - see Appendix 4 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is < TEL, orange TEL – ERL, and red is > ERL). See text for a description of sediment quality guidelines.

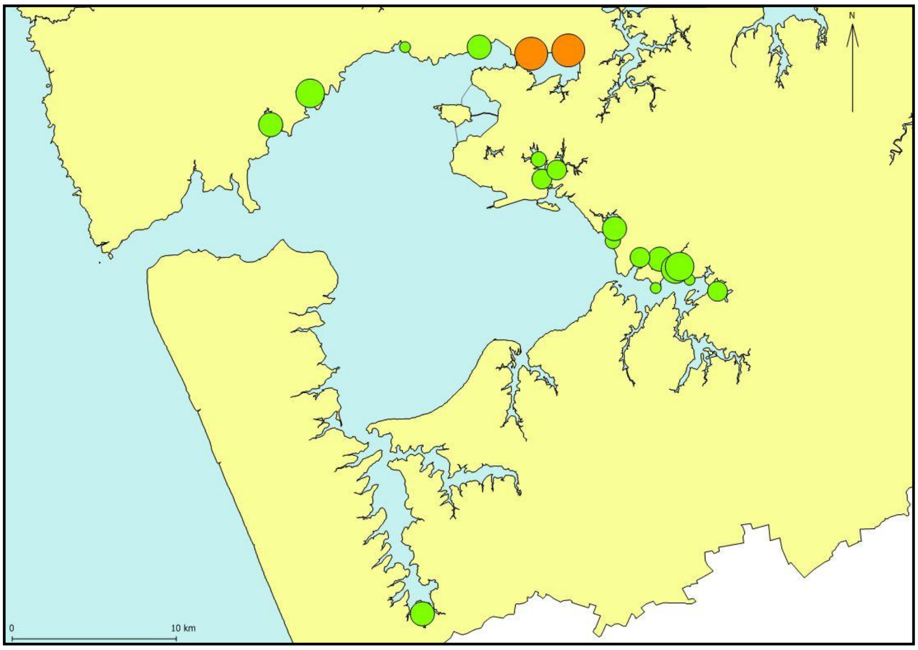
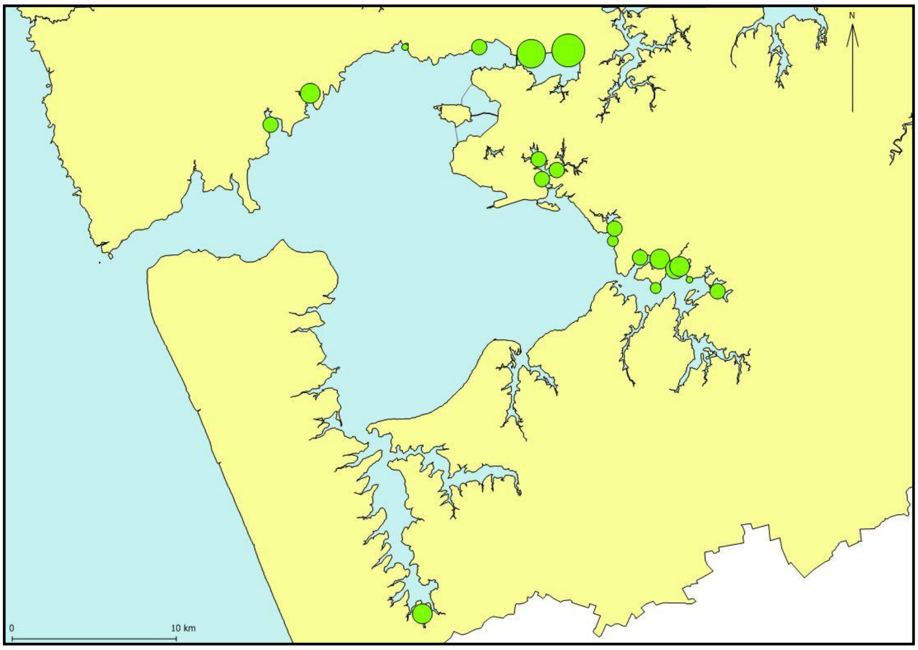
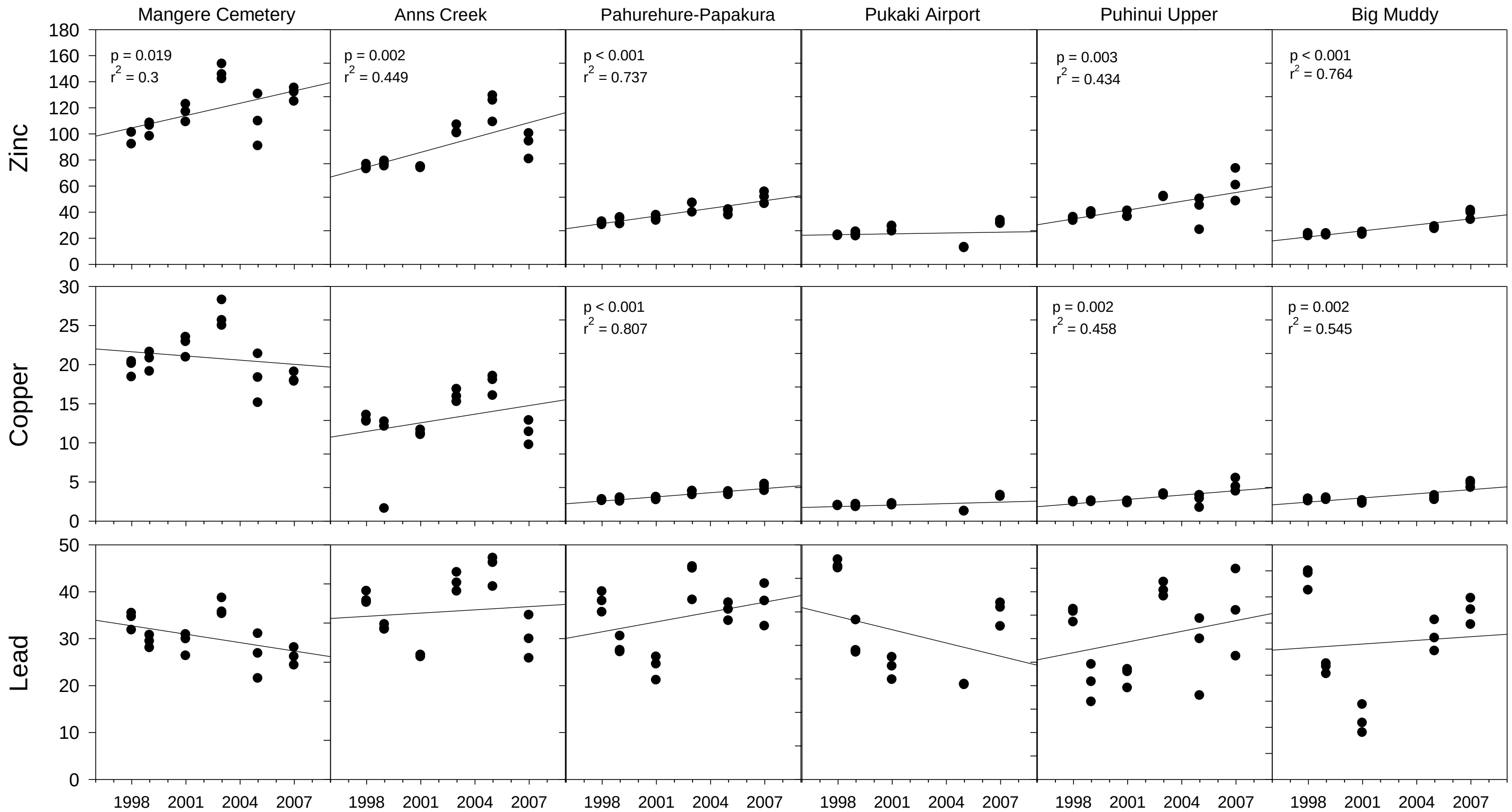


Figure 15: Map showing relative sediment concentrations of total lead (mg/kg) in Mangere Inlet (from Kelly 2007b, and Reed and Gadd 2009 - see Appendix 4 for the actual data and sampling year). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is < TEL, orange TEL – ERL, and red is > ERL). See text for a description of sediment quality guidelines.



Repeated sampling of the five State of the Environment monitoring sites between 1998 and 2007 has also allowed trends in the concentrations of copper, lead and zinc in the fine sediment fraction to be determined (Reed and Gadd 2009). Linear regression indicates that statistically significant trends of increasing zinc concentration occurred at the Mangere Cemetery, Anns Creek, and Pahurehure-Papakura, Puhinui Upper, and Big Muddy sites between 1998 and 2007. Over the same period, significant, increasing trends in copper concentration occurred at the Pahurehure-Papakura, Puhinui Upper, and Big Muddy sites. Lead concentrations fluctuated among years, but significant linear trends were not detected at any of the monitoring sites (see Figure 10).

Figure 10: Trends in the concentrations (mg/kg) of zinc, copper and lead in the <63 μm sediment fraction (extracted using weak acid digestion) at the five State of the Environment monitoring sites in Manukau Harbour. Probability and r^2 values are shown for sites with statistically significant linear trends (obtained using least squares regression).

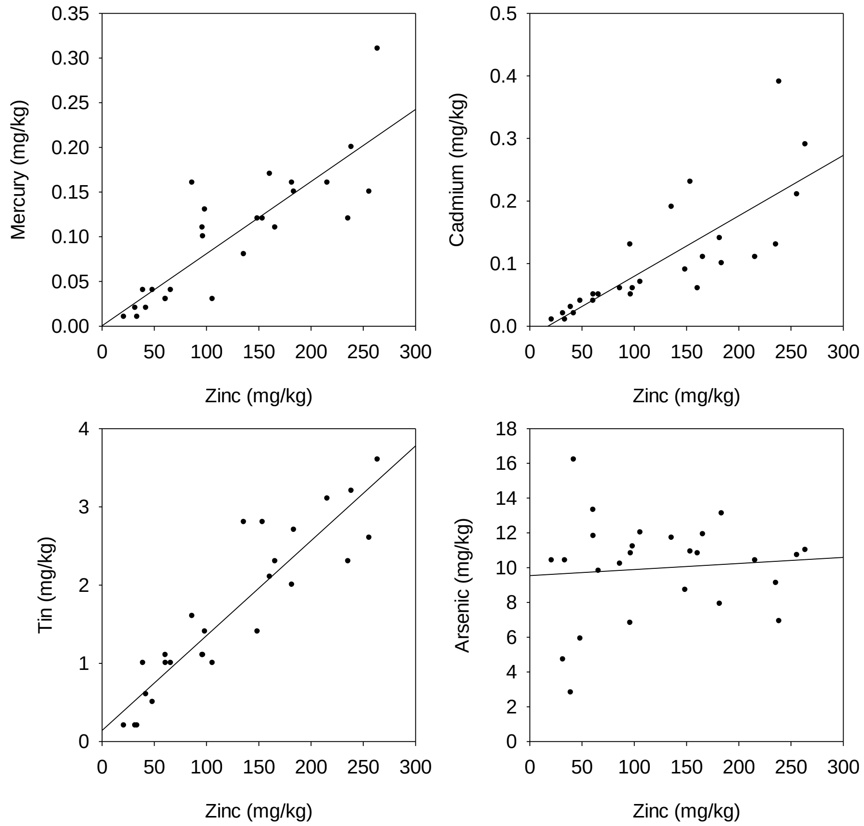


The sediment concentrations of most of the other metal and organic contaminants that have been measured are low, relative to sediment quality guideline values at the Manukau SoE sites (Reed and Webster 2004, McHugh and Reed 2006). The exceptions are:

- dieldrin, which exceeds the ARCs environmental response criteria guideline value at the Anns Creek and Mangere Cemetery sites;
- DDT concentrations which are approaching TEL sediment quality guideline values at the Anns Creek and Mangere Cemetery sites; and,
- arsenic, which exceeds ERL sediment quality guideline values (i.e. 8.2 mg kg^{-1}) at all of the Manukau sites.

Unlike the other trace metals measured, arsenic concentrations are not correlated with the concentration of key urban stormwater contaminants such as zinc (Figure 17). In fact, highest arsenic concentrations occur in some of the "cleanest" SoE monitoring sites (e.g. 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 Manukau Harbour are therefore likely to be within the natural range. Consequently, arsenic contamination is not considered to be a significant issue.

Figure 17: Relationship between the concentrations of zinc and mercury, cadmium, tin, and arsenic. Metals were extracted from the <500 μm sediment fraction using weak acid digestion (data from McHugh and Reed 2006).



A number of other studies have also examined sediments and sediment contamination in Manukau Harbour. A harbour-wide investigation of heavy metal pollution in Manukau Harbour was carried out by Gladsby et al (1988), and also reported by Williamson et al (1992). These studies determined the concentration of copper, lead, zinc, nickel, iron, cobalt, chromium, cadmium and magnesium in 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, but 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.

Watercare monitor the effects of the Mangere Wastewater Treatment Plant on the coastal environment in the NE Manukau. The sediment monitoring component of their programme included the annual analysis of metals (copper, lead, zinc, mercury and cadmium) and persistent organic compounds (DDT, chlordane, lindane, heptachlor and heptachlor epoxide, dieldrin, endrin and total chlorophenols) between 1995 and 2007 from 6 to 15 sampling stations (Bioresearches 2008a). In 2007, most metal concentrations were below sediment quality guideline values (Figure 18). The exceptions were copper concentrations, which were above TEL guideline values in the area previously occupied by oxidation ponds 3 and 4, and zinc concentrations, which were above ERL guideline values on the Onehunga foreshore. Dieldrin and DDT concentrations also exceeded sediment quality guideline values in the old oxidation pond areas, and dieldrin exceeded ERL values on the Onehunga foreshore.

Figure 18: Relative concentrations of a) copper, b) lead, c) zinc, and d) mercury obtained from sediment samples collected as part of the Watercare Services Ltd's Harbour Environment Monitoring Programme (Bioresearches 2008a). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is < TEL, orange TEL – ERL, and red is > ERL). See text for a description of sediment quality guidelines.

a. b. c. d.

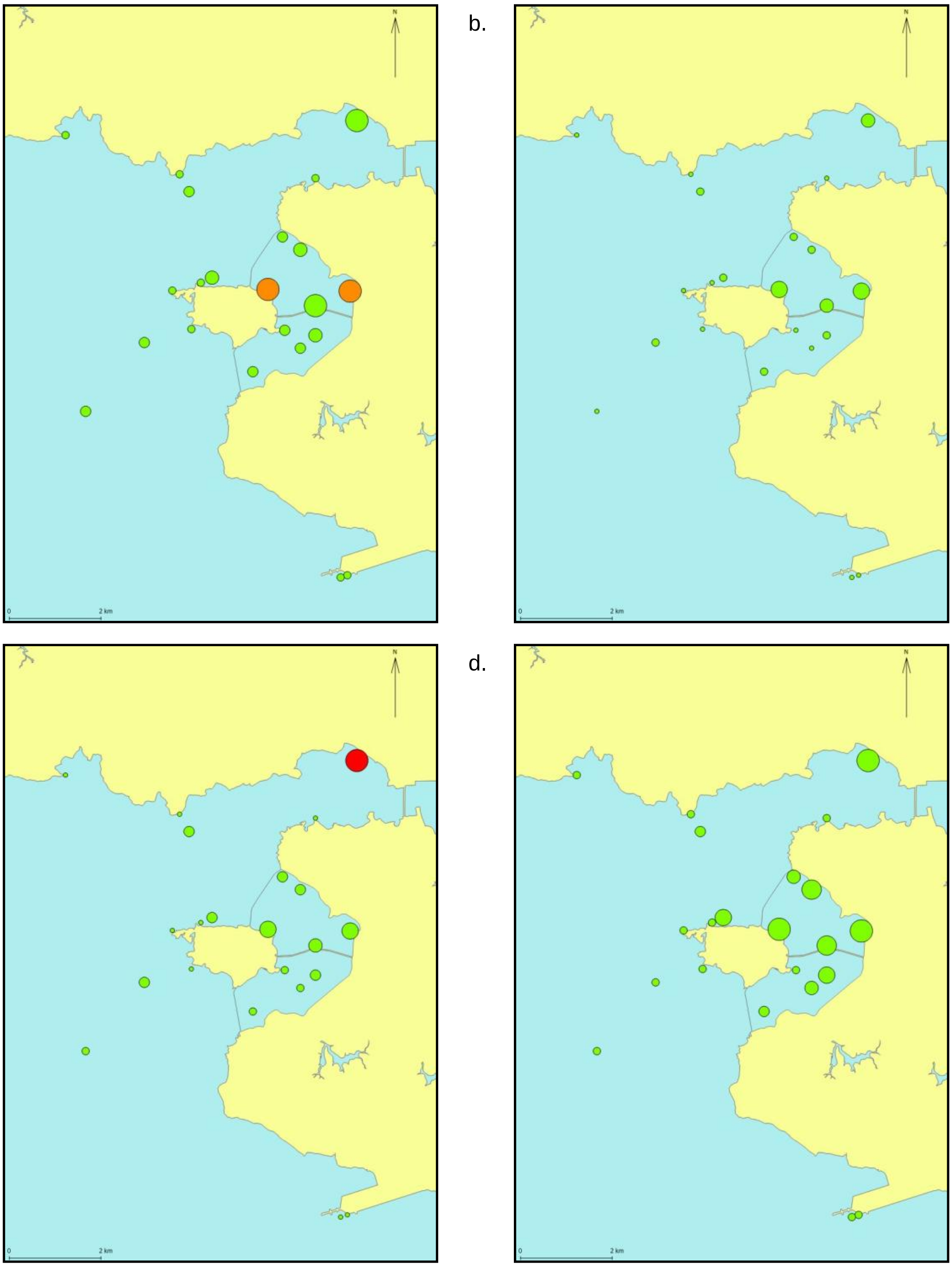
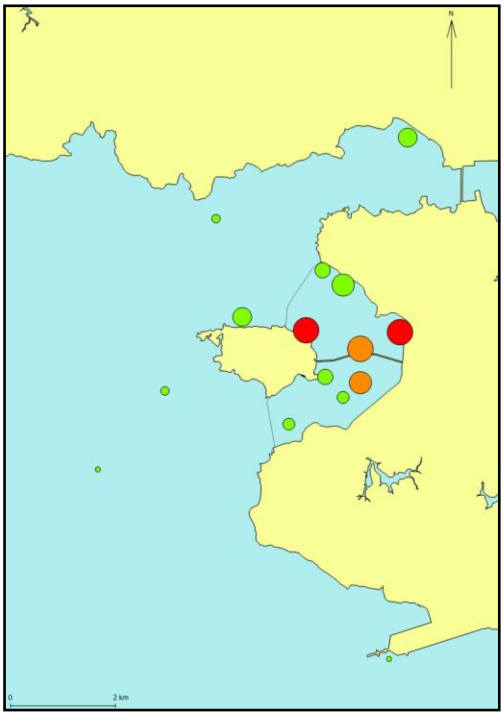
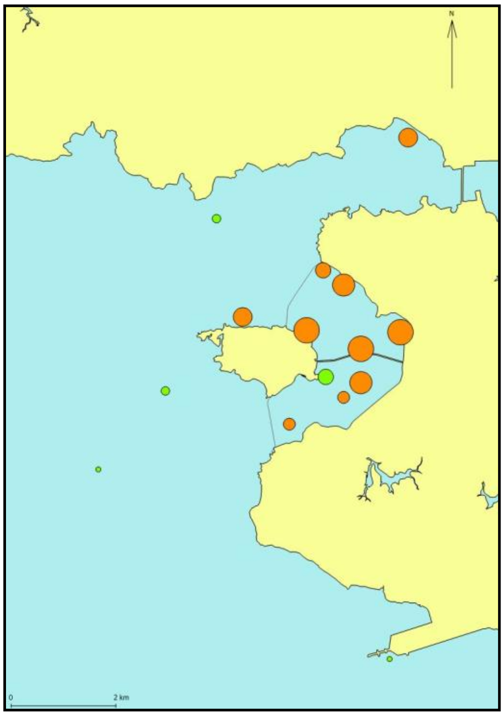


Figure 19: Relative concentrations of a) DDT, and , b) dieldrin obtained from sediment samples collected as part of the Watercare Services Ltd's Harbour Environment Monitoring Programme (Bioresearches 2008a). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is < ERL, orange ERL – TEL, and red is > TEL). See text for a description of sediment quality guidelines.

a.



b.



Surface sediment concentrations of copper and zinc were also obtained in 2007, from 42 sites in the south-eastern Manukau to calibrate a contaminant accumulation model being developed for the ARC (Reed et al 2008). Concentrations were obtained from the <25 μm, 25-63 μm, and 63-250 μm sediment fractions using strong acid digestion (nitric/hydrochloric acid). (Figure 20 and Figure 21). The concentrations of copper and zinc were relatively low in all three sediment fractions, but TEL sediment quality guideline values were exceeded for zinc in the <25 μm sediment fraction at five sites on the eastern side of the Papakura southern motorway causeway[4]. Concentrations tended to be slightly higher close to the shoreline and in the upper reaches of Pahurehure Inlet. Highest copper and zinc concentrations were detected in the muddiest sediments and concentrations tended to be greater in the finest sediment fraction (<25 μm). Six cores samples collected as part of the study also indicated that total zinc and copper levels had increased 1–2 fold over background levels over the past 50 years (approximately) (Figure 22).

Sediment copper, lead and zinc concentrations were also measured in sediment samples collected from Oruarangi Creek, approximately two years after it was reconnected to the sea (i.e. in 2007 – see Section 3.2). Zinc concentrations (extracted from the <500 μm sediment fraction using strong acid digestion) ranged from 78 – 216 mg kg^{-1}, copper concentrations from 5 – 35 mg kg^{-1}, and lead concentrations from 7 – 31 mg kg^{-1} (Mills 2007). These concentrations are amongst the highest recorded in Manukau harbour. Relatively high zinc concentrations (i.e.

[4] Note that these guideline values provide a useful reference point, but are not indicators of potential ecological effects when applied to the individual sediment fractions discussed here.

above ERL sediment quality guideline values) have also been detected at one sampling site in the Waiuku River mixing-zone associated with the BHP New Zealand Steel stormwater discharge into Waiuku River (Bioresearches 2005).

Contaminant accumulation in marine sediments depends on catchment loads and subsequent dispersal in the receiving environment. Williamson et al (1996) examined suspended sediment and metal fluxes in Mangere Inlet. Mass fluxes were greater during the flood than the ebb tide, so mobilised contaminants were returned to the inlet, which acted as a sediment and contaminant sink. The potential for contaminants to be permanently immobilised within the seabed by diagenetic processes associated with bioturbation was investigated by Williamson et al (1995). 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, they concluded that permanent metal immobilisation did not occur in the top 26 cm of sediment.

Contaminant accumulation in Mangere Inlet was subsequently modelled by Croucher et al (2005b), who predicted sediment and zinc accumulation in 17 “deposition zones”, using a particle tracking model and estimates of catchment sediment and zinc runoff from 16 consolidated outfalls. Predicted sedimentation rates ranged from 0.01 mm yr^{-1} to 0.54 mm yr^{-1}, with highest accumulation rates occurring in Hillsborough Bay. Other sheltered areas with elevated sediment accumulation rates (0.09 to 0.22 mm yr^{-1}) 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 yr^{-1}.

150 year predictions of zinc accumulation in the silt fraction were also provided for each of the deposition zones. However, since 2005, Auckland City and Metrowater have collected more detailed landuse 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 to occur in Hillsborough Bay. Notably, the zinc concentrations at this site were still increasing at the end of the simulation period. Anns Creek and Harania Creek also had relatively high rates of increase, and concentrations also increased over the full simulation period. However, future zinc concentrations in Anns Creek and Harania Creek were substantially lower than those predicted for 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.

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

Contaminant accumulation modelling has also been carried out in the southeast Manukau Harbour. Green (2008a, 2008b, and 2008c) used the USC3 (urban stormwater contaminant model version 3) to predict long term (2001–2100) sediment, copper and zinc accumulation in 23 sub-estuaries covering the area east of the Auckland International Airport. Four landuse and contaminant management scenarios were modelled:

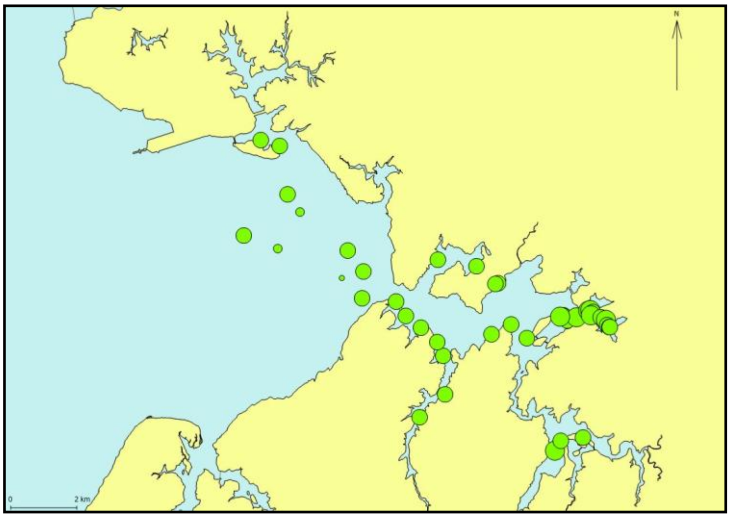
1. Future population growth and urban development with no additional stormwater treatment or source control.
2. Future population growth and urban development with zinc source control but no additional stormwater treatment.
3. Future population growth and urban development with no source control but realistic, additional stormwater treatment.
4. Future population growth and urban development with zinc source control and realistic, additional stormwater treatment.

With no additional source control or stormwater treatment, copper and zinc were predicted to accumulate in most sub-estuaries, with copper and zinc concentrations exceeding TEL guideline values at a number of places during the modelling timeframe. Zinc was predicted to accumulate most rapidly in Pahurehure Basin, east of the Papakura motorway causeway, and exceeded TEL levels within 18 years under the no additional treatment or source control scenarios (Table 3). Under these scenarios, zinc concentrations also exceeded ERL values in five other sub-estuaries within 51 to 68 years. Copper concentrations exceeded TEL values in 12 sub-estuaries over the modelling timeframe. Most of these exceedances occurred in the later part of the modelling period, but three sub-estuaries exceeded TEL values within 42 years. Copper ERL guideline values were exceeded only in the Waimahia Creek sub-estuary after 93 years.

