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Habitats of particular significance for fisheries management: the Kaipara Harbour

New Zealand Aquatic Environment and Biodiversity Report No. 129

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The Kaipara Harbour is New Zealand's largest estuary, and has been identified as a system which supports important fisheries functions both for the harbour proper, and for the wider west coast North Island ecosystem. This review is divided into a number of linked sections. Firstly, we use written records and accounts to create a narrative of the environmental history of the harbour, extending back to the late 1800s. The early history of kauri logging and flax gathering, followed by pastoral farming, exotic forestry and sand mining is discussed, along with the legacy of increased sedimentation and other environmental changes associated with some of these industries. The development, and in some cases subsequent decline, of harbour fisheries for species such as grey mullet, sand and yellow-belly flounder, school shark, rig, kahawai, rock oysters, and green-lipped mussels are described, along with official catch statistics going back to the early 1930s. Recreational fisheries' catches are less well documented, but recent harvest estimates for the harbour from 2006–07 are presented, with catches being dominated by snapper, kahawai, and red gurnard. Following this historical section, we then present results from a Local Ecological Knowledge (LEK) survey of 31 long-time local residents, who were asked to rank the relative abundance of various fish and shellfish species, biogenic habitats, and environmental changes over the time period of their association with the harbour; as well being asked a series of 'open' questions to obtain information about change over time. Of the residents surveyed, the oldest association with the harbour started in the 1930s. Significant changes over time were recorded, with all of the finfish (bar one) and shellfish populations quantified, and habitats such as seagrass, observed to have substantially declined in abundance. Conversely, mangrove forests increased in spatial extent, as did non indigenous species (NIS), including Pacific oysters and Asian date mussels. A narrative was generated from the answers to the open questions, and collectively indicated that the upper reaches and arms of the harbour have become muddier and shallower, biogenic habitats have been lost, and the ranges in the upper harbour of species such as snapper and trevally have retracted. Participants also reported: reductions in the average size of some species, loss of fishing spots to mud for species such as pipi and cockles, changes in fish behaviour, such as large schools of big snapper no longer feeding in very shallow waters, dense scallop beds once, but no longer, associated with seagrass meadows, and very large schools of parore and other species once associated with the 'grasslands' (seagrass meadows). These LEK interviews helped document what the Kaipara Harbour was like historically, and what has been lost from the ecosystem over the last 80 years.

The next section reviews current knowledge about the Kaipara Harbour from recently published studies, and new data collected during fish-habitat surveys of the harbour. In this section we discuss: fringing habitats (salt marsh and mangroves), sediments and bathymetry, benthic communities, rock oyster reserves, scallop beds, small fish in mangrove forests, intertidal flat fish assemblages, seagrass meadows (both subtidal and intertidal), upper harbour grey mullet nurseries, towed camera and beam trawl surveys of the subtidal area, and set net sampling for larger fish in the upper harbour reaches. No fish species were found to solely rely on any one habitat type, but different habitats were dominated by different fish species, many of which were small non-commercial species such as exquisite gobies, triple-fins, specked soles, and anchovies. In terms of commercial fisheries species, mangrove forests were nurseries for small juvenile grey mullet and short-finned eels, while bare tidal flats provide nursery grounds for yellow-belly flounder, sand flounder, and larger sized juvenile grey mullet. The lower edges of intertidal seagrass meadows also supported very small grey mullet juveniles, and to a lesser extent small juvenile kahawai, while the subtidal seagrass meadows held relatively high densities of juvenile snapper (under 100 mm) (5.18 ± 1.0 per 100 m^2) and trevally

(4.49 ± 1.7), as well as a range of other species, as sampled in 2006. Recent sampling in 2013 of the same habitats (samples still being processed) returned provisionally similar numbers, indicating that this area is consistently important as a nursery habitat for fisheries species. Sampling of Asian date mussel beds with substantial red algal canopies in the same 2013 survey also returned high numbers of juvenile snapper, comparable to those observed for subtidal seagrass, suggesting that this non-indigenous species (NIS) with its associated algal canopy may be providing a juvenile nursery function in some settings. A beam trawl and towed camera survey of the shallow subtidal flats and channels found these areas to be dominated by snapper, with juveniles, sub-adults, and adults all returning higher densities from areas containing biogenic habitat structure (e.g. sponges, horse mussels, algae, hydroids, and a NIS bryozoan). Such habitats and associated snapper densities were notably less common in the north harbour than in the south, thought to be due to the flow of sediments and freshwater from the Wairoa River into the northern part of the harbour during flood events. A set net survey targeting juvenile rig in the eastern arms of the harbour returned the highest densities of juveniles sampled across a number of North and South Island estuaries, with the authors concluding that the Kaipara Harbour was probably the most important rig nursery in the country. An appreciable number of juvenile school sharks was also caught in that survey, which combined with the LEK historical accounts of female school sharks coming into the harbour to pup, suggests that the Kaipara may be a critical nursery area for this species also. Threats and stressors to the fisheries' functions of the harbour were examined also, and we concluded that increased sedimentation was the greatest issue.

In the final empirical section, aerial photography was used to successfully map the subtidal seagrass meadows of the southern Kaipara Harbour, with ground-truthing showing a high classification success for the three primary habitat classes of seagrass (both subtidal and intertidal), Asian date mussel beds, and bare sediments. In addition, this imagery was used to inform a 2013 juvenile/small fish beach seine survey in February/March 2013 of the southern Kaipara Harbour subtidal seagrass and date mussel habitats (about 150 station sampled, as part of the MBIE 'Coastal Conservartion Management' (CCM) programme).

Finally, a series of Kaipara Harbour fisheries habitat knowledge gaps are identified and discussed, including: the functional role of individual habitats for different life history stages of fisheries species; density dependence, connectivity (fish movement); spawning and larval supply; effects of land-based threats and stressors, especially sedimentation; and modelling of habitat change. Suggestions are made on possible approaches to the longer term monitoring of important fisheries habitats, in particular of the extensive subtidal seagrass meadows of the southern Kaipara Harbour.

1. INTRODUCTION

Fisheries management is moving towards a more integrated approach, where the habitats and ecosystems that support fisheries production are viewed as intrinsic to sustainable fisheries management. Such concepts form part of the now widespread movement towards "*Ecosystem Based Fisheries Management*" (EBFM) and other holistic ecosystem management initiatives. Such approaches recognise that marine environments are not homogeneous, and that some areas and places may be ecologically, economically and socially more important than others. Identifying and delineating such places can be demanding, requiring high-quality empirical data, the optimal interpretation of that data, and allowance for scientific uncertainty and the limits of currently available technological tools. Nevertheless, successfully doing so is a fundamental component of these new approaches.

In this report, we focus on one ecosystem that supports important fisheries functions, the Kaipara Harbour, located on the upper west coast of the North Island of New Zealand. At 743 km^2, 60% of which is subtidal, it is New Zealand's largest harbour (Figure 1). This harbour has in the last 15 years become the focus of a number of research projects, as well as increased attention from natural resource managers including regional councils and the Ministry for Primary Industries (MPI). Local communities, including the Integrated Kaipara Harbour Management Group (IKHMG), iwi, local fishers and land owners in the Kaipara catchment have been and continue to be proactive in its care and management. Kaipara Harbour contains the only remaining example on the west coast of extensive subtidal seagrass meadows, which are now known to be important juvenile fish nurseries, including for snapper and trevally. More broadly, Kaipara Harbour has been shown to support the majority of snapper recruits to the adjacent open west coast, underpinning the substantial SNA 8 fishery (Morrison et al. 2009). Similar functions are suspected for other coastal fish species. As well as supporting adjacent coastal fisheries through the export of juvenile fish, the harbour also supports commercial fisheries within its extent, including those for grey mullet, flatfish (yellow-belly and sand flounder), and rig, as well as recreational and customary fisheries for these and other species such as snapper, kahawai, scallops, cockles, oysters and pipi. Its wider ecological and benthic values are also high (Hewitt & Funnell 2005), especially in the southern harbour, where it is thought that the wide harbour entrance and associated wave energies provide some protection from sedimentation (through the winnowing of muds by wave and wind energies). Despite this, significant historical environmental degradation has occurred in the harbour, including reductions in the abundance of many fisheries species (beyond that expected from normal sustainable fisheries management practices), increased sedimentation, large losses and gains in 'fringing' vegetation, and the introduction and spread of marine NIS species. In response to these ongoing stressors, and 'newer' industries such as aquaculture, management agencies have increased their focus on the harbour, including: the Auckland Council (AC) study of the benthos of the southern harbour (partially in response to new Aquaculture Management Areas (AMAs) (Hewitt & Funnell 2005), a review of the ecology and activities in the harbour (Haggitt et al. 2008), and an increased frequency and extent of monitoring by AC (water quality, and intertidal benthic communities). MPI has also increased its focus on the harbour, with a review of set net catch rates for harbour fisheries in response to fisher concerns (Hartill et al. 2004), rock oyster and scallop population surveys (Kelly 2009, 2010), and work on grey mullet stock structure (GMU200901); as well as supporting two MBIE funded research programmes that have included fish/habitat research in the Kaipara, "*Fish usage of estuarine and coastal habitats*" and "*Coastal Conservation Management (CCM)*". This report builds on these previous and current work-streams, with the aim being to contribute to a more holistic management approach to Kaipara Harbour's fisheries functions and associated economic and societal values.

Figure 1: Kaipara Harbour with place names referred to in this report.

In this report, we assemble and assess available information on Kaipara Harbour habitats, the roles they play for fisheries, and potential threats and stressors to those roles. Both primary and grey literature sources are used, in some cases re-working some of the raw data used, to maximise its interpretation with respect to the Kaipara Harbour. Some recent MBIE programme data not yet published in the primary science literature are also included; notably a small fish beam trawl survey undertaken across the harbour, and a very recent (March-April 2012) extensive juvenile/small fish survey of the southern Kaipara Harbour's subtidal seagrass meadows, Asian date mussel patches and bare sediment habitats.

The report is structured as three main sections, and a shorter discussion/recommendation section. The first section deals with the environmental history of the Kaipara Harbour, which is intrinsically intertwined with human activities (e.g., Figure 2a, b), starting with early European records documenting the exploration and exploitation of natural resources. While acknowledging Māori as tangata whenua, we do not include historical oral histories and other tribal material, which were outside the scope of this report. For a good background to such histories, we direct the reader to "The Kaipara Report" (available from http://www.waitangitribunal.govt.nz/), and the webpage of the Integrated Kaipara Harbour Management Group (IKHMG) (http://www.kaiparaharbour.net.nz/Publications). In this first report section, we cover the development of natural resource based industries around the harbour, changes to the harbour environment since it was first settled by Europeans, and the development of fisheries in the harbour (for shellfish and finfish). We then introduce the findings from Local Ecological Knowledge (LEK) interviews of thirty one long-time residents of the Kaipara area, including commercial and customary fishers, who actively fished or used the harbour. The LEK process used a semi-structured interview process, including ranking scores, to semi-quantitatively measure environmental changes occurring between the 1930s and 2010, and to develop a historical narrative based on the observations of the interviewees.

The second section reviews contemporary empirical studies of physical and biological patterns and processes occurring within the harbour. This includes scientific papers, government agency reports, and other literature, as well as the presentation of various data sets both new and already published (including some re-worked). While our focus was on fisheries habitats and function, this required us to look broadly at a range of related themes and processes in the harbour such as fringing vegetation, sediments, the benthos, and a range of habitats and the fish life stages they support. Threats and stressors to the harbour's ecosystems (and by extension its fisheries values) are then reviewed and assessed, including sedimentation, eutrophication, sand mining, fishing, aquaculture, and the introduction of NIS species. Aspects of some of these threats have already been extensively reviewed in earlier reports, and the reader is directed to those reports for greater detail and discussion (e.g., land-based effects on coastal fisheries, Morrison et al. 2009).

The third section of the report describes the use of aerial photography to map critical fisheries habitats in the southern Kaipara Harbour (principally subtidal seagrass meadows), with associated validation using video and visual inspection of seafloor habitats. This work also captured new information on the spatial distribution and extent of NIS Asian date mussel beds, and discusses some provisional findings from a very recent MBIE-funded juvenile/small fish survey, designed using the habitat maps created as part of this project.

Finally, in the general discussion and recommendations section, we summarise what we now know about Kaipara Harbour's fisheries habitats and functions, and where important data and knowledge gaps still lie. We make recommendations for further research to quantify the functions of different habitats for fisheries production (some of which is already in progress). Additional recommendations for ongoing monitoring of key fisheries habitats (and associated fish populations) are suggested to enable the efficacy of fisheries and other management regimes to be assessed.

Figure 2a: a) Water colour painting of members of the Ngati Whatua tribe about 1855 utilizing a shellfish bed in Kaipara Harbour (painted by William Fox); b) Encampment in Helensville in 1863; c) Local women about 1930 shucking toheroa for the local cannery. (Source a) Alexander Turnball Library; b) Helensville Museum; c) Matakohe Museum).

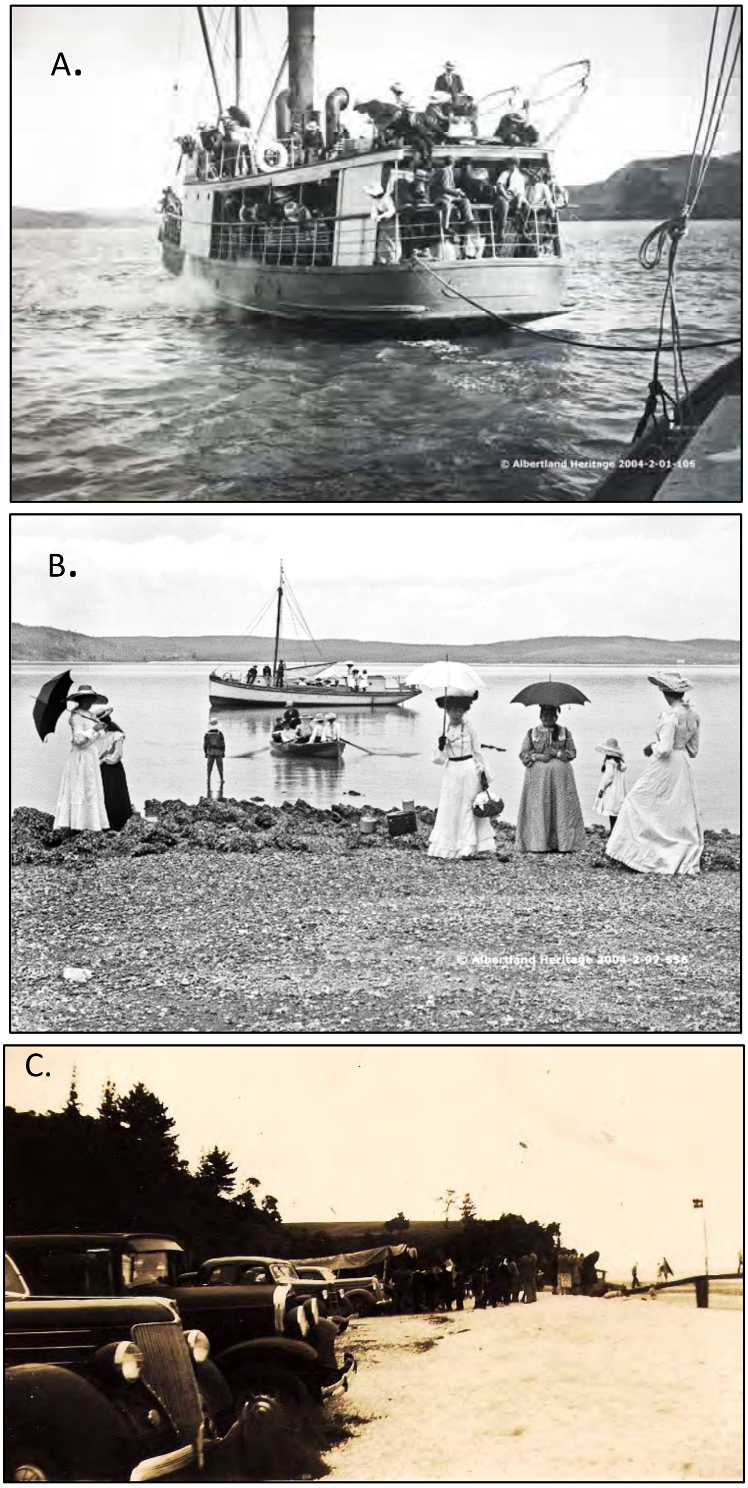

Figure 2b continued. a) Fishing at deep hole on Oruawharo River about 1904 on the way to a picnic at Morgan's Bay; b) Picnic group disembarking from the "Ivy" about 1906 at a landing off Marsh's Beach Warehine; c) A day out at Shelly Beach in the 1940s (Source: a, b, Albertson's Museum, Wellsford; c) T. McMurdo).

Overall Objectives

1. To identify and map areas and habitats of particular significance in the Kaipara Harbour that support fisheries, and assess potential fishing and land-based threats to their function.

Specific Objectives

1. Collate and review information on the role and spatial distribution of habitats in the Kaipara Harbour that support fisheries production.

2. Assess historical, current, and potential anthropogenic threats to these habitats that could affect fisheries values, including fishing and land-based threats.

3. Design and implement cost-effective habitat mapping and monitoring surveys of habitats of particular significance for fisheries management in the Kaipara Harbour.

2. A HISTORY OF EXPLOITATION

2.1 Historical Accounts

Early European settlers began arriving in the Kaipara around 1839, to work predominantly in the kauri (*Agathis australis*) timber industry. First settlers were followed by the 'Albertlanders', assisted settlers who emigrated from Britain between 1862 and 1865 to "*the promised land*", with many settling in the Oruawharo, Paparoa and Matakohe areas. Many early accounts describe the landscape with some awe. In the southern Kaipara, "*magnificent stands of kauri covered almost all of the higher country, while totara and kahikatea predominated on the alluvial valley floors and river margins*" (Murdoch 1988). In the northern Kaipara, the higher land fringing the Wairoa River and its tributaries contained kauri down to the water's edge. Jane Mander describes the kauri in the late 1880s as "*towering up out of the depths on either side of the open way, row upon row of colossal grey pillars, seeming eternal*" (cited in Scott 1995). However, it was the thousands of acres of swamplands containing vast tracts of flax (*Dacrycarpus dacrydioides*) that initially attracted European attention for harvesting. Flax was one of the first exports from the harbour (Figure 3). However, fluctuating prices for flax saw the rise and fall of many mills, which eventually became uneconomic (Murton 2000, Ryburn 2000).

Kauri Timber and Gum

From 1840, pit sawing and provision of spars for the British navy were some of the first industries in the northern Wairoa until the first sawmills opened in 1862. During the first 100 years of European settlement, forestry boomed with 1 200 000 hectares of forest harvested (Figure 3) (Scott 1995). Until the 1890s kauri was the main target followed by kahikatea (Ryburn 2000). It was estimated that timber exported from the port of Kaipara during the halcyon years (up to 1912) made up as much as 65% by value of New Zealand's total timber exports. By 1912, timber exports had begun to decline and by 1918, contributed only 17% by value, further reducing to just under 3% by 1926 (Murton 2000). Concomitant with the rise of timber milling was the high number of ships and coastal steamers visiting the port. In 1906, Kaipara was regarded as one of the largest ports of entry for sailing vessels in the colony, with vessels navigating up the rivers as far as Pahi and Port Albert (Figure 1). By 1915, the industry that built the boats essential for the early transport needs of the Albertlanders, had begun to wane. Following the decline of the easily accessible timber resources, gum digging intensified, particularly in the Wairoa region. Once the best quality gum from higher ground had been exhausted by digging and 'paddocking' (excavating areas to a depth of 6–7 feet), large areas of swampland were subsequently drained (Ryburn 2000). The subsequent decline in kauri and gum digging saw settlers turning their hands to dairy farming. Kaipara port officially closed in 1947.

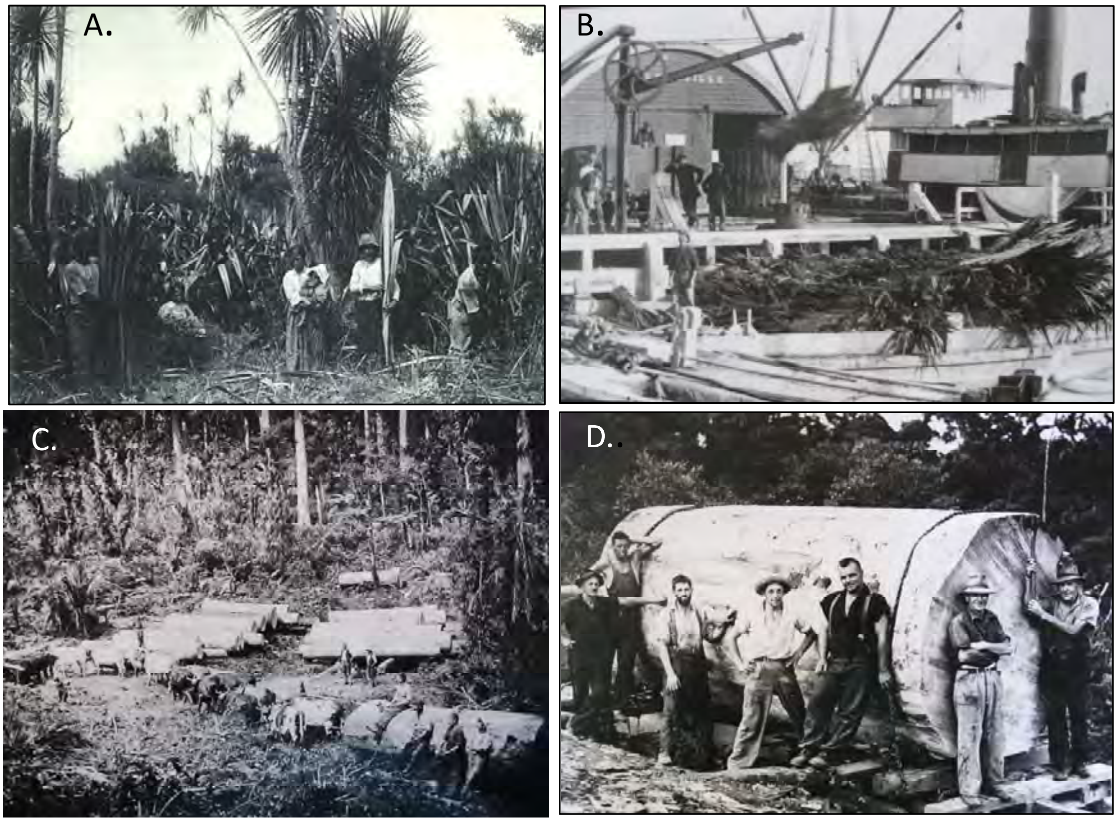

Figure 3: a) Flax cutting, Lake Ohia, Kaitaia, about 1919; b) loading flax into a vessel at Helensville; c) kauri logging with bullocks in the Kaipara catchment 1890–1910; one of the last logs of native timber to be milled in the Kaipara, about 1930. (Source: a) Alexander Turnball Library G-6285, b–d), Hellensville Museum)).

Agriculture/Forestry

Once the kauri timber was removed from the hills and kahikatea timber from the swamps (Figures 3 and 4), large areas were drained and agricultural development surged during the 1870s (Murton 2000). The scale of these Government funded reclamations is revealed in the Tokatoka swamp (Wairoa River) drainage scheme, which initially comprised 15 000 acres of marshland. Others areas included Glorit (635 acres), Kukutango (274 acres) and Oyster Point (368 acres) (Murton 2000). Most reclamation occurred between 1880 and 1920, with certain areas emerging as some of the most productive farming land in the region. However not all drainage was successful, with some areas reverting back to salt marsh and mangroves following salt leaching into the pasture. The advent of refrigeration in the early 1900s and subsequent growth of the dairy industry and sheep farming saw increased settlement of the land with numerous dairy companies becoming established around the harbour (e.g. Port Albert, 1903; Helensville, 1911) (Ryburn 1999, Makey 2010). By the 1920s and 1930s, with most of the easily accessible indigenous forest gone, exotic forests began to be planted over large areas. Further planting has occurred since the 1950s, particularly adjacent to the upper tributaries of the Wairoa River on old kauri cut-over lands (Murton 2000). Current forest plantations are located at Woodhill, Riverhead, Pouto and Topuni (Makey 2010).