Zinc source control was predicted to have little effect on the model outcomes, but some gains were achieved using stormwater treatment. The best gains were obtained from sub-estuaries that trapped sediment and metals from mixed rural–urban sub-catchments. This included sub-estuaries clustered around the mouth of Glassons Creek, on the southern side of Pahurehure Inlet (i.e. Karaka, Glassons Mouth West, Glassons Mouth East, Cape Horn and Drury Creek Outer), inner Drury Creek, and Pukaki Creek. However, potential gains had to be viewed within the context of a low overall threat to these sub-estuaries. Intermediate, and potentially more tangible gains were obtained for the inner, sheltered reaches of Pahurehure Inlet (Pahurehure Inner and Pahurehure Basin) and for Puhinui Creek, where contaminant risk was greater. Small gains were obtained for Papakura and Waimahia Creek sub-estuaries, which also had a higher risk of contamination.

Figure 20: Relative copper concentrations in the a) <25 μm, b) 25-63 μm, and c) 63-250 μm sediment fractions of 42 sites in the southeast Manukau Harbour (from Reed et al 2008). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is < TEL, orange TEL – ERL, and red is > ERL). See text for a description of sediment quality guidelines.

a.



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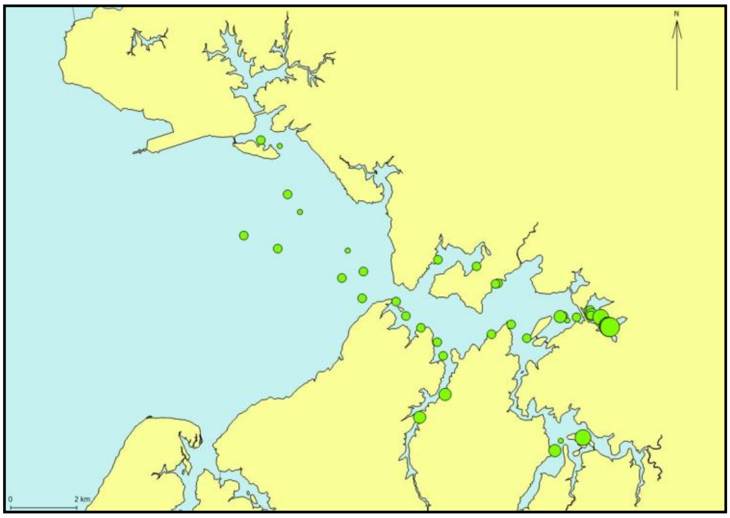

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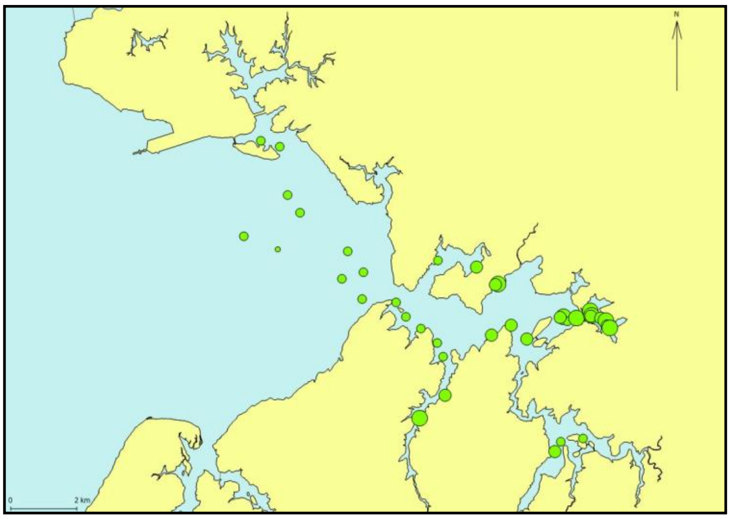
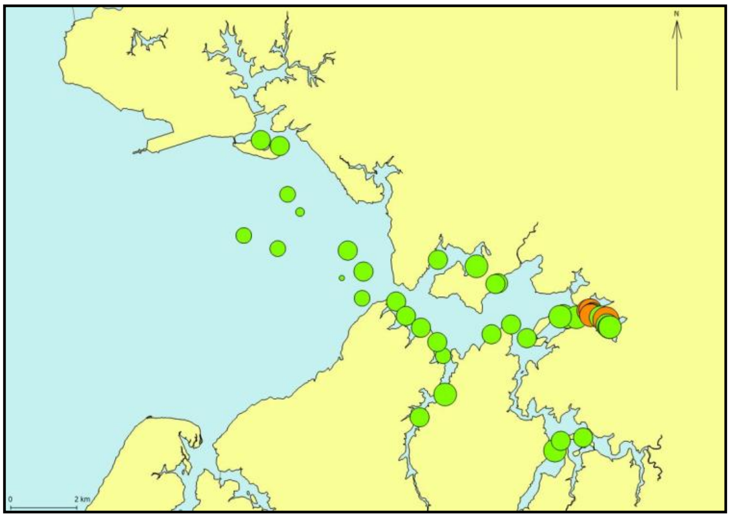


Figure 21: Relative zinc concentrations in the a) <25 μm, b) 25-63 μm, and c) 63-250 μm sediment fractions of 42 sites in the southeast Manukau Harbour (from Reed et al 2008). Dot size varies according to concentration and the colour scheme indicates concentrations in relation to international sediment quality guidelines (green is < TEL, orange TEL – ERL, and red is > ERL). See text for a description of sediment quality guidelines.

a.



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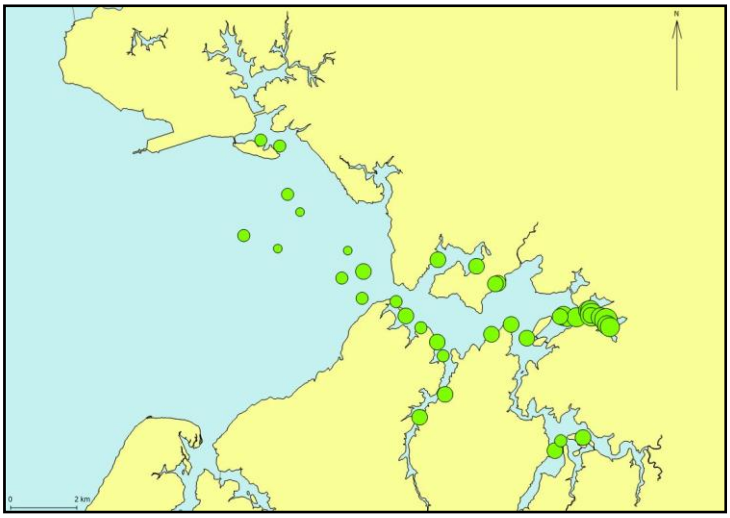

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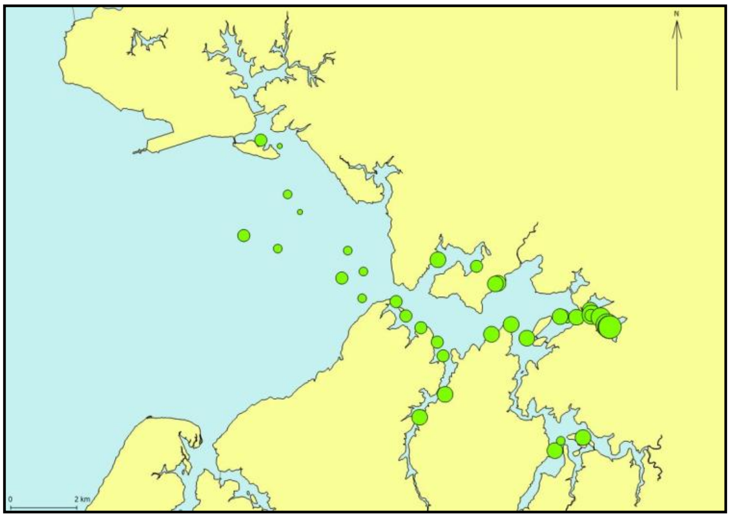


Figure 22: Sediment core profiles of zinc and copper concentrations from six sites in the south-eastern Manukau Harbour (from Reed et al 2008).

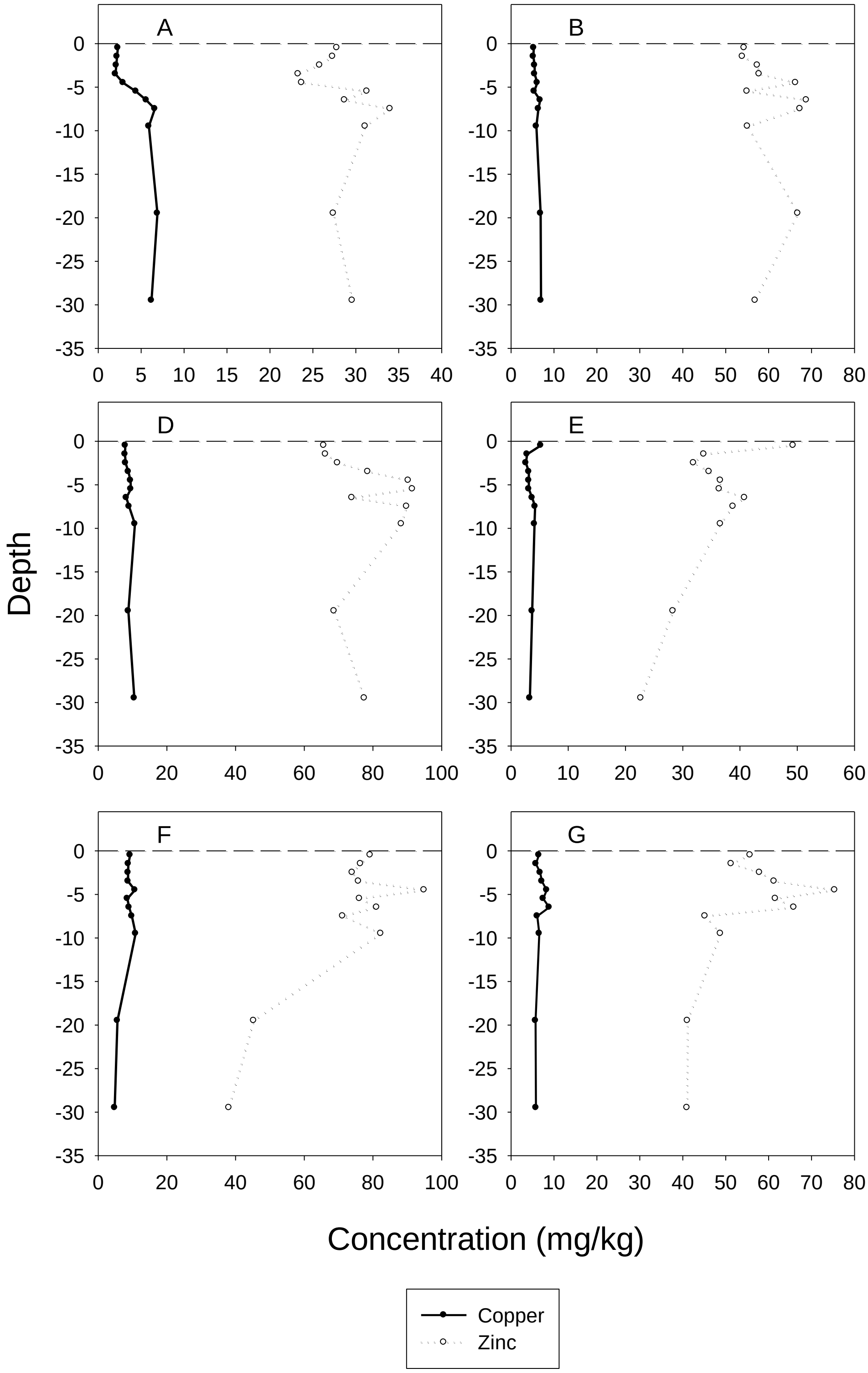


Table 3: **Predicted number of years before TEL, ERL and PEL sediment quality guideline values are exceeded in modelled sub-estuaries of the south-eastern Manukau Harbour with no additional stormwater treatment or contaminant source control measures (from Green 2008).**

	Copper			Zinc		
Sub-estuary	**TEL**	**ERL**	**PEL**	**TEL**	**ERL**	**PEL**
Hikihiki Bank						
Karaka	93					
Glassons Mouth West	72			90		
Glassons Mouth East	76			80		
Cape Horn	85			94		
Drury Creek Outer	67			72		
Pahurehure Inner	51			37	68	
Pahurehure Basin	53			18	62	
Papakura	37			25	51	
Kauri Point						
Waimahia Creek	34	93		27	51	
Weymouth						
Wairoa Island						
Puhinui Creek	42			35	57	
Pukaki Creek	83			79		
Drury Creek Inner	66			90		
Glassons Creek Inner						
Clarks Creek						

6 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.

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 five 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 landuses ranging from highly urbanised to those dominated by rural activity and/or bush.

Two groups of contaminants are assessed: trace metals (cadmium, chromium, copper, lead and zinc) and organic contaminants (PAHs, DDT, dieldrin, chlordane, lindane and PCBs). Marked changes are apparent in the concentrations of organic contaminants, which can be linked to source control initiatives (e.g. banning the use of products) and activities that have remobilised contaminants (i.e. rehabilitation of the Mangere wastewater treatment ponds). Changes in the concentration of persistent organic contaminants in oyster tissues are summarised below:

- 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 variable since 1995 (i.e. since a consistent set of PAH congeners has been monitored – see Kelly (2007a)). No consistent temporal trends are apparent in PAH concentrations, although there is some evidence of cyclical variation in the lipid normalised concentrations.

- Highest levels of DDT have been recorded at Granny's Bay (c.f. other Manukau sites) in 14 of the 16 years that monitoring has occurred (Figure 23). 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. Concentrations dropped in 2005, but rebounded again in 2006.

- 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 23). 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 have been consistently highest in oysters from the Granny's Bay monitoring site. At this site, PCB concentrations increased around the time when the

Mangere wastewater treatment ponds were decommissioned, matching similar trends in DDT and chlordane concentrations (Figure 23). Concentrations Granny's Bay site subsequently declined in 2005, but rebounded again in 2006. PCB concentrations in oysters from the other Manukau monitoring sites declined between 1995 and 1997, and have remained consistently low since that time.

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 (i.e. the southern oscillation index) rather than stormwater runoff (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 indicate that mussels in Mangere Inlet have:

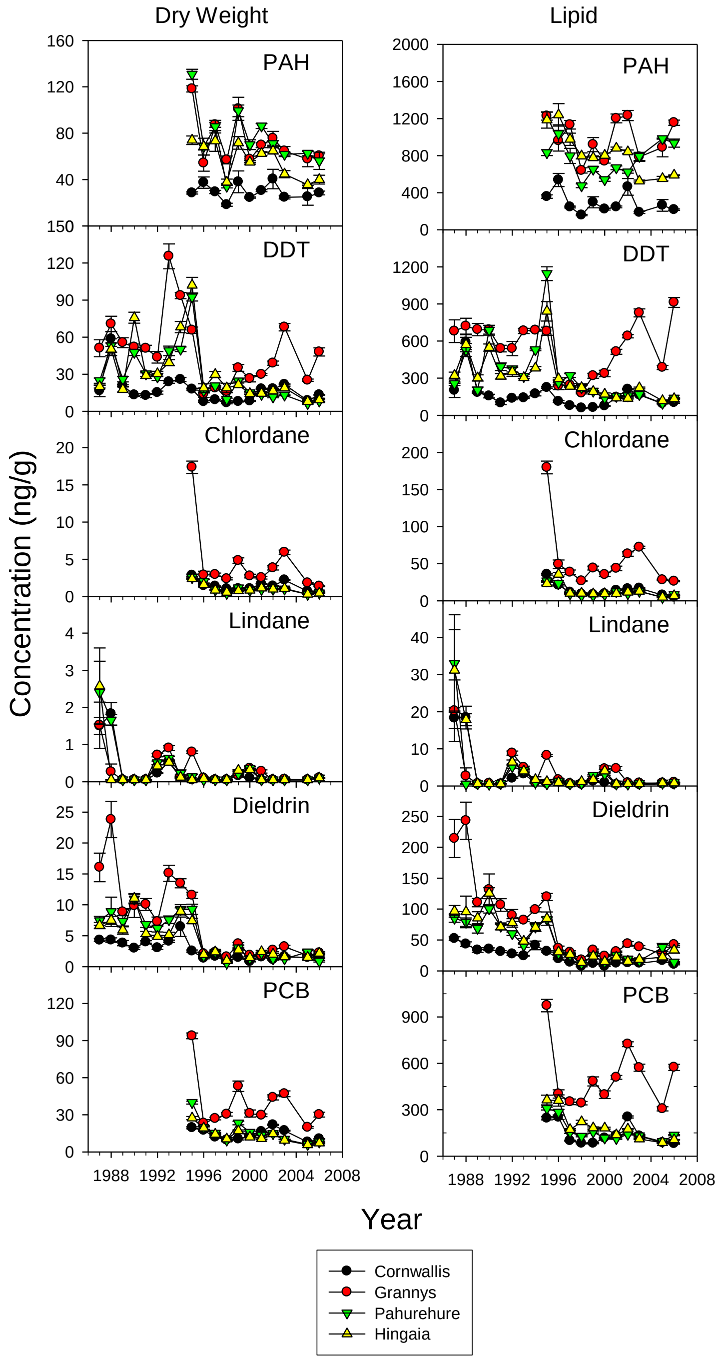
- intermediate concentrations of PAH,
- consistently, the highest concentrations of chlordane and DDT;
- relatively high concentrations of dieldrin and PCBs;
- low concentrations of lindane, which are similar to those of other sites.

Contaminant concentrations have also been analysed in the tissues of fish, birds and other benthic macrofauna. For instance, Simpson et al (1996) examined chlordane contamination in sediments and representative benthic macrofauna from a sandflat site at Cape Horn. Technical chlordane is a pesticide formulation containing in excess of 140 different compounds that has been extensively used as a non-systemic contact and stomach poison for the control of insects. Its major use in New Zealand has been as a wood preservative for plywood and timber. It is considered to be a significant environmental pollutant due to its widespread occurrence, toxicity to non-target organisms, propensity to bioaccumulate, and persistence in the environment. Sediment concentrations of technical chlordane were relatively low at Cape Horn, and lowest in the surface sediment layer. However, levels in benthic biota from the Cape Horn site were considered to be significant, but not severe, when compared to contaminated sites internationally. Concentrations were similar in all of the molluscs tested (91-117 ng g^{-1} lipid), but were twice as high in the polychaetes (202 ng g^{-1} lipid).

Evans et al (2001) tested the suitability of metallothionein gene induction as a biomarker of metal exposure in flounder (the metallothionein protein family is recognised as having a high affinity for divalent metal ions). Metallothionein gene induction was significantly, and positively, correlated with copper and zinc concentrations in flounder livers, but values were lower in the livers of flounder from the "polluted" site (Mangere Inlet) compared with the "clean site" at Te Matuku Bay (Waiheke Island).

In contrast, Diggles et al (2000) found that the concentrations of organic contaminants were elevated in the livers and bile of yellow bellied flounder caught around Onehunga, and Thompson and Dowding (1999) found high lead concentrations in the blood of South Island oystercatchers caught around Mangere Inlet. Those investigations are covered in greater detail in Sections 9 and 10.

Figure 23: Concentrations of organic contaminants in oysters collected from Cornwallis, Granny's Bay, Pahurehure, and Hingaia between 1987 and 2006. 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 (data sourced from ARC shellfish contaminant database).



7 Water Quality

The Auckland Regional Council has been continuously monitoring water quality at six sites in the Manukau Harbour since 1989 (Clarks Beach, Weymouth, Grahams Beach, Mangere Bridge, Puketutu Point and Shag Point) and at one site since 2009 (Manukau Heads). 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 from the ARC's 27 coastal water quality monitoring sites (including the six Manukau sites) was carried out in 2008 (Scarsbrook 2008). The Manukau Harbour sites tended to have lower water clarity than other harbour sites in the Auckland Region, and the highest maximum dissolved oxygen levels, with extremes of almost 180% saturation (Figure 24). Analysis of the full time series of data also indicated that Mangere Bridge, Puketutu Point and Shag Point have been heavily enriched in nitrogen compared with other sites, and that this pattern was particularly strong for NO_2-N (nitrite) and NH_4-N (ammoniacal nitrogen), which are indicators of wastewater discharges (Figure 24). Nitrite levels (NO_2-N) were also elevated at the three other Manukau sites. Soluble reactive phosphorous and total phosphorous also showed marked elevations at the Mangere Bridge, Puketutu Point and Shag Point sites.

Six water quality variables were used to provide a simple water quality index based on their long-term median values. The parameters included in the index were: total suspended solids; nitrate-nitrogen; ammoniacal-nitrogen; soluble reactive phosphorous; total phosphorous; and faecal coliforms. Sites were ranked for each variable and individual ranks were added to give an overall score. Mangere Bridge, Puketutu Point Weymouth, and Shag Point were scored the lowest of the ARC's 26 water quality monitoring sites (the Goat Island site was excluded from the analysis), all having "poor" water quality. Clarks Beach was ranked 17th, and Grahams Beach 10th, with "fair" and "good" water quality respectively.

In other parts of the Auckland Region there was a strong positive association between median salinity and the average water quality ranking, supporting the hypothesis that overall water quality was strongly influenced by catchment (i.e. freshwater) runoff. However, this relationship was less apparent for the six Manukau Harbour sites, suggesting that the influence of catchment runoff is overwhelmed by the discharge from Mangere Wastewater Treatment Plant.

Having said that, water quality in Manukau Harbour has shown dramatic improvements since the ARC's monitoring programme began, with the most significant changes occurring since the recent upgrade to the Mangere Wastewater Treatment Plant. Total suspended solids (Figure 25a), turbidity and total phosphorus (Figure 25b) all show significant decreasing trends between 1987 and 2007. Faecal coliforms and ammoniacal-nitrogen concentrations also declined significantly at sites closest to the Mangere Wastewater Treatment Plant (i.e. Puketutu Point, Mangere Bridge and Shag Point). Nitrate-nitrogen concentrations decreased at Graham's Beach and Shag Point and soluble reactive phosphorous showed decreasing trends at Clark's, Graham's, Mangere Bridge and Shag Point. These improvements have been partially offset by increases in nitrate-nitrogen and soluble reactive phosphorous at Puketutu Point since 2001, and an increasing nitrate-nitrogen trend at the Weymouth site.

Large scale climatic conditions also appear to influence water quality in Manukau Harbour. For instance, temperature, nitrate-nitrogen and ammoniacal-nitrogen also showed an association with the southern oscillation index (SOI) across Manukau Harbour, with values tending to be higher during positive (La Nina) phases of the SOI and lower during the negative (El Nino) phases (Scarsbrook 2008).

Table 4: Median values of total suspended solids (TSS); nitrate-nitrogen (NO_3-N); ammoniacal-nitrogen (NH_4-N); total phosphorous (TP); soluble reactive phosphorous (SRP); and faecal coliforms (FC) at the ARC's coastal monitoring sites and their overall water quality rankings (From Scarsbrook 2008).

Site	TSS	NO3-N	NH4-N	TP	SRP	FC	Average rank	WQ ranking
Mahurangi Heads	3.6	0.007	0.0085	0.03	0.0135	1	22.6	Very Good
Orewa	4.4	0.0045	0.005	0.03	0.015	1	22.6	Very Good
Ti Point	3.5	0.008	0.01	0.03	0.01	1	22.3	Very Good
Browns Bay	4	0.009	0.006	0.036	0.02	1	21.3	Very Good
Chelsea	7.9	0.015	0.01	0.04	0.02	5	17.6	Good
Dawsons Creek	12	0.01	0.0115	0.04	0.02	4	17.3	Good
Hobsonville Jetty	11.9	0.016	0.011	0.04	0.02	4	16.9	Good
Tamaki	11	0.014	0.017	0.041	0.02	4	16.5	Good
Whau Creek	16.4	0.01	0.01	0.045	0.02	8	15.6	Good
Grahams Beach	14.5	0.029	0.02	0.05	0.024	1	14.3	Good
Waimarie Road	13	0.0215	0.02	0.0475	0.02	13	13.6	Good
Henderson Creek	18	0.017	0.01	0.049	0.02	17	13.1	Good
Paremoremo Ski Club	13	0.0305	0.02	0.05	0.02	30	11.8	Fair
Lucas Creek	16	0.027	0.02	0.05	0.02	26	10.9	Fair
Confluence	14.1	0.036	0.02	0.05	0.02	22.5	10.8	Fair
Shelly Beach	59.7	0.02	0.032	0.076	0.02	2	10.1	Fair
Clarks Beach	25	0.046	0.0275	0.06	0.023	2	9.6	Fair
Rawawaru Creek	14.7	0.041	0.03	0.05	0.02	110	9.1	Fair

Town Basin	8.45	0.1675	0.055	0.05	0.02	800	8.6	Fair
Rangitopuni Creek	13.3	0.083	0.03	0.06	0.02	140	7.7	Poor
Panmure	17.5	0.052	0.031	0.06	0.024	79	7.5	Poor
Brighams Creek	15	0.074	0.03	0.06	0.021	130	7.1	Poor
Shag Point	21.05	0.102	0.1375	0.1495	0.0995	7	6.6	Poor
Weymouth	27	0.104	0.0385	0.064	0.03	8	6.6	Poor
Puketutu Point	18.8	0.154	0.305	0.23	0.17	49	4.2	Poor
Mangere Bridge	36	0.282	0.318	0.3005	0.21	33	2.7	Poor

Figure 24: Box plots of a) total suspended solids concentrations, b) dissolved oxygen (% saturation), c) nitrite-N concentrations, and d) ammonia-N concentrations at the ARC's 27 coastal water quality monitoring sites.

Results were pooled from the full time-series of monitoring data (data sourced from ARC water quality database).

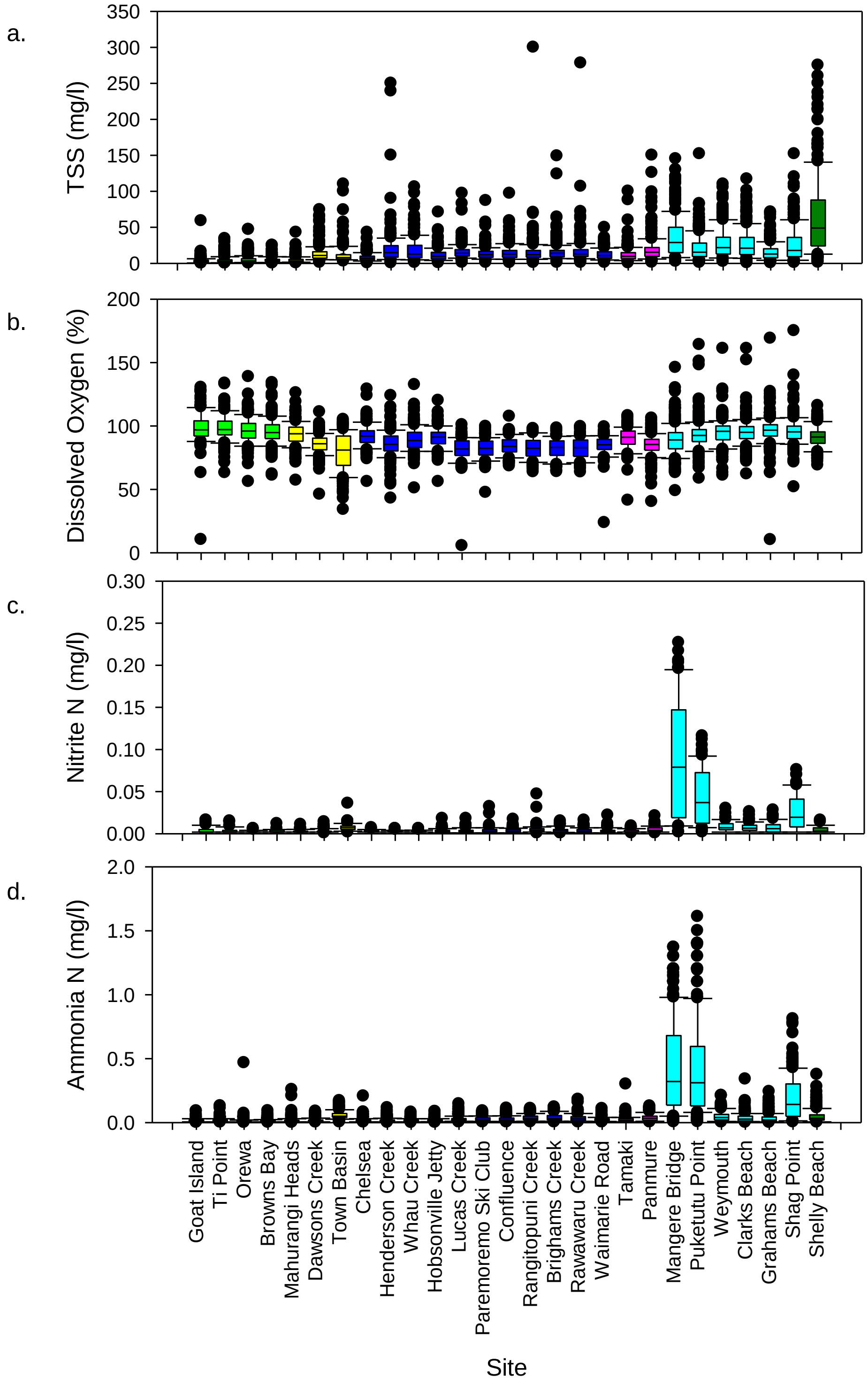
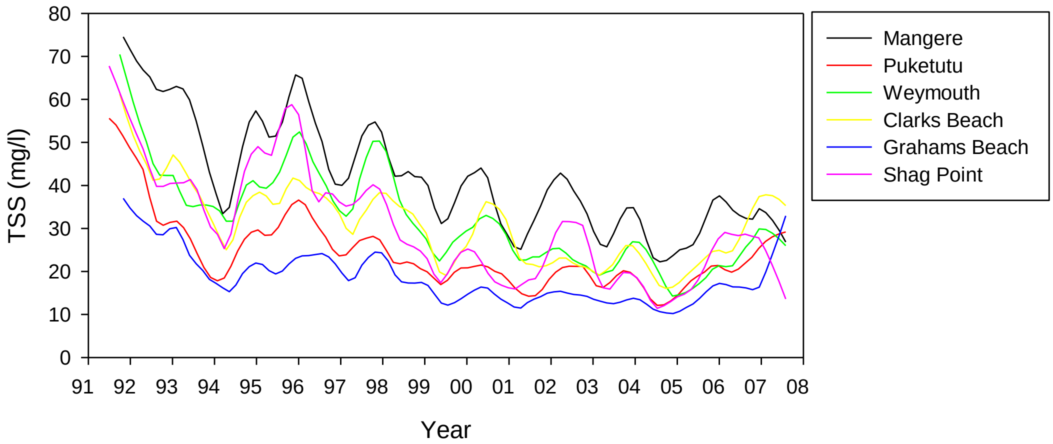


Figure 25: Loess smoothed trends in a) total suspended solids (TSS) and b) total phosphorus data from the ARC's six coastal water quality monitoring sites in Manukau Harbour (data sourced from ARC water quality database).

a.



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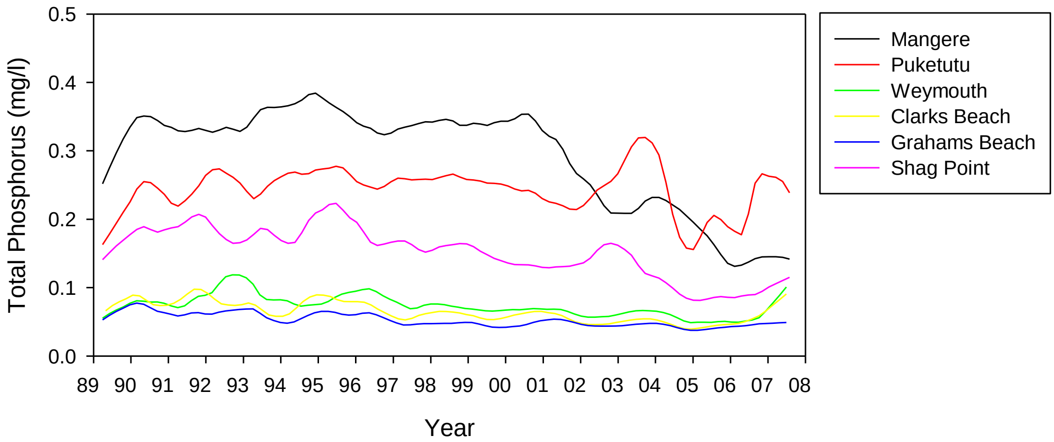


8 Benthic Fauna

8.1 ARC Monitoring and Benthic Health Investigations

Long term state of the environment (SoE) monitoring of benthic communities in the Manukau Harbour was initiated in 1987 by the Auckland Regional Water Board (a precursor to the ARC), as part of the Manukau Action Plan. Initially, six sites were monitored. These were: Cape Horn, Auckland Airport, Puhinui Stream, Elletts Beach, Karaka Point and Clarks Beach. Monitoring was subsequently reduced to two representative sites in 1993 (Auckland Airport and Clarks Beach), which have now been monitored every two months[5] since the programme started. Monitoring of the Cape Horn site was re-established in August 1999 and has continued through to the present time. Additional sampling of Cape Horn was carried out by NIWA from February 1993 to December 1995, with funding from the Foundation of Research, Science and Technology. Periodic monitoring of the other three sites also occurred for two year periods between August 1999 and April 2001, and August 2006 and April 2008. (see Hewitt and Hailes 2007).

The monitoring consists of collecting twelve ecological core samples (13 cm diameter, 15 cm depth), from each site at 2-monthly intervals. The abundance of 21 taxa is quantified in the ecological samples. These taxa were either selected for their ecological importance, or to provide a range of responses to different anthropogenic impacts.

Since August 1999, sediment samples have also been gathered by compositing 2 cm deep core samples collected next to every second ecological sample. These samples are used to determine sediment grain size and organic content. The same methods are also used to obtain samples for the analysis of chlorophyll *a* concentrations (see Section 5).

Long-term monitoring has shown that large scale climatic processes such and the El Nino southern oscillation have a strong effect on the abundance of some species. Among others, these species include cockles (*Austrovenus stutchburyi*), wedge shells (*Macomona liliana*), nut shells (*Nucula hartvigiana*), the amphipod *Waitangi brevirostris*, and the polychaetes *Magelona ?dakini* and *Boccardia syrtis*. Other species also display multi-year patterns, but these cannot be explained by ENSO cycles.

Multi-year cycles in the abundance of individual species has complicated the detection and interpretation of long term trends in the ecological data. For instance, 24 species displayed statistically significant trends in abundance at the Auckland Airport, Clarks Beach and Cape Horn sites between 1987 and 2005, but only five species displayed such trends between 1987 and 2007. All of the latter were from the Cape Horn site. At this site, five species displayed downward trends in 2005, but not in 2007, although none of these actually increased in abundance between 2005 and 2007. Rather, counts had declined to low numbers, which were being maintained. The five species were: cockles (*Austrovenus stutchburyi*), wedge shells (*Macomona liliana*) and the polychaetes *Boccardia syrtis*, *Orbinia papillosa*, and *Prionopsio aucklandica*.

[5] Apart from two occasions in October and December 1988

The benthic community at the Auckland Airport was the most stable between 1987 and 2007, with *Macomona liliana* consistently being the dominant species. In contrast, variability in the composition of the benthic community at the Clarks Beach site was relatively high, but no consistent temporal trends were apparent. The community at Cape Horn has also changed during two distinct periods: one between 1996 and 1998, and another between October 2000 and 2001. Since October 2001, community composition at Cape Horn has been relatively stable.

Funnell et al (2003) suggested that community changes at Cape Horn may be related to the upgrade of the Mangere Wastewater Treatment Plant and the associated decommissioning of the oxidation ponds. Hewitt and Hailes (2007) tested this further by examining how well the changes matched expected community responses to changes in ambient water quality, and also, whether the changes were explainable by ENSO. They concluded that changes to the Cape Horn community were related to the the upgrade of the Mangere Wastewater Treatment Plant because:

1. ENSO could not explain changes in the abundance of all taxa.

2. The changes that occurred corresponded well with those predicted to occur as water quality improved.

3. Changes in overall community composition suggested two periods of change; the latter of which corresponds with the breaching of the ponds in 2001 rather than the onset of ENSO in 2003.

The ARC's ecological SoE monitoring sites are all located in the main body of the harbour, where sediment-bound contaminants do not tend to accumulate to environmentally significant concentrations (Green 2008a, Green 2008b). Consequently, the SoE sites are buffered from the effects of stormwater contaminants. The ARC therefore established the Stormwater Contaminant Monitoring Programme to monitor the sediment concentrations of key contaminants and their associated ecological effects in more susceptible parts of the harbour (Kelly 2007b). The specific aims of that programme are to:

1. provide site-specific information on the quality of the urban marine receiving environment and the effects of stormwater runoff;

2. assist in the analysis of options for managing urban stormwater quality; and,

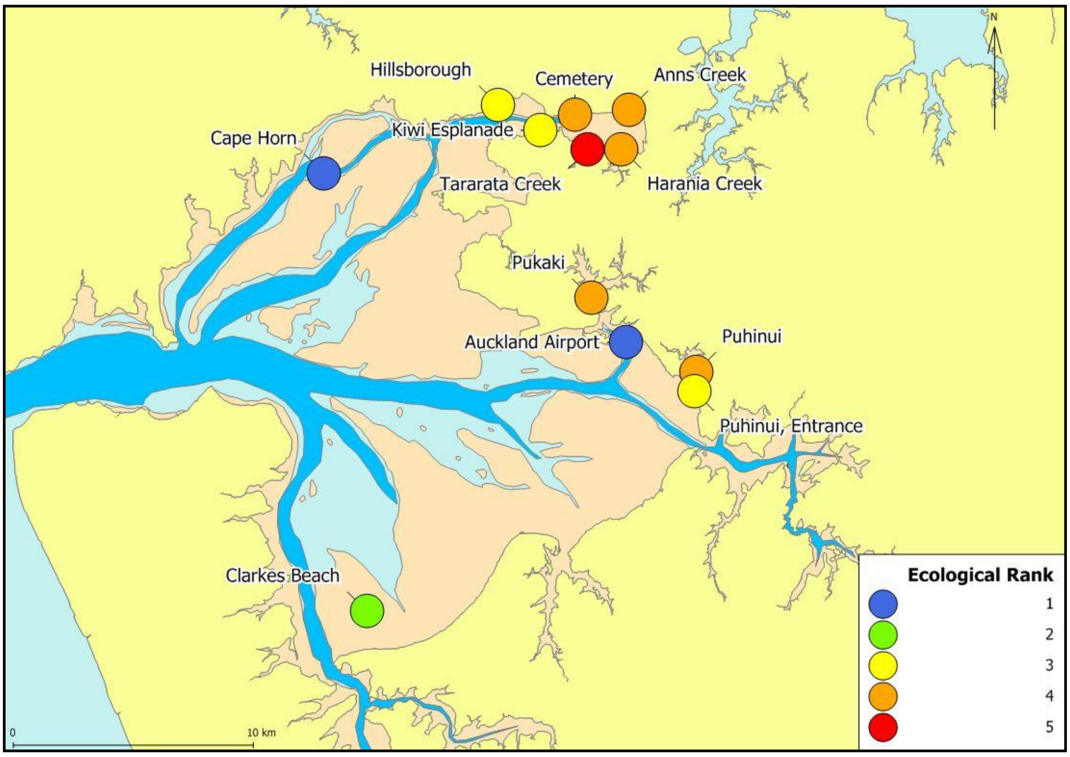
3. measure the performance of management initiatives aimed at improving urban stormwater quality and the efficacy of regional stormwater policy and network consent conditions.

Ecological data from the Stormwater Contaminant Monitoring Programme is analysed using the ARC's benthic health model, which ranks the "health" (i.e. ecological condition) of benthic communities from 1 (= healthy) to 5 (= degraded) (Anderson et al 2006). This ranking is based on the relationship between the copper, lead and zinc concentrations, and benthic community structure.

The benthic community rankings for six stormwater contaminant monitoring sites (Kelly 2007b), plus three additional sites sampled during the development of the ARCs benthic health model (Anderson et al 2006), and three SoE monitoring sites (Cape Horn, Auckland Airport and Clarks Beach) (Anderson et al 2006) are shown in (Figure 26). The ecological condition of benthic communities within side-branches of the harbour were degraded, with the benthic community at

Tararata Creek having the worst condition (health rank 5). The ecological condition of communities at the Ann's Creek, Mangere Cemetery, Harania Creek, Pukaki and Puhinui sites was only slightly better, all with a health ranking of 4. Condition improved towards the mouth of the side-branches, and out into the main body of the harbour. As such, Kiwi Esplanade, Hillsborough and Puhinui Entrance sites had health ranks of 3, while the three SoE sites had ranks of 1 or 2.

Figure 26: Ecological condition of benthic communities in Manukau Harbour. Condition is ranked from 1 (blue = healthy) to 5 (red = degraded).



The most recent data obtained for the benthic health model and stormwater contaminant monitoring were also reanalysed to examine benthic biodiversity, total abundance, and the distribution patterns of a number of individual species (data from Anderson et al 2006 and Kelly 2007b). The Shannon's diversity index is a commonly used measure of diversity that takes into account the number of taxa (species richness) and how evenly the number (or biomass) of individuals is spread amongst these taxa (equitability). The latter consideration is an important feature of the index, as one community may have more species, but lower richness than another, if one (or a few) taxa are numerically dominant. Interpretation of Shannon's diversity index is therefore aided by specific information on species richness and equitability. Four measures of diversity were therefore examined: 1) the number of taxa per sample; 2) the total number of individuals; 3) the Shannon diversity index (using base e); and, 3) Pielou's evenness index.

Pielou's evenness index is a measure of how even (i.e. 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.

Benthic biodiversity was greatest at the Clarks Beach SoE site in the main body of the harbour (38 species) and lowest at the Anns Creek site on the northern shore of Mangere Inlet (13 species). The number of species ranged from 20 to 28 at the other 10 sites (Figure 27a). Clear differences were also apparent in the number of individuals obtained from each site. Large numbers of individuals were obtained from the sheltered Mangere Inlet and Pukaki sites (938 to 1935 animals per site) (Figure 27b). The high counts were primarily due to large numbers of the 10 – 30 mm, deposit feeding polychaete worm, *Heteromastus filiformis* (Figure 28a), which had total counts of 1682 at Tararata Creek to 722 at Harania Creek. A number of other tolerant species (Hewitt et al 2009) were also associated with sites located within the Mangere and Pukaki side-branches. Relatively high numbers of *Artritica bifurcata* (sedentary, 2 – 5 mm deposit feeding bivalves), neridae (highly mobile, 30 – 60 mm predatory polychaete worms) and mud crabs (*Helice*, *Hemigrapsus* and *Macropthalmus*) were obtained from these sites. The dominance of these few species is reflected in the low Shannon's diversity and Pielou's evenness index values obtained from these sites (Figure 2728c and d).

Relatively few *H. filiformis*, neridae and *A. bifurcata* were obtained beyond the sheltered side-branches. Cockle counts were greatest around the entrance to the inlets (Figure 28b), and species such as the wedge shell *Macomona liliana*, crustacean *Colorstylis* spp. (Figure 28c), deposit feeding polychaete *Magelona ?dakini* and deposit feeding bivalve *Hiatula* sp. had higher abundances in sandy, exposed sites. This is consistent with expected patterns, as cockles, wedge shells, *Colorstylis* spp., *Magelona ?dakini* are all sensitive to environmental degradation (Hewitt et al 2009). The high Shannon's diversity and Pielou's evenness index values for these sites also indicates that their communities were not strongly dominated by one or a few species, rather individuals were relatively evenly spread among species (Figure 27).

Figure 27: Relative values for the (a) number of species, (b) number of individuals, (c) Pielou's evenness index and (d) Shannon's diversity index of species richness for benthic dwelling macroinvertebrates at 12 sites in Manukau Harbour (data from Anderson et al 2006 and Kelly 2007b). Values are represented by the size of circles.

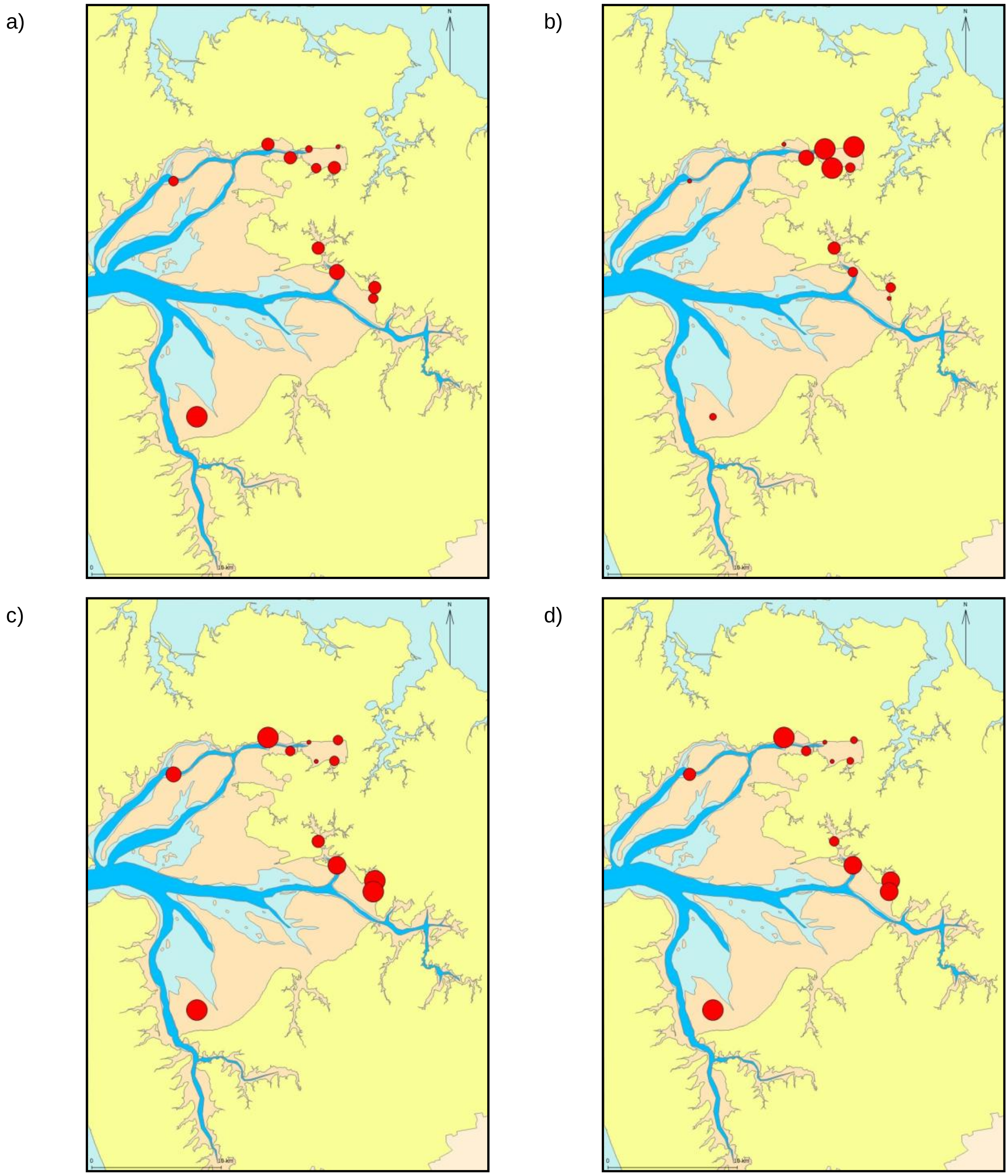
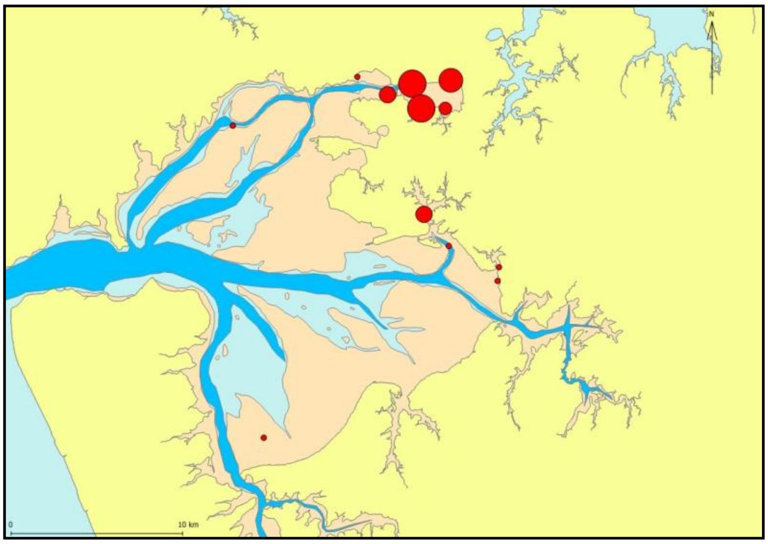
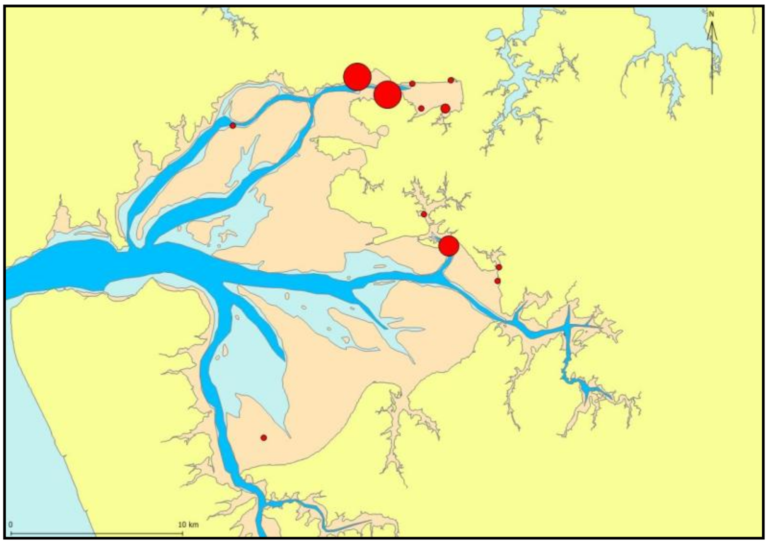


Figure 28: Relative abundance of a) the polychaete *Heteromastus filiformis*, b) cockles (*Austrovenus stutchburyi*), and c) the cumacean crustacean *Colorstylis* at 12 sites in Manukau Harbour (data from Anderson et al 2006 and Kelly 2007b). Relative abundance is represented by the size of circles.

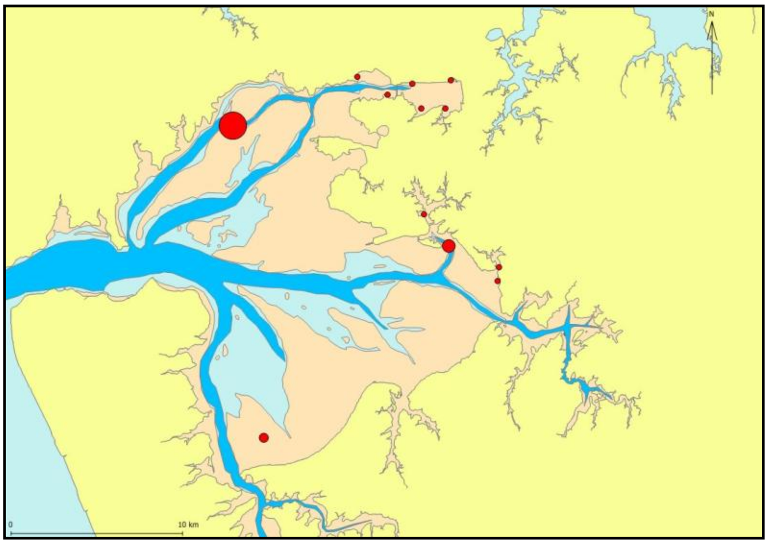
a)



b)



c)



8.2 Other Studies

8.2.1 Large Scale Surveys

Valuable datasets on the benthic fauna of Manukau Harbour have been gathered during more than 70 years of investigations and research. The detailed surveys of the benthic fauna of Manukau Harbour ostensibly began with Powell's (1937) survey of "sea-bottom" communities at nine sites in the northern Manukau (that were sampled to provide a comparison with east coast sites). Other researchers have subsequently conducted surveys in relation to a variety of activities and interests. Since the 1970's, relatively large scale ecological surveys carried out in the harbour have included:

- Benthic surveys in relation to an investigation of potential sites for a thermal power station (1970's and early 1980's).
- Monitoring by Watercare Services Ltd between 1995 and 2007 in relation to the discharge of the Mangere Wastewater Treatment Plant and the decommissioning of the four wastewater treatment ponds in the early 2000's.
- A survey of the West Coast and harbour entrance by Hayward and Morley (2004).
- Habitat mapping of Pahurehure Inlet.
- Ministry of Fisheries shellfish surveys.