Current agricultural production survey statistics reveal an increase in the numbers of dairy and beef cattle (particularly in northern Kaipara) (Figure 5), with concomitant declines in sheep numbers (Makey 2010). This has also led to a greater area of fodder and grain cropping, particularly of maize (Makey 2010). However, southern Kaipara has seen an increase in the numbers of dairy farms being converted into lifestyle blocks (Makey 2010, P. Yardley, pers. comm.). Horticulture, urbanisation and other forms of land use have continued to intensify in recent decades (Makey 2010, Gibbs et al. 2012).

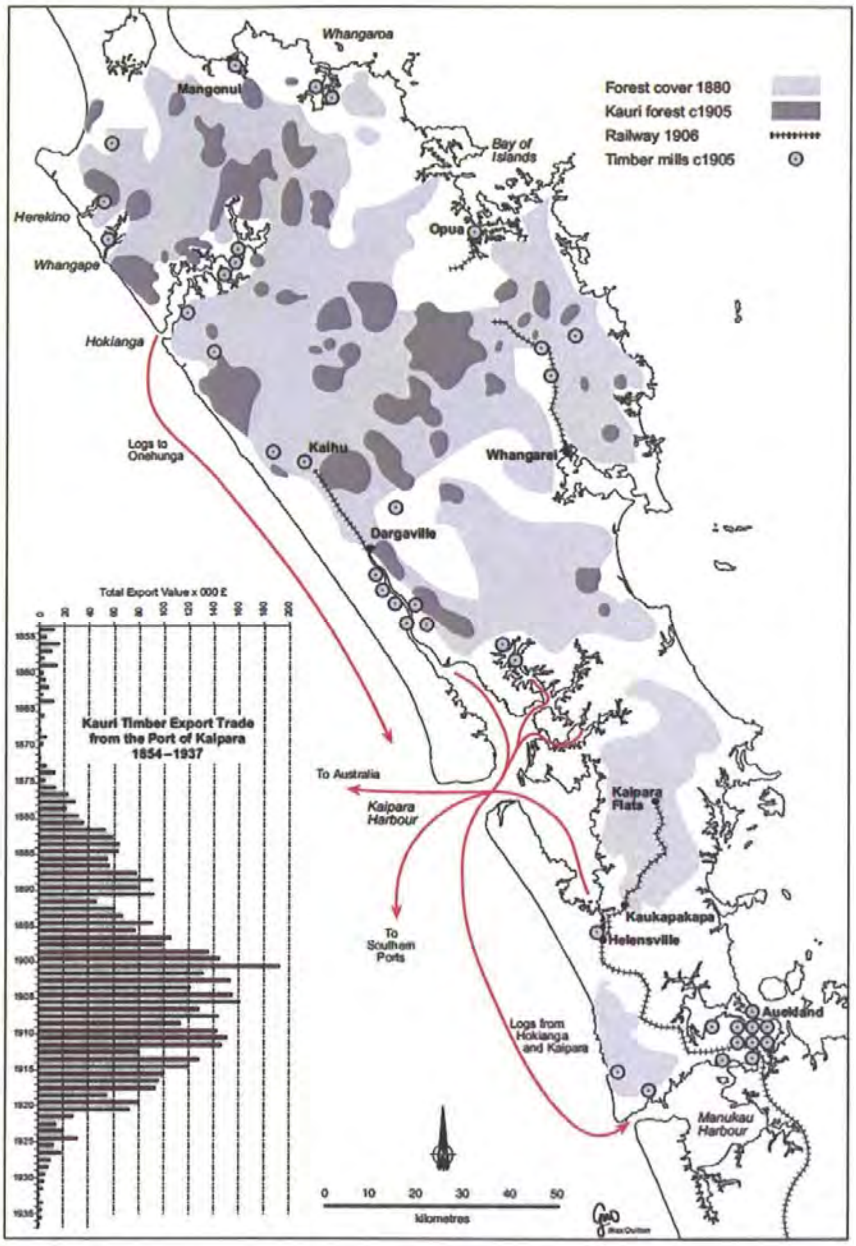

Figure 4: The kauri trade from the port of Kaipara 1854–1937; Historical forest cover 1880 and kauri forest coverage around 1905. (Source: Ryburn 2000).

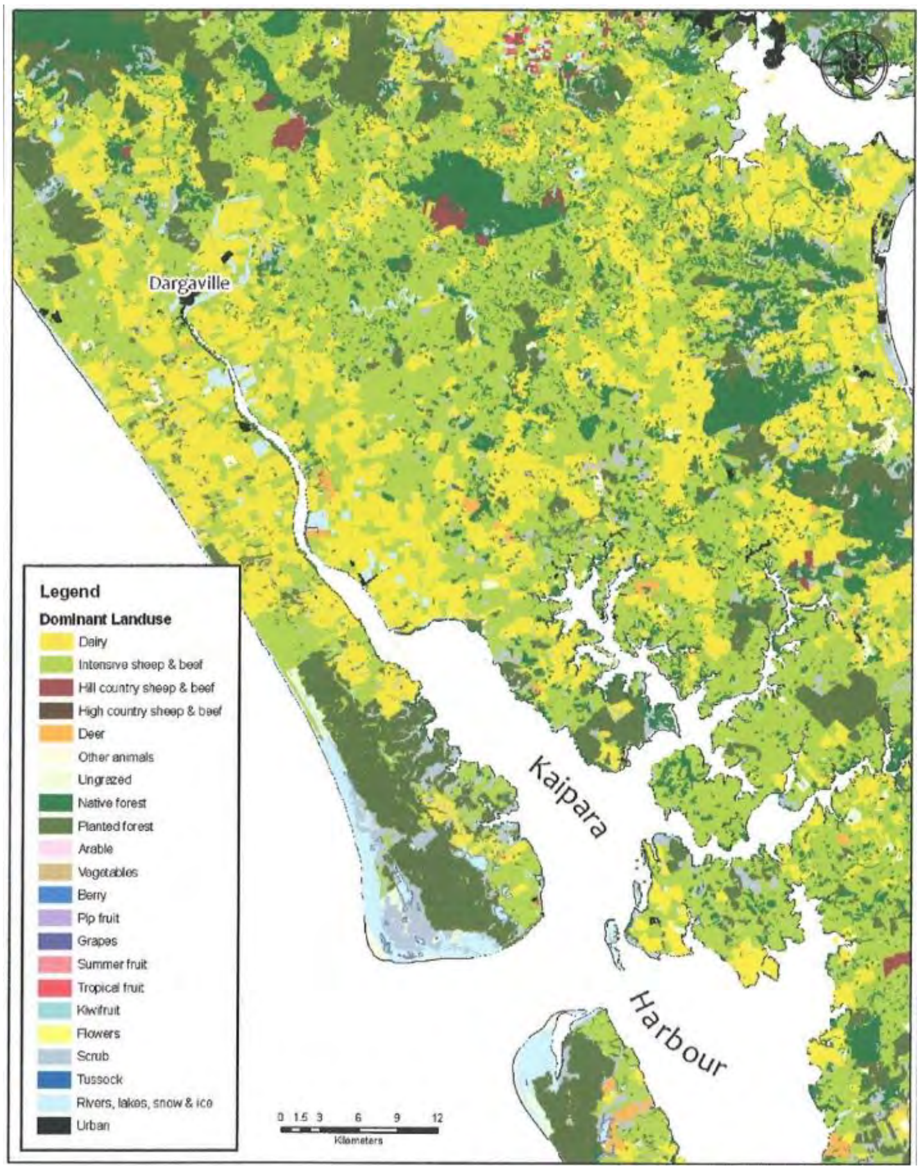

Figure 5: Current land use types surrounding Kaipara Harbour. (Source: Landcare Research Agriquality; Makey 2010) (Note: the 'Rivers, lakes, snow, and ice' class is an error in the orginal source: these should be labelled as 'sand' or similar).

Sand Mining

As the timber industry ceased, the demand for sand and gravel extraction from within the harbour increased (MDAR 1923). Until the late 1950s, virtually all of the sand and shingle extraction from the foreshore came from the southern end of the Hukatere Peninsula, particularly around Tinopai, and from a number of beaches on the western side of the harbour (Waikere, Okaro, Punahaere), predominantly for local use (Murton 2000). From the 1950s, sand was extracted offshore and mechanically loaded onto barges, predominantly in response to the demand for construction and increasing prices in the Auckland market. By 1973, about 11 000 cubic meters were being removed on an annual basis. However, locals were becoming increasingly concerned at the amount of erosion occurring on the beaches on the east coast of the harbour (Haggitt et al. 2008). Sand extraction adjacent to Pouto Point was abandoned due to the effects on shoreline erosion (NRC 2002, Haggitt et al. 2008). Current resource consents (2008–2012) allow for about 250 000 cubic meters of sand to be mined (via suction pumps) annually from inside the harbour (Tapora Bank), followed by 336 000 cubic meters annually for the next 15 years. A further 300 000 cubic meters per year can be extracted from outside the harbour entrance (Haggitt et al. 2008, Yardley 2008). Concerns have been raised about possible negative consequences of this sand mining.

2.2 Environmental change

Although early records suggest that the Kaipara Harbour and its tributaries have long been associated with 'muddy', turbid conditions, the large-scale environmental changes documented within the Kaipara Harbour (i.e., deforestation, kauri-gum extraction, conversion to pastoral agriculture) have collectively substantially increased catchment sediment loads into the harbour. This has created concomitant flow-on effects to water clarity, benthic community structure (e.g. increases in mud tolerant species), declining biodiversity, and declines in key biogenic-habitat forming species such as mangroves, seagrass, and bed-forming bivalves) (e.g., see wider reviews by Morrison et al. 2009, Swales et al. 2011, Morrison et al. in press). In many instances there have been shifts from sand to mud dominated systems, due to the increased deposition of fine terrigenous silts and clays (Swales et al. 2011). Order of magnitude increases in Sediment Accumulation Rates (SAR) relative to pre de-forestation values have been documented in other northern estuaries (e.g. Oldman & Swales 1999, Swales et al. 2005a, 2007; see summary table 1 in Morrison et al. 2009).

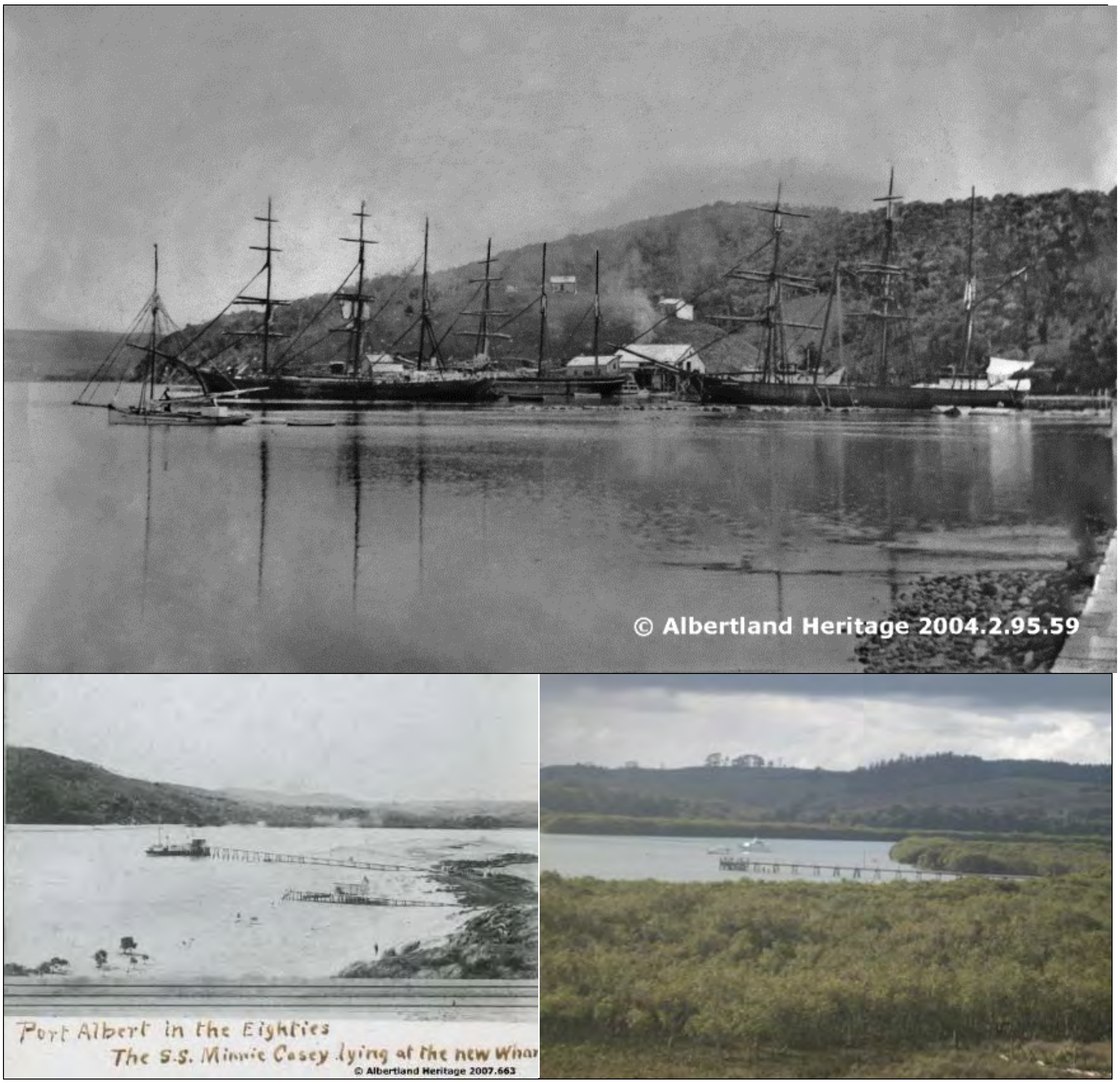

Figure 6: a) Timber ships loading at the Raekau sawmill at Port Albert Wharf in 1885 (note floating logs in front of ships); b) the 'Minnie Casey' alongside the Port Albert wharf in the 1880s (note few small mangroves lower front, sandy beach); c) wharf in 2013 showing the expansion of mangrove forest into the former channel area. (Source: a, b, Albertland Museum, Wellsford; c, M.L.).

Figure 7: The Hargreaves Family (after whom Hargreaves Basin is named) who settled at Oneriri, enjoying a family picnic on a white sandy beach 1902. Early settlers enjoyed accessible harbour edges with white sandy beaches. (Source: The Albertland Museum).

Historical and anecdotal evidence reveals the increasing deposition of mud and shallowing of many channels within the Kaipara Harbour. Frank Glavish, an early resident (1912–2013) recalled that the eastern shore of the southern Kaipara (Kaipara Flats) had shallowed markedly over his lifetime with "*some places nearly 3 feet higher than what it was in my young days*" and now being unable to cross the flats in his boat due to it being "*filled up by silt coming down from the hills in floods*" (RNZ 2009, Murton 2000). Trevor Scott, a retired local fisherman, recalls as a young boy being able to hear the flounder sucking crabs off the banks at Awaroa at night with his grandfather, but noted that now "*there was slimy mud covering everything*". Port Albert, once navigable by large schooners and largely mangrove free, is today characterized by shallow, muddy waters and expansive swathes of mangroves extending along the shoreline towards the channel (M.L., pers. obs.) (Figure 6).

Anecdotal and historical photographic evidence reveals the loss of many white sandy beaches (e.g., Figure 7) to expansive mudflats and encroaching mangroves prior to the 1940s (McShane 2005). For example, in the northern Kaipara, the Brookes family settled in the 1860s, constructing Minniesdale House, located adjacent to the Oruawharo River. This was located near an excellent beach "…*as good as any sea beach, sandy and shelly, so white and fine a place for bathing. There are plenty of oysters on bits of rock about 50 yards out which we can get when the tide is out…A boat can just get up to the end of the creek which is about half a mile wide at the mouth and at the top 2 yards wide. With a net 2 yards wide and one foot deep we could catch as many fish at once as would last a week*" (unpubl, letter by Hovey Brookes, 1862, cited in McShane 2005). Current imagery reveals the fundamental changes of this river mouth, beach and presumably its associated shellfish beds (Figure 8).

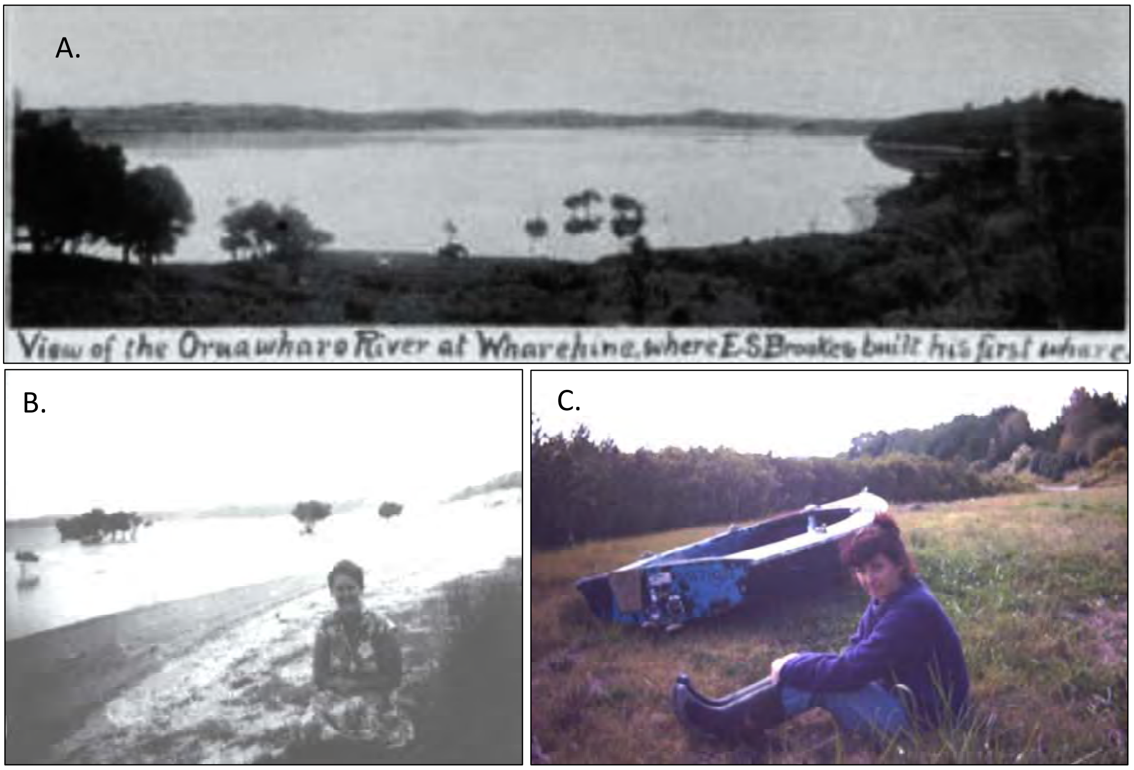

Figure 8: a) View of Oruawharo River (1862) at Wharehine, where Minniesdale House was built in 1868 on its shores by the Brookes family (large solitary mangrove trees present); b) Photo of Mrs Bracey, a more recent owner of Minniesdale House taken at Sandy Beach about 1960 with a few mangroves appearing in the bay; c) Linda Clapham, present owner of Minniesdale House - sitting on Sandy Beach about 2004 in the same position as previous photo, with a backdrop of extensive mangrove forest. (Source: http://www.rmastudies.org.nz/documents/MangrPtDFRed.pdf)

Associated with this increased sedimentation, there has been a shallowing of some areas of the harbour. A hydrographic comparison of selected areas of Kaipara comparing the soundings made by HMS *Pandora* in 1852, and those published on the 1995 hydrographic chart was made by Murton (2000). He argued that while precision was difficult to determine due to the different units of measurement and scale between the two surveys, the overall trends of shallowing water depths were readily evident. Sediment deposition was most evident in areas where both tidal and river energy are lower (upper harbour locations), while in areas of strong tidal flow or prone to flood events sedimentation was minimal (e.g., ‘The Funnel’ and Gittos Point on the Oruawharo River) (Table 1).

Table 1: Water depths of Kaipara Harbour locations in the years 1852 and 1995, depth changes between these two times, and annualised rate of sedimentation/erosion. Locations where shallowing has occurred are italicised. Hydrographic charts (Source: Murton 2000).

Kaipara Harbour areas and specific locations	1852 depth (m)	1995 depth (m)	Change (m)	Rate (mm/year)
Wairoa River				
Mangawhare	9.14	7.30	1.84	13.14
Te Kopuru	5.48	7.00	-0.52	-10.85
Ruawai	5.48	4.00	1.48	10.57
Sail Point (close)	16.46	16.20	0.26	1.85
Sail Point (Subritzkey Chl.)	7.3	7.60	-0.30	-2.14
Bushy Point	18.29	12.00	6.29	44.92
Araparoa River				
Puki Point	14.63	12.20	2.43	17.35
Matakohe Channel	1.82	0.50	1.32	9.42
Puriri Point	20.12	13.00	7.12	50.85
Rocky Point	23.78	20.00	3.78	27.00
Te Kopua Point (close)	1.8	0.70	1.10	7.00
Te Kopua Pt (other side)	7.31	6.70	0.61	4.35
Te Kopua Pt (main channel)	18.29	12.00	6.29	44.92
Otamatea River				
Funnel (deepest sounding)	36.58	35.00	1.58	11.28
Tanoa (deepest sounding)	10.97	8.30	2.67	19.07
Te Hoanga Point	3.6	1.50	2.10	15.00
Whakaki (deepest sounding)	12.8	4.20	8.60	61.42
Oruawharo River				
Gittos Point (deepest sounding)	5.48	5.10	0.38	2.71
Oneriri Point (deepest sounding)	12.8	13.70	-0.90	-0.64
Downstream (1.8 miles) from Pt Albert	4.57	2.20	2.37	16.92
Tauhoa Channel				
Orongo Point (deepest sounding)	12.8	11.8	1.00	7.14
Orongo Point (shore sounding)	1.8	0.80	3.00	7.14
Southern Kaipara				
Makarau River Channel	4.57	2.20	2.37	16.92
Aotea Bluff (deepest sounding)	18.29	15.60	2.69	19.21
Oyster Point	3.65	2.50	1.15	8.21
Puharekeke Creek	3.65	2.10	1.55	11.07
Confluence of Kaipara and Kaukupukupu rivers	5.48	4.20	4.08	29.14

Other environmental changes include the draining and reclamation of hundreds of hectares of intertidal flats, mangroves and salt-marsh habitats for pastoral use (Rowan 1917), with the construction of stop banks, drainage canal and flood gates at the seaward boundaries of the reclaimed areas. Although the majority of reclamation occurred prior to the early 1900s, recent analysis of aerial photography has revealed further reclamation occurred after the mid 1960s (see Swales et al. 2011). These large reclamations (hundreds of hectares) would have led to local changes in tidal flows, wave fetch and sedimentation processes (Swales et al. 2011). Anecdotal evidence suggests that ‘non return gates’ installed to prevent flooding in the northern Kaipara have affected the migration of mullet up into the tributaries, with a local resident noting that *“it has stopped mullet, along with eels and whitebait going up to breed. We used to find juveniles at the top of Ruawai – like a moving mass”* (B. Searle, pers. com. Dargaville).

Other environmental impacts arising from the timber and iron sand industry include the dumping of ballast from the ships prior to loading, leading to the introduction of non indigenous species (NIS). New Zealand waters now hold about 170 established species of introduced plants and animals, with the original pathway of introduction of many of them being unknown.