Summaries of these surveys are provided to illustrate the range, and type of community and habitat data that has been collected.

8.2.2 Power station surveys

Several studies were carried out to characterise intertidal and subtidal communities in Manukau Harbour that were either directly, or indirectly, related to identifying a suitable site for the construction of a thermal power station in the 1970's – 1980's (Ken Grange, Regional Manager, NIWA Nelson, pers. comm. 12th June 2009). These studies initially examined broad-scale ecological patterns covering most of the harbour (Grange 1977, 1979) and subsequently focussed on Mangere Inlet, Puketutu and Pahurehure as specific areas of interest (Grange 1982).

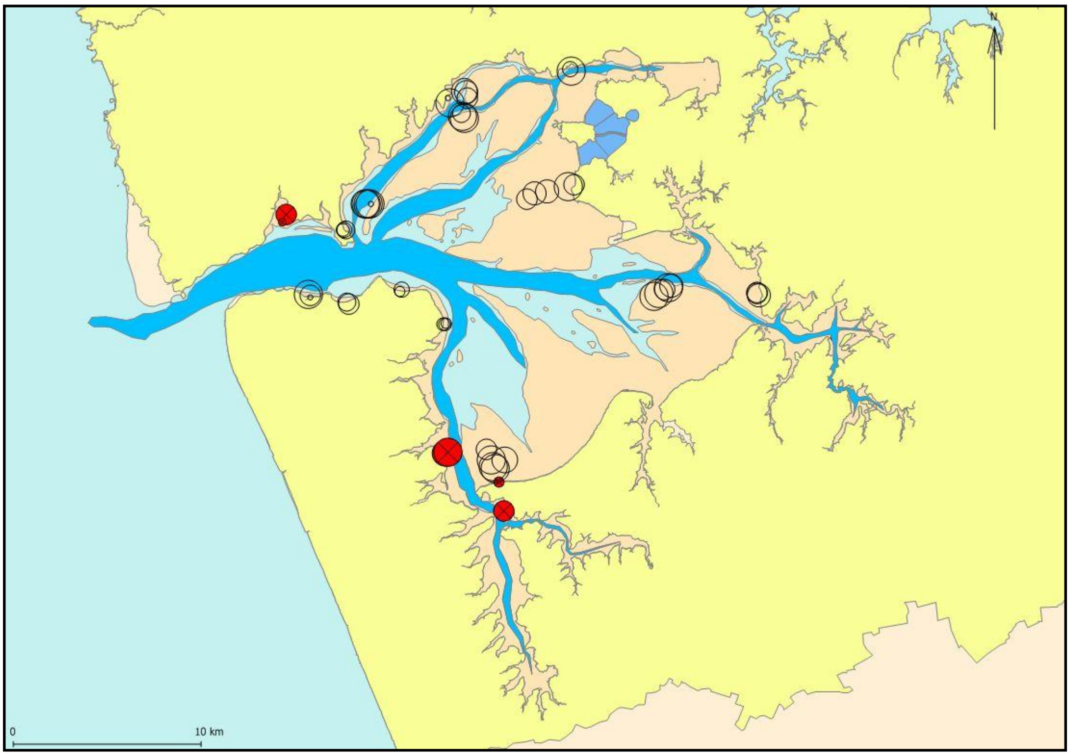
Grange (1977) sampled soft-shore benthic communities at 57 stations from 17 intertidal sandflats to obtain background information on the "natural" ecology of the harbour. The stations were selected to cover most of the habitats in the harbour. However, reaches above Onehunga were not sampled to avoid the potentially modifying influences of industrial pollution. Sediment texture was also measured at each site and 50 cm core profiles were taken to examine the relationships between species composition, feeding mode and sediment characteristics.

Sediment characteristics (rather than tidal height or locality) were found to determine the type of community present, with deposit feeders favouring fine sands and suspension feeders favouring medium sands. This was evident in plots showing the relationship between sediment grain size and the proportion of deposit feeders (and by implication the proportion of suspension feeders) present at each station. However, three groups of sites were identified as outliers. These were considered to have "unstable" species compositions, which probably reflected changes in local environmental conditions. Core samples taken at Waiau Pa stations (on the eastern shore of Waiuku River) showed clear evidence of recent sediment deposition with a 5 cm silt layer overlying a deeper base of sand. The composition and size structure of species present at these stations indicated that the community was shifting from one dominated by suspension feeders to one dominated by deposit feeders. Similar community patterns were also recorded at Fosters Bay, Huia where evidence of fine sediment accumulation was also recorded. However, the opposite change appeared to be occurring at Pollok Beach, where the abundance of deposit feeders was higher than expected for the high proportion of coarse sediment found at the site. The reasons for the patterns displayed at Pollock Beach were not readily apparent.

Overall, the most widespread species were the bivalves *Austrovenus stutchburyi* (cockles), *Macomona liliana* (wedge shells), *Nucula hartvigiana* (nut shells), *Soletellina siliqua* (sunset shell), the anemone *Anthopleura aureoradiata* and the polychaete *Owenia fusiformis*.

Figure 29: Relative proportion of deposit feeders on the intertidal flats of Manukau Harbour (indicated by circle size) in 1975 (Grange 1977).

Sites with "unstable" communities are shown in red.



The broad-scale intertidal survey of Grange (1977) was complimented by a survey of benthic communities at 42 subtidal stations spread throughout the harbour (Grange 1979). Samples were collected from subtidal flats and channels that ranged in depths from 1 to 16 m, using a naturalist's dredge with 1 mm mesh. Community types were grouped based on the similarity of species assemblages among stations, and named according to the dominant species (see Appendix 5 for the methods used to identify dominant species).

Four community groups were identified by the similarity analysis (Figure 30).

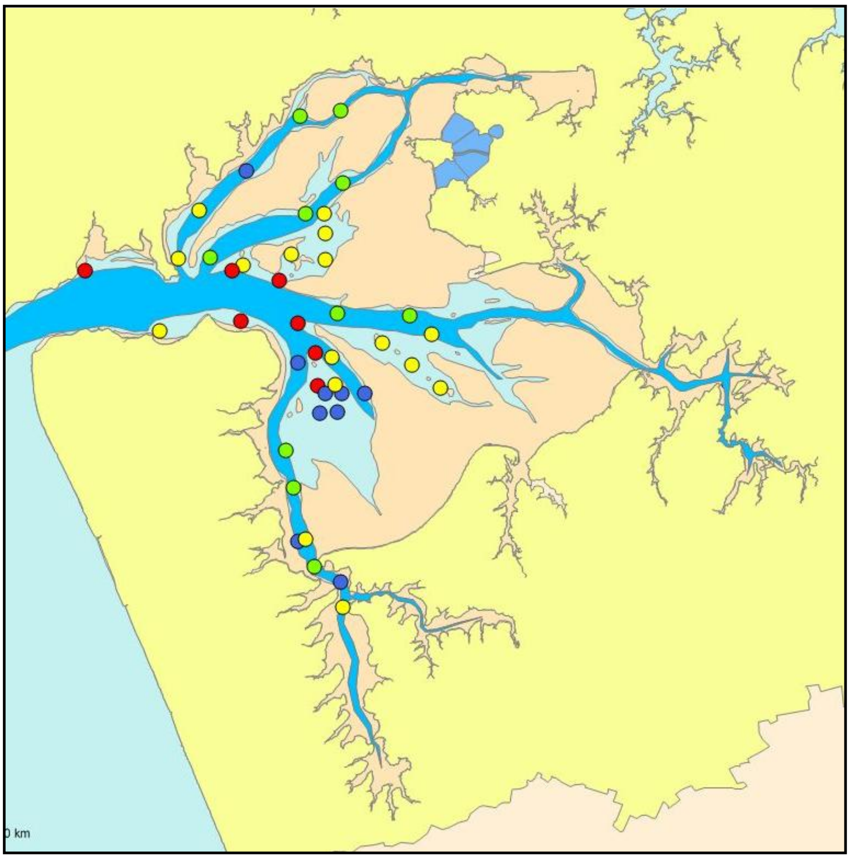
1. **Group 1 (*Microcosmus* / *Notomithrax* community)** consisted of nine shallow water stations with coarse sediments composed of dead bivalve shells and small rocks. This group had the highest average species diversity and was dominated by the simple ascidian *Microcosmus kura* and the half-crab *Notomithrax minor*. These species were not dominant in any other group and were therefore regarded as indicator species. The coarse nature of the substrate also provided attachment for sessile suspension feeders such as the sea squirt *Styela plicata*, the sponges *Callispongia ramosa* and *Halicondria moorei*, and the sessile gastropod *Zegaleurus tenius*. The group contained a large proportion of mobile surface dwelling carnivores such as the starfish *Coscinasterias calamaria* and the crabs *N. minor* and *Halicarcinus varius*. Microscopic and encrusting algae growing on dead shells supported the grazing chitons *Terenochiton inquinatus* and *Acanthochitona zelandica*.

2. **Group 2 (*Halicarcinus / Bugula* community)** contained nine deep water (> 7 m) stations in the main channels. Sediments were relatively coarse with dead shells, shell grit and very little sand. Species characteristic of this community also occur in other communities, with the dominant species being the crab *Halicarcinus varius* and polyzoan *Bugula neritina*. Apart from the attached *Bugula neritina*, the bryozoan *Zoobotryon pellucid*, algae *Gracilaria secundata* (*chilensis* (Cohen et al 2004)) and slow moving turret shell *Maoricolpus roseus manukauensis*, the community was characterised by mobile surface dwelling species (mainly crustaceans).

3. **Group 3 (*Amalda / Myadora* community)** contained 16 stations in shallow parts of the channels. The sediments mainly consist of medium to fine sand with mud or shell grit at some stations. The fauna was relatively diverse, with large numbers of individuals in some samples. Indicator species were the carnivorous gastropod *Amalda australis* and suspension feeding bivalve (*Myadora striata*). However, the community was characterised by a large number of secondary species, which were mainly infaunal deposit-feeding polychaetes and bivalves. The algae *Gracilaria secundata* (*chilensis* (Cohen et al 2004)) was also a dominant species. Carnivorous whelks (*Cominella* spp.) and crabs (*Pagarus* sp.) were also common.

4. **Group 4 (*Fellaster / Pagurus* community)** was the smallest group, containing seven stations in shallow water of the outer harbour. Sediments were clean, well sorted, fine sand with considerable amounts of iron-sand. It was the least diverse group, dominated by the sand dollar *Fellaster zelandiae*, the hermit crab *Pagurus* sp. and the gastropod *Pervicacia tristis*. The community contained no secondary species.

Figure 30: **The approximate distribution of the four community groups (1 blue, 2 green, 3 yellow and 4 red) on the subtidal flats and in channels of Manukau Harbour, as identified by Grange (1979). See text for a description of the dominant species in each group.**



A semi-quantitative survey of benthic macrofaunal associations was subsequently carried out in the Mangere Inlet, Puketutu and Pahurehure areas in the 1980's, as part of a more targeted assessment of potential locations for a combined cycle power station (Grange 1982). Other locations surveyed were Whau Creek and the Upper Tamaki Creek. Samples were collected using a box dredge, washed and the species present identified and counted. Species associations were then grouped using the methods of Grange (1979, see above), and named according to the two most dominant species.

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. However, clear patterns were apparent in the spatial distribution of these species associations (Figure 31). Notable patterns 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 28). Overall, the six species associations in Mangere inlet were:

1. *Acanthochitona* / *Macrophthalmus* association: three subtidal stations restricted to deep water in the western-outer inlet. Low species diversity with sediments consisting of poorly sorted fine sands.

2. *Austrovenus* (formally *Chione*) / *Anthopleura* association: seven mainly low-tide stations in eastern-central parts of inner inlet with very fine sediment of poorly sorted coarse silt. Moderate species diversity relative to other Mangere Inlet sites (but low relative to other areas) with high proportion of deposit feeders.

3. Cirratulid / *Helice* association: five stations off Onehunga wharf and southern point at entrance to Harania Creek, with very poorly sorted fine sand and low species diversity.

4. *Glycera* / *Nucula* association: nine stations in central parts of inner inlet and outer inlet (including subtidal areas), with poorly sorted fine to very fine sands. Moderate species diversity relative to other Mangere Inlet sites (but low relative to other areas).

5. *Macrophthalmus* / *Cominella adspersa* association: 12 intertidal and subtidal stations spread throughout western- central parts of inner inlet and outer inlet. Wide range of sediment types ranging from very coarse sands to coarse silt. High overall diversity relative to other Mangere Inlet sites.

6. *Ninoe* / *Zeacumantus* association: 17 stations located at the eastern end of the inner Inlet, at the mouth of Tararata Creek and off Kiwi Esplanade. High diversity and large numbers of individuals relative to other Mangere Inlet sites. Community dominated by deposit feeders tolerant of reduced salinities. Sediments were poorly sorted fine to very fine sands.

Seven species associations were identified around Puketutu Island. Obvious patterns in the spatial distribution of the species assemblages around Puketutu were less apparent than in Mangere and Pahurehure Inlets. However, species composition generally reflected variation in sediment characteristics across the survey area, and the position of stations on the shore relative to tidal height and subtidal channels. The seven groups distinguished around Puketutu included:

1. *Austrovenus/Notacmea* association: 10 stations in intertidal areas that were mostly higher than mid-tide around the island. Species diversity was relatively low, and the number of individuals was high. Sediments were mainly fine sands.

2. *Pontophilus/Leptomya* association: five stations close to Purakau Channel or along its branches, with high species diversity and well sorted, very fine sands.

3. *Pomatoceros/Lepidonotus* association: four low-tide stations on the shores of Purekau Channel with high species diversity and numbers of individuals. Sediments were poorly sorted medium sands.

4. *Coscinasterias/Maoricolpus* association: three subtidal Purekau Channel stations with high species diversity and well sorted coarse sands.

5. *Boccardia/Macrophthalmus* association: eight stations that were mainly in sheltered mid-tide areas with very fine sand. Low average species diversity and number of individuals.

6. *Balanoglossus/Aglaophamus* association: seven low-tidal or sub-tidal stations to the southwest of Puketutu, with mainly poorly sorted fine sands and average species diversity and numbers of individuals.

7. *Scolecolepis/Nicon* association: three mid-tide stations south of Puketutu Island, with poorly sorted fine sands, high diversity and low numbers of individuals.

Only three species groups were identified in Pahurehure Inlet, with a clear gradient from inner to outer parts of the inlet Figure 33. The groups included:

1. *Austrovenus/Cominella* association: 23 stations with poorly sorted fine sands or coarse silts that occurred throughout the inlet, but were most common in mid section. The group contained common intertidal species with relatively high species diversity and numbers of individuals.

2. *Helice/Amphibola* association: eight stations in the upper reaches of the inlet with well sorted coarse silts. Low species diversity and numbers of individuals, with species that are tolerant of low salinities.

3. *Xymene/Nucula* association: 12 intertidal and subtidal stations in the outer inlet, with moderately or poorly sorted very fine sands and coarse silt. Moderate species diversity, but high species richness (due to the relatively even spread of individuals among species).

Figure 31: Species assemblages in Mangere Inlet identified by Grange (1982). The assemblages are: 1) *Acanthochitona / Macrophthalmus* (light blue) 2) *Austrovenus / Anthopleura* (dark blue), 3) *Cirratulid / Helice* (green), 4) *Glycera / Nucula* (yellow), 5) *Macrophthalmus / Cominella* (orange), 6) *Ninoe / Zeacumantus* (red). Actual locations were taken from maps presented in the original report and are therefore approximate.

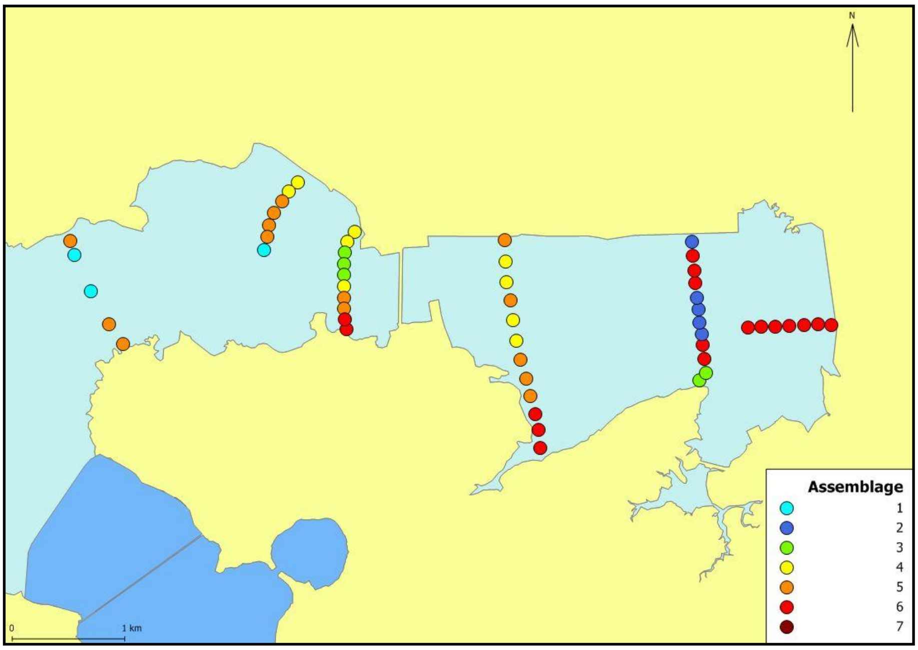


Figure 32: Species assemblages at Puketutu Island identified by Grange (1982). The assemblages are: 1) Austrovenus/Notacmea (light blue) 2) Pontophilus/Leptomya (dark blue), 3) Pomatoceros/Lepidonotus (green), 4) Coscinasterias/Maoricolpus (yellow), 5) Boccardia/Macrophthalmus (orange), 6) Balanoglossus/Aglaophamus (red), and 7) Scolecolepis/Nicon (brown). Actual locations were taken from maps presented in the original report and are therefore approximate, and the locations of the old wastewater treatment ponds are shown.

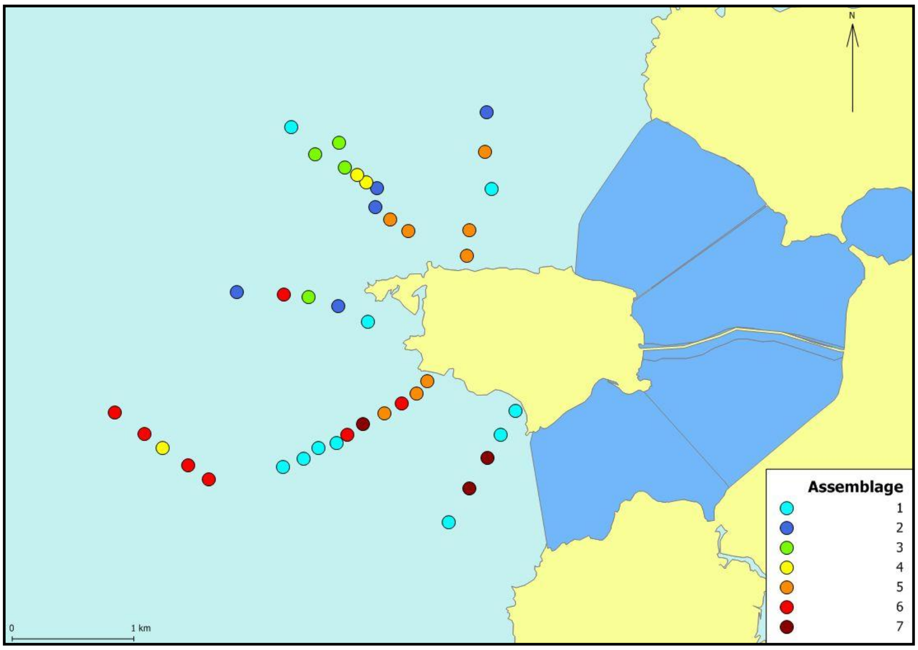
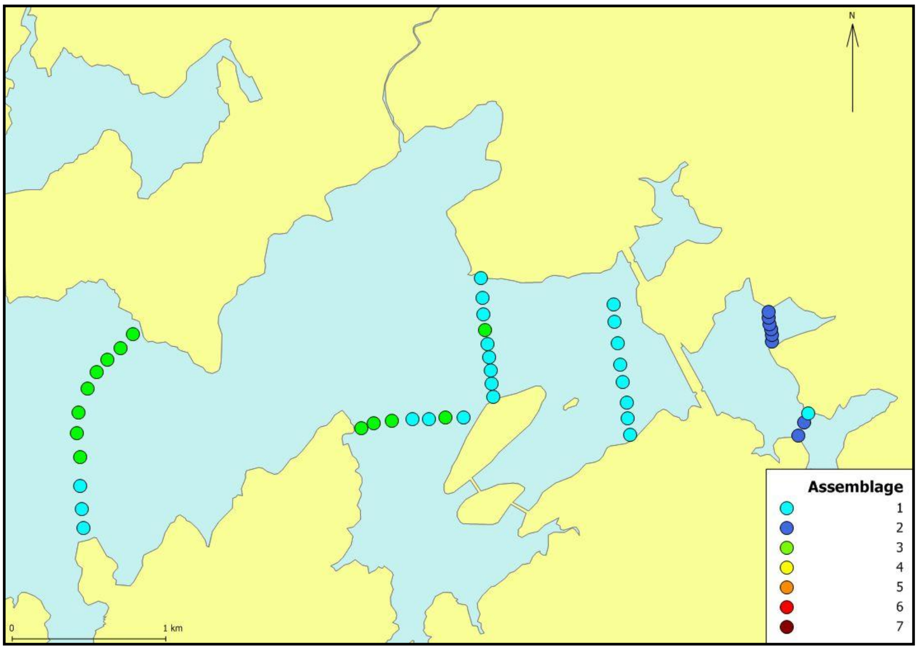


Figure 33: Species assemblages in Pahurehure Inlet identified by Grange (1982). The assemblages are: 1) Austrovenus/Cominella (light blue) 2) Helice/Amphibola (dark blue), and 3) Xymene/Nucula (green). Actual locations were taken from maps presented in the original report and are therefore approximate.



8.2.3 Intertidal communities of the harbour entrance

Hayward and Morley (2002) describe intertidal communities on the exposed west coast and northern shore of the harbour entrance, based on surveys carried out between January 1998 and March 2002. The surveys were conducted during low spring tides and covered all accessible intertidal areas of the coastline. All species observed during a thorough search of each location were recorded (including dead taxa), and ranked according to their relative abundance. The distributions of microhabitats, rocky substrates, distinctive macro-communities, and key organisms were also mapped in the field. Transects were then used to create shore profiles at 13 sites and to map the zonation of dominant species across the shore. Data were presented as site specific species lists and abundance rankings, maps and illustrations showing the distribution of biota and habitats, and diagrams showing shore profiles and species zonation. Cluster analysis was also used to group species assemblages.

In total, 598 species were recorded between Muriwai on the west coast and Big Muddy Creek in Manukau harbour. Six major habitats and associated communities were specifically identified in the harbour entrance. These major habitats were:

1. **Sheltered rocky shores** which line a significant portion of the coast. The rock substrate was volcanic conglomerate (Piha Formation) between Paratutae and Little Huia and around the end of Puponga Point. Everywhere else it was slightly softer volcanic grit or sandstone (Cornwallis Grit and Waitemata Sandstones).

2. **Sheltered boulder beaches** which were present in a number of places, such as on the east side of Paratutae, at Boulder Bay, Destruction Gully, Kaiteke Pt., Huia, and Puponga and Lawry Points.

3. **Sheltered sandy and muddy shores** in a number of large sheltered bays (Huia, Kakamatua, Mill, Armour Bays) with extensive intertidal muddy sand flats, as well as smaller bays with narrower stretches of intertidal sand (Little Huia, Orpheus, Kaitarakihi, Cornwallis).

4. **Estuaries** supporting brackish water biota at the mouths of Huia, Kakamatua and Nihotupu Streams. The Huia and Kakamatua Stream estuaries are small compared with Big Muddy Creek estuary at the mouth of the Nihotupu Stream

5. **Minor areas of salt marsh and salt meadow** around the mouths of the Karamatura, Huia, and Kakamatua Streams, and the fringes of the mangrove forest in Big Muddy Creek

6. **Mangrove forest** which fills much of Big Muddy Creek bay. A few plants also occur in Huia Stream and Kakamatua estuaries, and in the shelter of Swanson Bay.

8.2.4 Monitoring associated with the Mangere Wastewater Treatment Plant

Watercare Services Ltd have periodically monitored benthic communities in the north-east corner of Manukau Harbour in relation to the discharge and activities of the Mangere Wastewater Treatment Plant (Bioresearches 2008a). Their monitoring programmes have included:

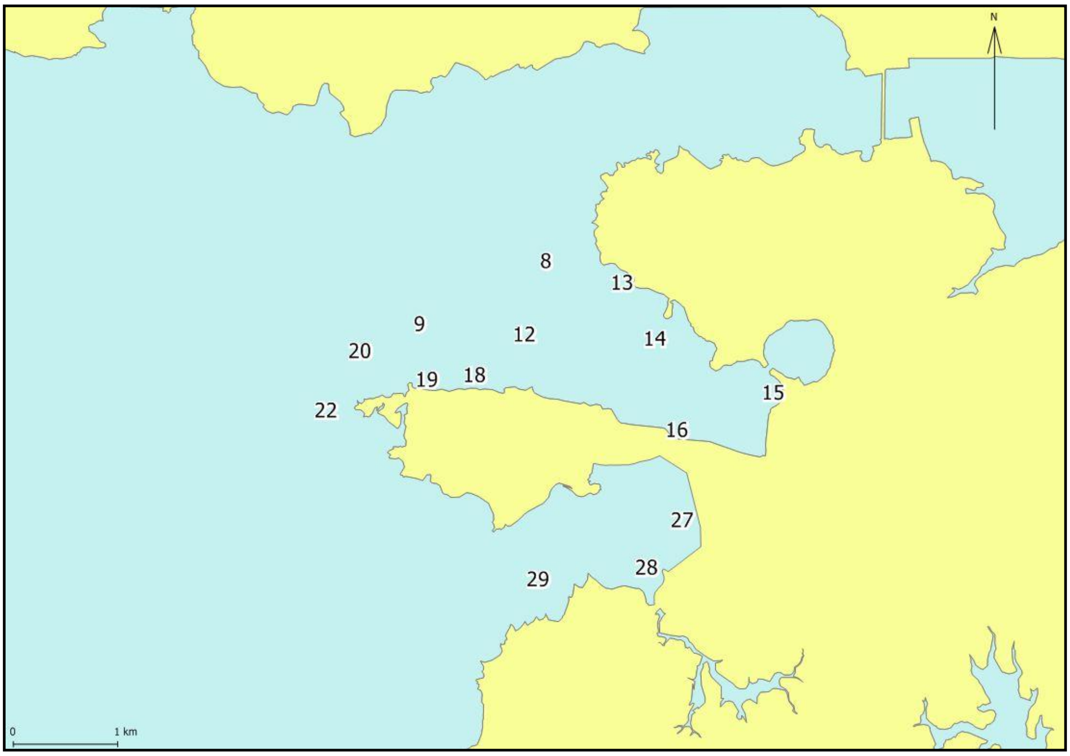
- Annual monitoring of seven sites between 1995 and 2000 (Sites 8, 9, 12, 18,19, 20, 22 – see Figure 34). At each station five randomly located samples are collected using a 15 cm diameter by 15 cm deep core.

- Sampling of an additional seven sites in the areas previously occupied by wastewater treatment ponds, in December 2002. At each station 12 randomly located samples are collected using a 15 cm diameter by 15 cm deep core.
- Annual monitoring of all 14 sites between November 2003 and November 2007 (see Figure 34) using the methods described above.

Samples were sieved through 0.5 mm mesh and all biota are identified and counted.

Marine species rapidly colonised the decommissioned pond areas, and species counts and Shannon Weiner diversity continued to increase between 2003 and 2007. However, total counts were variable and did not display consistent trends over time. Communities in the pond areas are numerically dominated by pollution tolerant species such as *Heteromastus filiformis*, but sensitive species such as cockles and wedge shells have also colonised these areas, and now occur in relatively high abundances. Species counts and Shannon Weiner diversity in sites beyond the decommissioned ponds have either been relatively stable, or have declined since 1995. Similarly, the total number of individuals has also declined at most of these sites.

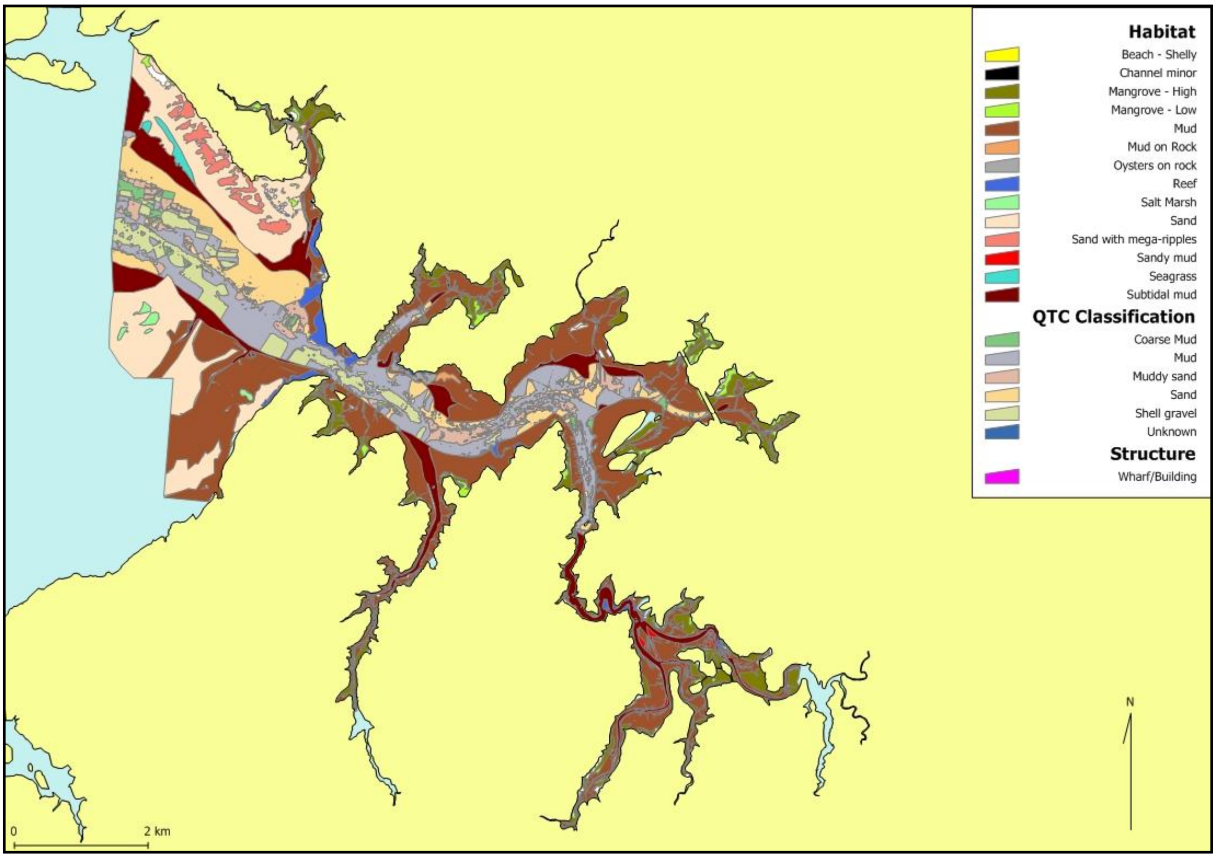
Figure 34: Ecological monitoring sites (numbered) in Watercare Service's Harbour Environment Monitoring Programme (HEMP) (Bioresearches 2008a).



8.2.5 Pahurehure Inlet Habitat Mapping

Habitat maps of Pahurehure Inlet have been produced by NIWA (Morrison et al 2000) and Kingett Mitchell Limited (Kingett Mitchell Limited 2005). Morrison et al (2000) used data obtained from an acoustic survey of subtidal channels, aerial photos and field surveys to produce a relatively broad-scale, standalone map of the inlet (see Figure 35).

Figure 35: Habitat map of Pahurehure Inlet from Morrison et al **(2000).**



A further rapid ecological survey of the upper Pahurehure Inlet was subsequently commissioned by the ARC to support the development of the Pahurehure Inlet Coastal Compartment Plan (Kingett Mitchell Limited 2005). Kingett Mitchell Limited (2005) identified 12 main coastal habitats within that area (Figure 36):

1. **Beach fringe** at the upper end of the shoreline between the terrestrial environment and the true intertidal zones. The habitat had few epifauna, with wrack line faunas dominated by sand hoppers (*Talochestia quoyana*) and insect larvae (beetles and flies) were likely to be the dominant species. Burrows of the mud crab *Helice crassa* and other crustaceans were also present.

2. **Man-made shores** comprised of retaining walls and rubble, which provided substrate for barnacles and oysters.

3. **Sandstone platform**, which occurred in patches throughout the study area and were generally devoid of marine fauna, although a mixed community of green algal mats and barnacles occurred in places.

4. **Salt marsh marine faunal habitat** with sediments consisting of muddy sands and small gravels on which the mud snail, *Amphibola crenata* and the dark water snail, *Potamopyrgus estuarinus* were characteristically present. Mud crab burrows were also common in the transition zone from salt marsh habitat to the pneumatophore zone of mangrove forest.

5. **Mangrove fauna** dominated by mud snails, mud crabs, oysters (*Crassostrea gigas*), barnacles and a range of polychaete worms.

6. **Fine sandy mud** with high numbers of *A. crenata* and the hornshell, *Zeacumantus lutulentus*. Cockles, *Austrovenus stutchburyi* and wedge shells *Macomona liliana* occurred within the upper 5-10 cm of sediment, and Pacific oysters, mud crabs and patches of the algae *Gracilaria* sp. occurred in some areas. The small brown mussel *Xenostrobus securis* occasionally occurred within this habitat, often in association with Pacific oyster clusters. Shells of the Asian date mussel (*Musculista senhausia*) were also observed in places.

7. **Shelly mud** with live cockles and wedge shells common in the upper substrate layer and live horn-shells on the surface, in patches of standing water. The mudflat topshell (*Diloma subrostrata*) and purple-mouthed whelks (*Cominella glandiformis*) were also present in lower abundance. *Amphibola crenata* were occasionally present.

8. **Fine sand** with a species composition similar to that found in shelly mud.

9. **Medium sand** which was generally devoid of epifauna apart from the simple brown ascidian, *Microcosmus kura*, which was occasionally observed. Cockles, mud crabs, sponge fragments, and a few mud snails were also present in places.

10. **Very soft gloopy mud** with Pacific oysters occurring as lone individuals or in denser groups. High numbers of crustacean burrows were also found and live cockles occurred occasionally. Small mud snails, hornshells, other mollusc and algal epifauna were observed within and on oyster clumps.

11. **Oyster beds** with dense, extensive clusters of Pacific oysters. Small *A. crenata*, the black sea slug *Onchidella* sp., hornshells, the mudflat top shell *Diloma subrostrata*, small brown mussels *Xenostrobus securis*, *Graciliaria* sp. and other alga occurred on, and within, the oyster beds.

12. **Water courses** including smaller drainage channels containing high abundances of *A. crenata* and *P. estuarinus* in their upper reaches. Pacific oysters occasionally protruded from the sediment on surrounding banks and from mounds within the channel, and mangroves lined the upper reaches.

Coastal and adjoining terrestrial habitats were then ranked for ecological significance based on their distinctiveness, representativeness, ecological context, potential sustainability, and current condition. Habitats within the coastal marine area that ranked highly were: salt meadows, particularly for their value as habitat for shore birds and wading birds; and fine sand habitats for their overall abundance and diversity of marine fauna, their importance to wading birds, and their potential to support seagrass communities (although seagrass was not actually found during the survey). Water courses, areas of medium sands, tall mangrove and number of other spatially limited categories (e.g., sandstone platforms, beach fringes, salt marsh rushes/sedges and native plantings) were considered to be of medium to high significance. Fine sandy-mud, and low and establishing mangroves ranked medium-low, and areas of cleared and damaged mangrove, very soft gloopy muds, Pacific oyster beds and man-made structures were all ranked low (Figure 37).

Figure 36: Distribution of habitats identified by Kingett Mitchell Limited (2005) in Pahurehure Inlet.

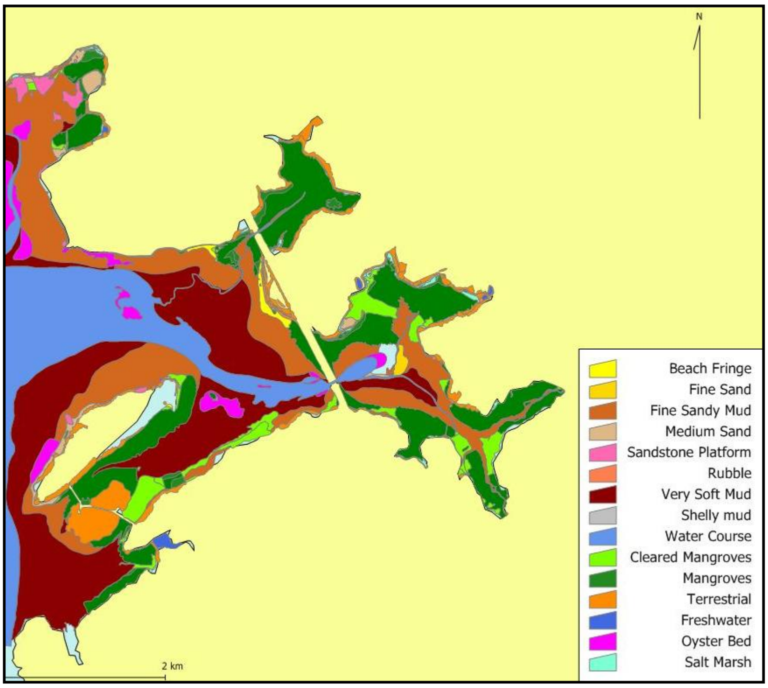
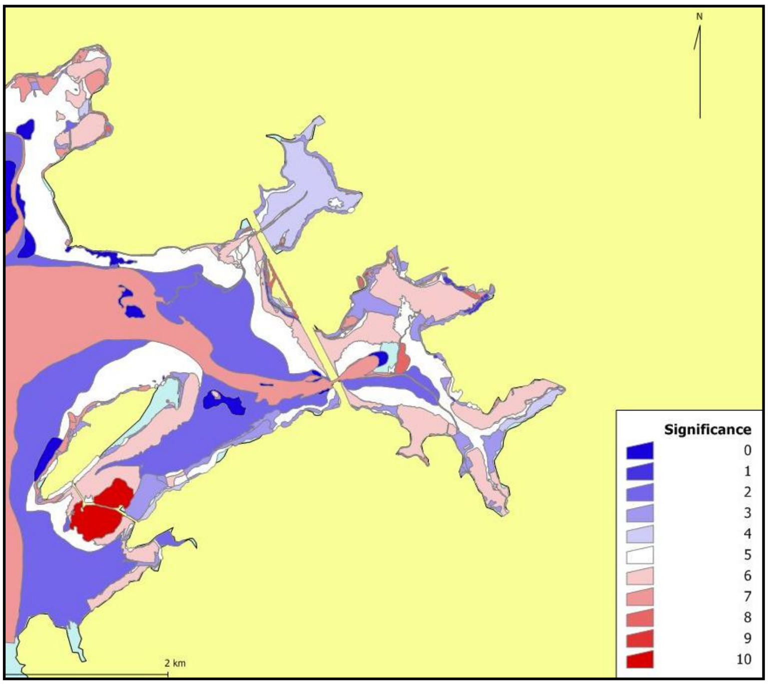


Figure 37: Significance rankings of habitats identified by Kingett Mitchell Limited (2005) in Pahurehure Inlet



8.2.6 Ministry of Fisheries Shellfish Monitoring

The Ministry of Fisheries has intermittently surveyed intertidal populations of pipis (*Paphies australis*) and cockles (*Austrovenus stutchburyi*) on beaches in the Auckland metropolitan area, including Mill Bay, Cornwallis and Grahams Beach in the Manukau Harbour, since 1992 (Pawley and Ford 2007). Individual surveys provide estimates of population abundance and size frequencies, but the methods used have changed over time, which limits the potential for trend detection. The most recent surveys indicated that:

- In 2006, no pipis or significant cockle beds were found at Grahams Beach, where the survey site covered an area of approximately 1.7 km long by 140 m wide. The cockles that were present were generally very small, (typically 11-12 mm) and patchily distributed, with greatest densities occurring in areas influenced by stream runoff (Pawley and Ford 2007).
- In 2001, the Mill Bay survey site was estimated to contain 5.21×10^6 ($\pm$ 0.56×10^6 SE) cockles and 1.76×10^6 ($\pm$ 0.61×10^6 SE) pipis. These estimates were not significantly different from estimates obtained in 2000.
- The 2004 population estimates for the Mill Bay survey site were 4.23×10^6 ($\pm$ 0.49×10^6 SE) cockles and 1.41×10^6 ($\pm$ 0.27×10^6 SE) pipis. No significant difference in cockle the population estimate or mean cockle size was detected between 2003 and 2004. However, significantly more pipis were found in 2004, with a greater proportion of the population contained in the smaller size classes (Walshe et al 2005).
- In 2001, the Cornwallis survey site was estimated to contain 1.86×10^6 ($\pm$ 0.23×10^6 SE) cockles and 1.15×10^6 ($\pm$ 0.30×10^6 SE) pipis. Pipis were confined to the mid tide zone at the southern end of the beach, and were found in 97 stations (c.f. only 2 stations in 1996).

A scallop survey of Clarks Beach was also conducted in 2004-05, but the results were relatively uninformative, because only 11 scallops were found.

8.3 Research on ecological patterns and processes

8.3.1 Contaminant effects

Manukau Harbour has been regularly used as a study site for investigating the effects of contamination on benthic macrofauna and microfauna, due to its relatively long history of urban and industrial development (particularly in Mangere Inlet), and associated pollution issues (see Section 3). Studies conducted in the harbour have used a number of approaches to examine ecological effects, ranging from testing the behavioural reactions of individual species exposed to contaminated sediments, through to examining relationships between sediment-contaminant concentrations and community composition. Biological effects at Manukau Harbour sites have been tested using control-impact type experiments, or by sampling along contaminant gradients. A summary of the key studies is provided below.

Published studies have had a strong focus on community structure in relation to contaminant gradients and the effects of contaminants on species recruitment. Henriques (1980) examined the effects of pollution (specifically, nutrient enrichment) and the presence of macrovegetation on the diversity and density of large benthic fauna (i.e. retained on a 6.25 mm sieve), at eight soft-shore intertidal habitats in the early 1970s. The habitats were delineated according to their tidal height, proximity to pollution sources (close or remote), substrate characteristics (mud or sand), and vegetation (non-vegetated, dense algae beds (*Gracilaria secundata* - renamed *chilensis* (Cohen et al 2004)), dense mangroves, and dense seagrass). Formal statistical tests were not carried out, but a visual analysis of various indices of diversity and abundance appeared to indicate that pollution reduced faunal density and had a slight effect on species diversity. *Gracilaria secundata* (*chilensis* (Cohen et al 2004)) did not appear to affect the underlying benthic community, but species diversity was higher on both seagrass flats and in mangrove forests relative to non-vegetated habitats. Faunal density was also higher in mangrove forests, but it was slightly lower on seagrass flats.

Thrush and Roper (1988) and Roper et al (1988) used a more rigorous approach to examine contaminant effects, by combining field observations with experimental tests. They compared the composition of benthic communities and the settlement of benthic macrofauna at six sites around the harbour with similar sediment textures, but varying contaminant levels (note that only one site was markedly polluted: Mangere Inlet), and then conducted experiments to test for variation in the settlement of benthic macrofauna at each site. The only obvious relationship between benthic community structure and contamination were low numbers of species and individuals at the Mangere Inlet site (Roper et al 1988). This site also had the lowest median number of species and the lowest number of individuals colonising settlement trays (Thrush and Roper 1988). This led Roper et al (1988) to conclude that "the level of pollution, almost certainly from runoff, has had a severe effect on the community structure at this station".

Roper et al (1995) went on to examine the settlement behaviour of the wedge shell *Macomona liliana* in relation to: 1) sediments with artificially elevated metal contaminants; and, 2) sediments from four "contaminated" sites (Harania Creek, Grannys Bay and Mangere Inlet within Manukau Harbour, and Hobson Bay in the Waitemata Harbour) and two "uncontaminated" reference sites (Wairoa Island and Raglan Harbour). The spiked sediments induced clear behavioural responses in juvenile wedge shells, but sediments obtained from the contaminated and uncontaminated sites produced ambiguous results. For instance, although the burial of juvenile *M. liliana* was slowed in sediments from contaminated sites, the differences were not statistically significant. Drifting rates on uncontaminated sediments from Raglan, and contaminated sediments from Mangere Inlet and Hobson Bay, were significantly higher than rates on uncontaminated sediments from Wairoa Island and contaminated sediments from Grannys Bay. Crawling was unaffected by the sediment-contaminant levels. The results therefore suggested that contaminated sediments have an effect on juvenile wedge shells, but the lack of consistent behavioural responses meant that this conclusion could not be verified.

In recent years there has been a shift towards the use of more powerful statistical methods, which tease apart the relationships between ecological and environmental variables. The use of multivariate statistics has been particularly useful for examining links between stormwater contaminants and benthic community structure. Anderson et al (2002) and Hewitt et al (2005) describe the development the ARC's "benthic health model", which clearly identified changes in the composition of benthic communities along an urban pollution gradient. The study included 58 estuary and 76 harbour sites from across the Auckland Region, that were subjectively ranked from 1 (unpolluted) to 5 (polluted) for environmental quality. The Manukau Harbour sites included in the analysis were the six ecological SoE sites (Cape Horn, Auckland Airport, Puhinui Stream, Elletts Beach, Karaka Point and Clarks Beach), plus sites in Puhinui and Big Muddy Creek. A variety of analytical techniques were tested, including distance based redundancy analysis (dbRDA) on Hellinger-transformed data (Hewitt et al 2005), canonical correspondence analysis (CCA) (Hewitt et al 2005), and canonical analysis of principal coordinates (CAP) (Anderson et al 2002, Hewitt et al 2005). Strong relationships were found between pollution rank and benthic community structure, with all three techniques producing comparable results. However, CAP was recommended for ongoing use because it performed slightly better than the other methods. To provide consistency with the ARC's sediment contaminant environmental response criteria (ERC), ecological health was ranked from green (good) to red (poor).

The benthic health model was subsequently refined by: using a better spread of sites from across the Auckland Region; using actual measurements of contaminant (copper, lead and zinc) concentrations rather than a pollution ranking; and using a 5 point scale for ranking ecological health (Anderson et al 2006, Kelly 2007b). The results obtained from the revised model were similar to the original (i.e. a strong relationship was found between contaminant concentrations (copper lead and zinc) and community structure), but the refinements made the model more robust. Figure 26 shows the ecological health rankings for sites from the Manukau Harbour.

Thrush et al (2008a) used the dataset of Anderson et al (2006) to isolate the effects of several environmental stressors on 42 species using multiple regression analysis. Regression models were used to identify the additive, multiplicative, synergistic and antagonistic effects of contaminant (copper, lead and zinc concentrations) and environmental variables (mud content and organic content (TOC)). An additive effect was one where the effects of two or more stressors added together to produce a larger total effect. A multiplicative effect is one where the effects of two or more stressors multiply to produce a much larger total effect. Effects were further interpreted as being synergistic or antagonistic based on whether they increased or decreased the effect of the main contaminant.

Regression models explained a statistically significant proportion of variation in the abundance of 38 of the 42 taxa (Thrush et al 2008a). Changes in the abundance of most taxa were predicted by two or three environmental stressors. Taxa responding to metals generally displayed a stronger correlation to one particular metal, with copper tending to be more influential than lead or zinc. However, in some cases more than one metal was important. Furthermore, the effects of metals tended to be stronger at sites with higher levels of mud or TOC, suggesting that they compounded the effects of other environmental stressors. Only one taxon showed a different response. The effect of copper on the abundance of Nereidae was lower at sites with low mud content, suggesting that for Nereids, low mud concentrations are a stressor.

Hewitt et al (2009) used the same dataset to derive sediment quality guidelines for copper, zinc, and lead, from field-based species-sensitivity distributions. Sediment quality guidelines were derived from the concentrations where statistical modelling predicted that a 50% decrease in abundance of 5% of the taxa occurred. The sediment quality guidelines obtained from the analysis of species-sensitivity distributions ranged from 6.5 - 9.3 mg/kg for copper, 18.8 - 19.4 mg/kg for lead, and 114 - 118 mg/kg for zinc. The percentage of the variation explained by copper was generally fair to good, with an $R^2 > 36\%$ for all of the species that displayed a 50% reduction in abundance at the derived effects level. However, model fits were more variable for lead and tended to explain less variation for zinc.

Benthic microfauna have also provided useful insights on how changes in environmental quality have led to a corresponding change in the composition of marine fauna. The contaminant-related ecological history of Mangere Inlet was reconstructed from foraminiferal[6] records obtained from sediment core samples (Matthews et al 2005). Foraminiferal communities in the sediment record reflect different periods of human presence and activity:

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

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

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 outfalls in inner parts of the inlet (e.g. meat works and tanneries). In the latter half of this period, foraminifera disappear altogether, or are very sparse in a core located next to the discharge from the Southdown meat works, 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.

8.3.2 Recruitment and movement

The distribution patterns of benthic macrofauna are likely to reflect the combined influences of larval production and dispersal, recruitment processes, and post-settlement movement and mortality. In turn, each of these processes is influenced by a variety of other factors, of which, habitat type and quality are likely to be particularly important. Larval dispersal, recruitment and moment processes have therefore been the focus of a number of studies carried out in Manukau Harbour.

Juvenile and adult dispersal by drifting is relatively common amongst benthic macrofauna. Cummings et al (1995) collected an abundant and diverse drift fauna that contained 40 benthic macroinvertebrate taxa including: 1 oligochaete; 18 polychaetes; 2 crabs; 8 isopods; 2 echinoderms; 1 gastropod; and, 9 bivalves. All of the bivalves and gastropods were post-settlement juveniles, 3 mm or less in size, while most of the polychaetes were either metamorphosing planktonic larvae or young benthic stages. In contrast, most of the arthropods were adults. The taxa caught in the water column varied with sampling date, time of day, state of the tide, and depth of sampling. Commito et al (1995) found that wind had a significant influence on post-settlement dispersal, with the abundance and diversity of benthic macrofauna caught in water column traps being positively related to wind conditions.

Turner et al (1997) examined whether the post-settlement movements of benthic macrofauna was an active or passive ecological process. Traps were used to measure the total flux of sediment and biological material, by collecting all sediment and animals moving as part of the bedload and in the water-column. This method was complimented by pans filled with defaunated sediment to measure the net flux of sediment and biological material across the sediment surface (i.e. sediments and animals were free to move into and out of the pans). The abundance of some species, such as the cockle *Austrovenus stutchburyi*, were positively related to the weight of sediment in bedload traps, and wind conditions over the study period. This suggested that these species moved through passive transport processes, but it did not exclude the possibility that active dispersal was also used. The abundance of other species, such as the wedge shell *Macomona liliana*, was not significantly related to the weight of sediment retained in bedload or water column traps, suggesting that the transport of these species was an active process. Norkko et al (2001) (also reported in Cummings (2005)) confirmed that bivalve dispersal was decoupled from sediment bedload transport on an experimental site near Wairoa Island, further illustrating the importance of active dispersal. Norkko et al (2001) found that within one tidal cycle, post larval and juvenile bivalves moved over scales of meters. Modelling indicated a 50% turnover of post-larval (<1 mm) bivalves in ¼ m^2 plots within 17.4 hours, whereas 50% of juveniles (1–4 mm) turned over within 31.5 hours.