2.3 Development of Fisheries

Early European explorers and settlers to the Kaipara Harbour commented on the bounty of the harbour. Mackenzie (1855) noted that *"the whole harbour ... a distance of 80 miles, seems to be actually swarming with largest and finest mullet in the world"*. The accuracy of such claims is questionable because the recruitment of potential European settlers to the New Zealand colonial settlements involved some degree of embellishment, which influenced (some) writers' prose. Barlow (1888) described how *"snapper can be caught line-fishing at a rate of 60–70 per hour per line of two hooks, and of an average weight of about 9lbs each; mullet averaging about two pounds each in weight could be netted at a rate of 120 dozen a day by two men"*. H. Nicholls (80 years old) commented that *"On the way to school in the morning we would slap the water with tea tree sticks, and mullet would flop into the boat…with up to two dozen inside the boat at once"*(RNZ 2009; Scott 1995). Fish were plentiful throughout the harbour, with snapper still being caught three miles up the Hoteo River during the 1930s (Frank Glavish; RNZ 2009).

Historically, the harbour sustained major commercial fisheries including grey mullet, flatfish, school shark and rig, and a number of shellfish fisheries comprising native oysters, tuatua and green-lipped mussels (Murton 2000, Hartill 2004, Haggitt et al. 2008). While no consistent data are available on the quantities of fish caught in the harbour prior to 1915, earliest records reveal that grey mullet dominated the catch, supporting one of the first commercial fisheries within the harbour between the late 1870s and 1895, followed by flounder, snapper and other species. Catch records for 1914–1915 (originally expressed in units of 'dozens') included 660 000 grey mullet; 240 000 flounder; 156 000 snapper; 12 000 trevally and 2 400 red gurnard (cited in Murton 2000, Haggitt et al. 2008).

At its peak, the grey mullet fishery supported three canneries, employing a quarter of Helensville's population (Murton 2000, Haggitt et al. 2008). Following concerns of overexploitation and declining stocks, a closed season was declared from December 1886 to the end of February 1887. A formal study undertaken in 1895 by Sir James Hector concluded that there was a paucity of information on mullet, a conclusion reiterated one hundred and ten years later by Paulin & Paul (2006). By 1900 the fishery had largely collapsed as a result of reduced market demand, fishermen targeting more favourable species in Hauraki Gulf, and lack of government subsidies to canneries, although stocks had largely recovered by 1910 (Murton 2000, Haggitt et al. 2008).

Following the 'canning boom' and due to the limited local market, grey mullet and increasing landings of flounder and snapper were railed south to Auckland from Helensville (Marine Department Annual Report 1924). However, Kaipara fisherman were marginalized by the rail transport costs, the lack of insulated wagons, and competition from Auckland-based steam trawlers landing fish more cheaply. By 1917 the Kaipara fishing fleet had declined by 50%. Over this period (1900–1917), flounder dominated catches and were considered the only fish worth something *"the others were worth nothing. I could only get tuppence a pound for snapper and that wouldn't pay the freight to Auckland…there was no value at all in snapper, nobody wanted them"* (Murton 2000, Frank Glavish RNZ 2009). Although the overall tonnage of fish landed dropped precipitously during the depression, and declined again during WWII (Figure 9), species such as mullet, flounder and snapper still dominated catches until the late 1940s, when shark fishing became a lucrative fishery, largely undertaken by the Scott brothers and the Scrivens (KHSFG 2003). School sharks entering the harbour to pup were the primary target, with 10–15 000 sharks caught each season during the 1950s, ranking first or second by weight in the country (Murton 2000, Third 2013a, T. Scott pers. comm.). However, by 1972 the profitable Australian market had collapsed amid fears of high mercury levels. Although there was a subsequent resurgence in landings between 1976 and 1985, this has since substantially declined. As of about 2003, rig were becoming a significant commercial species, and to a lesser extent so were kahawai and trevally (KHSFG 2003). However, examination of catch records since that time has shown rig catch to decline and then return to similar levels as in 2003, while trevally and kahawai have fluctuated up and down, without an overall large increase (see following sections).

Relatively recent research on the Kaipara Harbour's set-net and ring-net fisheries for flatfish, grey mullet and rig based on catch-effort data from the 1989–00 to 2000–01 fishing years, suggests that although fishing effort has increased with catch rates peaking in the mid 1990s, all have since declined (Hartill 2004). Current catch data reveal that the majority of annual catch tonnages of commercial fish species are in decline, particularly since 2010 (MPI 2013). Grey mullet continues to dominate present day landings, followed by short-finned eels, yellow-belly flounder, sharks, kahawai and trevally (Hartill 2004, Paulin & Paul 2006, McKenzie & Vaughan 2008, MPI unpubl. data,). Overall, the harbour's fisheries are coming under increasing pressure, with evidence of increasing spatial competition and conflict between commercial fishers on the harbour, particularly over the past decade (KHSFG 2003, Peart 2007, Haggitt et al. 2008). A combination of increasing numbers of part-time fishers, the introduction of synthetic mono filament nets in the 1970s, the replacement of the original rag nets (which allowed more juveniles to escape), the ability to work many areas of the Kaipara in various weather conditions with a more mobile fleet of dory boats, trawling and long-lining targeting the Kaipara Harbour entrance and adjacent coast (particularly for snapper), and changing fishing rules have all resulted in increased fishing pressure (KHSFG 2003, Haggitt et al. 2008, Makey 2010). For example, commercial trawl fishing data reveal that between 400 and 802 trawl shots per 6 × 6 minute grid (121 km^2) were fished across the entrance of the harbour over a five year period from 1/10/2004 to 30/9/2009 (Makey 2010).

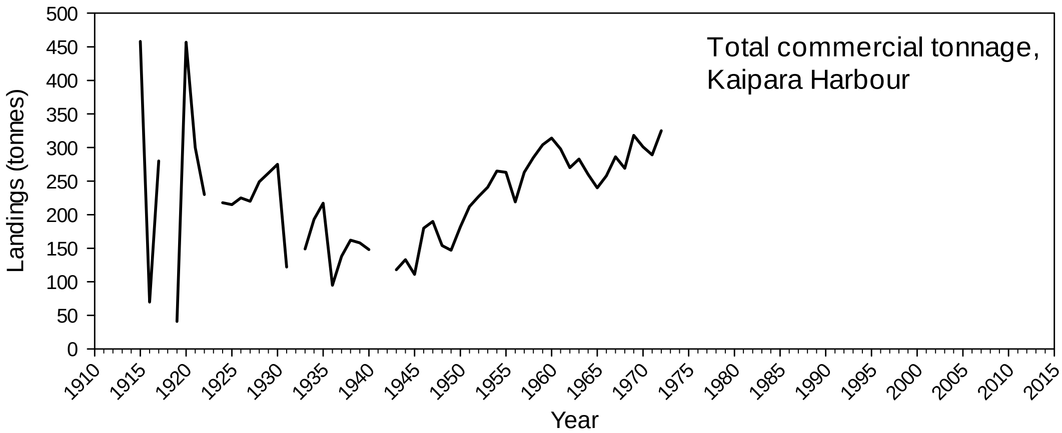

Figure 9: Weight of total commercial fish catch, 1915–1973 (tons). (Source: 'Marine Department Annual Reports' Appendices to the Journal, House of Representatives, H-15, 1916–1972; Ministry of Agriculture Fisheries, Reports', Appendices to the Journal of House of Representatives, C-5, 1973–1974; cited in Murton 2000). (Total for the 1931–32 year has been corrected to 276 t, original value of 132 t cited by Murton was a transcription error).

Commercial catch statistics for finfish species since 1932

Commercial fishing activities from the Kaipara Harbour are currently reported to the Ministry for Primary Industries within General Statistical Area 044. Historical landings data provided here were derived from a number of sources. These include:

- 1931–1973: Annual Reports on Fisheries, compiled by the Marine Department to 1971 and the Ministry of Agriculture and Fisheries to 1973 as a component of their Annual Reports to Parliament published as appendices to the Journal of the House of Representative (AJHR); Francis & Paul (unpubl. data).
- 1974–1982: Ministry of Agriculture and Fisheries, Fisheries Statistics Unit (FSU) calendar year records published by King (1985); Francis & Paul, unpubl. data, see Francis & Paul (2013).
- 1983–1987: Ministry of Primary Industries computer extract from FSU database, by calendar year
- 1988–1989: Due to the transition between official reporting systems, landings were very poorly reported. Francis & Paul (unpubl. data) estimated landings from adjacent years.

- 1990–2012: Ministry for Primary Industries computer extracts from all relevant catch effort databases, by calendar year.

Grey mullet (Mugil cephalis)

Grey mullet landings averaged about 45 t per year between 1930 and the late 1970s, followed by an increase in local market demand which saw landings rapidly rise to 340 t in 1985 (Figure 10). Annual landings of mullet from the Kaipara Harbour have since fluctuated between 200 and 359 t. It comprises the Kaipara's largest fishery, contributing between 25–50% of the total New Zealand grey mullet catch (Paulin & Paul 2006). Both set net and ring netting techniques have been historically used to target grey mullet (QMA GMU 1), but the majority of catch in recent years has been caught by ring netting (Hartill 2004, Paulin & Paul 2006). While prior research indicated that landings (Hartill 2004), and catch rates (Watson et al. 2005) were declining within the harbour, more recent landings are comparable to the 1990s (see also Paulin & Paul 2006). However, lack of information on grey mullet biology and ecology continues to make it difficult to determine maximum sustainable yield for this species (Paulin & Paul 2006).

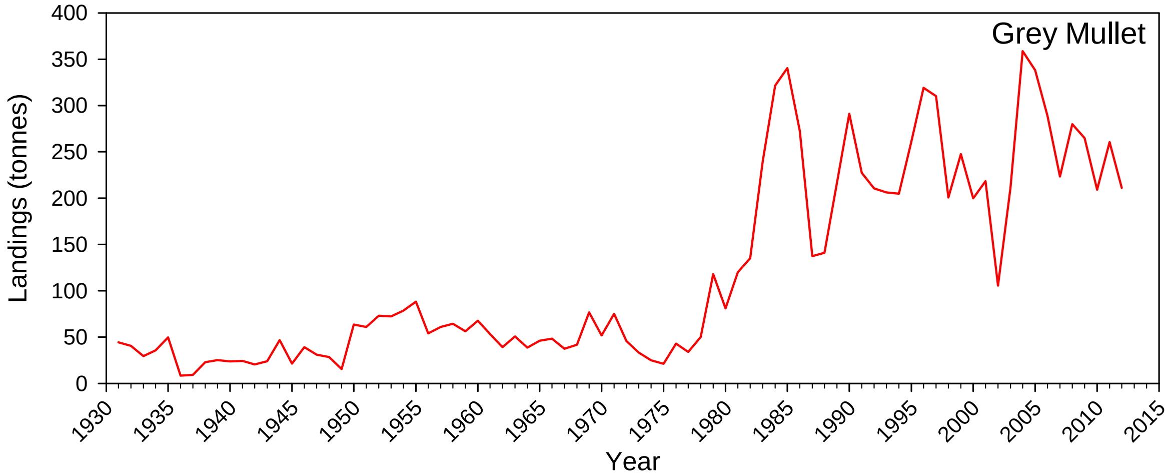

Figure 10: Reported catch history of grey mullet from the Kaipara Harbour. Data are expressed per calendar year. Sources: 1931–1975: (Francis & Paul, unpub. data); 1976–2012: MPI (unpub data).

Flatfish species (yellow-belly flounder Rhombosolea leporina and sand flounder R. plebia)

In terms of both effort and catch, the largest set net fishery within the Kaipara Harbour is that targeting flatfish species, comprising yellow-belly, and to a lesser extent, sand flounder (Figure 11) (Hartill 2004). Landings increased steadily from the 1940s to 174 t in 1972. Catches subsequently fluctuated, rising to 336 t in 1985. Following the introduction of the Quota Management System (QMS) in 1986–1987, landings dropped sharply to about 8 t, gradually increasing to a peak of 140 t in 2001. Catch rates have since declined to about 30 t in 2012, with anecdotal reports from local fisherman in northern Kaipara of catch rates falling precipitously over the past year (P. Yardley; C. Harrison pers. comm.; RNZ 2012). The majority (90%) of fishing around 2004 was undertaken by the Kaipara-based fleet (Hartill 2004), however localized depletion might have been occuring around that time period as there were anecdotal reports of an influx of fishers from elsewhere (KHSFG 2003, Hartill 2004, B. Hartill, NIWA,. pers. comm). No subsequent analysis has been done following up this work.

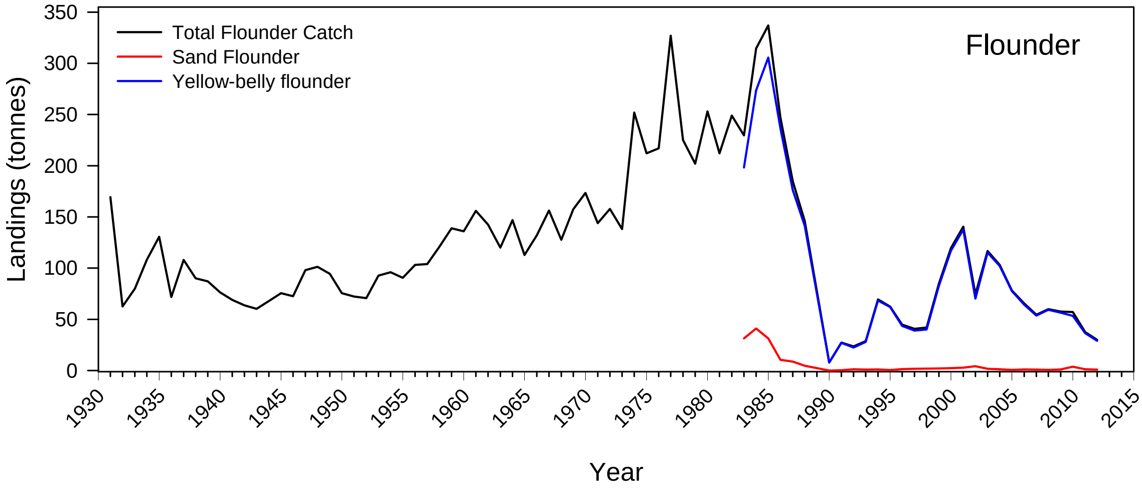

Figure 11: Reported catch history of flounder from the Kaipara Harbour. Data are expressed per calendar year. (Sources: 1931–1975, Francis & Paul, unpub. data; 1976–2012; MPI, unpub data).

Snapper (Pagrus auratus)

Earliest statistical records (1931–1932) show that snapper was the second most important commercial fish caught in the Kaipara (Figure 12), comprising 23% of the commercial catch at about 62 t (Murton 2000, MPI unpubl. data). Landings dropped during the depression years (in the 1930s) and further declined during World War II to 10 t. Although subsequent landings fluctuated, by 1954 overall tonnage had increased to pre-war levels of 61 t. This was largely attributed to "*increased trawling on the grounds off the west coast*" (Marine Department Annual Report 1924). Successive landings declined substantially, with the exception of one sharp increase in 1973 to 54 t, followed by a second lower peak of 24 t in 1984. Since the late 1980s catch rates plummeted sharply and have remained low, averaging just 1.5 t. Coinciding with declining snapper landings was the expansion of foreign fishing vessels from the mid 1950s and 1960s (e.g., Japanese long liners), and subsequent pair trawling targeting the harbour entrance (particularly over the spawning period), which many fishers consider to have contributed to the falling stock size (Murton 2000, KHSFG 2003, Third 2013b).

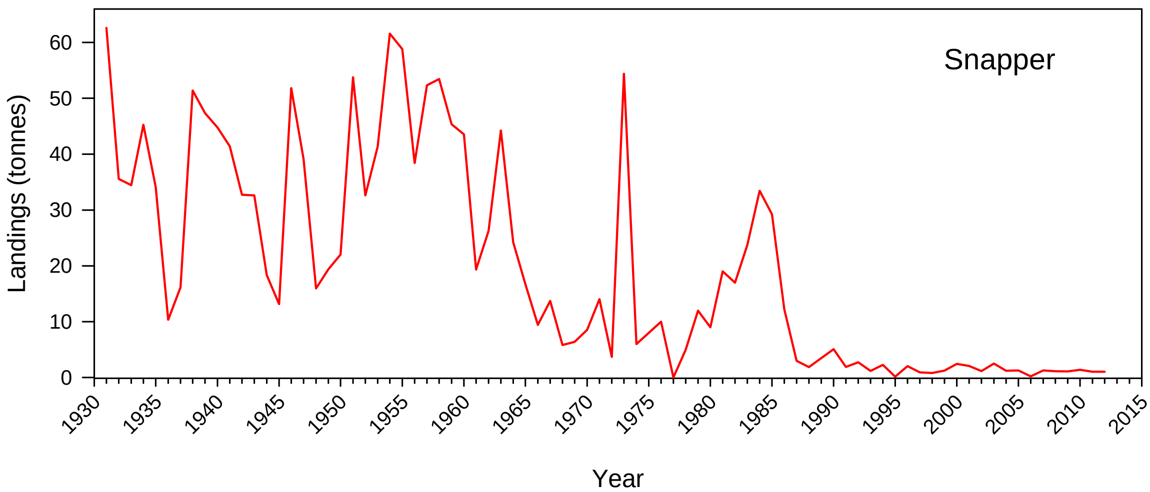

Figure 12: Reported catch history of snapper from the Kaipara Harbour. Data are expressed per calendar year. (Sources: 1931–1975, Francis & Paul, unpubl. data; 1976–2012, MPI, unpubl. data).

Trevally (Pseudocaranx dentex)

Trevally landings increased steadily from the late 1930s to reach 7 t in 1962 before declining in the mid 1960s (Figure 13). Catch rates have since fluctuated reaching a peak of 40 t in 1983 before declining sharply between 1986 and 1988, to a low of about 2 t. Recent landings have averaged around 15 t.

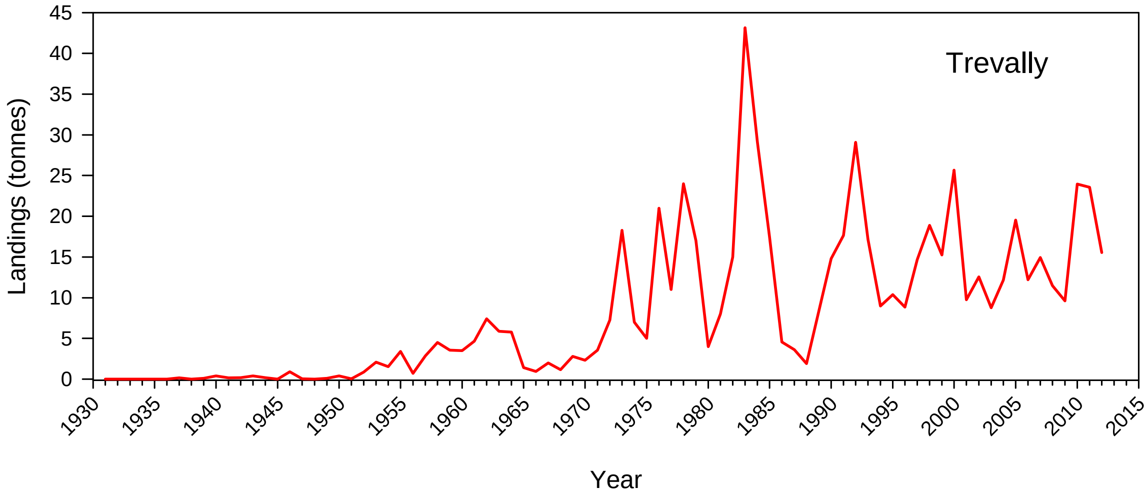

Figure 13: Reported catch history of trevally from the Kaipara Harbour. Data are expressed per calendar year. (Sources: 1931–1975, Francis & Paul, unpubl. data); 1976–2012, MPI unpubl. data).

Kahawai (Arripus trutta)

Catches of kahawai averaged between 3 and 5 t from 1937 to 1979 with a sharp rise to 33 t in 1981, followed by a further increase to 49 t between 1984 and 1986 (Figure 14). Landings fell sharply in 1988 before increasing again to a peak of 54 t in 1992. Subsequent catch rates have fluctuated around 27 t, with the tonnage landed falling to 19 t in 2012.

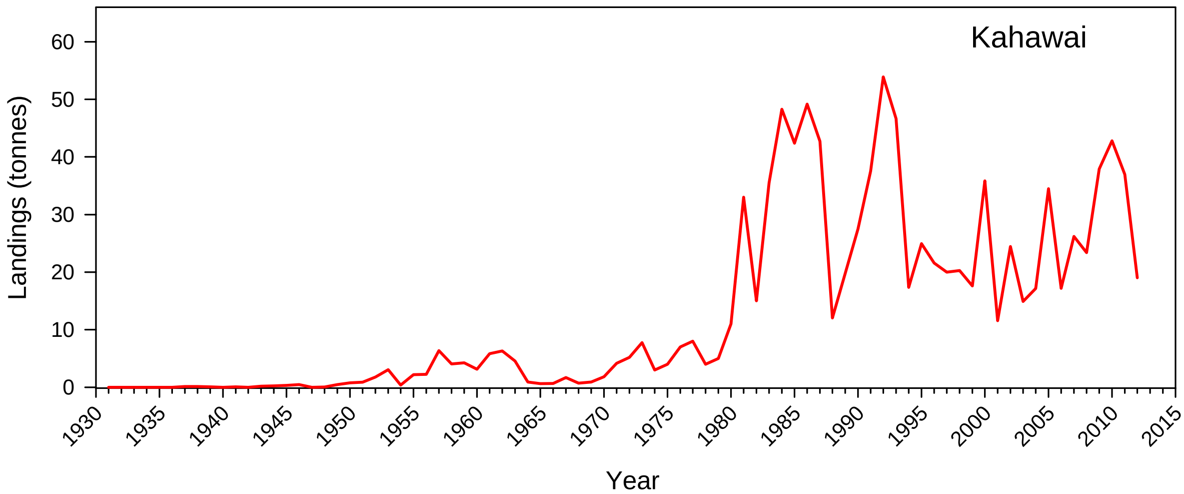

Figure 14: Reported catch history of kahawai from the Kaipara Harbour. Data are expressed per calendar year. (Sources: 1931–1975, Francis & Paul, unpubl. data; 1976–2012, MPI unpubl. data).

School shark (Galeorhinus galeus)

School shark catches (Figure 15) increased steadily from 1945 to almost 100 t in 1968 (Paul & Sanders 2001). Landings reported during the 1940s are thought to be underestimates due to unreported shark catches associated with the lucrative liver oil fishery (Ayers et al. 2006). After steady landings during the 1950s and 60s, catches dropped sharply between 1970 and 1975, and similarly in 1977–1979, as a result of perceived health risks from high mercury levels. Landings increased sharply to over 120 t in 1976 with the introduction of coastal gill nets, and again to 181 t in the mid 1980s. The introduction of the QMS in 1986–87 brought reported landings down to 7 t, with catch rates steadily rising to a peak of 59 t in 2000. Landings have since declined steadily, with a drop of 50% between 2004 and 2005. This decline is thought to be mainly attributable to fishers retiring from the fishery (Ministry of Fisheries Science Group 2006). The reported catch in 2012 was only 0.11 t (Francis & Paul, unpubl. data; see Francis & Paul 2013). Fluctuations in pre-QMS landings were largely driven by market demand, firstly for liver oil and then for flesh (the latter for both the Australian and local market), with no evidence of catch rates being limited by school shark abundance (Ayers et al. 2006, T. Scott, pers. comm.). However, there are current concerns about the number of school shark being caught as bycatch. Ministry for Primary Industries data suggest that an estimated 60% of catches in SCH 1 over 2003–2008 were caught while targeting other species, with only 40% as targeted catch (Haggitt et al. 2008).

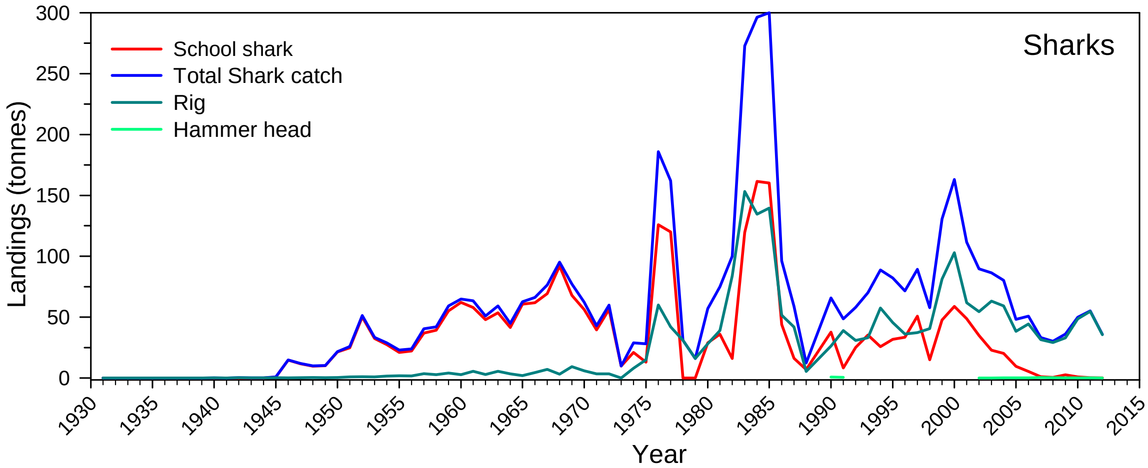

Figure 15: Reported catch history of school shark, rig and hammerhead shark species from the Kaipara Harbour. Data are expressed per calendar year. (Sources: 1931–1975, Francis & Paul, unpubl. data; 1976–2012, MPI, unpubl. data).

Rig (Mustelus lenticulatus)

Rig catches from the Kaipara Harbour have followed similar trends to those seen in the school shark fishery (Figure 15). Low catch rates were recorded from the 1940s, with a sharp rise to 60 t in 1976 and subsequent decline in 1979. Fishing effort and catches increased substantially between 1990 and 2000, peaking at 103 t. These increases were accompanied by a downward trend in catch per unit effort, suggesting a rig abundance decline in the Kaipara over this period (Hartill 2004). There has subsequently been a steady decline in catch with a small increase in 2011 (MPI unpubl. data). The Kaipara based fishing fleet was responsible for about 80% of the total rig set net fishery in the mid 1990s, but this has now fallen to between 60–65% of the total catch (Hartill 2004).

Hammerhead shark (Sphyrna zygaena)

Hammerhead sharks have been commercially caught only from the mid 1980s and comprise a modest fishery with landings ranging between 0.5 and 5 t (Figure 15).

Ray species – smooth skate Dipturus innominatus and/or rough skate Dipturus nasutus; and eagle ray Myliobatis tenuicaudatus

Commercial fishing records for ray species began in the 1980s, with modest annual reported landings of skates (2–4 t) and other ray species (0.5 t) (Figure 16). Since 2005 landings of these species have been negligible. Eagle rays have only been caught commercially since 2003, with landings increasing sharply to around 7 t between 2007 and 2010. Landings have since declined in 2012 to 5 t.

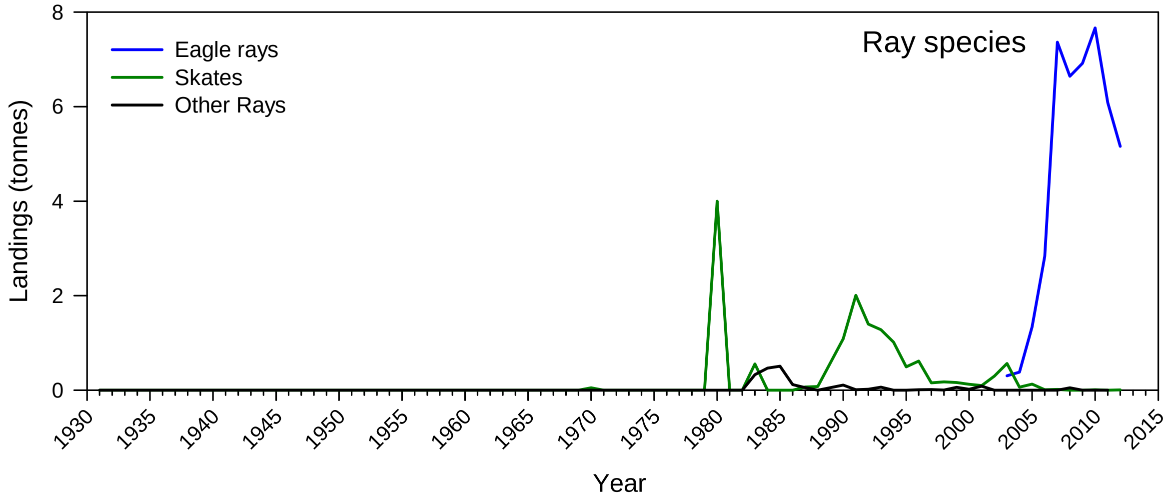

Figure 16: Reported catch history of ray species from the Kaipara Harbour. Data are expressed per calendar year. (Sources: 1931–1975, Francis & Paul, unpubl. data; 1976–2012, MPI, unpubl. data).

Eels (short-fin Anguilla australis, long-fin Anguilla dieffenbachii)

Eels have been caught commercially since 1973, with landings peaking at 83 t in 1978 (Figure 17). Landings between 1982 and 1992 were negligible but rose between 1995 and 2000 (about 17 t), with a further sharp increase from 2004 to peak at 134 t in 2007. Landed catches have since fluctuated, declining to 91 t in 2011. From the mid 1990s the catch has been largely dominated by short-finned eels, with long-finned eels making a modest contribution.

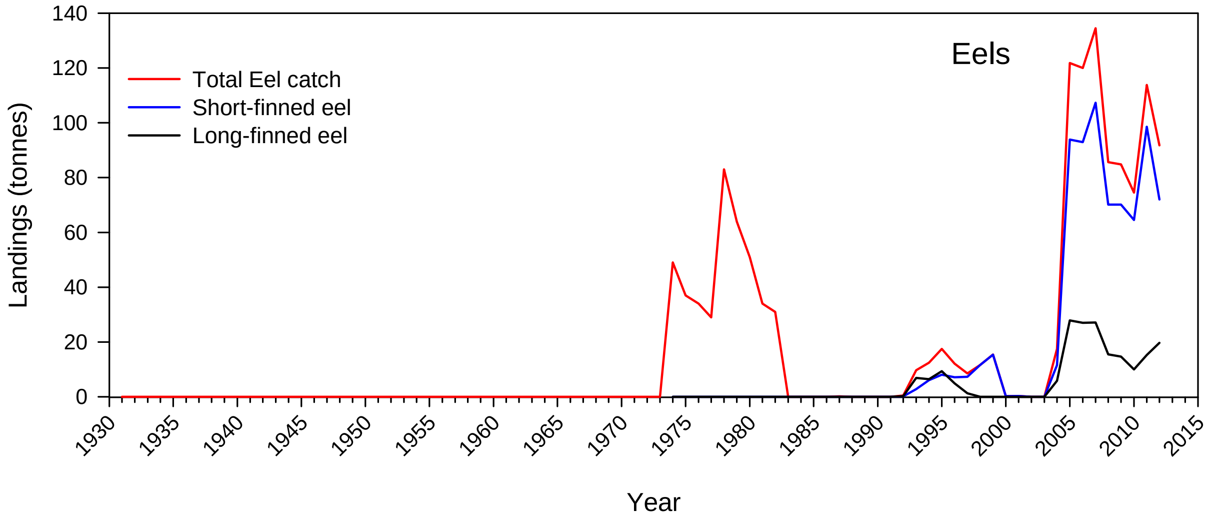

Figure 17: Reported catch history of eels from the Kaipara Harbour. Data are expressed per calendar year. (Sources: 1931–1975, Francis & Paul, unpubl. data); 1976–2012, MPI, unpubl. data).

Other finfish species

Commercial landings of parore (*Girella tricuspidata*) were first reported in 1955, fluctuating between 1 and 4 t through the 1960s (Figure 18). Landings peaked at 12.5 t in 1984, before sharply dropping by 50% in 1985. Since then catch rates have continued to fluctuate, averaging around 8 t, reaching a peak of 14 t in 2010 and declining to 10 t in 2012. Landings of red gurnard (*Chelidonichthys kumu*), although caught in small numbers from the late 1930s, increased sharply in 1984 to 7 t. Annual landings have since varied between 6 and 8 t, declining to 1 t in 2012 (Figure 18). Yellow-eyed mullet (*Aldrichetta forsteri*) have been caught commercially since 1985, peaking at 7 t then declining to about 1 t in 2012 (Figure 18). Modest landings of jack mackerel (probably *Trachurus novaezealandiae*) have been reported during the past 30 years, averaging less than 0.1 t between 1983 and 2012 (Figure 18).

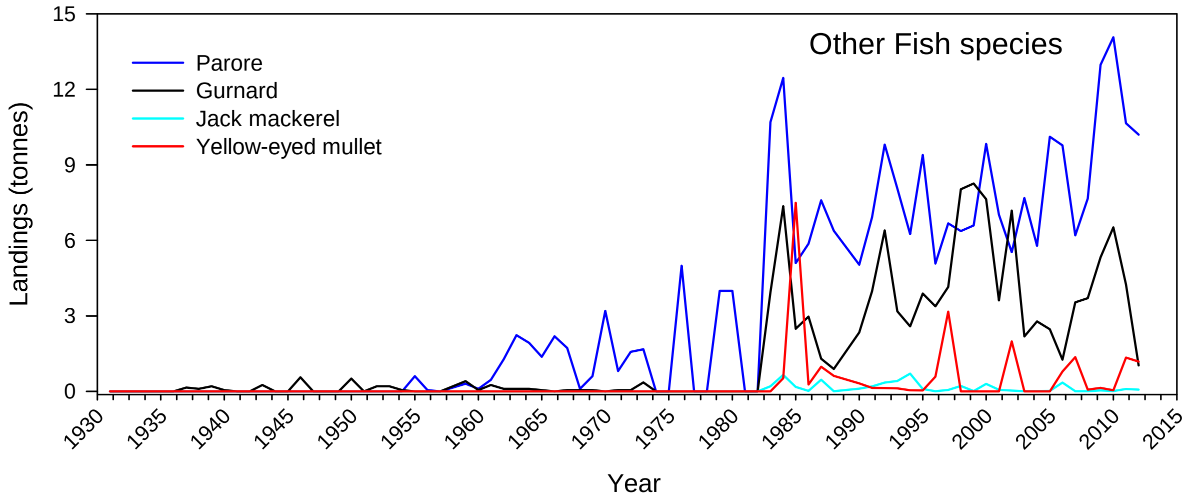

Figure 18: Reported catch history of minor fish species from the Kaipara Harbour. Data are expressed per calendar year. (Sources: 1931–1975, Francis & Paul, unpubl. data; 1976–2012, MPI, unpubl. data).

Available catch statistics for shellfish species from the 1920s to the present

Rock oysters (Saccostrea glomerata)

Traditionally rock oysters were of great importance to the Māori communities inhabiting the Kaipara areas, and historical accounts suggest that their access was subsequently restricted on racial grounds in a way that would not be deemed acceptable today (for a detailed historical account, see chapter 10 of Makey 2010). Government concerns about the depletion of rock oyster beds, both in the Kaipara and other areas (Whangaroa, Whangaruru, and Manukau harbours, and Mangonui Inlet, Bay of Islands) led to the first fisheries law being passed in New Zealand (the Oyster Fisheries Act 1866). Some areas were set aside as "Māori oyster reserves", including six locations in the Kaipara Harbour – a survey of five of the six Kaipara Harbour areas was completed in 2008 (Kelly 2009). Commercial harvesting of the Kaipara Harbour's native oyster beds began in the 1880s with modest catches being landed for local consumption and later for transportation to Auckland via rail (Murton 2000) (Figure 19). By 1927–28, with evidence of local depletion, management areas were established and the 'cultivation' of artificial oyster beds began with placement of rocks into the lower foreshore and later construction of hollow rock walls in well sheltered bays which continued until the mid-1950s. By the late 1950s the cultivation experiment was deemed unsuccessful. This was attributed to siltation, overgrowth of immature oysters from heavy spatting, little effort to thin the beds, and not enough pickers to permit adequate harvesting. The number of harvested sacks dropped from a high of 10 000 sacks in 1917 to just over 2000 per year in the early 1960s, and ceased in the 1970s, when the commercial culturing of Pacific oysters began (Figure 20) (Murton 2000).

Figure 19: Harvesting of wild rock oysters for the local market in the Kaipara Harbour, and loading on a vessel for transport. (Source: Albertland Museum).

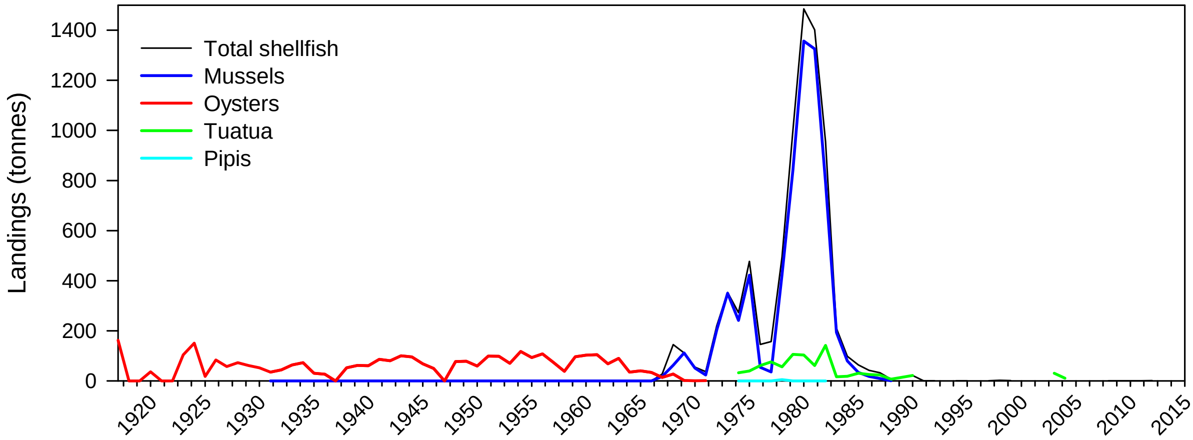

Figure 20: Reported catch history of shellfish species (wild fisheries only) from the Kaipara Harbour. Data are expressed per calendar year. (Sources: 1917–1930, Murton 2000; 1931–1975, Francis & Paul, unpubl. data); 1976–2012, MPI, unpubl. data).

Annual native oyster harvests ranged from about 50 to 100 t from the 1930s to the late 1960s, although with several years of no reported catch. Landings ceased after the NIS Pacific oyster arrived and a commercial culture industry was established.

Green-lipped mussels (Perna canaliculus)

Commercial harvesting of green-lipped mussels began with handpicking of inter-tidal beds. Following the demise of the shark fishing in the early 1970s, some fisherman turned to dredging for green lipped mussels in the "Graveyard" area just inside the harbour entrance. These mussel beds were spread over miles, with up to 14 dredges working the area at its peak (Third 2013b). Trevor Scott, a retired fisherman, recalls collecting 200 sugar-bags per week from Papa Rock, growing on rock ballast dumped last century after ships crossed the bar. However, too many licences were issued, making it unprofitable (Scott 1995), and by the early 1980s only three or four boats remained. Dredging continued until landings declined in the early 1990s. Records for the commercial harvest of green lipped mussels show an increase in landings from 17 t in 1966 to a peak of 349 t in 1973, before increasing sharply again to 1357 t in 1981 (Figure 20). Catch rates then fell sharply through the 1980s, and the commercial harvest had ceased by 1990. Cultivated mussels then effectively replaced wild fishery catches. No stock assessments or biomass estimates were ever made for the fishery (Haggitt et al. 2008, MPI 2013). Intertidal mussels continue to be harvested recreationally at Coates Bay, while subtidal mussels also occur in dense beds in the Wairoa River Arm, which are periodically dredged (Haggitt et al. 2008).

Tuatua (Paphies subtriangulata)

Although not a true harbour-associated species, 'prolific' subtidal beds of tuatua are reported from the harbour mouth between Pouto Point and North Head, and off Manukapua Island (Tapora), with intertidal beds occurring at Manukapua Island (Grace 1995–2004; cited in Haggitt et al. 2008). However, tuatua have not been recorded at this latter site during recent monitoring (Makey 2010). Historically, extensive beds of tuatua at Bayleys Beach were commercially harvested for 30 years, before the beds "*disappeared almost overnight*" in 1995. It was suggested that the increased use of pesticides and sprays on nearby pine plantations were a contributing factor (B. Searle, pers. comm.). Commercial tuatua landings from TUA 9 (effectively Kaipara Harbour catches) started in 1975, and reached a peak of 142 t in 1982–83, before declining to catches of about 20–30 t a year. Commercial catches largely ended by 1992 following a moratorium, with only one or two fishers remaining, and fishing being intermittent since that time (with some catch in 2004–2006). Recent landings have averaged only 0.03 t between 2009 and 2012 (Figure 20).

Toheroa (Paphies ventricosa)

This large endemic surf clam is found on both the north and south Kaipara ocean beaches, and historically was an important and very abundant fishery, also supporting a cannery (Murton 2000). While not found in the harbour, it is mentioned here for completeness. In 1966 their popularity was such that an estimated 50 000 people, in about 12 000 vehicles visited the north Kaipara Beach in just one weekend, during a two-day open season (Murton 2000). Closed seasons were introduced but toheroa numbers continued to decline rapidly, and today no commercial or recreational harvesting is permitted. Potential factors attributed to their decline included overexploitation, weather events (i.e. strong easterly winds and low tides), changing water tables due to pine plantations, and mortality from vehicles crushing juveniles, although no definitive causes have been clearly established (Morrison & Parkinson 2001, Murton 2006, Williams et al. 2013).

Pacific oysters (Crassostrea gigas) (aquaculture only)

With the appearance of this NIS species, wild harvests of native rock oysters ceased, and a large scale oyster farming industry commenced (Haggitt et al. 2008). Currently, Biomarine Ltd operates seven oyster farms in the Kaipara Harbour; one open harbour farm producing 24 million oysters a year in the southern Kaipara (off Te Hoteo River) and six sheltered oyster farm leases in the northern Kaipara (i.e. the Arapaoa and Otamatea Rivers) (Kelly 2009). The northern leases were regarded until recently as sites of national significance for collection of spat for oyster farming (Makey 2010). However, the arrival of a particularly lethal herpes virus (OsHB micro variant; first discovered in Europe in 2007) into the northern Kaipara in early 2010 saw almost total mortality of oyster spat. The area has not been utilized for spat collection since then (J. Dollimore, Biomarine, pers. comm.). The virus also caused about 50% mortality rate in adult oysters.

Recreational fisheries

Historical recreational fishing activity

There are no quantitive estimates or records of recreational catches from the Kaipara Harbour, for any species (finfish or invertebrates) prior to 2006. However, a long history of family and other photographs clearly demonstrate that fishing has been and continues to be an important pastime and food gathering activity for many people (Figures 21a and 21b). Cultural harvesting is also important and probably widespread, but again no quantitative data are available.

Figure 21a: Family and trip fishing photographs, from 1906 to the 1990s. a) Early settler families about 1906 - Moffat’s and Halfpenny’s in front of the original Marsh House with Oruawharo River in the background; b) Fishing party about 1916 near mouth of Araparera River at “Beresford Farm” owned by the Barrs c) Caught at Tinopai wharf in the 1920s. L-R: Harold Cliff, Arthur Cliff, Ralph Cliff, Gordon Cliff, Dem Fenwick. (Source: a, The Albertson Museum; b, Tudor Collins, Takapuna Library; c, Matakohe Museum).

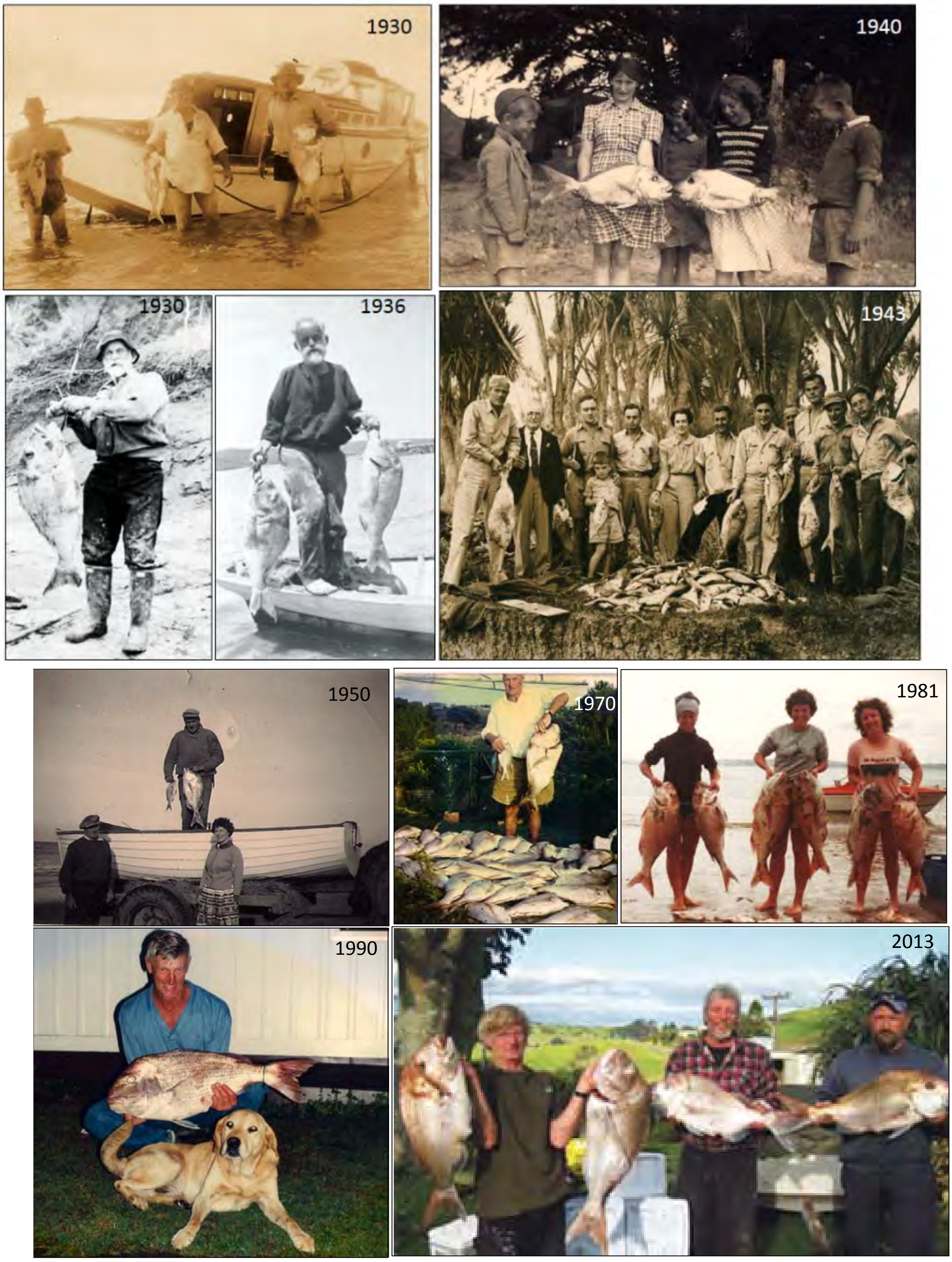

Figure 21b: Family and trip fishing photographs, from 1906 to the 1990s continued. Top row: Large snapper catches from 1930s and 1940s. Second row: Jimmy Lord with a 13.6 kg snapper at Tinopai in 1930 and another large catch in 1936. A group of kiwi and US soldiers after a days fishing in northern Kaipara (Araparera River) in 1943. Third row: Snapper catches from the 1950s, 70s and 80s. Bottom row; Gary Greaves (on left) with 10.5 kg snapper in 1990, recent catch in 2013. (Source: T. McMurdo (1930×2, 1936, 1940, 1970, 1990); Tudor Collins (1943); R. Scott (1950); D. Subrizsky (1981), Kaipara Lifestyler (2013)).