The resident fauna present at a site can influence the settlement and recruitment patterns of conspecifics and other species. Turner et al (1997) found a negative relationship between background density of large *M. liliana* and colonisation by smaller conspecifics (0-4 mm) and other bivalves, including *A. stutchburyi, Cyclomactra ovata* and *Nucula hartvigiana*. This suggested that variation in the densities of *M. liliana* may have a significant influence on the colonisation and spatial patterns of benthic macrofauna. The tube-building spionid polychaete *Boccardia syrtis* has also been found to limit the settlement of *M. liliana* on Te Tau Bank in the northern Manukau harbour (Cummings et al 1996).

Taylor (1999) also examined the influence of environmental factors on the reproduction and recruitment of the *M. liliana* in Manukau Harbour. Favourable habitats were located in the mid-low tide regions of the large intertidal sandflats that were subject to 6-8 hours immersion per tide. These areas were characterised by sediments composed of well sorted fine sands. In favourable habitats *M. liliana* populations had: high densities of adults; equal to female biased sex ratios; relatively high levels of post-larval recruitment; and high survivorship and/or persistence of post larvae to juvenile stages except in habitats characterised by tube-building spionid polychaetes where survivorship was low. Less favourable habitats were located in sheltered bays with sediments composed of moderate to poorly sorted sands. Populations in these habitats had: moderate-low densities of adults; equal to male-biased sex ratios; lower levels of post-larval recruitment; and, low survivorship and/or persistence of post-larvae to juvenile stages.

Suitable habitat was more limited in northern parts of the harbour, and Taylor (1999) postulated that larval supply to populations in the northern harbour may be limited by the hydrodynamic separation of northern and southern water masses (Bell et al 1998). Evidence suggested that the mixing of *M. liliana* larvae between the main channels to the north and south of Karore Bank was limited.

8.3.3 Scallops

Scallops are found in many shallow subtidal areas of the harbour (pers. obs.), but the main recreational harvesting areas are Clarks Beach and the Cornwallis/Mill Bay area, where there is easy access to the scallop beds. Scallops are not fished commercially in the Manukau Harbour, but stakeholders have raised concerns about overharvesting, and the collection of undersize shellfish by recreational fishers. However, MFish have very little empirical data on scallop populations in the harbour (pers. comm. Laura Mitchell, Fisheries Analyst, Ministry of Fisheries).

8.3.4 Oysters

Manukau Harbour contains populations of native rock oysters (*Saccostrea commercialis*), the larvae-brooding Chilean oyster (*Tiostrea chilensis*, commonly called Bluff oysters) (Jeffs et al 1997) and Pacific oysters (*Crassostrea gigas*). Pacific oysters became established and spread throughout Manukau Harbour shortly after their arrival in New Zealand, sometime between the 1950's and late 1960's (Keen 1990). Large, dense beds now cover upper intertidal in many parts of the harbour. In a number of areas, they restrict human access to the foreshore and are therefore regarded as a nuisance species (Grant and Hay 2004)[7].

Feral populations of Pacific oysters are also likely to affect intertidal ecosystems by displacing other species and modifying physico-chemical processes such as:

- decreasing water flows over the intertidal/shallow subtidal mudflats;
- decreasing turbidity through filter feeding;
- trapping fine sediments;
- increasing recycling rate of nutrients such as nitrogen, phosphorus and silicon;
- increasing the removal of pollutants from the water column through bioaccumulation.

Conversely, Pacific oysters provide substrate and structure that serves as refugia and habitat for many mobile and sessile benthic fauna (Grant and Hays 2004).

Pacific oyster shape varies among locations, but size generally increases down the shore (Keen 1990, Kelly 2004). Oyster settlement occurs in spring and autumn, and is followed by rapid growth. Growth rates are high at Onehunga, but tend to be slower at Cornwallis (Keen 1990).

Although Pacific oysters remain problematic in terms of their environmental effects, their abundance of has declined in some parts of the harbour, without the need for direct human intervention. BHP New Zealand Steel have been monitoring oyster densities at a number of sites in Waiuku River since 1985 (Bioresearches 2008b). Oyster densities at five of their six monitoring sites steadily declined between 1987 and 2008, while mean oyster size remained relatively constant. The decline in oyster abundance is most apparent at the Taihiki Creek control site, where densities dropped from ca. 95 oysters per 0.25 m^2 in 1987 to almost zero in 2008. Mud deposition is suspected to have contributed to that decline.

Chilean oysters are not as conspicuous and Pacific oysters, but Jeffs et al (1997) found that populations in Manukau Harbour and the Hauraki Gulf were more fertile than other populations in New Zealand. These populations brooded larvae at a small size and young age, and on average produced higher numbers of larvae relative to other populations. Chilean oysters reached a size of 93 mm on Te Tau Bank in the northern Manukau, and were estimated to begin brooding within one year of settlement. This was 6 to 24 months earlier than times reported elsewhere.

[7] However, their value as a food resource is also recognised, and they are used as an internationally comparable species for monitoring the biological uptake of contaminants (see Section 6).

9 Birds

Manukau Harbour contains extensive sand and mudflats, which are a rich food resource for shore birds. The approximately three hour tidal difference and short distance between Manukau Harbour, Waitemata Harbour and Tamaki Estuary also allows waders to extend their feeding times by easily moving between the west and east coasts. Maps produced from Ornithological Society surveys indicate that the Manukau Harbour has relatively high numbers of endemic and native taxa, and is a national “hotspot” for bird diversity in coastal and wetland habitats (Robertson et al 2007). Of 3096, 10 km x 10 km grid cells covering the whole of New Zealand, three grids in and adjoining Manukau Harbour were ranked in the top ten for the number of bird taxa observed within them. Taxa numbers in these three cells ranged from 88 to 110 bird species (including birds associated with wetland and terrestrial habitats). The areas around Mangere and Manukau Heads are also “hotspots” for nationally critical endangered bird taxa (threat code 1), and the north and eastern Manukau is a “hotspot”nationally vulnerable (threat code 3) bird taxa. Manukau Harbour supports over 20% of the total New Zealand wader population, and it is likely that more than 60% of all New Zealand waders use the harbour on a temporary basis (Watercare Services Ltd 2008). The harbour is also internationally important for the diversity and number of Northern Hemisphere waders that feed in it during the New Zealand summer (Watercare Services Ltd 2008).

Mangere Inlet, in the north-eastern Manukau Harbour is used by a range of New Zealand resident and migratory shore birds. The value of this area is recognised through the designation of coastal protection areas and areas of significant conservation value (Figure 7 and Table 1), 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 the Mangere area (Appendix 6). Of these, 15 species have been classified as threatened (Hitchmough et al 2007), with seven species having threat codes 1, 2 or 3[8] (i.e. black stilt (1), brown teal (2), grey duck (2), New Zealand dotterel (3), Caspian tern (3), reef heron (3) and wrybill (3)).

The Ornithological Society of New Zealand have conducted annual summer and winter bird censuses in Manukau Harbour since 1960 (Watercare Services Ltd 2008). Over that time summer and winter populations of South Island pied oystercatcher and godwit have increased, while summer populations of knot and winter populations of wrybill have increased (Watercare Services Ltd 2008, Figure 38 and Figure 39). The wader population for the entire harbour is estimated to be increasing by about 1065 birds annually.

Census data indicates that waders regularly move between roosts. When numbers are high at the Puketutu roost (adjoining the Mangere Wastewater Treatment Plant), numbers are low at the Onehunga roost. Similar patterns are apparent between the Airport lagoon roost and Puketutu and Onehunga roosts (Watercare Services Ltd 2008).

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

Figure 38: Summer counts of South Island pied oystercatchers (SIPO), wrybill, bar-tailed godwit, knot, pied stilt and New Zealand dotterel in the northeastern Manukau Harbour between 1960 and 2008 (based on Ornithological Society of New Zealand data provided by Watercare Services Ltd).

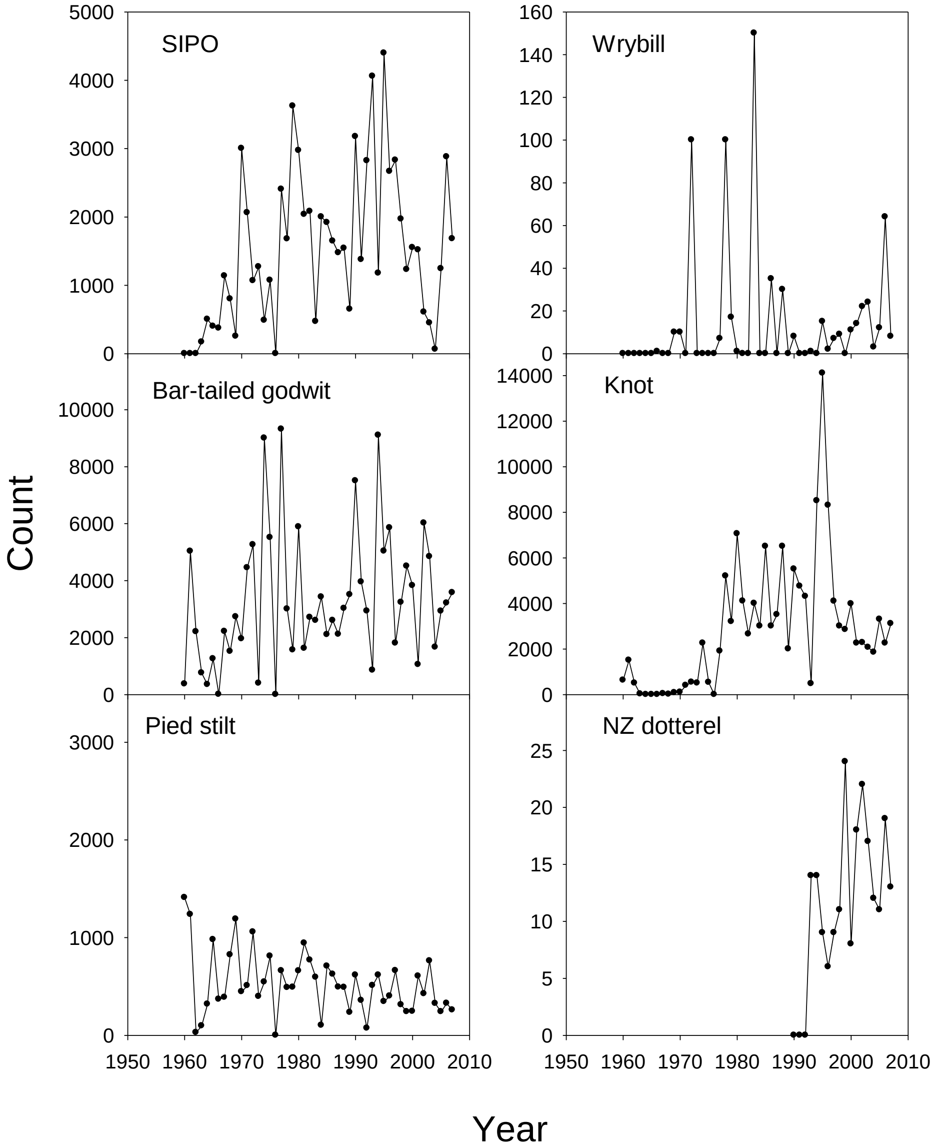
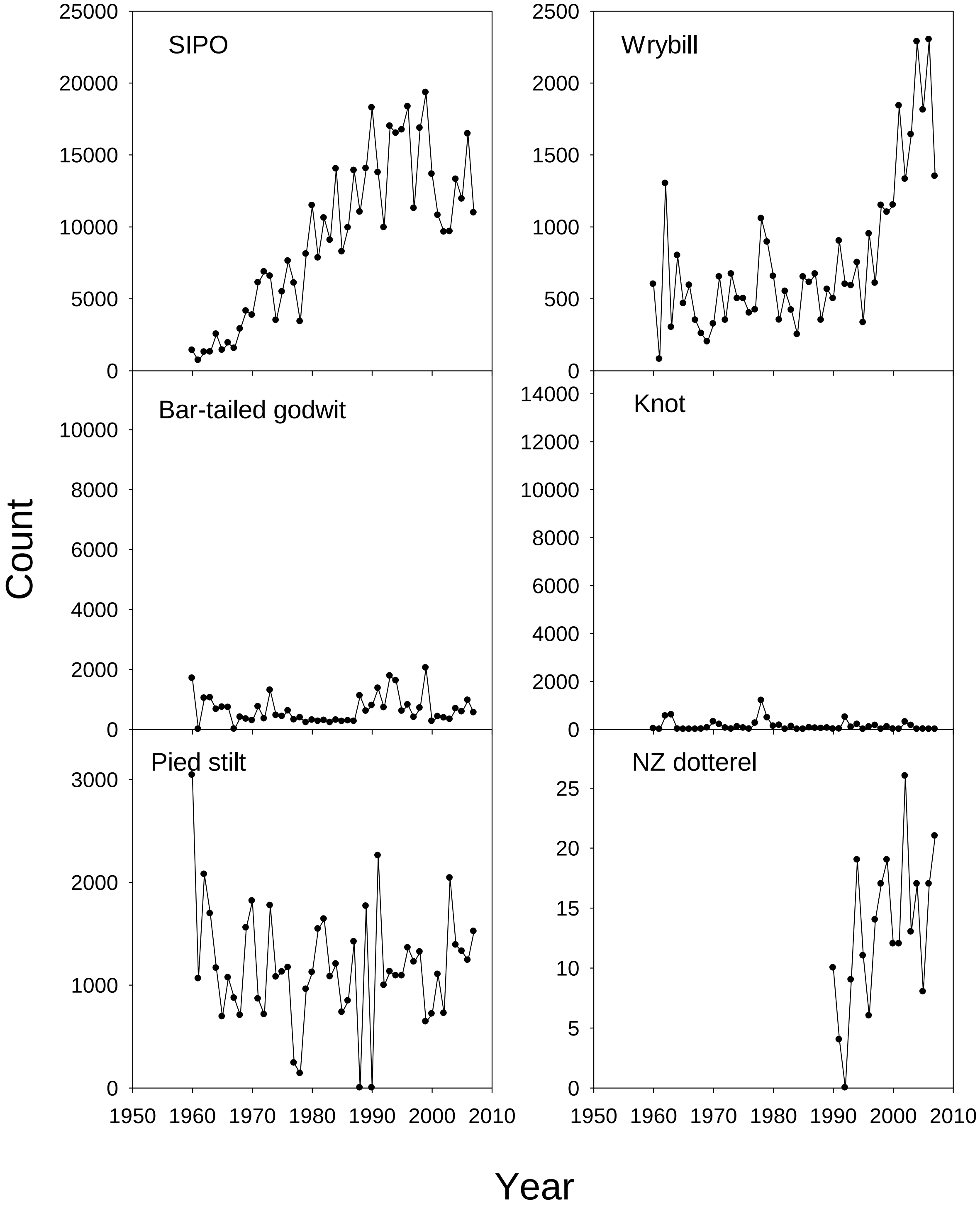


Figure 39: Winter counts of South Island pied oystercatchers (SIPO), wrybill, bar-tailed godwit, knot, pied stilt and New Zealand dotterel in the northeastern Manukau Harbour between 1960 and 2008 (based on Ornithological Society of New Zealand data provided by Watercare Services Ltd).



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 banning of shore bird shooting in 1940. In winter around 65% of pied oystercatchers in New Zealand were counted at three sites: Manukau Harbour, Kaipara Harbour and the Firth of 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 the 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.

Cummings et al (1997) observed high densities of waders foraging on sandflats around Wairoa Island (adjoining Auckland International Airport). Densities ranged from: 204 South Island pied oystercatchers per km^2; 168 bar-tailed godwits per km^2; 480 red knots per km^2; 10.4 ruddy turnstone per km^2; and, 0.6 plovers per km^2. On the receding tide, waders followed the water line out from their high tide roosts on Wairoa Island, to forage on the surrounding sandflats. The diet of red knot and bar-tailed godwit varied considerably among sites and through time at the study site, and consisted of small prey (5 - 15 mm in length) such as cockles, wedge shells, polychaetes and to a lesser extent, crustaceans (crabs and amphipods). In contrast, the droppings from South Island pied oystercatchers contained no identifiable hard parts, indicating that they fed on prey that had been hammered (wedge shells) or prised (cockles) open. Analysis of fresh shells indicated that South Island pied oystercatchers selected bivalves within a well defined size range (i.e. 25 - 37 mm for wedge shells and 18 - 23 mm for cockles) and individual oyster catchers were estimated to consume a maximum of 556 wedge shells per day.

Thompson and Dowding (1999) considered whether foraging in the more polluted parts of Manukau Harbour increased heavy metal concentrations in the South Island pied oystercatchers. Mercury, lead and cadmium concentrations in blood of oystercatchers from Mangere Inlet were compared with those from a rural, control site in the South Kaipara Harbour. Mercury and cadmium concentrations were low at both sites and no significant differences were 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 wet weight, which Thompson and Dowding (1999) suggested could lead to sub-clinical toxicological effects.

10 Fish

The Manukau Harbour has always been an important source of fish for subsistence, commercial and recreational fishers. Data provided by MFish indicates that Manukau harbour is a West Coast “hotspot” for recreational fishing, and that boat-based recreational fishing effort tends to be greater in the main channels of the central harbour (Figure 40) (see Hartill et al 2007 and Hartill et al 2008). Recreational effort is also high on the West Coast, directly offshore from the harbour entrance. Shore based line fishing, netting and spear fishing are also popular in the harbour. Structures that provide good line fishing access, such as the old Mangere Bridge in Mangere Inlet, regularly attract large numbers of anglers (Figure 41).

Fisheries landing data from 2003 to 2008 shows that that the main commercial fish species caught in Manukau Harbour (by landed greenweight) are grey mullet, flatfish, rig, kahawai, trevally, yellow eyed mullet, parore, red gurnard, and snapper respectively (Data provided by the Ministry of Fisheries) (Figure 42). Data reported in MFish Plenary reports were used to examine the contribution that the Manukau Harbour makes to national commercial catches (http://fpcs.fish.govt.nz/Science/Plenary.aspx). Manukau Harbour is a particularly important area for the grey and yellow eyed mullet fisheries, with around 25% of the national commercial catches coming from the harbour (Figure 42). The harbour also makes a significant contribution to the parore fishery, contributing around 6% to the total commercial landings of this species. Commercial landings of rig and flatfish comprise about 2.5% of total landings each, whereas the catches of kahawai, trevally, red gurnard and snapper are relatively minor at the national scale (all < 1%). Set nets are the primary commercial fishing method used in the harbour, but seine fishing is also common. A small amount of commercial line fishing for snapper also occurs.

Figure 40: Relative estimates of recreational fishing effort obtained from aerial surveys. Plots provide an: a) broad scale, and b) local scale perspective of fishing effort. Effort increases from blue to green, yellow, orange and red. Data were obtained from MFish as described in Hartill et al (2007) and Hartill et al (2008).

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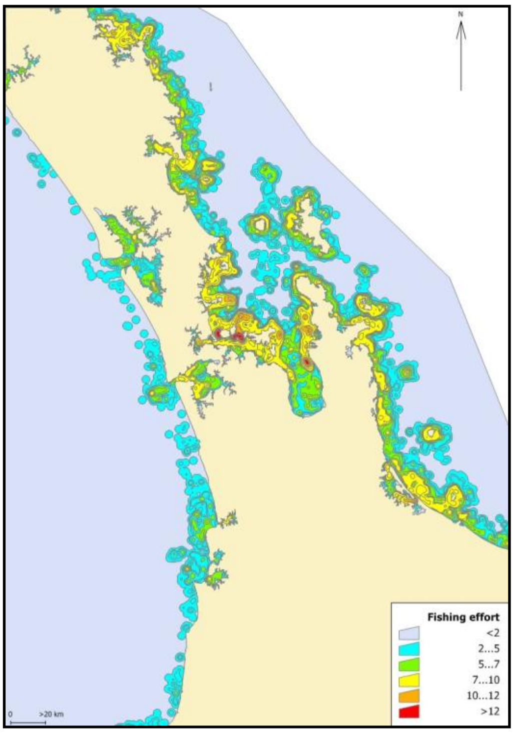

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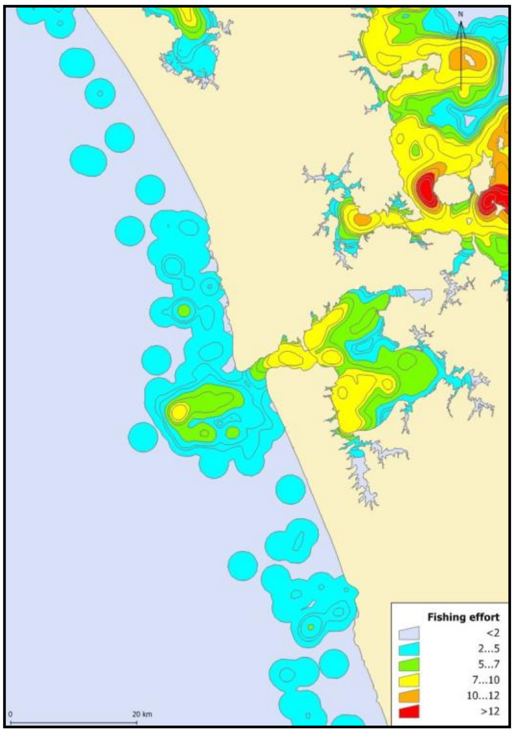
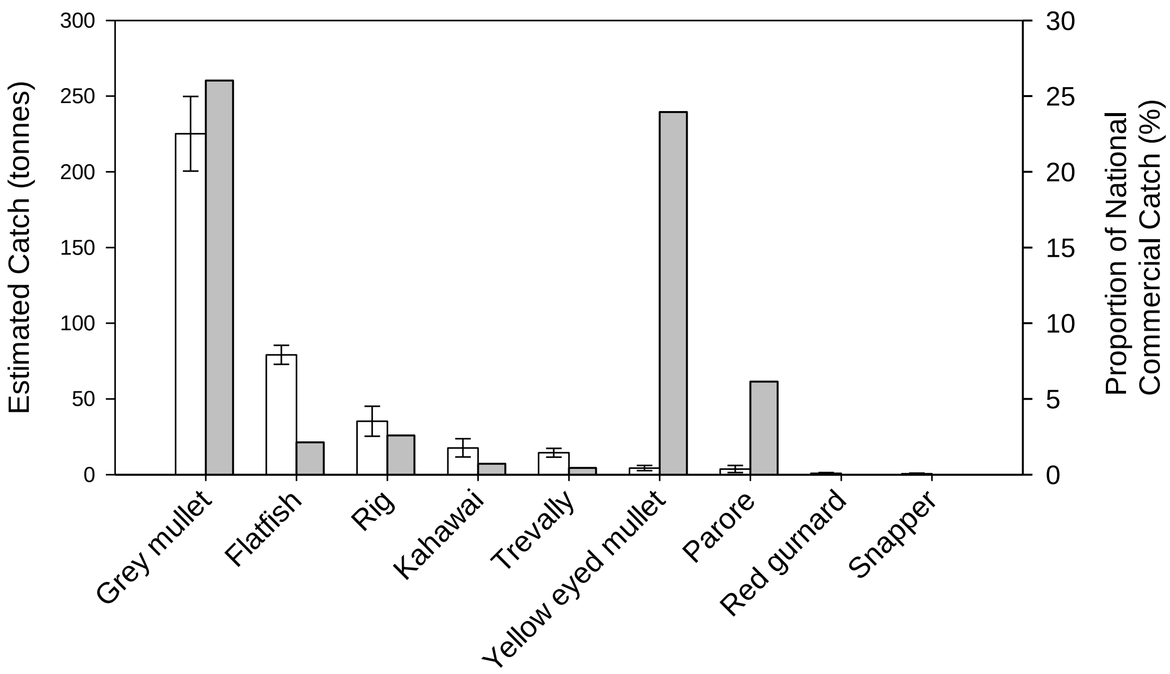


Figure 41: Recreational fishing from old Mangere Bridge in Mangere Inlet (May 2008).

Figure 42: Annual commercial landings of finfish species caught in Manukau Harbour between 2003 and 2008 (open bars: mean of reported greenweight estimates ± 1 S.D.) and contribution that the Manukau Harbour commercial catch makes to the national commercial catch. Manukau catches were derived from averaged annual landings between 2003 and 2008, whereas national commercial catch was obtained from averaged annual landings between 2003 and 2007).



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 and 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 9m), were obtained from Mark Morrison (NIWA), and raw fish diversity data was plotted without correcting for tow length (Figure 43). Species count data were then corrected for tow length (count/metre towed) and plotted to illustrate the distribution of individual fish species (Figure 44).

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. Fish diversity was greatest in Waiuku River (8 to 12 species), with the highest number of species being obtained from the upper reaches of the Taihiki Creek tributary. Nine fish species were also obtained from one site in Pahurehure Inlet and seven species were obtained from one site in Mangere Inlet, but all sites in the main body of the harbour had 6 or less species (Figure 43).

Similarly, greater numbers of fish were caught in side-branches of the harbour. Waiuku River (including Taihiki Creek) had the highest corrected counts of anchovy, exquisite goby, garfish, mottled triplefin, grey mullet, estuarine triplefin, red gurnard, smelt, and speckled sole. Pahurehure Inlet had the highest corrected counts of sand goby and yellow-belly flounder, and Mangere Inlet had the highest corrected counts of yellow eyed mullet and sand flounder (Figure 44). Fish numbers were generally low in the main body of the harbour.

Figure 43: 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.

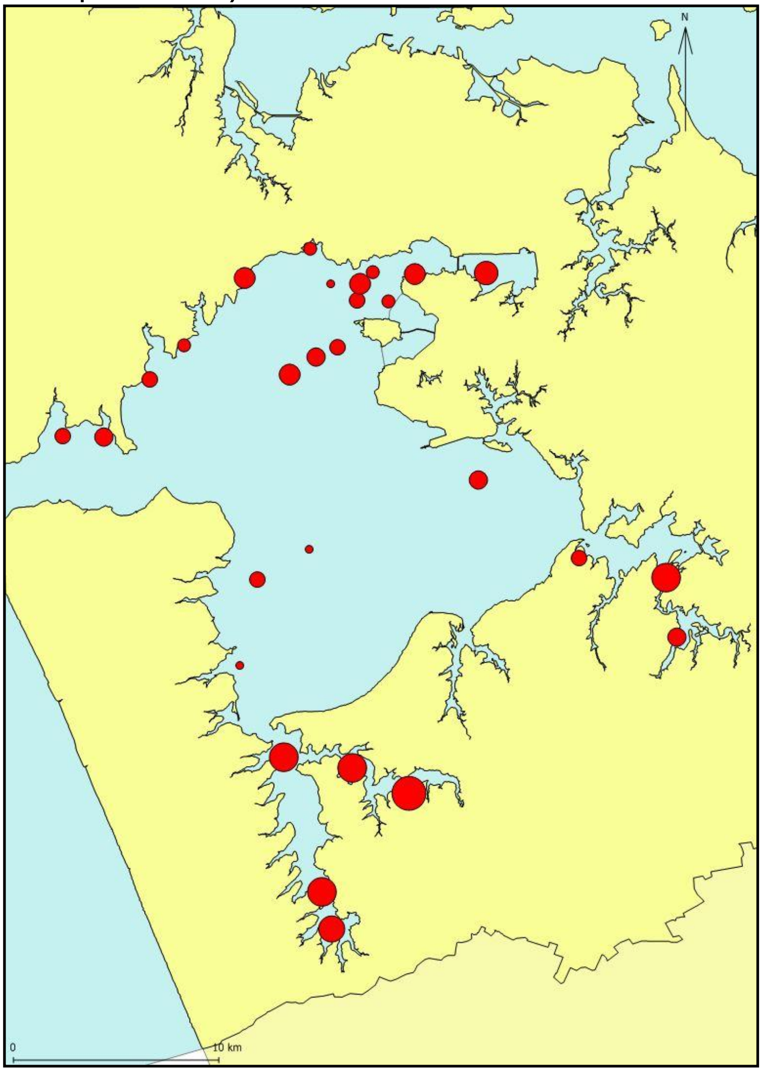


Figure 44: Relative distribution of a) yellow eyed mullet, b) grey mullet, c) yellow bellied flounder, d) sand f lounder, e) speckled sole, f) red gurnard, g) mottled triplefin, h) estuarine triplefin, i) exquisite goby, j) anchovy k) smelt, and l) garfish in Manukau Harbour (Morrison and Francis unpublished data).

Data obtained from beach seine nets. Dot size varies according to counts per meter towed.

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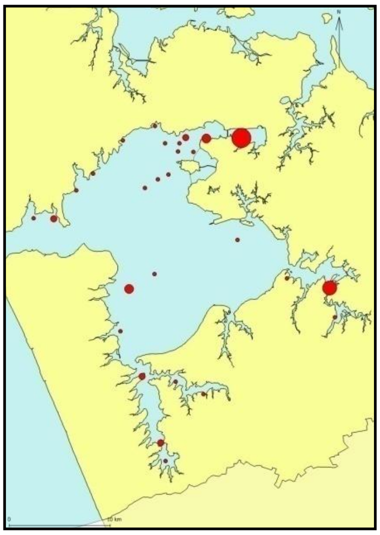

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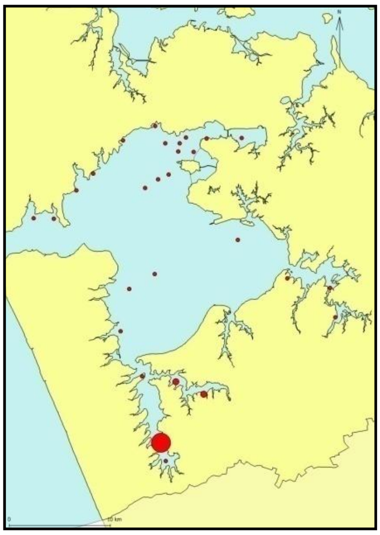

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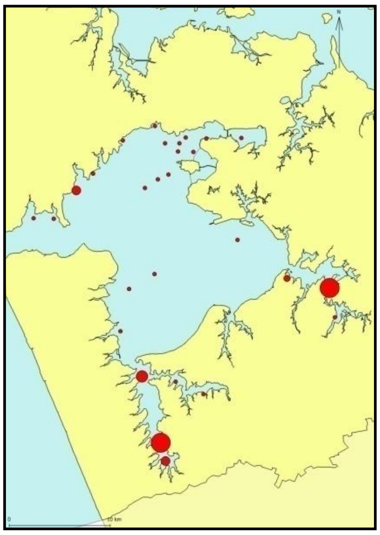

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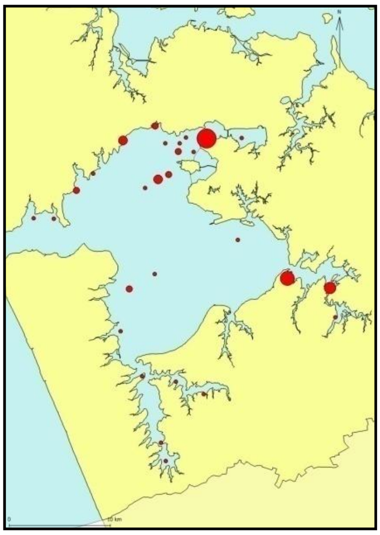

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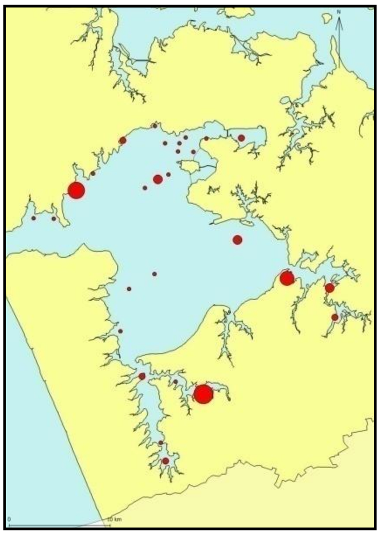

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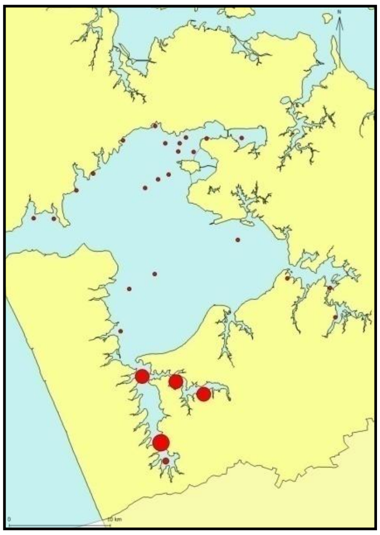

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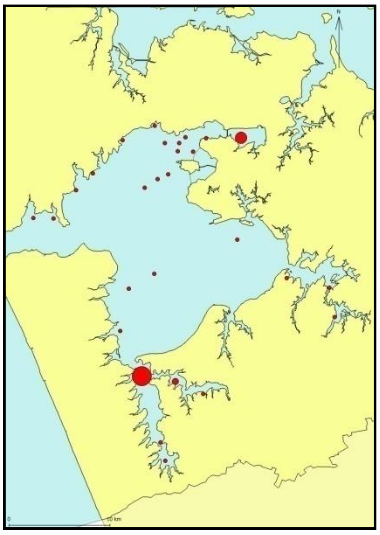

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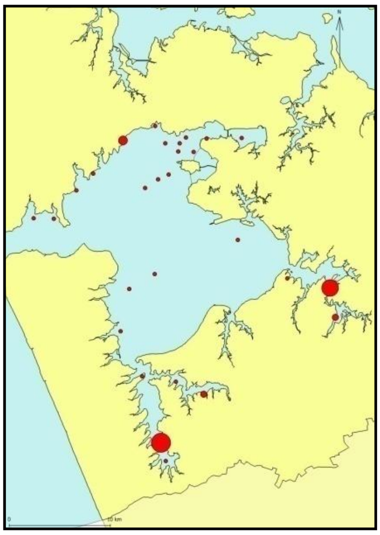

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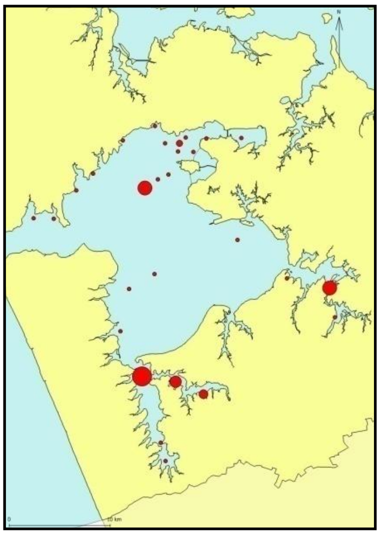

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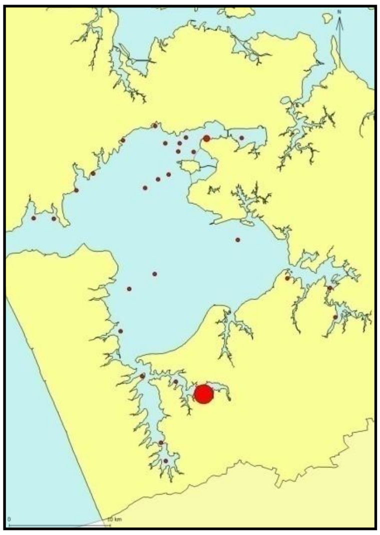

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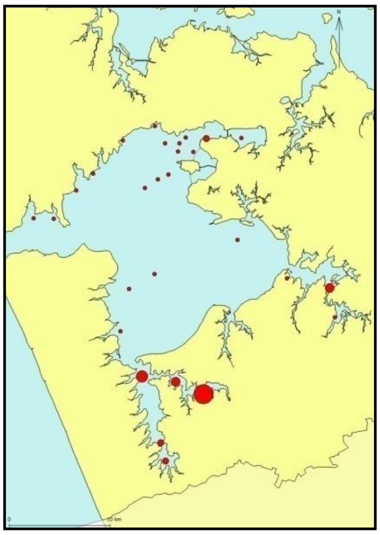

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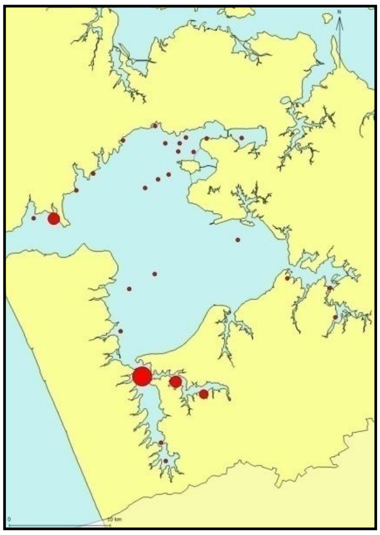


Beach seine and outrigger trawl surveys have also been used to examine fish movements in relation to tide (high, low) and diurnal (night, day) phases in Pahurehure Inlet (Morrison et al 2002). Seventeen species of fish were caught (Table 5), with the most abundant being anchovy (*Engraulis australis*), yellow-eyed mullet (*Aldrichetta forsteri*), goby (*Acentrogobius lentiginosus*), and speckled sole (*Peltorhamphus latus*). Most fish were less than 100 mm in length, and were either the juveniles of large fish species, or the adults of small fish species. Two assemblages of species, which co-occurred in time and space, were identified from the beach seine data:

1. yellow-eyed mullet and anchovy which were abundant in the daytime, low tide samples but rare in the night time, low tide samples;

2. goby, speckled sole, yellow belly flounder, sand flounder and triplefin which were more abundant at low tide than at high tide.

Three assemblages were identified from the outrigger survey:

1. anchovy, garfish and sand flounder which were consistently present at both high and low tide, day and night and in two or three of the tidal zones;

2. goby, speckled sole, yellow belly flounder, Jack mackerel, and triplefin were most abundant at night, though speckled sole was also caught during the day;

1. yellow-eyed mullet and grey mullet were most abundant in low tide samples, though yellow-eyed mullet was also often caught at high tide.

At high tide, fish generally spread themselves across the tidal flats, and did not accumulate in a band that followed the rising and falling tide line, or in particular tidal zones. Rather, the whole tidal flat appeared to be utilised. Two exceptions to this pattern were observed. Goby and triplefins were most abundant near the channel, and were not caught in high tide beach seines.

Data suggested that some species moved hundreds to thousands of metres over a tidal cycle, and that this scale of movement occurs by night and day for most species. At low tide fish concentrated in the deep channels, immediately adjacent to the tideline. Consequently, species diversity and abundance estimates were higher for the beach seine samples taken at low tide.

Table 5: Fish species obtained from beach seine and outrigger trawl surveys in Pahurehure Inlet (Morrison et al 2002).

Species Name	Common Name
Engraulis australis	Anchovy
Aldrichetta forsteri	Yellow-eyed mullet
Acentrogobius lentiginosus	Goby
Peltorhamphus latus	Speckled sole
Mugil cephalus	Grey mullet
Rhombosolea leporina	Yellow belly flounder
Rhombosolea plebeia	Sand flounder
Tripterygiidae	Triplefin
Hyporhamphus ihi	Garfish
Trachurus novaezelandiae	Jack mackerel
Pseudocaranx dentex	Trevally
Leptoscopus macropygus	Estuary stargazer
Anguilla dieffenbachii	Longfin eel
Genyagnus monopterygius	Spotted stargazer
Ophisurus serpens	Snake eel
Syngnathidae	Pipefish
Retropinna retropinna	Common smelt

Yellowbelly flounder (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 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 subsample of fish. A subsample 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 (i.e. the most contaminated site) also had a higher prevalence of pre-neoplastic (i.e. 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.

Research conducted by NIWA (led by Mark Morrison) has recently estimated the contribution that harbours make to the open West Coast snapper population (Morrison et al 2009, NIWA 2009). NIWA estimate that 98% of West Coast snapper originate from Kaipara Harbour. Conversely, <2% of west coast snapper originate from Manukau Harbour. This is unexpected given that the two harbours are similar in size and physical characteristics. The reasons for this difference are unclear, but potential links to environmental degradation cannot be ruled out. Morrison et al (2009) (reporting on unpublished work being carried out by M. Lowe), indicated that the physiological condition of juvenile snapper was negatively related to suspended sediment loads. Parasite loads and gill deformation also increased with increasing levels of sediment. Sediment also affected the feeding habits of juvenile snapper. Pelagic prey dominated their diet in clear estuaries, while benthic prey dominated their diet in turbid estuaries (including Manukau Harbour). Morrison et al (2009) suggest that these changes may reduce the overall food supply available to juvenile snapper, and perhaps the nutritional value of their food. Furthermore, these affects may be compounded by reduced feeding efficiency in turbid environments. Tank experiments showed that the foraging success of juvenile snapper decreased with increasing suspended sediment levels. A number of sediment-related, sub-lethal effects were also recorded in tank experiments conducted over one month. These included: increased coughing and gulping at the surface; paler colouration; higher respiration rates; and decreased activity.

Juvenile snapper have a strong association with structurally complex habitats such as subtidal seagrass beds (Schwarz et al 2006) and horse mussels (Morrison et al 2009). Morrison et al (2009) report that in West Coast estuaries, most juvenile snapper were associated with the presence of live horse mussel beds. In the Manukau and Kaipara Harbours, these were found in spatially discrete patches or strips on the edge of the main subtidal channels. In the Kaipara Harbour, juvenile snapper were also strongly associated with subtidal seagrass meadows. Large scale losses of seagrass have occurred in Manukau Harbour (Henriques 1977, Inglis 2003), and the distribution of horse mussel beds may have also been reduced due to high suspended sediment concentrations in the harbour (Scarsbrook 2008), and horse mussel's sensitivity to sediment (Ellis et al 2002, Hewitt and Pilditch 2004, Safi et al 2007). Habitat loss may, therefore, also be a factor involved in the relatively low contribution the Manukau Harbour makes to the West Coast snapper population.

11 Vegetation

One of the most widely distributed and conspicuous coastal plants in Manukau Harbour is the mangrove *Avicennia marina*. Mangroves can impinge on human use and the perceived value of the coastal environment. Consequently, some sectors of the community regard mangroves as a nuisance, and seek to limit their spread. Illegal clearances have occurred in most areas of Pahurehure Inlet, with tall mangroves more frequently targeted (Kingett Mitchell Limited 2005). Kingett Mitchell Limited (2005) found that some areas were being maintained free of mangroves by the active weeding of propagules, while others were being left to regenerate.

The extent of mangrove expansion was examined by plotting 2006 mangrove cover using GIS and aerial photographs provided by the ARC (Table 6, Figure 45) and comparing this with information reported in earlier studies. Maps produced from 2006 aerial photographs indicated that mangrove cover was most extensive in muddy, sheltered side-branches of the harbour. Few mangroves occurred in the exposed main body of the harbour, and when they did, they invariably occurred in the lee of a physical barrier. Mangrove cover also tended to be more sparse in the wider main channels of Waiuku Creek and Pahurehure Inlet. The total area covered by mangrove forests in 2006 was estimated to be approximately 1100 ha. Waiuku Creek and Pahurehure Inlet had the greatest areas of mangrove cover, reflecting their physical size. However, Clarks Creek, which is a long, narrow inlet, had the greatest proportion of area covered by mangroves.

Mangrove cover in Manukau Harbour has increased markedly over the past 50 years, with the most substantial increases occurring in the past 30 years. Aerial photos also show that mangroves were absent from Mangere Inlet, or limited to an occasional scattered tree in 1959. Mangrove cover slowly increased over the next 17 years and by 1976 Ann's Creek contained approximately 1 ha of mangroves, while Harania and Tararata Creeks contained approximately 4 ha of mangroves each (Henriques 1977). After the mid 1970's mangroves spread more rapidly, to cover around 97 ha by 2006. Similar expansion also occurred in other parts of the harbour. For instance, over the same period cover in Waiuku and Taihiki Creeks increased from 60 to 274 ha, and from 113 to 272 ha in Pahurehure Inlet. Overall, since 1976, total mangrove cover in Manukau Harbour has increased by around 250% from approximately 447 ha to approximately 1100 ha.

Table 6: Estimated area covered by mangroves in 2006 and 1976 (Henriques 1977). 2006 areas were estimated from GIS shapes obtained from aerial photographs.

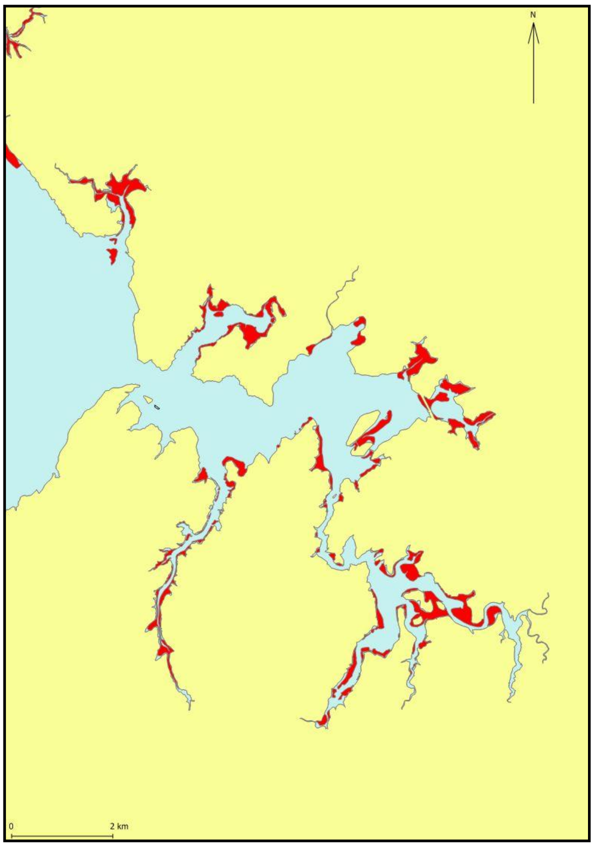
Locality	2006 Mangrove Area (Ha)	1976 Mangrove Area (Ha)
Pahurehure	272	113
Puhinui	40	30
Pukaki	136	88
Mangere Inlet	97	9
Clarks Creek	113	52
Waiuku Creek (including Taihiki)	274	60
Awhitu Peninsula (north of Clarks Beach)	91	41
Big and Little Muddy Creeks	57	50
Other	20	4
Total	1100	447

Figure 45: Mangrove distribution (red areas) in the a) northern, b) south east, and c) south west Manukau Harbour.

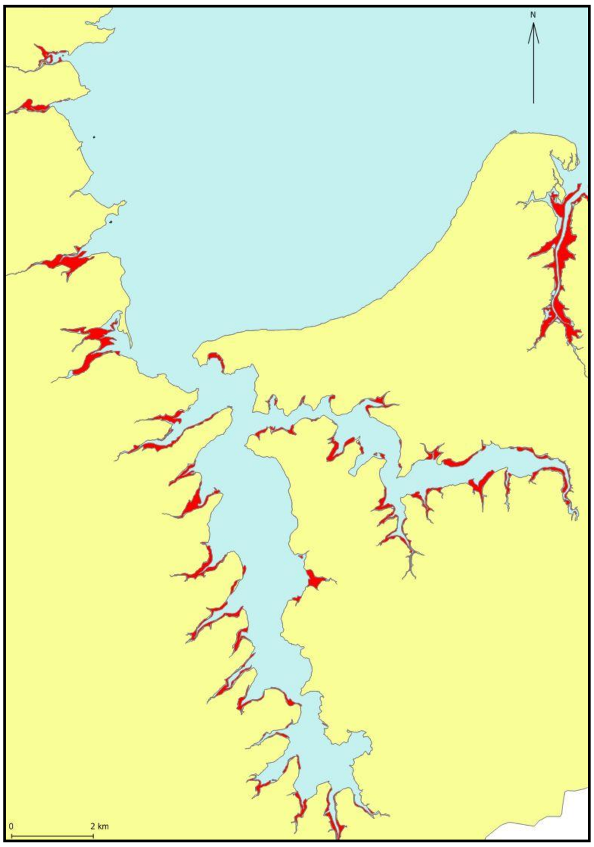
Data were plotted from 2006 aerial photographs provided by the ARC.

a)

b)



c)



Seagrass is another conspicuous and ecologically important vegetative habitat within the harbour. Seagrass cover declined considerably between the early 1960's and mid 1970's, possibly due to infection by the fungus *Labyrinthula* (Henriques 1977). In the mid 1970's seagrass (*Zostera novazelandica*) covered a total of 171 hectares in Manukau Harbour or about 1.2% of the intertidal area of the harbour. This represented about 19% of the total vegetated area. Seagrass beds mainly occurred on open, intertidal sandflats of the harbour, with patches located at the mouth of Big Muddy Creek, on Karore, Hikihiki and Hangore Banks, beside Papakura Channel, on the foreshore between Clarks Beach and Seagrove, on the east coast of Awhitu Peninsula and in Big Bay (Henriques 1977). The largest areas of seagrass flats were located between Clarks Beach and Seagrove, covering a combined area of around 123 ha, which comprised 72% of total seagrass cover in the harbour. Coverage at the other locations was relatively limited with the second-largest area found on Karore Bank (ca. 19 ha total cover). Seagrass cover is reported to have increased during the 1990's (Turner et al 1999), but up-to-date empirical data is lacking.

Henriques (1977) also estimated that the harbour contained around 91 ha of saltmarsh in 1976. Saltmarsh was found in Mangere Inlet Drury Creek, along the coast between Clarks Creek and Pahurehure Inlet, between Seagrove and Clarks Beach, in Waiuku River, Parakau Creek, Rangiriri Creek, Matakawau Creek, Kauritutahi Creek, and in the Creek between Kauritutahi Creek and Binnies Bay. He also noted 10 hectares of native salt marsh in the northeast and south east corners of Mangere inlet. The Auckland Regional Plan: Coastal also identifies a small, upper-intertidal area with a diverse mix of native saline vegetation in the south-eastern corner of Mangere Inlet. The plan indicates that the area also contains maritime marsh and a 0.25 ha meadow of batchelor's button, *Cotula coronopifolia* and designates it as a Coastal Protection Area because of 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 it is the type locality for the shrub, *Coprosma crassifolia*, which still grows naturally on nearby Hamlins Hill.

The introduced cordgrass *Spartina alterniflora* and a hybrid variant were historically planted in some parts of the harbour for land reclamation purposes. In the 1970s, *Spartina* was not common and appeared to be limited to a few patches covering a total of ca. 10 ha, which generally occurred below native saltmarsh vegetation. Patches were located on the southern shore of the Pahurehure, in Blackbridge Creek, on the foreshore between Clarks Beach and Seagrove, and in Waipipi Creek. *Spartina anglica* was introduced at Karaka Point in the mid–1970s and planted at two mid-tide sites that were approximately 0.5 km apart. These were used to test the effects of *Spartina* control (using herbicide) on sediment remobilisation (Swales et al 2005). The above ground cover of *Spartina* completely disappeared within three months of herbicide application, but roots and rhizomes persisted for much longer. The below-ground biomass was also a better predictor of bed elevation. Modelling predicted that the loss of accumulated sediment from sprayed *Spartina* beds would take 6–10 years. Swales et al (2005) concluded that the adverse sediment effects of *Spartina* control would be minimal at wave-exposed sites, if the treated areas are small relative to the size of the estuary.

Gracilaria is a bloom forming red algae species that is commonly associated with elevated nutrient inputs. Two, easily confused, species are present in Manukau Harbour: the native *Gracilaria chilensis* (previously referred to as *Gracilaria secundata*) and the (apparently) introduced *Gracilaria sp.* (Wilcox et al 2007). These species are difficult to distinguish morphometrically, but can be separated using chemical and genetic assays (Cohen et al 2004, Wilcox et al 2007). The introduced Australian brown alga *Dictyota furcellata* has also been reported from a sheltered, shallow, subtidal site on the south-western shores of Manukau Harbour (Nelson et al 2004).

The extent of *Gracilaria* meadows increased in Manukau Harbour after the Mangere Wastewater Treatment Plant began operation in 1960. The area covered by *Gracilaria* in the vicinity of the plant steadily increased from approximately 7 ha in 1960 to around 110 ha in 1976, which constituted around 85% of total *Gracilaria* cover in the Harbour. In the mid 1970s *Gracilaria* meadows were also found on Te Tau and Motukaraka Banks, in Blockhouse Bay, Big Muddy Creek, Little Muddy Creek, on the southern shore of Papakura Channel and near the entrance to Pahurehure Inlet.