Recent recreational fin-fish harvest estimates

Recreational fishing in the Kaipara Harbour accounts for a significant proportion of the non-commercial harvest taken on the west coast of the North Island, because of the harbour's proximity to

Auckland and its sheltered waters. The most comprehensive source of information on the nature and extent of the recreational fishery in the Kaipara is that provided by an aerial-access survey of the SNA 8 fishery, which was conducted by NIWA in 2006–07 (Hartill et al. 2011). This survey method combines aerial counts of boats fishing in the late morning with boat ramp interview data collected throughout the same surveyed days, to provide a harvest estimate for commonly caught species such as snapper. Flights were conducted on 45 days throughout the 2006–07 fishing year, and interviews were conducted at the two busiest boat ramps in the harbour; at Shelly Beach and at Tinopai. Although the survey focused primarily on snapper harvesting, interviewers also counted and measured landings of other species that were landed at surveyed ramps.

The spatial distribution of boats observed from the air suggests that fishing occurs throughout the harbour, but most activity occurs in deeper waters (Figure 22). Although levels of shore based fishing effort were not quantified during these flights, there appeared to be relatively few surfcasters fishing in the harbour, and most of those were observed fished along the northern side of South Head, on the sand spit at the end of Okahukura Peninsula, and off the Shelly Beach wharf.

Snapper accounted for just over half of the catch observed by boat ramp interviewers, and kahawai and red gurnard accounted for most of the remainder (Figure 23). Most of this catch was taken by rod and reel from boats, although small numbers of yellow-eyed mullet, grey mullet, flatfish and small shark species such as rig and school shark were also taken by fishers using set nets. Some recreational fishers use dredges to harvest scallops and mussels, but the level of recreational shellfish harvesting in most parts of the harbour is probably relatively inconsequential.

Most of the snapper measured by interviewers were less than 40 cm in length, but larger fish up to 75 cm in length were occasionally landed (Figure 24). A wide size range of kahawai were landed, but most were over 40 cm in length, which is the size of onset of sexual maturity.

The aerial-access survey provided harvest estimates for snapper only. The estimate of 72.4 tonnes for a combined Hokianga and Kaipara Harbour stratum was almost entirely taken from the Kaipara. This snapper harvest estimate accounted for 28% of the total recreational harvest estimated for the west coast of the North Island. Estimates from a national panel survey recently completed by the National Research Bureau (NRB) suggest that the recreational catch on the west coast in 2011–12 was more than twice that estimated in 2006–07 (NRB, unpublished data).

The length composition and tonnage of species commonly landed by recreational fishers probably varies considerably from year-to-year, but this sector probably accounts for a significant proportion of the catch of snapper, kahawai, and red gurnard landed from this harbour in recent times.

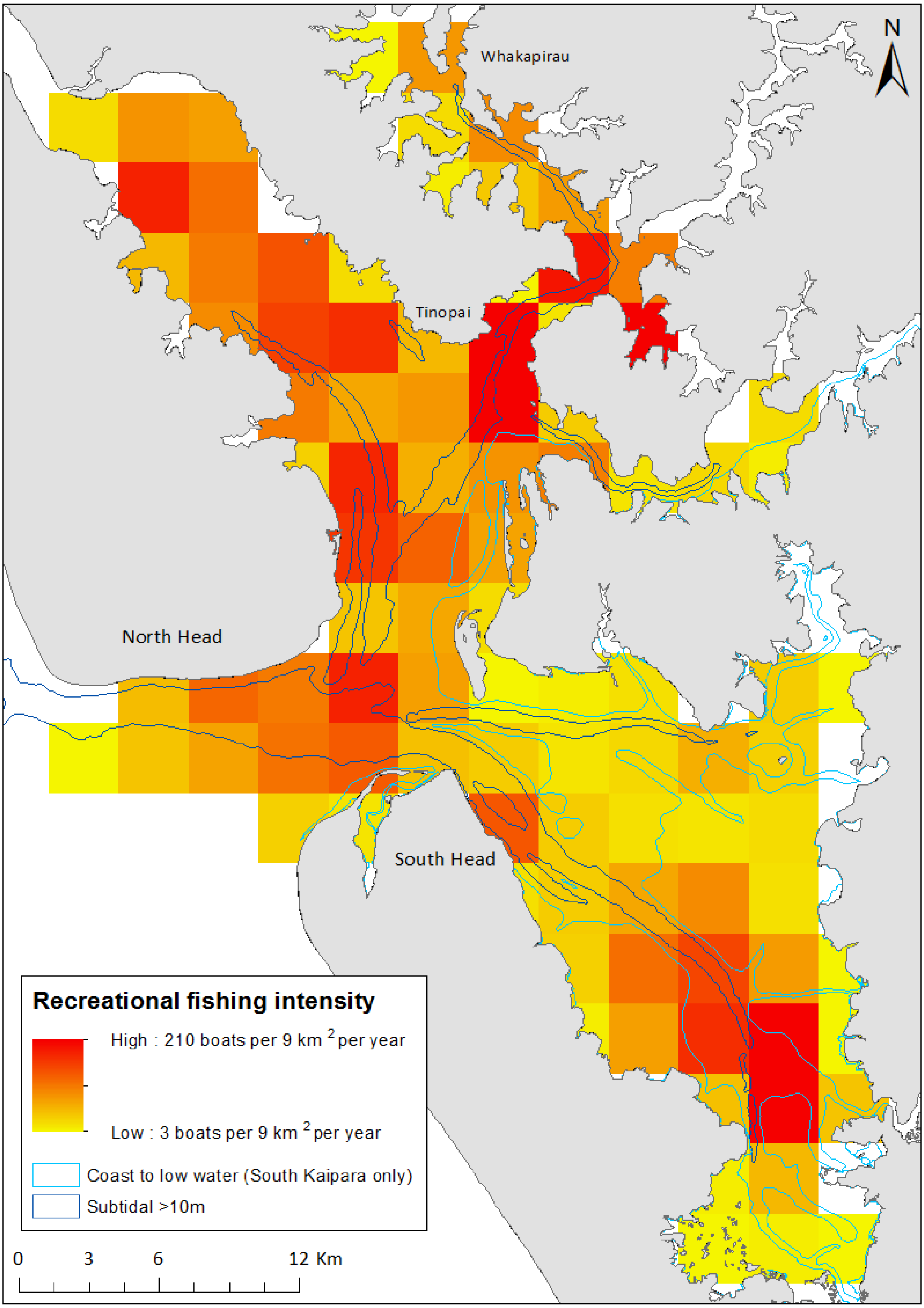

Figure 22: Relative intensity of boat based recreational fishing effort in the Kaipara Harbour based on aerial survey flights conducted on 45 survey days in 2006–07.

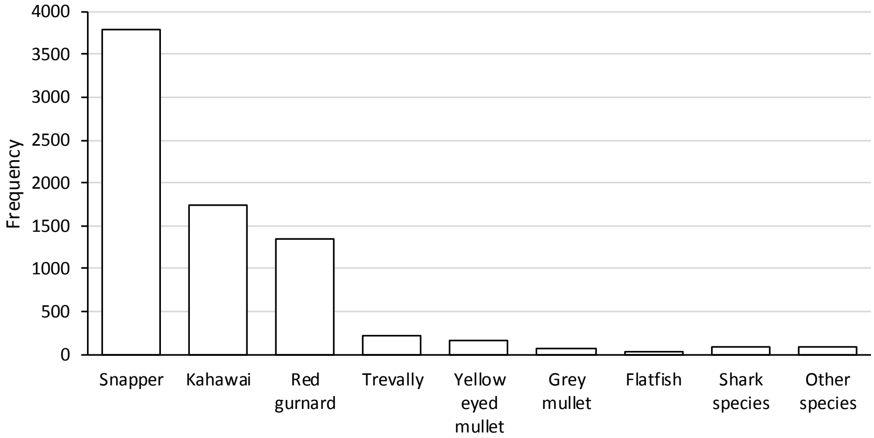

Figure 23: Finfish species landed by recreational fishers fishing in the Kaipara Harbour who were interviewed in 2006–07.

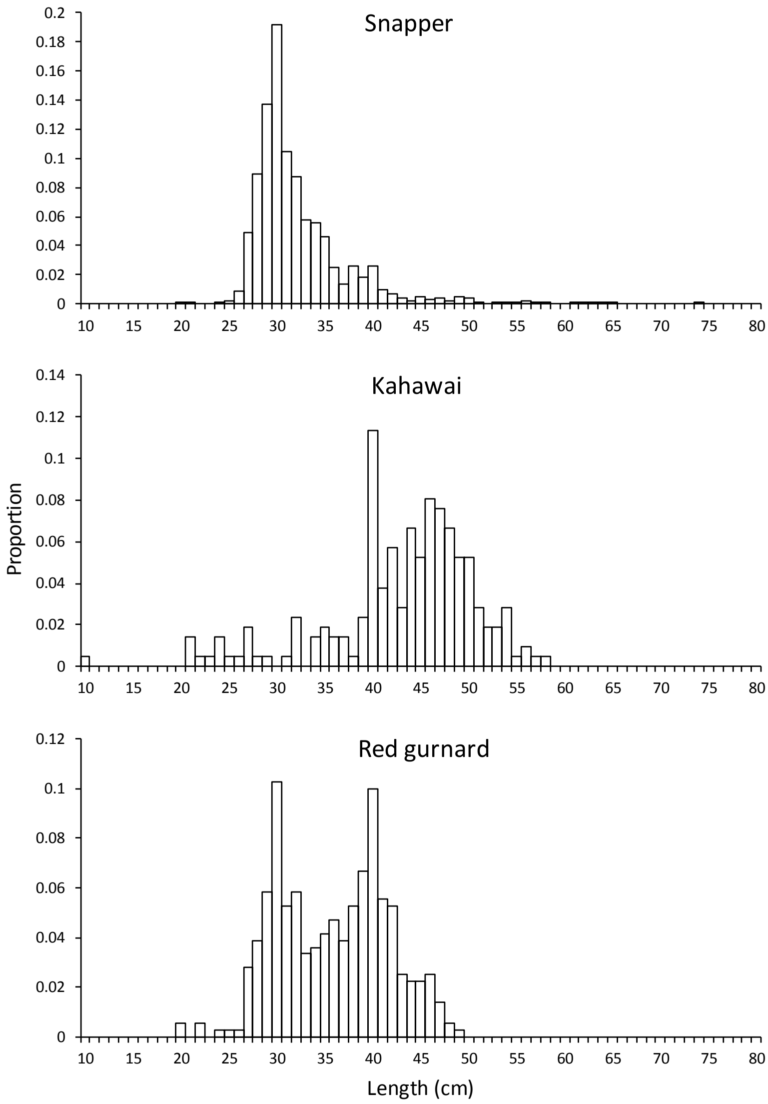

Figure 24: The size composition of the three species most commonly landed by recreational fishers from the Kaipara Harbour in 2006–07.

3. LOCAL ECOLOGICAL KNOWLEDGE (LEK)

This section covers the use of face-to-face interviews by researchers with people who have had a long association with the Kaipara Harbour, in order to learn more about how the habitats, species, and environemtal conditions of the harbour may have changed over time.

3.1 Interview methods

The issue of who are 'experts', and how to select a representative sample from the overall potential LEK population has received some attention in the LEK (and also Traditional Ecological Knowledge, TEK) literature, as well as more broadly across the use of scientific experts in forums (e.g., Huntington 2000, Davis & Wagner 2003, Drew 2004, Davis & Ruddle 2010, Drescher et al. 2013); this issue was raised in the AEWG presentation of this project. Drescher et al. (2013) addresses the rigorous use of expert knowledge in ecological knowledge in detail (note: their use of expert is not confined to only those with formal science training); while Davis & Wagner (2003) and Davis & Wanger (2003) offer robust critiques of the LEK field in general (largely focussed on terrestrial examples). Drescher et al. (2013) suggested that if a large enough expert pool was available, then random or stratified random strategies could be used, but observed that non-random selection processes were far more common, 'Chain referral sampling' (such as snow ball sampling) was one approach, where an initial expert was selected, and then that person nominated extra experts. Multiple independent starting points for experts (i.e. selecting initial experts from different places or groups) was seen as one way to maximise contact with and selection from the overall 'expert' population. Davis & Ruddle (2010) suggested that the best approach was through systematically gathered peer recommendations, using a structured sampling technique, where experts were rank-ordered depending on their peer's views of them. However, Drescher et al. (2013) observed that peer selection could potentially lead to selection bias or 'underestimated knowledge variance' due to the nominating of 'like-minded people' (population clustering). The issue of participants being polarized by social or political debates central to their expert contributions was also noted; the suggested solution in such situations was stratification of the selection pool.

In this project, participants were identified and recruited using a project information "flyer" distributed to local organizations (Appendix 1), community groups, iwi/hapu organizations and the personal networks of the interview team, as well as snow-ball sampling (asking initial expert interviewees for other recommended contacts). There was no pre-existing list of possible experts; this wide range of independent contact approaches through multiple channels maximised our chances of reaching as many experts as possible from the 'expert pool'. Multiple contact points also reduced the potential for 'population clustering'. While 'self-selection' through the flyer was an inherent component of expert selection; the great majority of our successful contacts were made by us through our direct approaches, and subsequent expert referrals; the flyer returned 2–3 contacts only.

One possible alternative partial approach, as suggested subsequently by the AEWG, might have been to use past fishing quota (or landings data) to identify commercial fishers (39% of the LEK interviews) for possible inclusion. This would potentially have provided an overall expert pool for commercial fishers (assuming that the records were suitable, and any privacy issues could be worked through), and possibly enabled a ranking of their expertise (e.g. by catch, or number of years fished). Such an approach could be trialed in future if similar work was carried out elsewhere.

The issue of potential differential participation rates (i.e, of people chosing not to participate based on similarly held viewpoints forming a cluster, which is then under-represented in the final sampled group) is also a possible bias. As the interview process was a completely voluntary process, and we have no mechanism to quantify if such a process was occurring, it remains an unknown potential bias, although we suspect it would be small, given the general concerns about the harbour apparently held by fishers and other users of Kaipara Harbour (see KHSFG 2003).

In order to obtain local ecological knowledge from the Kaipara region, a series of one-on-one semi-structured interviews were carried out. All those individuals contacted were long-time residents in the region, with extensive histories (20 or more years) of either commercial, recreational or customary fishing (including shellfish gathering) (Figure 25). NIWA has no human ethics approval process. However, the primary interviewer (L. Makey) is a PhD candidate at the Auckland University of Technology (AUT), and in addition to the ENV200907 interviews reported on here, ran a shorter social values interview section for her AUT thesis work. Interviewees were fully informed of the separate nature of the two interview components. The social interview section (not part of ENV200907) required and received approval from the Auckland University of Technology Ethics Committee (AUTEC). That approval required that the research was undertaken within the parameters outlined in the approved application, including adherence to key ethical principles for research: the principles of the Treaty of Waitangi (i.e., Partnership, Participation, Protection), informed and voluntary consent, minimisation of risk, respect for rights of privacy and confidentiality, research adequacy, avoidance of conflict of interest, truthfulness, and limitation of deception. In lieu of a formal NIWA process/protocol, we adopted the consent process used by AUT, and all participants were provided with an information sheet outlining the project brief and how the data would be used (Appendix 2) and asked to sign a confidentiality agreement and informed consent form at the outset of the interview, as well being given a verbal description of the forms and the process.

Interviews were guided by a set of specific questions, which also allowed for less structured (open-ended) conversations based on the interviewees' experience and knowledge of fishing and other sites that were important to them. In the more structured part of the interview participants were asked about changes in the abundance and size of key species, the extent of habitats, and changes in the environment of the Kaipara Harbour since their first experience of the harbour. For each environmental parameter / habitat / species, the participants were asked to score abundance, extent, or quality across a series of time periods (decades), as relevant to that individual. For the decade in which abundance / extent was thought to be highest, a score of 10 was assigned, with all other decades (as experienced by the interviewee) scored relative to that decade (range of 0–10). If no change was observed across all the time periods this was noted. Participants were asked to rely solely on their own recollections and leave cells blank where they didn't know, didn't notice, didn't remember, or didn't visit during that time period. The possible causes of the changes observed were also sought. Marine charts were used throughout the interview to allow participants to identify the sites they were referring to, and audio recordings were made, subject to their permission.

Not all participants had recollections dating back to the earliest decade (1930s), and therefore it was necessary to scale the scores from those participants whose time series began in a later decade. This was done following the method of Taylor et al. (2011), whereby for each species, the scores of those whose experiences were more recent were re-scaled so that their score in their initial decade matches the average of those starting in the 1930s for the same decade; with all subsequent decades scored relative to their first decade. Scores for subsequent decades were scaled in the same manner.

Of the 45 people approached initially, 31 Kaipara residents from Dargaville, Helensville, Ruawai, Port Albert, Tinopai, Whakapirau, south Head and Pouto were interviewed between July and November 2010. Of these, 12 were classed primarily as commercial fishers (past and present), 12 as recreational, and 7 as primarily customary fishers. The spatial coverage of the participants was broad, covering the Kaipara Harbour entrance, main channels and inner arms. The results of the combined ranked scores are presented in the following sections along with an accompanying narrative developed from the comments and memories of the respondents reflecting their combined views on the environmental changes that have taken place, the declines and increases in different habitats and species of fish and shellfish.

Our definitions of 'habitat' in the questionnaire and interview were inherently those of the 'biotope", but with a focus on single species habitats that were readily identifiable (Diaz et al. 2004). For example, this included seagrass meadows, mangrove forests, and green-lipped mussel beds – noting the use of collective grouping terms such as meadows, forests, and beds. No specific densities per unit area, or extents were given to the interviewees, but it was made clear during the interviews that we were interested in spatial extents of these habitats as a whole, and that isolated individuals (e.g. a mangrove tree, or a single seagrass clump) did not constitute a habitat as such in the context of this work.

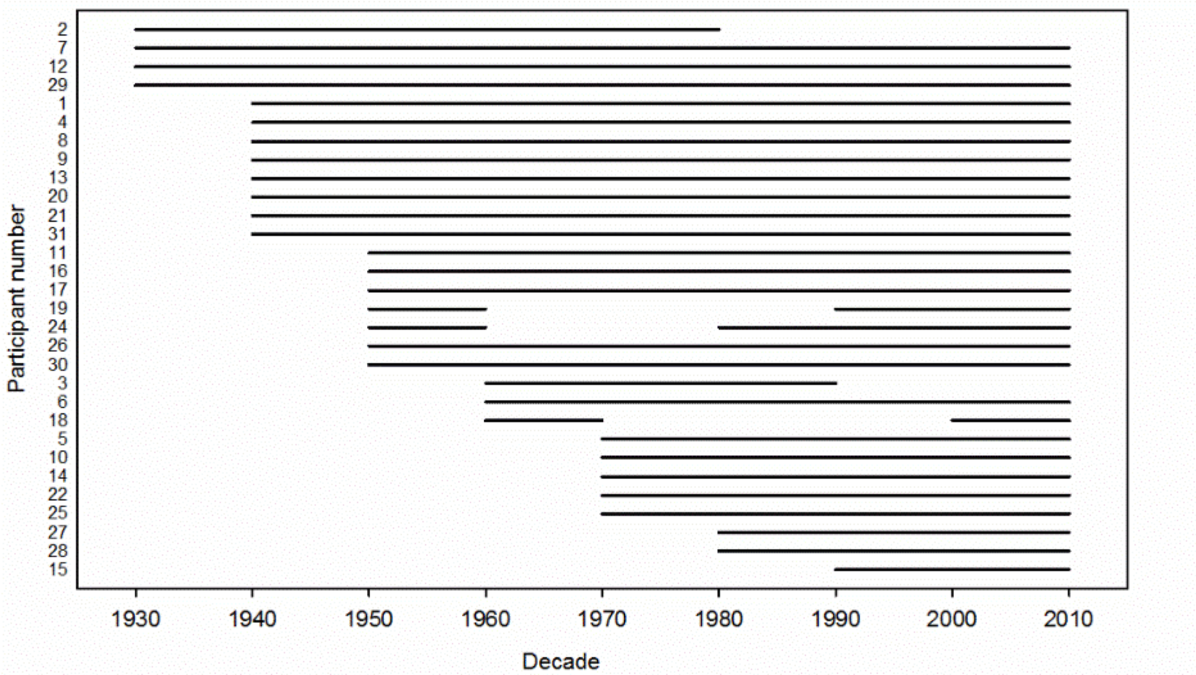

Figure 25: Years over which different participants provided information on the Kaipara Harbour.

3.2 Results

Habitat forming plants and shellfish

Many participants believed the harbour has always had relatively murky, muddy water (participant numbers 14, 27, 4, 1, 13, 8, 29, 17, 24; Note, these are the unique sequential numbers given to a specific interview, and are not given here in any particular order), as reflected in the combined ranked scores for water clarity, suspended sediment and seafloor muddiness (Figure 26). There was an overall trend in increased seafloor muddiness (30%), and a decline in water clarity (in this case a high value equates to good water clarity). One participant (8) recalled his father talking about how ships would "*put their noses up Kaihu River to get freshwater for the ships barrels"* and that Aratapu Creek, above Te Kopuru was once a navigable river. Another remembered "*clear blue water coming way up here*" referring to Raupo Creek and Tikinui, often reaching as far up the river as Te Kopura (12). Up until the 1950s, there were "*beautiful white sandy beaches*" at the Tikanui ferry wharf, Johnson's Bay across from Ruawai, and places such as Taingaehe and Punahaere Creeks, Tangikiti and Kelly's Bays (27, 12, 8). These bays have now become muddier, with mangrove stands encroaching, although sand has returned in recent years to places such as Punahaere Creek and Tangitiki Bay (27, 18). This was attributed to pine plantations and riparian planting at Tangikiti Bay, as well as a recent (2009–10) dry spell, which resulted in improved water clarity in the upper reaches of the harbour. Other bays mentioned by interviewees where mangroves have colonized or expanded include Okaro Bay (8), and Awaroa Creek, where the build-up of sediment, mangroves and Pacific oysters has in-filled the once navigable creek separating Burgess Island (10, 29). The size of banks in the Wairoa River were believed to be increasing, such as the Aratapu Bank, and the mud flats off Raupo. In these upper reaches of the river the introduction of bull rushes and Manchurian grass has enhanced the accumulation of sediment run-off and destroyed many previous floundering spots. Further down river, sedimentation has made navigation of some channels such as the one between Fifty Acre Bank and Tangitiki Bay difficult at low tide (8, 12, 29, 17). Although water quality has recently improved, "brown water" reaches all the way down to Bushy Point during dry summers, and one participant has observed a decline in water clarity as close to the entrance as Poutu Point, recalling how previously it was possible to see mussels on rocks on the seabed at the base of the sandstone cliffs at Pouto Lighthouse.

In the Kawau-Parua Inlet of the southern Kaipara, the channels that, in previous generations, were navigable with kauri logging rafts up as far as Helensville, have been reduced to "*just a trickle*" by the build-up of sediment (1, 2, 22), and mangroves, described as previously being "*few and far between and around 1–2 m high, now they are everywhere and 3 m high."* As well as filling the channels, the encroaching mangroves had also caused the loss of mud flats traditionally targeted for flounder (1, 12). In the Mairetahi Creek, one participant (16) described previously being able to take a 32 m barge up at low water, whereas now it was impossible to turn a dinghy in the creek due to the sediment and mangroves (4). The Hoteo River was "*full of mud for 2 years*", following the felling of the Dome Valley pine plantation, and was now lined with mangroves (28). One participant recalled a stand of very large (about 10 m) mangroves at Omokoiti Flats that had died off by the 1940s. In all other areas, increased muddiness and mangrove expansion were described, including; Makarau (24), Gum Store Creek and Tapora Bank (26), and Parekawa (24) and Taumata Creek (6), and on the peninsula coast where the mangrove stands had replaced salt marsh habitat. As at Wairoa, the 2009–10 drought resulted in improved water clarity in the Kaipara River as far as Helensville (16).

In the Oruawharo River, previously sandy beaches off Tanoa and in Hargreaves Bay have now become lined with mangroves. Hargreaves Basin was described as having "*silted up badly [from] mud, coming down river from Hargreaves."* Several other areas along the shores and creeks of the Otamatea, Kaiwaka and Arapaoa rivers were noted as being colonized by mangroves stands in recent decades (20), although some participants didn't think there had been much change since the 1970s (5, 14). The overall ranked scores for the extent of mangrove stands indicated resident's perception of a steady expansion since the 1930s and 1940s, doubling in size overall (Figure 26, 27).