Watercare Services Ltd monitored *Gracilaria* biomass at nine stations between 1995 and 2001, and at 15 stations between 2002 and 2007 (Bioresearches 2008a). Substantial reductions in the mean biomass of *Gracilaria* appear to have occurred since the recent upgrade of the Mangere Wastewater Treatment Plant (Figure 46), with mean biomass dropping from values of up to 477 g m^{-2} to zero, or very low levels (<12 g m^{-2}), at three of the worst affected sites (sites 11, 19 and 31). However, the biomass of *Gracilaria* at monitoring Site 4 has remained relatively high. The amount of area covered by macroalgae also declined markedly in Mangere Inlet and on the western side of Puketutu Island following the upgrade of the treatment plant and a smaller reduction in cover also appears to have occurred at sites between Waikowhai Bay and Big Muddy Creek (Figure 47). However, macroalgae cover has remained relatively static on the northern side of Puketutu Island and increased in the area previously occupied by ponds 3 and 4.

Figure 46: Changes in the mean biomass (dry weight) of *Gracilaria* between 1995 and 2007 at Watercare Services Ltd's four worst-affected sites (from Bioresearches 2008a).

Data collected prior to the upgrade of the Mangere Wastewater Treatment Plant are shown in red and data collected after the upgrade are shown in green. Note that the maximum, mean biomass recorded at Watercare's other 11 monitoring sites is 56 g/m^2.

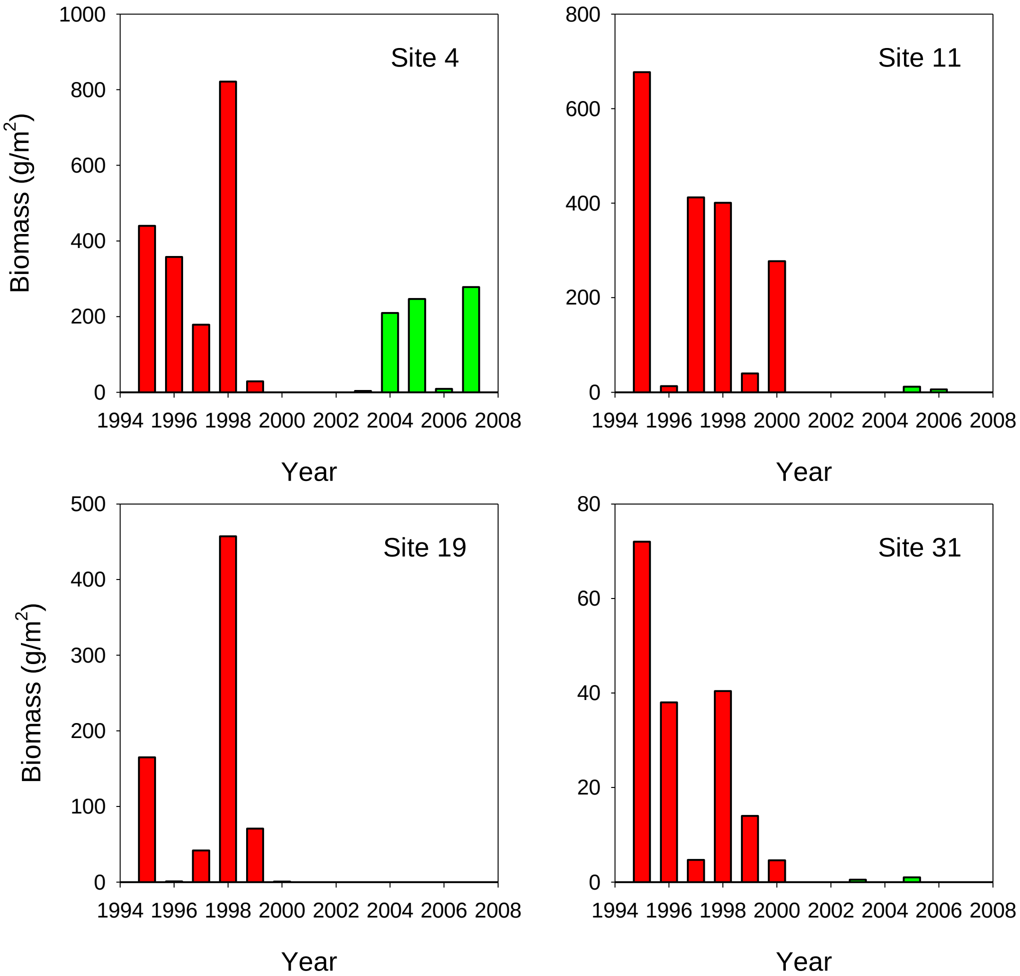
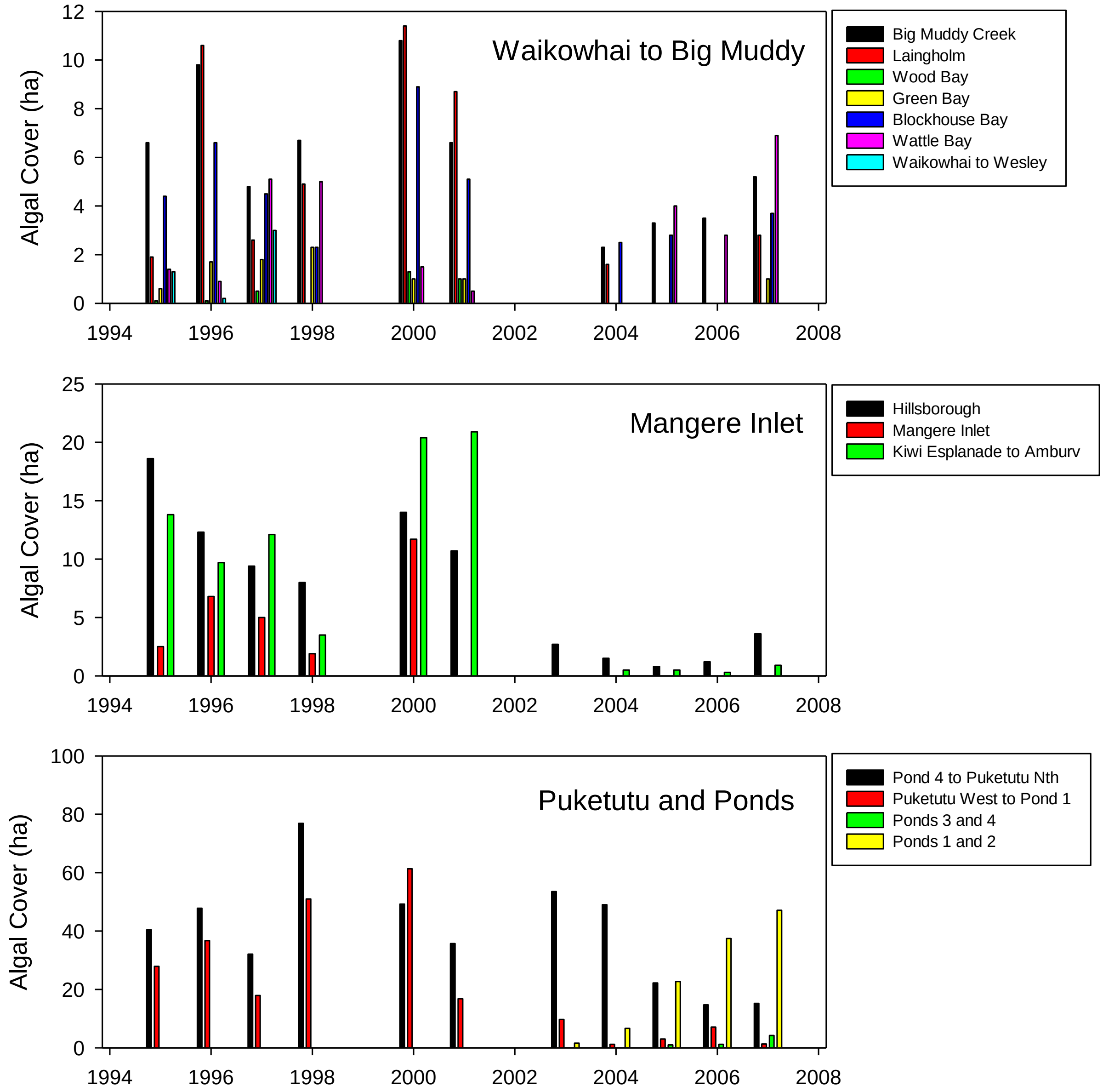


Figure 47: Changes in the area covered by macroalgae prior to (earlier than 2002) and following (after 2002) the upgrade of the Mangere Wastewater Treatment Plant (data from Bioresearches 2008a).



12 Synthesis

The knowledge obtained from over 70 years of research and monitoring in Manukau Harbour has provided a strong base of information for a broad level evaluation of the values and condition of the harbour. Available data shows that there is a wide variety of habitats and associated species assemblages in the harbour. Habitat diversity reflects the large size of the harbour, its geology, complex shoreline, and hydrodynamics. Habitats and species assemblages vary according to substrate, sediment texture, exposure, tidal height and currents. Habitat diversity is also enhanced by the presence of habitat forming species such as coastal vegetation and structurally complex benthic fauna.

The harbour's extensive intertidal sandflats and mudflats contain highly productive benthic communities, which mediate physico-chemical processes, sustain bird and fish populations, and provide important food resources for people living in the Auckland Region. The harbour is a particularly important feeding area for native and migratory wading birds and is recognised as a national "hotspot" for coastal bird diversity and endangered bird species. Intertidal sandflats in the central harbour generally consist of sandy sediments, which contain diverse communities that have a high proportion of large, environmentally sensitive and highly valued species (Gibbs and Hewitt 2004, Hewitt and Hailes 2007, Hewitt et al 2009). The sandflats are drained by subtidal channels, which provide habitat for sedentary subtidal invertebrates and a low tide refuge for mobile fish species. The main channels and shallow subtidal sandbanks of the harbour are heavily targeted by recreational fishers seeking finfish and scallops.

Relatively small, intertidal and subtidal reef and boulder habitats occur around the margins of the harbour. These support a variety of mobile and sessile reef species, with affiliations that grade from to coastal to sheltered harbour (Hayward and Morley 2004). Highly valued areas of coastal vegetation are also scattered throughout the harbour (Section 11). These include large seagrass beds, saltmarsh, coastal-forest vegetation sequences, and mangrove forests. These areas are important for their vegetation and landscape values, and as habitats utilised by coastal and marine fauna. Saltmarsh and mangrove cover is greatest in inlets and side-branches of the harbour. These areas are also more sheltered and muddier than the central body, and therefore contain a different mix of benthic macrofauna. Side-branches are particularly important for juvenile fish, which tend to be more diverse and abundant in these areas (Section 10).

Published information clearly shows that Manukau Harbour has an unenviable history of environmental management. Side-branches of the harbour tend to trap sediments and associated stormwater contaminants (Section 5). Consequently, they are becoming muddier, more infilled, and mangrove expansion is increasingly being viewed as a significant issue (Sections 5 and 11). However, concentrations of the key stormwater contaminants: copper, lead and zinc, are relatively low, except in Mangere Inlet and Oruarangi Creek (Section 5.1). The worst affected inlet is Mangere Inlet, which received direct discharges of industrial and domestic waste for around a century. The commissioning of the Mangere Wastewater Treatment Plant significantly improved the condition of Mangere Inlet by eliminating the direct discharge of untreated industrial wastewater. However, ongoing stormwater runoff (Croucher et al 2005b, Kelly 2007b) and isolated discharges of point-source contamination are still issues (e.g. Clarke 2007). Oruarangi Creek has also been heavily impacted by modification, catchment development and the associated effects on stormwater runoff (Section 3.2). Unfortunately, concentrations of copper and zinc in a number of other areas are predicted to increase above sediment quality guidelines over the next 18-100 years, and modelling suggests that contaminant source control and stormwater treatment can only slow (not reverse) this process.

Side-branches with urban catchments tend to have degraded benthic communities, even though current concentrations of stormwater contaminants are relatively low. Clear gradients in ecological condition are apparent between the central harbour and the upper reaches of tidal inlets (Section 8). Despite this, all of the tidal inlets still contain functioning benthic communities that continue to provide a range of functions and services (e.g. contributing to food-webs and geochemical processes). The central body of the harbour is less susceptible to sediment and contaminant accumulation because it is large and energetic, and a high proportion of sediments are trapped in tidal inlets. Long term water quality data also indicates that suspended sediment concentrations declined between 1987 and 2007 in the main body of the harbour (Scarsbrook 2008). However, long term sediment texture data suggest that transitory sediment deposits do occur at Clarks Beach (these have also been observed personally) and monitoring also indicates that the benthic community at the Clarks beach site is highly variable (Hewitt and Hailes 2007). Modelling also suggests that a significant proportion of sediment derived from south-east catchments is exported to the main body of the harbour (Green 2008a). Consequently, the potential for suspended sediments and transitory sediment deposits to affect benthic communities in the main body of the harbour cannot be ruled out.

The expansion of *Gracilaria* beds between 1960 and 1976 (Section 11), and more recent analysis of long term water quality data (Section 7), also indicates that the water quality in the harbour has been heavily influenced by the discharge from the Mangere Wastewater Treatment Plant from 1960 onwards. The 2001 upgrade to the plant significantly improved water quality, but the effects of the discharge are still distinguishable.

Invasive species have also had a significant impact on harbour ecosystems and values, particularly Pacific oysters. The harbour could become more susceptible to the establishment and spread of invasive species if environmental degradation reduces the resilience of the harbour ecosystem. Fishing is also likely to have had a major impact on target species and the broader harbour ecosystem. The harbour is known to be heavily fished by recreational scallop harvesters and commercial and recreational fin-fishers, but published information on fishing in Manukau Harbour is limited, and no information was obtained on fishing related impacts on non-target species. However, it is particularly disturbing that recent research shows that less than 2% of West Coast snapper originate from Manukau Harbour, compared with 98% from Kaipara Harbour, which is similar in size and physical characteristics (Section 10). The reasons for this discrepancy are unknown, but environmental degradation cannot be ruled out as a contributing factor.

12.1 Conclusions

Manukau Harbour has very high ecological values due to its highly productive intertidal flats, the large number and diversity of waders and other coastal birds, variety and cover of coastal vegetation, and importance to fish.

The Mangere Wastewater Treatment Plant has had a major influence on water quality in the harbour since 1960. Although the treatment of industrial and domestic wastewater improved environmental quality in Mangere Inlet, the discharge from the plant has negatively affected overall water quality in the harbour. Having said that, water quality has steadily improved since 1987 and recent modifications have further reduced the impact of the plant.

Moderate levels of sediment contamination occur within Mangere Inlet, the decommissioned Mangere oxidation ponds, and Oruarangi Creek. Sediment quality in other parts of the harbour is relatively good, but it is predicted to degrade in a number of areas that adjoin urban catchments. Sedimentation and mangrove expansion is also occurring in tidal inlets around the harbour. This has led to a change in habitat cover and is likely to be degrading mudflat communities. Sediment is also dispersed to the central harbour and could be affecting the broader harbour ecosystem. Invasive species such as Pacific oysters have also had a major impact on human and the natural ecological values of the harbour. The effects of fishing are unknown, but are also likely to be significant.

Available data clearly shows that ecological communities, and environmental characteristics and quality vary widely around Manukau Harbour, and that spatially discrete habitats are linked, to varying degrees, through passive dispersal and biologically active processes. The effects of stormwater discharges should therefore take into account the environmental values and quality of the immediate receiving environment, and the potential for cumulative, broader scale impacts. Broad scale impacts could occur through the widespread dispersal of sediment and stormwater contaminants, or by degrading localised receiving environments that have especially important ecological roles. The latter includes areas of importance for rare or migratory species (e.g. birds), and areas of importance to particular life stages (e.g. juvenile fish).

13 Acknowledgements

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16 Appendix 1: Cultural protection and preservation sites

Figure 48: Locations of cultural protection (green) and preservation (orange) sites identified in the Auckland Regional Plan Coastal.

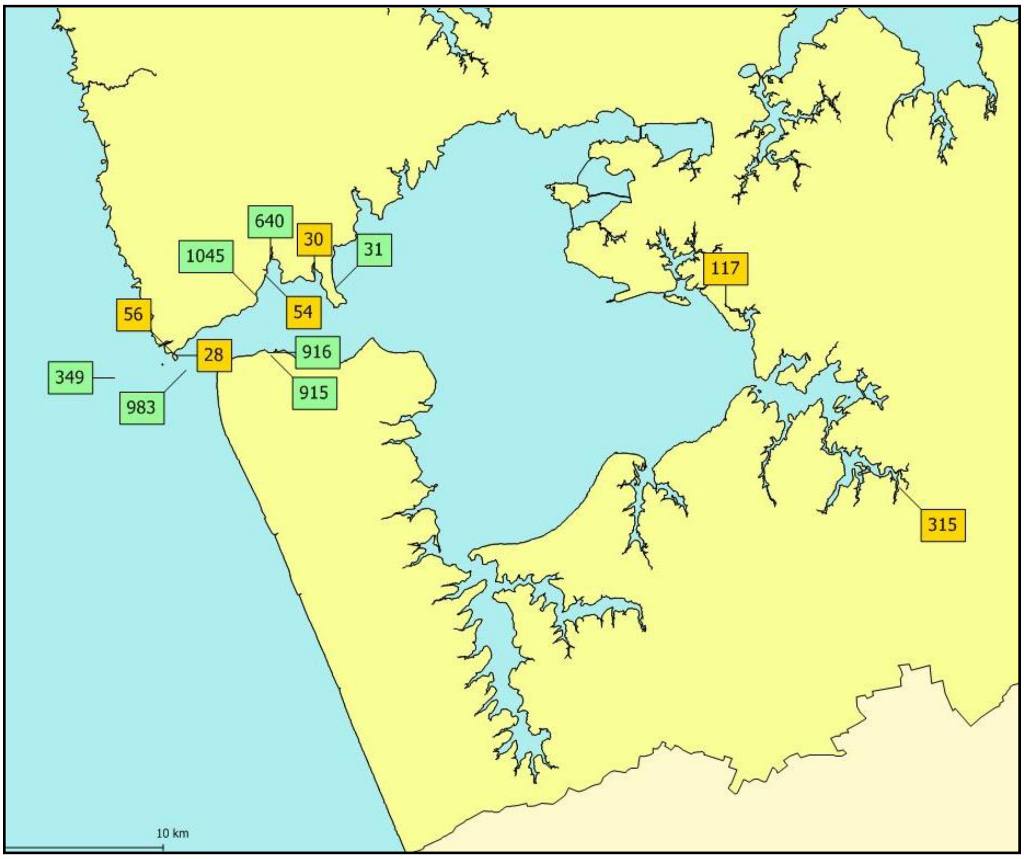
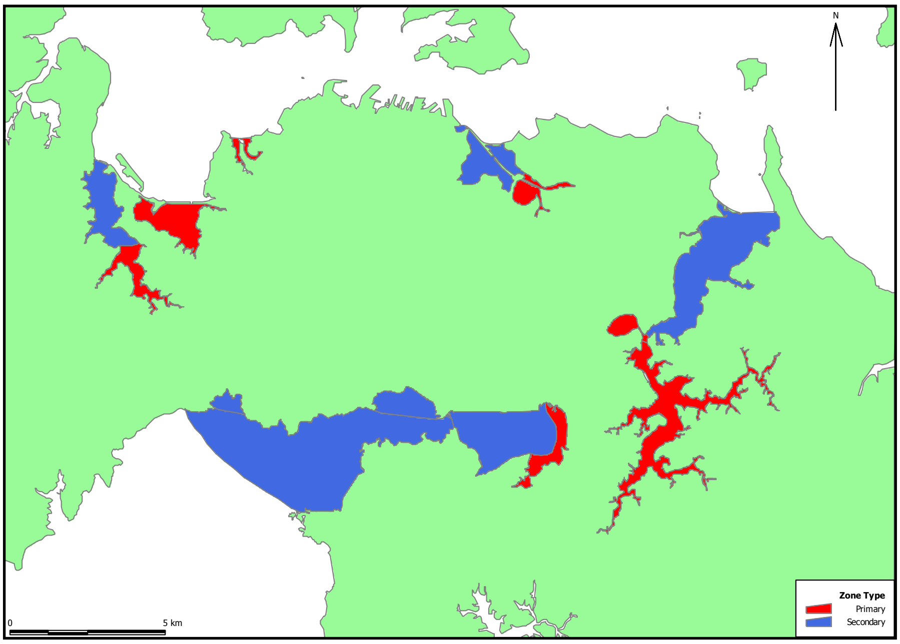


Table 6: Desriptions of cultural protection and preservation sites identified in the Auckland Regional Plan Coastal.

Site Number	Designation	Description
28	Preservation	Wharf Site Whatipu Wharf Site Whatipu, Paratutai, Manukau Heads
30	Preservation	Wharf Site/ Tramway Site Kakamatua Wharf and Tramway Site Kakamatua Inlet, Manukau Harbour
54	Preservation	Sawmill Site Manukau Timber Company Mill Site Hinge Bay, Manukau Harbour
56	Preservation	Tramway Karekare-Whatipu Tramway Karekare-Whatipu,Waitakere Ranges
117	Preservation	Fish Traps Puhinui Fish Traps Puhinui Stream, Manukau Harbour
315	Preservation	Landing Site Slippery Creek Landing Site Slippery Creek, Drury, Manukau Harbour
349	Protection	Shipwreck H.M.S. ORPHEUS Between Orwell and Outer Banks, Manukau Heads, Manukau Harbour, map location estimated
915	Protection	Midden (Archaic) Matatuahu, Archaic Midden, University Excavation site, Te Pirau Point, Wattle Bay, South Head, Manukau Harbour
916	Protection	Midden (Archaic) Matatuahu Archaic midden Te Pirau Point, Wattle Bay, South Head, Manukau Harbour
983	Protection	Shipwreck P.S. PIONEER Middle Bank, Manukau Heads, Manukau Harbour, map location estimated
1045	Protection	Ford Little Huia Ford Little Huia, Manukau
31	Protection	Wharf Cornwallis Wharf Cornwallis, Manukau
640	Protection	Landing Huia Landing Huia Bay, Manukau

17 Appendix 2: Alternative depositional zones

Figure 49: Alternative depositional zones identified by Auckland City Council – Metrowater



18 Appendix 3: Sediment quality guidelines

Table 7 Sediment quality guidelines for copper, lead and zinc

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

19 Appendix 4: Metal concentrations

Table 8: Copper , lead and zinc concentrations obtained from ARC monitoring sites.

Site Name	X_NZTM	Y_NZTM	Zone	<500Cu-Mean	<500Pb-Mean	<500Zn-Mean	<63Cu-Mean	<63Pb-Mean	<63Zn-Mean
Anns Creek	1762214	5911375	OZ	24	27	150	26.4	36.3	178.2
Mangere Cemetery	1759965	5911179	OZ	21	24	130	18.3	26.2	130.6
Pukaki Airport	1760623	5903545	SZ	7.1	9.3	56	7.5	10.0	62.4
Pukaki, Upper	1760410	5904750	SZ	5.6	9.1	47.3	5.3	12.7	49.7
Pukaki, Waokauri	1761535	5904107	SZ	8.8	13.1	69.6	6.0	13.3	54.3
Puhinui, Entrance	1764945	5899795	OZ	4.1	7.8	51.3	5.0	10.1	47.7
Puhinui, Upper	1765064	5900551	SZ	9.2	12	110	10.6	14.3	118.2
Waimahia Creek East	1767789	5898668	DZ	9.3	15.0	78.3	6.0	13.0	60.7
Waimahia Creek West	1766612	5898765	DZ	8.3	13.4	67.8	6.0	12.9	58.7
Pahurehure, Middle	1767561	5896924	OZ	2.4	5.9	24.4	5.3	11.7	46.0
Pahurehure, Papakura	1771307	5896717	DZ	7.6	13	73	10.1	18.7	99.4
Pahurehure, Upper	1769610	5897428	OZ	1.8	3.8	18.0	6.7	14.2	57.3
Papakura Stream Lower	1768760	5898075	SZ	10.1	15.7	76.0	6.0	13.1	51.3
Papakura Stream Upper	1769006	5898214	SZ	11.5	17.8	86.2	6.0	14.0	54.0
Waiuku	1753313	5877050	SZ	9.4	17.0	92.6	6.7	16.3	81.3

Blockhouse Bay	1752272	5911617	OZ	0.0	0.0	0.0	11.0	19.0	68.0
Little Muddy	1746483	5908784	SZ	11.4	14.9	60.9	10.0	14.8	59.7
Hillsborough	1756792	5911582	OZ	9.5	13.4	67.6	13.0	20.0	81.3
Big Muddy	1744463	5906831	SZ	9.1	9	56	11.0	12.9	74.5

20 Appendix 5: Measuring species dominance

The methods used by Grange (1979) to classify species dominance are provided below.

Dominant, subdominant, and secondary species were identified for each group, as defined below:

- Dominant species occurred in more than 50% of stations and had a community score (see below) of > 25%.
- Subdominant species had a community score of <25%.
- Secondary species did occur in <50% of stations, but had > 50% of their total distribution within a particular community group (i.e. species assemblage), if they occurred at 4 or more stations throughout the harbour.

The community score (expressed as a percentage of the total possible community score) was used to provide an objective rank of dominance based on the following criteria:

1. **Percentage Distribution**: the percentage of stations the species occurred in, within the community group. Recall that it must have occurred in > 50% of stations in the group;
2. **Bioindex Value**: obtained by ranking the 10 most abundant species at each station within the ccommunity group, and scoring them from 10 (rank 1) to 1 (rank 10). The points were then summed for each species;
3. **Fidelity Index**: the proportion of the total count for each species, that occurred in the community group.

Where: Community Score = (Percentage Distribution + Bioindex Value) x Fidelity Index

21 Appendix 6: Bird species list

Common Name	Latin Name	Origin	Threat Status
All black stilt and 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	
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	

Common Name	Latin Name	Origin	Threat Status
Grey duck	*Anas superciliosa superciliosa*	Native	2
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
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	
Siberian tattler	*Tringa brevipes*	Sraggler	
Sooty shearwater	*Puffinus griseus*	Native	
South Island pied oystercatcher	*Haematopus ostralegus finschi*	Endemic	
Southern Black-	*Larus dominicanus*	Native	

Common Name	Latin Name	Origin	Threat Status
backed Gull	*dominicanus*		
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