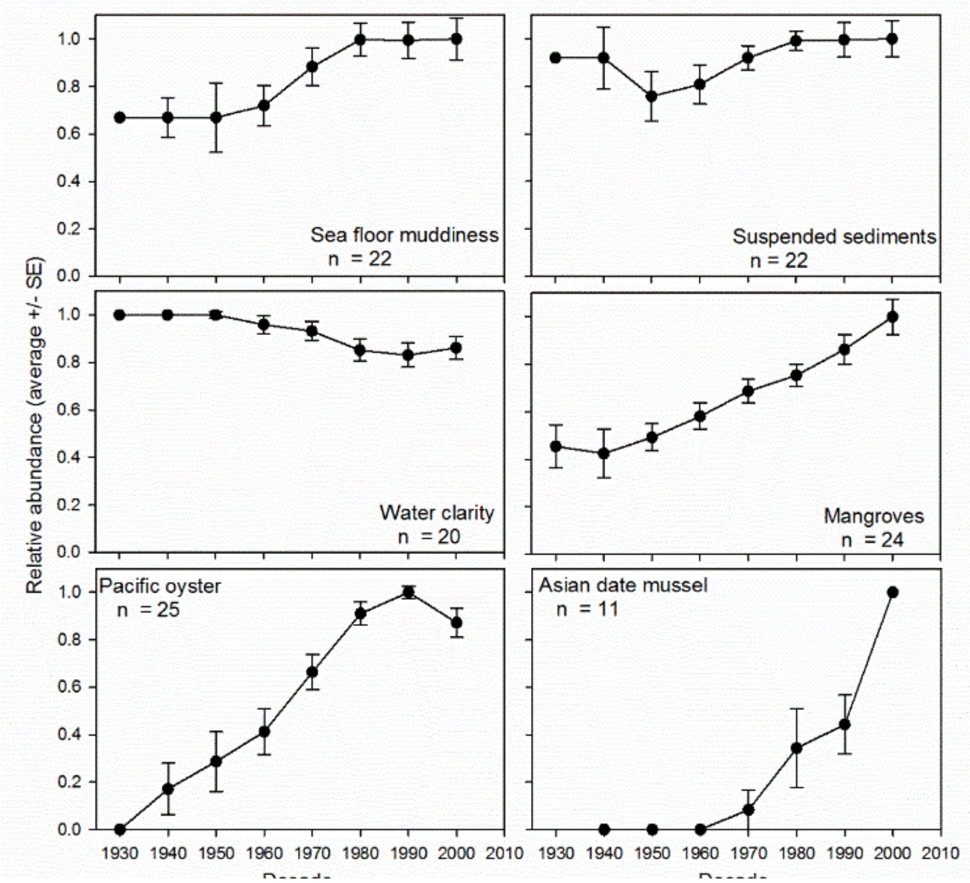

Figure 26: Scaled relative changes in environmental parameters and extent of mangrove, Pacific oyster and Asian date mussel habitat in the Kaipara Harbour, based on the memories of long-term residents of the harbour.

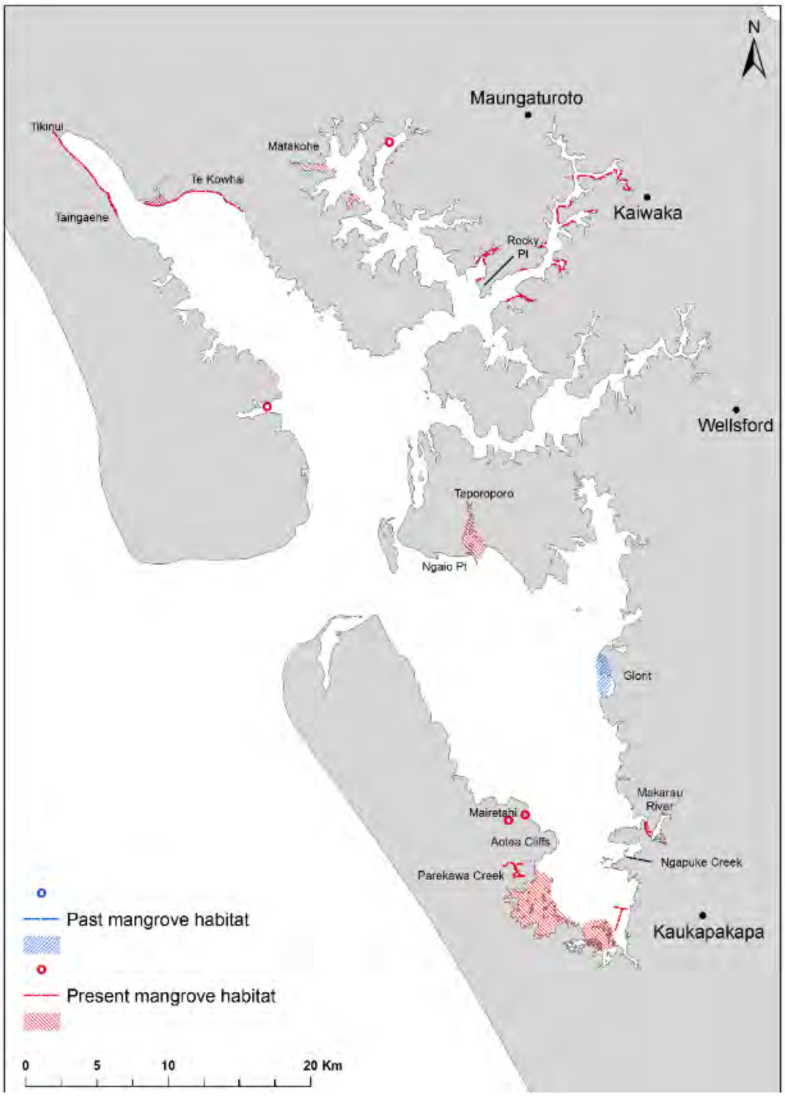

Figure 27: Past and present distributions of mangroves reported by interviewees. Locations were reported as either sites (denoted as circles), linear features (denoted as lines), or extensive areas (denoted as hashed zones).

Parts of the harbour adjacent to land still covered in native bush, such as at Te Kopua Bay and Whakapirau Creek (also has mangroves), had better water clarity than places further upriver such as at Pahi, where farming occurs adjacent to the river (14). Dairy and bull farming, especially where livestock had access to the waterways, was associated by interviewees with increasing muddiness, mangrove expansion and loss of shellfish beds, whereas division into lifestyle blocks with lower stocking density, fencing and riparian planting had all improved water quality in some areas. This was noted by one participant in Paparoa Creek following recent fencing and planting along the foreshore (17). The Whakaki River had some of the poorest water clarity with siltation levels "*twice the depth of the other rivers*", as a result of the lack of fencing and riparian planting in this catchment, and with planted forestry felled and left in the paddocks.

The influence of season, rainfall and prevailing weather on siltation and water clarity were mentioned. Less frequent storm events were thought to have resulted in the sediment build up not being washed away, e.g. Pahi Point (30, 31). In the Arapaoa River, it was suggested that the prevailing westerly winds kept the mangroves from building up on the easterly banks, compared to the Otamatea River, where the prevailing wind was against the tide, and the water was often murky at Port Albert.

The Pacific oyster was first observed by interviewees in the Kaipara during the 1970s and quickly became established despite efforts to remove it from areas where native oysters grew. These oysters initially grew very large, described as "*dinner plate sized*" by several, who recalled how a single oyster could be divided up to share amongst up to four people, and one interviewee kept a 16 cm shell (5, 12, 30). The introduced species also formed clumps, "*big soccer balls of them*", and as beds became established, with spat settling and growing on top of already established oysters, some would grow as long thin, vertical shells, nicknamed "*banana oysters*" (5, 30). Pacific oysters quickly spread and are now found along much of the foreshore of the Arapaoa, Otamaetea and Oruwharo Rivers and Creeks, and through the Funnel (21, 14, 5, 11, 9, 30, 20). In the northern Kaipara, Pacific oysters are found as far up river as Ruawai and Raupo (12, 13), all along the north peninsula coast wherever mangroves have colonized, including Tangitiki, Punahare, Tauhara, Okaro, and Waikeri Creeks, Kelly's Bay (11, 9, 12, 18) and along the Hukatere peninsula coast including Avril Flats and Bushy Point (8, 27, 29). The oysters and associated sedimentation were observed to have ruined many beaches, fishing spots, and former safe anchorages which are now no longer usable due to a build-up of oyster shells that could damage the hulls of boats, e.g. the former creek around Burgess Island, (12) and in the Narrows (10). In the southern Kaipara, Pacific oysters are found in Wainui Inlet, on Tapora Bank off Te Ngaio Pt, Omokoiti Flats near Taumata Creek, on the Kaipara flats off Mt Mataia, in the Kawau-Parua Inlet between Parekawa Creek and Te Kowhai Creek, and near the concrete blinker in the Kaipara River (24).

The combined ranked scores estimated a 9-fold increase in extent of Pacific oysters from zero in the 1930s up until the 1990s, followed by a decline in the 2000s (Figure 26), as reported for areas such as Avril Flats, Whakapirau and Batley Points. Declines in abundance were attributed to commercial harvesting, pollution, and sedimentation. Some believed that oysters are being outcompeted by the Asian date mussels and/or the occurrence of a flat worm (15, 5, 14, 29). In Harrison's Bay, Pacific oysters were thought to have been replaced by parchment worms (27).

Asian date mussels were first observed by interviewees in the Kaipara in the 1970s and 1980s (1, 17, 30), appearing initially in channels, and subsequently have "*taken over huge areas*", reflected in the 10 fold increase in combined abundance scores (Figure 26). These mussels grow in mats forming "*humps*" up to 1 m in height found from the intertidal to depths as great as 30 m (5, 30). The Whakaki River has become difficult to navigate due to the extensive mats and the build-up of silt associated with these mussels (5). Similar effects have been noticed in other areas such as Hargreaves Bay, where the mussels are believed to have created a dam, resulting in the infilling of the bay with mud, burying shellfish beds and making navigation of the Hoteo (30) and Tauhoa (28) rivers difficult at low tide. In the northern Kaipara, mussel beds were described as "*thick …half way to Dargaville*", reaching past Taingaehae (29) and also seen in Punahare Bay and south of Kelly's Bay (13). Some noted that fish such as snapper and flounder feed on the mussels (15, 29), one attributing the increase in juvenile snapper abundance to the expansion of this habitat. However, in some areas, a recent die back of the Asian date mussels has been observed (14), with mudflats and shellfish returning; Pacific oysters were '*extremely fat for the first time in 5 years*" (2010) and native oysters returning on the rocks.

Large areas of present day seagrass meadows were identified by multiple participants, concentrated in the Southern Kaipara, and including the intertidal areas on Tapora banks, outside of Gum Store and Te Ruapa Creeks, Hoteo Flats, the shallow subtidal area between the Tauhoa and Kaipara Channels, Omokoiti and Maretahi flats and Ngapuke Creek (16, 8, 7, 24, 6, 14, 19, 20, 29, 26, 28).

Although the areas outlined were extensive, most believed that there has been a decline in intertidal and subtidal seagrass meadows and this is reflected in the drop in scaled average ranking of around 50% between the 1930s and 1980s (Figure 28, 29). Some of the older participants had memories of when fishers avoided "*the grasslands*", or only set nets along the edges because of the tonnage of fish that would be caught, that, at the time were considered lower value, such as parore and snapper (1). Descriptors such as "*lush*", "*vast acreages*", "*50 hectares*" were used, and one interviewee talked about the seagrass being so abundant that it caused bilge pumps to clog up (16). Some areas were identified where seagrass had disappeared, or was no longer so extensive or healthy. These included the Kaipara flats off Kakanui Point near the “concrete blinker”, where intertidal seagrass was once found up into the gutters (1, 2, 7, 16, 30); the mid channel and off South Head (16); the Hoteo flats, where extensive grazing by swans was thought to have reduced the length of seagrass blades (28), and the entrance to the Oruawharo River, where a previously “*lush*” seagrass meadow of around 10–15 acres in size used to exist on Frenchmans Bank off Oruawharo Heads, which was described as “*one of the best*” seagrass areas in the harbour (8, 20, 30). Despite this overall picture of decline, some participants indicated that there had been an increase in the extent of subtidal seagrass since the 1980s (Figure 29).

Although none of the interviewees could remember seagrass being present in any of the inner estuaries, one recalled that previous older residents had described seagrass beds in Whakapirau Creek prior to the 1970s (14). Several believed they had snagged seagrass on longline hooks in the harbour entrance (3, 8, 11). Seagrass in the northern part of the harbour was either thought to be absent (21, 12, 27), or described as sparse compared to the southern Kaipara. Some had come across patches near Pouto Point (11, 13), in the channel just north of Tauhara Creek (13) and “*a little bit by the mangroves*” in Tangitiki Bay (18). The seagrass near Tauhara Creek was previously the location of the “main” scallop bed, which had been targeted using dredges.

The association between seagrass meadows and scallop beds was commented on by many. In the southern Kaipara, “*supersacks*” of scallops could be collected in the large beds of seagrass on Tapora banks off Ngaio Point and Gumstore Creek, and “the shallows” between the Kaipara and Tauhoa River channels (30, 19, 4, 11). One participant (26) recalled his father taking horses out to these “*massive*” beds to collect scallops by the sugar bag, full enough to feed an entire community. Another interviewee (1) recalled “*a carpet of scallop the size of dinner plates amongst the swan grass [seagrass]…vast acreages…would fill a sugar bag full in one trip*” and another described “*50 hectares, [of seagrass] and massive scallops*”, but believed the scallops had suffered a mass die off in the 1960s (11). In the Southern Kaipara channel, off South head, there had previously been “*a huge scallop fishery*” (20), and at Maritahi Creek, the scallops were so plentiful prior to the 1950s (4, 9), one participant recalled filling a 4 ft dinghy with them, but numbers had declined by the 1980s. The Kaipara flats off Glorit, and Kakanui Point near the “concrete blinker” were identified by multiple participants as extensive past seagrass beds where scallops were previously plentiful (1, 2, 7, 30), with several more noting that scallops could still be found here (28, 20, 4, 7).

In the entrance to the Oruawharo River, previous large scallop beds were associated with a “*lush*” seagrass meadow “*10–15 acres*” in size on Frenchman’s Bank outside Waikiri Creek. During the 1950s, scallops were collected by hand amongst the intertidal seagrass (20, 30), and can still be found here and as far up the river as Hargreaves basin and Takahe Creek (27). The shores of the Otamatea River between Tinopai and the Funnel, particularly on the Puketotara peninsula coast such as Barbara Bay, were described by many as being an area where scallops are still found, but were previously much more abundant and could be picked up “*by the bucket full*” while walking along the shoreline at low tide (10, 19, 12, 25, 11, 7, 15, 29). One participant estimated that he could collect two sugar bags worth of scallops from an area “*the size of the living room*” up until the 1960s, but another noted that most in this area were now undersized. Te Kopua Point and Batley Point were also noted as previously abundant scallop beds, “*in their millions*” (20, 19), and Tinopai was still considered one of the best areas. In the Arapaoa River, “*there used to be masses*” of scallops, which could be regularly collected between Pahi and Whakapirau, such as “Oyster Island”, off Whakapirau Beach (31, 17), and the coastline between Whakapirau Point and Te Kowhai Creek (15).

In the northern Kaipara, scallop beds were previously found in many of the bays along the peninsula coastline, including: Fifty Acre bank off Tangitiki, Kelly’s and Kotiroreka Bays and Doughboy and Beacon Point, Tauhara and Pouto Point (12, 10, 8, 13, 27, 9), (Figure 28). Scallop beds are still found off Beacon and Doughboy Point, in Okara Bay and around Bushy Point on the other side of the river (28, 13, 12).

The combined rankings for scallop abundance in the Kaipara show a steep decline between the 1950s and the 1980s, after which participants indicated a levelling off and slight improvement over the next two decades (Figure 29). Declining water quality, caused by pollution and farm run-off, increased pressure from dredging and an “explosion” in starfish numbers were given as reasons for observed declines. Mass die offs were reported in some beds; one participant (7) described finding a huge aggregation of scallops 1 ft deep near a freshwater water-fall and filling the dinghy he was in up to the seat level with scallops. However, returning on the next low tide, they found a layer of dead scallops 3 ft deep around the waterfall.

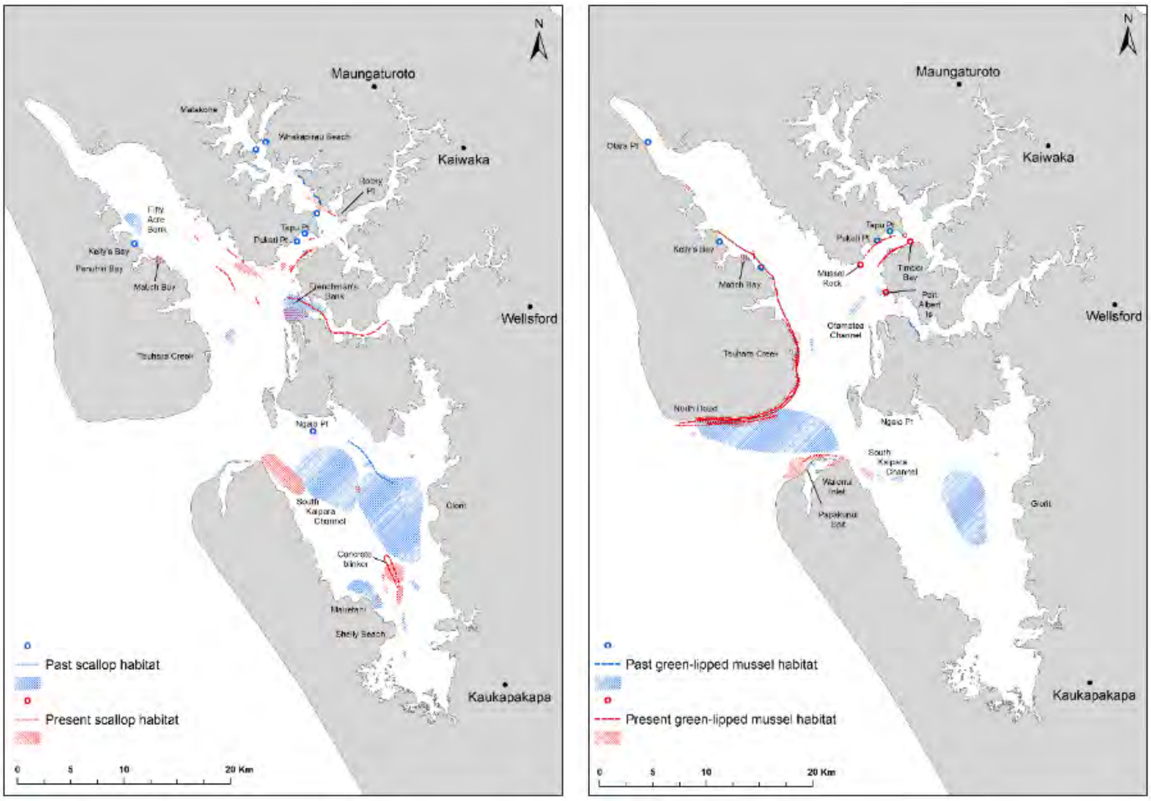

Figure 28: Past and present distributions of scallop beds (left) and green-lipped mussels (right) reported by interviewees. Locations were reported as either sites (denoted as circles), linear features (denoted as lines), or extensive areas (denoted as hashed zones).

Extensive green-lipped mussel beds were previously found in the channel along the northern peninsula, from the Graveyard (12, 10, 27, 11, 7, 6, 13, 30, 9, 1, 2), round to Midge Bay (8, 9), Pouto Point (10, 13, 27 ,30, 31, 11, 12, 9, 18, 20), Tauhara Creek (27, 9), Doughboy (13), Kelly’s (8), Tangitiki (13) and Kopuatete Bay (10) and as far as Otara Point (Figure 28). The mussels were found from low tide down as deep as 30 m on the sandstone rock. The beds were described as “*huge….about 17 acres*”, “*like a carpet*” at Pouto Point and “*fifty acres of them*” at Midge Bay. These were the main target of the dredge fishery, with one participant recalling getting 20 sacks of mussels from dredging in around 10 m water depth at the harbour entrance. Divers in cages were also used to collect mussels, which had been observed growing in columns 6 ft high (30). Dredging peaked in the 1970s and the combination of this fishing pressure, Cyclone Bola in 1988, and sand extraction activities were thought to have resulted in the decline or disappearance of many of these beds. The large mussel bed at Midge Bay was believed to have been buried under iron sand, however mussel beds were still present at the Graveyard, Pouto Point and described as being present in good numbers off Tauhara Creek. All these areas were also noted as being good snapper fishing spots targeted by recreational fishers. Mussel beds further up the river, such as at Kelly’s Bay, Otara Point, and Avril Flats, were believed to have most likely disappeared, although some can still be found in Clark’s Bay. On the southern side of the entrance, mussel beds can still be found off Papakanui Spit (2, 22, 16, 6). A previously "*prolific*" bed in the channel off Te Kawau Point was stated to have been illegally dredged and to no longer exist.

In the inner parts of the harbour, "The Funnel" area, including off Puketi, Tapu and Yellow Points (19), Timber Bay and Pakaurangi Point and into the Arapaoa as far as Whakapirau were recalled as previously "*full of mussels… just about anywhere you went ashore, there would be good sized mussels on the rocks*" (14). A "*massive*" bed of mussels was recalled off Tinopai by multiple participants, (12, 8, 17, 5), and "*the odd patch*" can still be found (17). Previous large mussel beds were also found at the entrance to Oruawharo River near Moturoa Island, and had attracted gatherers from all over the Kaipara, as well as being commercially dredged in the 1970s and 80s. Mussels were also found along the banks of Oruawharo Heads skirting a deep hole that was traditionally targeted for sharks (30). The decline or disappearance of many beds was reflected in the combined relative abundance scores which dropped by nearly 60% over the time period (Figure 29). Present day mussel beds were identified at Pakaurangi Point, Timber Bay and Mussel Rock.

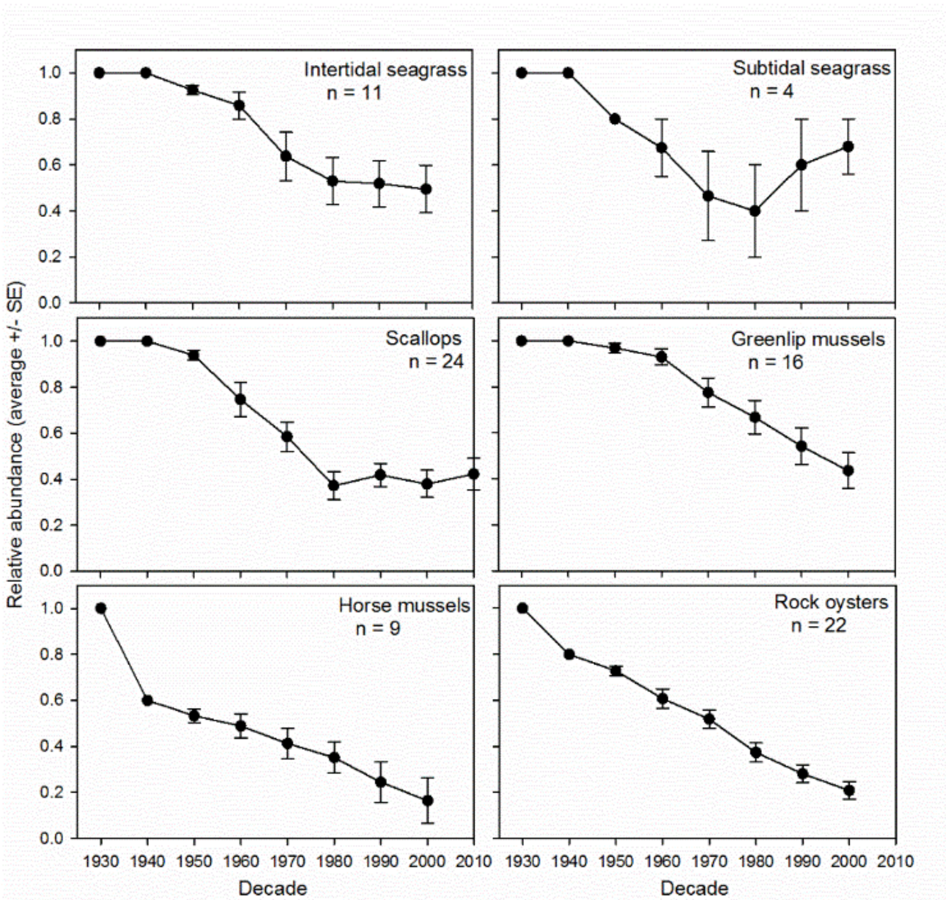

Figure 29: Change in relative extent and abundance of seagrass, scallops and habitat-forming shellfish in the Kaipara Harbour, based on the memories of long-term residents of the harbour. Note that only scallops were scored for 2010.

Another habitat-forming shellfish thought to have declined in extent were horse mussels, with the combined relative abundance trend showing an overall drop in abundance of over 80% (Figure 29). Sites of previous abundance included areas off Frenchmans (30) and Tapora banks (26, 7, 24), with one participant recalling "*when I was a kid, there was horse mussels everywhere, something we had to watch with bare feet…no horse mussels these days*" (26). They were also common, along with scallops, between Te Kopua and Pakurangi Point especially on the sandy gravel substrate. This area is now dominated by Asian date mussels (14). Along the northern peninsula, horse mussels are less abundant, but can still be found on Fifty Acre Bank (29), along the channels, on the shallow flats and off the bays between Matine, Beacon Point and Okaro Creek, as well as off Bushy Point on the other side of the harbour (9, 11, 13, 27, 29).

Native rock oysters were once found widely throughout the harbour, but abundances have declined by around 80% since the 1930s (Figure 29). They were described as being “*extensive*” between mid and high tide, from Pahi all the way along to the eastern side of the Arapaoa River (7, 5, 9), where they were commercially harvested in the past. Those above mid tide were often less plump and called “biscuits”. In the 1970s, one participant owned a small native oyster farm in Tahupo Creek and recalled attempting to protect them from Pacific oysters by removing the NIS Pacific species where it occurred. Rock oysters were also be found around the Tinopai/Hukatere peninsula and all along the north Kaipara peninsula preferring rock substrate and occurring at Island Point, Beacon Point, Pareotaunga Point and in Punahare and Tauhara Creeks (27, 9). Although largely outcompeted by Pacific oysters, and affected by siltation, some beds of native oyster still survive up creeks near the high tide mark, such as in Tahupo Creek (5) and along the Tinopai/Huakatere peninsula (27).

Other vegetation

A number of other habitats were listed, but very few participants felt able to score the extent of these; brown kelp, green and red algae, Manchurian rice grass, salt marsh, *Spartina* and sponge habitats. Only two participants discussed kelp beds; Pouto Point was mentioned as a site where kelp could be found, but both believed the kelp had declined. Four participants provided scores for green algae (probably *Entermorpha*/*Ulva* spp.), with two believing there was an increase in occurrence, attributing this to freshwater “seepage’ and nutrient run-off associated with livestock having access to the beach. Similarly, all but one of those scoring for red algae (probably *Gracilaria* spp.) suggested an increase, which they linked to prolonged periods of rain and the presence of sewage. Sponge habitat was only scored by three participants, all believing occurrence had declined. It was associated with sandstone, rock and boulder substrate and observed at Pouto Point (not extensive), along the coast to Okaro Bay in the north Kaipara (29, 13, 9) and Puri’s Reef in the northern channels of the Funnel region (9, 5). This habitat was not thought to be prolific, but was targeted by those fishing for species such as snapper and kahawai and sometimes snagged on hooks.

Other shellfish

Participant recollections of shellfish indicated historically extensive beds of cockles, pipi, and toheroa. In the southern Kaipara, one participant (1) talked about being able to visit any hard sandy shore as a child and gather cockles. Shelly Beach used to have a 1.5 m high wall of shells which are gone today, and there were “*truckloads*” throughout the bays and inlets along the South Kaipara Peninsula (27), as indicated by dead cockle shells in these areas. In the Arapaoa River, one participant (17) recalled camping holidays at Pahi and collecting "*bucket loads of cockles off beach*". Another (5) described there being “*heaps of pipis and cockles*”, that they could collect “*wherever you were*”, with the largest beds in shallow embayments between Whakapirau Point and Page Point. At Puriri Point / Tahupo Creek a previous cockle bed is now buried under silt (14). In the Matakohe, Paparoa and Whakapirau creeks the die off of cockle beds was linked with the introduction of Pacific oysters (21), resulting in “*massive banks of cockle shells [that] were a nuisance to fishermen*. In the Wairoa River many of the inlets along the peninsula coast were remembered as previously having good cockle and pipi beds (27, 13, 18, 7, 10); Taingaehe Creek, Kopuatete Bay, Charles Bay in “The Narrows”, Tangitiki Bay, Kelly’s Bays, Doughboy Point, Oneroa Bay, Waikeri and Punahaere Creek. There are still cockle beds present in some of these areas, but they are thought to have diminished. One participant had found cockles for the first time in 20 years between Taingaehe Creek and Kopuatete Bay, and noted that Pacific oysters were dying back in these areas. In the southern part of the harbour, present-day beds were also identified in Waionui Lagoon and Papakanui Spit (2, 22, 24), and on the Tapora and Omokoiti Flats along from Haratahi Creek (4, 24). In the inner estuaries, past cockle beds were also identified along the banks of the Oruawharo River, and along the whole of the inner Araopaoa River from Pahi to Whakapiau Bay (21, 14, 5). Few beds remain in these estuaries, although small cockles were found in places such as Whakapirau Beach (17) and up near Port Albert wharf (30), and Frenchmans Bay (4) (Figure 31).

The overall ranked scores of cockle abundance indicated a harbour-wide decline of over 70% since the 1960s (Figure 30). This decline was mainly attributed to sedimentation and farming, as well as cockles being outcompeted by Pacific oysters and heavily harvested by an increasing human population. The recent signs of recovery were linked to die backs of oysters and livestock being more frequently fenced off the waterways and beaches.

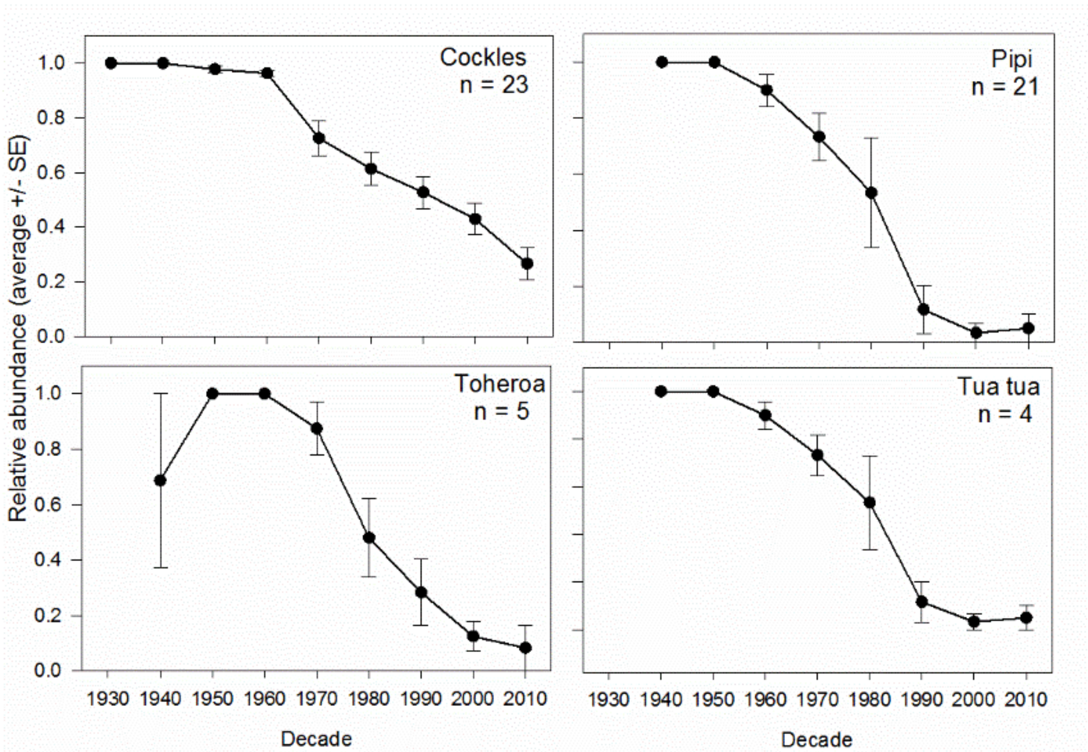

Figure 30: Change in abundance of shellfish in the Kaipara harbour, based on the memories of long-term residents of the harbour.

Similar to cockles, all those interviewed noted a decline in the number of pipi (Figure 30), with many having recollections of areas where previously it was easy to gather large numbers; "…*used to be an abundance of pipi at most beaches...started to decline when immigration into the area increased about 1960s*" (7). In the northern Kaipara, pipi were previously plentiful in bays and creeks along the peninsula, including Clark's Bay, Punahaere Creek (27), Oneroa Bay (10), Treasure Bay (between Te Ta Point and Beacon Point (also known as Matine Point), Te Hokono Bay (12), and Tauhara Creek (12, 11), (Figure 31). One participant used to go every weekend with his family to Doughboy Bay (south of Matine Point), to collect pipi as well as green-lipped mussels, cockles, spear flatfish and to go fishing for snapper (13). Pipi beds can still be found in many of these areas, although they are not as plentiful as in the past. Punahaere Creek was described as "*not what it used to be*" and thought to be affected by effluent run off from nearby dairy farms (27), whilst Tauhara Creek, was described as an old bed, but "*still abundant*", with "*hundreds*" of small pipi, especially up near the freshwater (27, 18, 9). Other present day pipi beds mentioned were; Okaro Creek (9, 7), Kelly's Bay (9), Clarks Bay, and Matine Point (29). On participant commented that pipi beds "*get better the further south you go*".

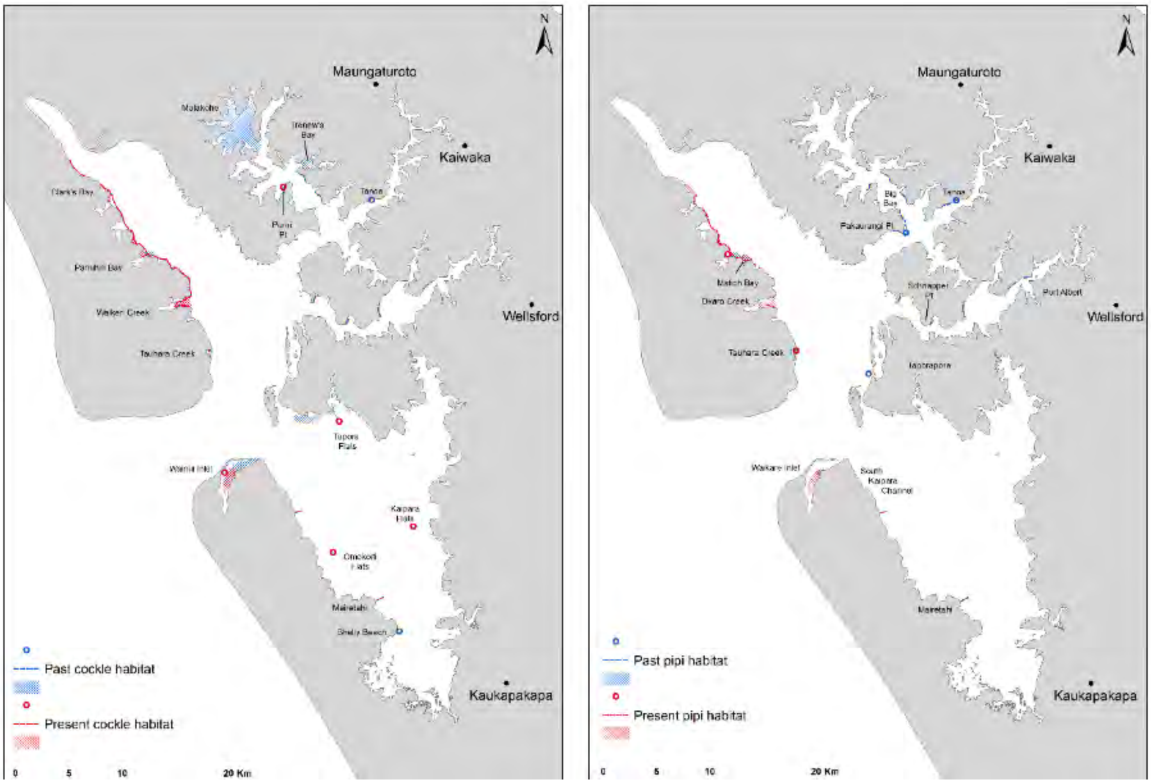

Figure 31: Past and present distributions of cockle beds (left) and pipi (right) reported by interviewees. Locations were reported as either sites (denoted as circles), linear features (denoted as lines), or extensive areas (denoted as hashed zones).

In the southern Kaipara, past pipi beds were identified at Mairetahi Creek and at Pararaha Point/Omokoiti Bay, but these are no longer present. Several participants still gathered pipi at Waionui Lagoon and at Papakanui Spit (2, 22, 9). In the inner estuaries, past pipi beds were identified at a number of sites. Other past pipi beds included Tapora Bank (20, 31), outside of Gum Store Creek (7) and Waikiri Creek (31), and multiple sites along the Otamatea Channel, Arapaoa and Oruwharo rivers including Coates Bay, Komiti Bay and Te Kopua Point. The foreshore on the north side of Pakaurangi Point was known as "*Pipiland*", and was mentioned by several interviewees (15, 31, 20), but started to decline as recreational gathering increased and this bed is now covered in mud and silt (15). Outside Tanoa marae, further along the Otamatea River, sedimentation has wiped out a large cockle and pipi bed present in the 1960s (20, 15). In the Arapaoa River, pipi disappeared from Pahi Beach about 15 years ago (31), and between Tahupo Creek and Puriri Point, there had been a "*95% die off of pipis and cockles*" and the bay is now full of Asian date mussels (15).

Far fewer participants felt able to score for toheroa and tuatua. Toheroa populations were indicated along the beaches of both the North and South peninsula, and the health of these populations was linked to the impact of pine forest plantation and felling cycles on freshwater supplies (1, 10, 18, 6). Previous tuatua beds were identified at Ripiro Beach, Glinks Gully and Mahuta Gap. One interviewee recalled going to the beach with his parents in the 1960s and taking a frying pan along with butter, bread etc, and being able to eat "*as many [tuatua and toheroa] as you wanted*". Commercial gathering of tuatua begun in the 1960s and 1970s and the combined abundance rankings show a dramatic decline to almost zero for both these species (Figure 30). Some surviving tuatua beds still exist in the entrance channels, and at Fitzgerald Bank and Papakanui Spit (30, 12, 16, 7, 9, 24). Another bed adjacent to the northern end of Woodhill Forest was thought to have recovered after pine trees had been felled eight years ago, allowing the nearby dune lakes to increase (6).

Commercial fish species

The main fisheries in the harbour at the time of the earliest recollections of participants were for yellow belly flounder, grey mullet and sharks. Older participants were able to remember when the harbour supported around 30 local fishers, with many of these based at Port Albert, Tinopai, Pahi, Te Kopuru and Ruawai. The number of fishers has now dwindled to "*a handful*". One participant (30) recalled how, at the time he entered the fishery in the 1950s, one of the older fishers at that time believed the fishery was in decline.

Yellow belly flounder

Those fishing in the northern Kaipara and Wairoa River (12, 27, 29) recalled favourite flounder spots in the early days (1940s) "*way up the river past Te Kopuru*", but also mentioned Tokatoka, Tauihu Creek, Clark's Bay, the Narrows, "Gordon's Bank, "Avril [Awaroa?] Flats", and further south, the bays and gutters off Hukatere, and as far down the river as Te Hakono Bay. These habitats were mud and sandy mud banks, which were also good for collecting cockles and pipi, but many of the up-river sites had been "*ruined with the [Pacific] oysters*". Large catches were recalled; one fisher (27) described how it was possible to catch 40–50 kg of flounder in just an hour, near Tokatoka, and a day's fishing yielding "*20–30 bundles*" (a bundle = 2 dozen fish), whereas one participant noted that "*you can't get a feed there now*". The same fisher (27) had caught half a ton in two hours at "Avril" Flats, and believed this was a small catch compared to other fishers at the time. Another participant (19) recalled seeing and playing with numerous "*very large*" flounder in the shallows as a child and quoted catches of up to 130 dozen fish using a 600 m net. Although the fishing spots up-river were no longer considered to be productive, many of the bays further down-stream (9) were still important fishing grounds, including Tauhara, Waikere, Tangitiki, Kelly's and Clarks Bay and Peach Point, which were considered to have "*an abundance of flounder (sand, yellow-belly) ... they seem to peak around Christmas then trail off. Juveniles are plentiful all year round".* "Avril" Flats (especially the gutters) are also still considered an important summer fishing spot, although the fishery has declined, with catch rates reduced from 3–4 bins/day to as little as 10 fish per day on occasion.

In the inner estuaries, such as the Arapaoa, one participant (14) recalled that when he first moved to the Kaipara in the 1970s, '*any bit of mud held flounder…couldn't set foot on a beach without upsetting a flounder and could literally lift them out of the water at the beach, they were that docile….now only the main bays are where fish aggregate."* One of these sites, where the mud flats in the bay between Puriri Point and Te Kopua Point were adjacent to native bush, was perceived to have cleaner water and better catches, being described as "*a prolific flounder area*" (14). On the Oruawharo River, Hargreaves Basin was an important floundering area until the shallowing of the bay by Asian date mussel mats and sediment prevented nets being set across the whole bay (30). In the southern Kaipara, a current fisherman regards Gardener's Flats to the east of Te Kawau Point as an important flounder area, although routine catches have declined from around 300 kg from a set when his father was fishing to 100 kg today. Other favoured fishing spots including Tauhoa River (30) and Mairetahi Creek, where one participant recalled his grandfather heading "*When the moths were on the window and water was calm they would spear up to 140 flounder in a tide with a tilly lamp, 1965*". Another (2) recalled a particularly good catch from the 1970s of 80 bundles (a bundle = "*10 lbs*", so around 400 kg total weight) using a 600 yard (550 m) net that filled the boat so that he had to walk it back to shore. The Tauhoa River is still considered a good area for yellow belly flounder, as well as grey mullet, particularly in winter, with 3–4 part-time boats working out of Helensville.

Overall, an almost 50% decline in the relative abundance of yellow belly flounder in the harbour was estimated by participants (Figure 32). Many interviewees believed heavy fishing effort had caused depletion, blaming dories coming in from other areas and a minimum mesh size that was too small. Impacts of land use such as run off and pollution were also noted, along with habitat loss from NIS species such as Pacific oyster and Asian date mussels.

Larger flounder were perceived by some to be more plentiful in previous decades with one fisher describing "*plenty of big ones…would hang over the side of your hand…if it wasn't a big one you* *didn't bother*." This participant (12) has a photo of his son with a 20 lb flounder caught in the 1970s. Another estimated that the breeding stock of larger fish had been depleted with the average size reduced from 40 cm down to 30 cm. Others didn't think the size of fish had changed. The combined estimates of average size by decade, suggested a drop from around 35–40 cm in the 1940s (n=2) to 31 cm in 2010 (n=8, SD=2.7 cm).

Most fishers noted that the larger yellow belly flounder moved between the harbour and the coast to spawn, often using the phrase "*en masse*". Certain sites are targeted at certain times of the year. In the southern Kaipara, flounder are caught first on Gardener's Flats in December and January, moving progressively further into the harbour throughout the summer (27). Another commented on a "*big rush*" as fish (presumably) moved out of the harbour in March and April, but which is now later in August and September. The flounder were thought to feed on the mud crabs (14, 16, 1), particularly in spring, but also on Asian date mussels (24). Juveniles were also thought to be mobile, utilizing tidal currents. One participant described large schools resembling "*great moving black masses travelling up the rivers, like whitebait schools*" that were previously a common sight, although not any more.

Sand flounder

Sand flounder (dab) were found in the same habitats as yellow belly flounder, but were never as abundant; making up a small part of the bycatch and having no commercial value historically (2, 5, 16, 25, 15). Several commented on the abundance of juveniles, which were described as "*Autumn leaves, everywhere at a certain time of the year*" and "*like little postage stamps*", with a "*huge influx into places such as Whakapirau Bay during spring and autumn of most years, but not all*" (1, 5, 14). Larger fish were thought to be resident all year round, with more caught at night and during winter (14, 16). One fisher recalled catching 750 lbs of dab in one set in Adams Bay (Okorako Creek, 31), and another commented that he used to be able to catch 8 to 15 lbs of dabs, as well as much higher numbers at times; "*…*[from] *300* [historically] *to just 3 the other day*." (14). Several participants believed there had been a recent increase, one commenting that there were "*a lot more these days, get them everywhere*" (29, 14).

Grey mullet

Heavy fishing pressure from both ring netting and set netting was perceived by many to have caused the nearly 60% estimated decline in grey mullet abundance (Figure 32). A number of participants recalled very large catches; one southern Kaipara resident (16) described previously seeing "*… huge schools of mullet, 5 acres across, jumping in broad daylight*", noting he hadn't seen such a phenomenon since the 1980s. Others talked about large numbers of fish being active at night; one (12) described being able to hear the mullet "*popping at the surface at night*" and believed there used to be much larger numbers, "*thousands of mullet*". Another (19) that they were so "*prolific at night, you could spear fish them*". The fish were observed to move into the harbour and up into the creeks before Christmas, with one participant observing spawning mullet as far upstream as the Kaihu River at Dargaville, and had seen fish stranded in the rushes when the tide receded. Several participants (26, 29) associated jumping mullet with spawning activity, and one recalled that these schools were previously not fished on until after spawning. However others commented that such schools were targeted by ring netters, who, in the early days (1930s) wouldn't even try to close the net, there were so many fish. Dry set netting (where nets are exposed as the tide dropped) was also commonly used by many fishers. The heavy cotton nets, about 400–500 m long usually caught more than enough fish; one commenting that he would often catch up to 100 dozen fish in a half day, which he would split, smoke and salt, and sell locally. Exceptionally large catches were also recalled. One participant (2) remembered being with his grandfather (1930s) and catching 750 dozen grey mullet (around 9000 fish = "*several tonnes of fish*") in one set in the Southern Kaipara, which took all day to get out of the nets, with the school sharks circling and biting off the heads of meshed fish. Another (31) caught around 1000 lbs of grey mullet (half a tonne) overnight in one tide at Te Kopua Point, although he commented that catches varied and sometimes there were none. When fishing contests started in the 1960s at Dargaville, one participant (7) sold mullet he caught off Ruawai for 20¢ each, for bait. He recalled launches filled so high with mullet that they were dangerously low in the water, and stated that he regularly caught enough mullet to fill a 1.5 t truck, with one days fishing estimated at 2.5 t, that filled up all available space in the delivery truck until it was so loaded down, it was limited to a slow speed with regular stops to pump up tyres.

The introduction of motorboats, trailers, nylon mesh, and changing regulations that opened up the Kaipara to mobile "dory" fishers from other areas were thought to be the main reasons for the observed decline in the abundance of grey mullet in the 1970s and 1980s. Several participants compared present day catch rates with those from the past. One customary fisher noted that from a 60 m net, catches had declined from around 200 fish when he first started fishing (1950s), to around 20 fish today. Another participant (30) suggested that 20 dozen fish was considered a good catch today, compared to former catch levels of 100 dozen, from much smaller nets with shorter soak times. Some (6 participants) commented on a reduction in size with several mentioning that "*good sized*" fish of around 70–75 cm were rarely caught (5, 7). Of those estimating the average size of fish by decade, the length declined from just over 40 cm in the 1940s (n=4, SD=8.9 cm) down to just under 35 cm (n=6, SD=7 cm).

Grey mullet is still an important fishery in the harbour with several participants commenting on the abundance of the species, one describing "*Huge runs of grey mullet where the brackish water hits the clear water across the sandbanks in the North Kaipara; can get runs right up to Dargaville Bridge and across flats*" (30). Another mentioned 160 bins [50 kg per bin] being landed from Shelly Beach in the recent past. Mullet grounds included Whakapirau Creek, Kirikiri Inlet, and Adams Bay (4) (named on marine chart as Okorako Creek) in the Arapaoa River, "Avril Flats", 5 Fathom Bank, Taingaehe and Ruawai Flats in the Wairoa River. The 2009–10 year was a poor year for mullet, with several believing that the drought and lack of freshwater had resulted in mullet not coming into the harbour in any number, and another commenting on not seeing any juveniles which were normally common throughout the shallower waters of the harbour.

Snapper

Snapper was described as historically a low value species, quoted as being worth two pence to sixpence a pound, compared to 2 shillings a pound for flounder. Snapper were called "*rough fish*" or "*trash fish*" and not targeted commercially. Fishers avoided "*the grasslands*", as "*there were tonnes and tonnes of snapper and parore, which would destroy the net*." One participant (31) recalled dry setting (stalling, where the net is set and left to dry out as the tide receeds, see Figure 33) at neap low tide instead of high tide to target flounder and avoid snapper, sharks and rays, which leave the river within the first few hours of the tide going out. This participant observed that "*….there was a huge amount of snapper in the harbour*", and this view was shared by most others interviewed, who recalled exceptionally large catches, and that large fish were easy to come across over a wider range than today, including the inner harbour tributaries. Examples of comments about large catches of snapper from the inner estuaries, the main harbour areas, and the open coast in previous decades are listed in Table 2. These memories reflect the importance of snapper as part of the family meals of older participants. Several commented that snapper, fresh or smoked was a staple part of their childhood diets (5, 6, 18), with one (18) recalling strings of snapper carcasses being dried (in the 1960s) and that "*every child had their own fish to eat*".

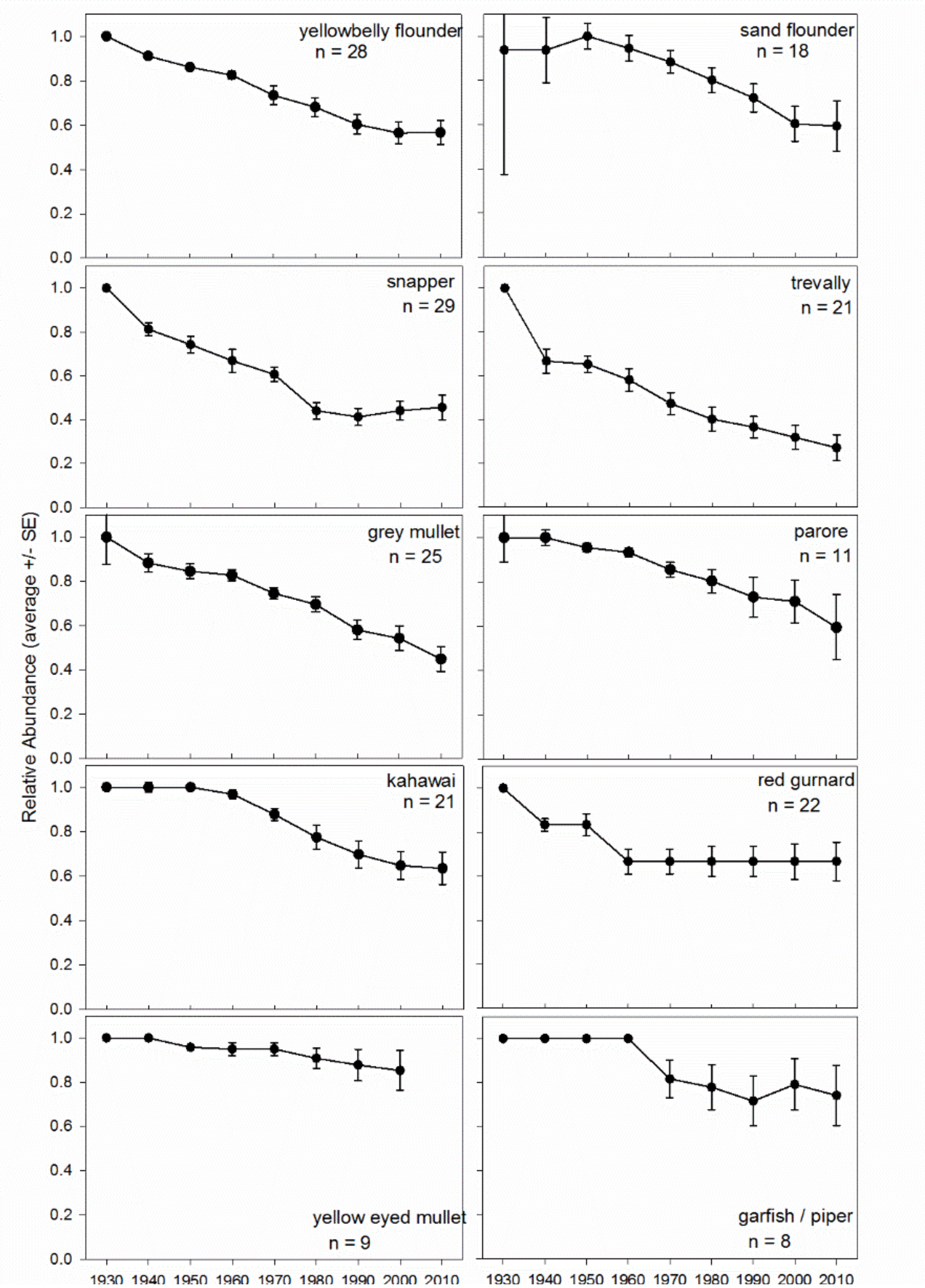

Figure 32: Change in relative abundance of fish species in the Kaipara Harbour, based on the memories of long-term residents of the harbour.

Figure 33: Fishing utilizing the ‘stalling’ method, unique to the Kaipara Harbour. Cotton nets were set at high tide. Once the immense tidal flows had subsided and extensive sandbanks were exposed at low tide, fish were collected from the sandbanks and gutters and flicked onto the intertidal flats (a–c), where they were loaded into punts to return to the boat (d). (Source: R. Scott).

A number of participants noted the occurrence of sizeable snapper in the upper reaches of the harbour, which would now be considered unusual. For example, one participant (12) recalled spearing a large snapper off Te Kopuru (Wairoa River) as a child in the 1930s and 1940s, when “the blue water came further up [the river] in those days.”, and another participant (13) reported large catches of snapper from the same wharf. A bit further downstream, another (29) recalled catching large snapper all year round off the wharf at Ruawai as a school boy in the 1930s and 1940s, noting that there hasn’t been a [legal-sized] snapper caught from the wharf “in a long time”. Participant 31 described how snapper (and trevally) could be found close to “Snapper rock” in the upper reaches of Pahi River, and another (25) recounted how he used to catch snapper “in the creeks” of the Arapaoa River using pipi tied up with cotton as bait. It was also common to catch snapper off Port Albert and Hoteo (28). Along with these memories, seven participants (26, 31, 5, 10, 1, 22, 19) recalled instances of snapper feeding in large numbers in water so shallow that their tails would be visible above the surface, or they could be heard feeding on shellfish. Participant 5 recalled that snapper and trevally were regularly seen “right up in the Whakapirau Creek”, and noted the recollections of older residents who had observed seagrass beds in the creek, mixed with cockle beds, where the snapper (and trevally) would feed. The water was so shallow that the tails could be seen above the water as they fed. Another participant (31) recalled a picnic in 1954/1955 adjacent to Paparoa Creek (inner Arapaoa River) and seeing snapper “snapping on shellfish with tails waving in the air”. Participant 10 commented that snapper “used to come right in and at low tide and you could see their tails sticking out of the water.” Similarly, participant 1 talked of often seeing “acres of snapper tails sticking out of the water” (in 14–18 inches of water) as the fish fed on the Kaipara flats (Southern Kaipara), around 100 m from shore (with an average size of around 8 to10 lb; large enough for tails to stick out of the water). Participant 22 recalled that his grandparents used to see the backs of the snapper feeding in the Makarau River (Southern Kaipara). Participant 19 indicated a site (“Yellow Point” in Coates Bay) where snapper would come onto sand banks with the tide to feed on large pipi, and their tails could be seen “flicking on surface of water”.

Table 2: Descriptions of large fish and large catches of snapper from the Kaipara Harbour since the 1930s recalled by interviewees.

Era	ID	Recollection
1930s	29	Described getting "*60–70 pounders*" when still at school, but that numbers of large fish "*started to die away quick*" once fishing pressure increased in the 1950s.
1940s / 50s	31	Remembered catches of "*10 dozen snapper, big and small*" i.e. over 1000 fish in one set when nylon was first introduced to replace the cotton
1940s / 50s	30	Pretty common to catch 20 lb snapper. Would catch 100 snapper and most would be over 10 lb, if they weren't, would throw them back.
1950s	13	As a teen commercial handline fishing for snapper at Te Kopuru (Wairoa River, could easily fill 44 gallon drums with fish (around 200 kg?).
1950s / 60s	30	Recalled would "*catch a tonne of mixed fish* (flounder, kahawai, trevally, snapper, red gurnard) *at night, in the gutters off Tapora and into Tauhoa channel*, (in the winter months only*), filling the boat and returning to Port Albert each night*".
1950s	26	Talked about catching "*the odd big one* (around 20 lb / 10kg) *nowadays*", but in 1950s these large fish were more common.
1950s	19	Father used to catch 10 lb snapper on sandbanks in Coates Bay using hand lines.
1940s / 60s	9	Estimated large fish at around 28 kg. "*After 1980s the larger ones got harder to find*", although can still sometimes catch fish 15–20 kg.
1960s	6	As a child in the 1960s, his father would head for the beach with the right easterly winds and use a kontiki with 20 hooks; within an 1 hour would catch enough fish for a feed, would only have to fish once, and never caught small fish, all were 10 lb or more.
1960s	26	Talks of using no. 8 wire to catch snapper off the beach by walking into water and wrapping the wire around their tail, and flicking onto the beach.
1960s	31	Used to regularly catch 7 lb snapper (40 cm) as a bycatch of commercial fishing for flounder (?). By the mid-1990s, there was virtually no snapper bycatch.
1970s	14	Described snapper abundance as "*prolific*" and recalled that he would be able to "*go out anywhere in a rowboat and catch the daily limit of fish in about an hour or so, not big, but all legal size*".
1970s	5	In the Arapaoa River could "*fill a sugar bag/sack with snapper in a couple of hours, all* "*pannies*" (around 27 cm)".
1970s	30	Described working on green-lipped mussel grounds out in the harbour entrance, "*the boys would put their lines over a catch 40–50 "big" snapper…and then suddenly it crashed*".
1970s	25	Average size of snapper was between 4–4.5 kg. Now average size is smaller, catch nothing bigger than the palm of the hand.
1970s	5	The odd big catch (eg 16 lb / 7 kg) caught off Port Albert and 20 lb fish caught off Tinopai.

Other comments indicated a perception that catches of larger-sized fish were also more common in previous decades (see Table 2). Many recalled "*the great big snapper in the old days*" (7, 4), that were less common in more recent decades. One of the oldest residents interviewed (29) talked of "*60–70 pounders*" being caught in the 1930s and another (31) estimated the average size of fish caught in the 1940s at between 60–70 cm. Comments and size estimates by decade indicate that 10–20 lb fish were being caught regularly up until the 1970s. However, many believed that these large fish virtually disappeared during the 1980s, although there are still occasional catches in certain areas, such as the Graveyard and South Channel (27). From the nine participants that provided size estimates by decade, the average length of snapper declined from 57 cm in the 40s and 50s (n=5, SD=7.5) to 30 cm at the end of the century (n=6, SD=8.3).

The combined scores of all participants indicated a 50% decline in the abundance of snapper between the 1930s and 1980s, after which abundance levelled off, with some observing a recent increase (Figure 32). The perceived decline in abundance and size of fish was most commonly attributed to commercial fishing pressure both inside and outside the harbour (70% of 20 interviewees), as well as fishing competitions targeting large fish. Only five participants cited habitat loss and pollution caused by changes in land use as a contributing factor. Following the introduction of "*meshing equipment*", nylon in the early 1950s, and different fishing practices, one participant (31) recalled that snapper were "*slaughtered…they were wiped out…would catch half a boat load of snapper and only 10 flounder*". Several noted that the habit of long and overnight soak times for flounder nets caught large numbers of small fish, including snapper, and high catches resulted in a lot of wastage at that time, with good quality fish being sold for fishmeal at low prices (3¢/kg). In the 1950s and 1960s, there were thought to be nearly 50 boats targeting snapper in the harbour (20), but the number has steadily declined to zero. A number of participants (n=8) believed heavy fishing pressure from foreign pair trawlers (and longliners) targeting snapper in the harbour entrance and just outside during the 1970s, 1980s and 1990s, had an almost immediate effect on the number of fish in the harbour.

Of those who still fish, recent improvements in catches were noted (9, 7, 14, 12), attributed by some to the Maui dolphin set net ban, and commercial fishers being pushed further offshore. The summer of 2009–10 was thought to have been a particularly good year, with several participants (27, 9, 12, 10) commenting on the increased frequency of larger fish (10 to 15 lb and 10 to 20 kg) being caught in the Wairoa River (including Aratapu – Naumai Bank and Te Kopuru) and snapper being caught as far up river as Mangawhare wharf, near Dargaville. This was attributed to the drier weather resulting in less run-off and clearer "blue" (salty) water reaching further up harbour. Similar observations were made for the Arapaoa and nearby estuaries (14), with larger fish (40–45 cm) being regularly caught, and locals able to catch their daily bag limit, which was previously a rarity. Not all participants noted an increase; a current charter operator from the south Kaipara (16) commented that the decline in snapper was the worst of all the species and has not improved. In eight years of running a fishing charter by participant 8, there had never been a day when the vessel got near the daily limit. Another who fished the entrance of the harbour (11) believed fishing has "*…got bloody worst...used to be outstanding...used to take a supersack not a sugar sack...with snapper*" and a third noted how hard it was now to catch snapper off the beach (8).

A number of key sites (both past and present) were identified where participants regularly caught snapper. Most are associated with areas of higher current, coarser substrate and often shellfish beds, particularly green-lipped mussels. Four participants (24, 16, 14, 27) commented on the preference of snapper for green-lipped mussels, as well as tuatua, cockles, "snapper biscuits" (sand dollars) and more recently Asian date mussels. One participant noted the disappearance of "*skinny snapper*" with "*large heads and jelly flesh*", thought to be a result of previous density-dependent competition for food that no longer occurs. The entrance of the Kaipara was identified by multiple individuals (when comparing: Entrance, South Head, South Channel, South Kaipara peninsula, Fitzgerald Bank, Papakanui Spit) as an important fishing area for snapper both past and present. One of the most frequently mentioned area was "the Graveyard", along the northern entrance channel (identified by eight participants), most commenting on the hard substrate (sandstone) and presence of green-lipped mussels. Green-lipped mussels were also noted at other sites in this area, along with sponges, cockles (southern Kaipara peninsula) and tuatua on sand (Fitzgerald Bank and Papakanui Spit). To the north, Pouto Point, Tauhara and Beacon Point were also cited as summer snapper fishing areas, and were associated with coarser substrates and green-lipped mussels, or softer sediment and horse mussels (Beacon Point) as well as sea grass in shallow water at Pouto Point. The green-lipped mussel beds at this latter site were previously much larger, described as "*[a] huge mussel bed here...off Pouto...calculated about 17 acres of mussel beds*". In the northern channels, the Funnel, Puri's Reef, Timber Bay and Pakaurangi Point were identified as snapper fishing spots along with grey mullet and kahawai, with sandy gravel-dominated substrate and a mixture of habitats listed; seagrass, scallop beds (Timber Bay), sponge gardens (Puri's Reef) and green-lipped mussels (Pakaurangi Point). In the southern Kaipara, the gutters off Tapora into the Tauhoa Channel was also mentioned as a productive fishing site in the past, especially at night during winter months, with the Kaipara river channel (off Te Kawau Point) identified as a present-day key fishing area. In previous decades, good fishing spots were often associated with shellfish and seagrass beds that no longer exist, which were found in the inner estuaries, such as at Snapper Rocks in the upper reaches of Pahi River and Te Kopua Point, Raepere Creek and Paproa Creek. The disappearance of shellfish beds in the Kaipara was linked to declines in snapper abundance by some participants.

Many interviewees described the appearance of small snapper (described as around 4–5 cm long) in the harbour over summer, one (14) describing that small fish "*come pouring into the harbour*" between January and March, and appearing in all habitats right up into the upper reaches of the harbour, and then disappearing once there was "*a cold snap*" (30) or the temperature dropped in April or May. In the south Kaipara, Omokoiti Flats were noted as an area where small (1.5 inches) snapper were found everywhere (1), as well as Kaipara Flats and Shelly Beach. One participant (13) believed that the snapper spawned on rough ground just outside the harbour, whilst another (29) commented that he had never seen them schooling like the mullet, even in previous decades (back to the 1930s) when abundance was higher. Larger fish (40–45 cm) were described as coming into the harbour in large numbers in October and early November and one current commercial fisher, who targets flounder and grey mullet described them as "*a pest in the set nets…especially in summer..*" While some commented that large snapper used to be plentiful all year round, more recently they are only caught during the spring summer period (9, 29). Others believed that there were adult resident snapper in the harbour that could be caught up in the shallows in winter (27).

Trevally

Trevally was another species thought to have declined in abundance by many of those interviewed, as indicated by the plot of combined rankings, which show a 70% drop in relative abundance (Figure 32). One participant described them as previously being "*thick in the harbour, just everywhere*", referring to the inner estuaries. Although not commercially targeted, he would often catch 5–6 a day to take home to the family to eat, whereas these days, "*don't see them up here, very rare, catch one maybe once every 2–3 years*". They were once common around Pahi Island (a tidal rocky habitat) with large fish, 10–12 lb / 45 cm sometimes caught, a size that would be unheard of now (14). Puketi Point, in the Funnel, was another good trevally spot, where the participant caught his largest trevally, over 70 cm in length and had heard recollections by older residents of "*massive amounts*" of trevally being seen feeding over the sand banks with their tails in the air (14). In the northern Kaipara, several participants implied that they can still be caught in large numbers at particular times of the year, although the best time of year varied from October to Christmas (12), or through to autumn (9, 27). A preference for gravelly bottoms and rocky areas and shellfish bait was noted and current fishing grounds include Clark's Beach, the Graveyard and Papakanui Spit in the harbour entrance, where green-lipped mussels are present (12, 11, 6). They are also observed to feed on crabs over mud flats at night (14).

Kahawai

Kahawai was described by several as "*vanishing*" in the 1980s (2, 5), although the combined rankings gave a 40% drop in abundance between the 1950s and 2000s (Figure 32). Large schools were observed in the harbour entrance in the 1950s (29) and could be caught "*by the sack full*" in this area up until the 1970s, when it was possible to make a living from smoking them (7, 14). Some participants talked of resident fish, and "*runs*" of ocean kahawai, that were observed coming down the coast with the whitebait in August (1, 11, 26, 13, 25) and entering the harbour to feed over winter and spring (25, 26, 13, 31). They were mainly found in the central harbour, with sites such as Fitzgerald Bank and Manukapua Bank identified as key winter fishing spots (1, 9), but also found further up river in areas such as Tahuara Creek, Puri's Reef, Pakurangi Point and Whakapirau Bay (17, 5, 2), with one interviewee recalling a family member catching 22 bins of kahawai "*up river*" in the Wairoa. Many of the sites listed were described as having a sandy/gravel substrate and shellfish or sponges. One noted that, since farmland has been fenced off in Whakapirau Bay, the seabed is less muddy, more "*shelly*" and kahawai have been observed chasing prey fish right into the shallows (2).

Parore

Also called the "Kaipara cod", parore were once considered a nuisance because of their numbers and the damage they could do to nets (and people) with the spines on their gills. Along with snapper and trevally, they were associated with "*the grass*" (sea grass) and were always reasonably common; one participant described parore "*as thick as thieves*" in the 1930s, and how fishers were always in fear of catching large schools because they destroyed the gear and cut hands and nets (1, 2). Another described how fishers would set nets with a gap next to the shoreline when the parore were around, to allow them to escape, using the term, "*leave the gate open*". If they set right up to the shoreline, they could catch hundreds; during a trip in the mid-1980s in the Kaiwaka River, a school of parore hit the net as it was being set and literally pulled it out of the boat. The net was "*just solid writhing mass of parore*". A tractor was needed to help unload the net and took a whole day to clear, removing 600 fish. The participant later heard that this part of the river was known as "*parore alley*" by local fishers (14). Although originally of no value, and often discarded, several participants noted that they were good shark bait (16, 29, 1), and were often targeted in winter with old nets just prior to their refurbishment. The nets would be set along the edge of sea grass patches in places such as the Kaipara flats, and could regularly catch 3 to 5 tonne of "*shit fish*" such as parore, trevally and kahawai, which would be frozen for shark bait the following summer. Other good fishing spots for this species included Makarau, Hoteo and Tauhoa rivers, Topuni / Oruawharo River, where one participant estimated could catch 1 t of parore in a 200 m net (30) and Okaro Bay in the northern Kaipara, where the creek was "*full of parore*" and hard to avoid getting spiked. (29).

Once snapper and other stocks started to decline, a market developed for parore. A good sized fish was described as being around 5 to 6 lb, but they could be up to 10 lb (27). It was believed that stocks were rapidly fished down within about 10 years by "*travelling fishermen*". One participant from the inner estuaries estimated that he catches around 10 parore in a year these days compared to 100 in one tide in the 1970s. However, several participants believed there was a recent increase in numbers (30, 27, 31, 29) or that they are still relatively plentiful (12, 25). One targets mangrove habitat in Punahare creek near the "*The Narrows*" along the Wairoa River, and has also seen large numbers (i.e. 90 fish in one net) caught at Pouto Point.

Red Gurnard

Gurnard were not targeted until recently, and several participants did not recall catching many in mullet or flounder nets (22, 25, 16, 18), and if they did, they would have been thrown back (2). One participant (29) recalled catching "*the odd bin when getting rig and flatfish.*" And another noted that he'd never seen gurnard in the harbour before the 1990s (22). Although not reflected in the rank scores, several (12, 14, 16, 18) fishers believed that gurnard numbers had increased in recent years; "*Seems the gurnard have taken off where the snapper left off.*" One participant (14) commented that his fishing grounds out in the Funnel and Otamatea Channel were now "*gurnard city…get them everywhere on the sand"* and that recreational catches of gurnard were now higher than snapper and kahawai. In contrast, one interviewee, who caught gurnard on longline, thought that catches had declined and that you needed to be in deeper water to catch them these days (8). Gurnard were caught on sandy habitat across the whole of the Kaipara, including the sand banks near the harbour entrance, (Fitzgerald Bank off Manukapua Island), the channel off south Kaipara on an incoming tide (1), off the beach and also up into the creeks (one noting that he could catch gurnard as far as Helensville (6)). Winter was perceived to be the best time for gurnard, especially in the outer harbour areas (1, 24, 6), although they were found further up-river in summer (16). There were several reports of very large (over 50 cm) females caught by a couple of participants (27, 14). The gurnard were sometimes full of roe, and in the spring, juvenile gurnard were abundant; "*if nets are left overnight can catch 100 juvenile gurnard …get huge numbers…about the size of your thumb or finger*". The adults had been found to prey on crabs and juvenile fish such as flounder, stargazer and snapper. Those who noted an increase in gurnard abundance believed that it may be due to reduced competition for food with snapper and trevally, and/or less reliance on shellfish beds.

Other fish species

Yellow-eyed mullet were not believed to be as common as grey mullet, but numbers had declined only slightly over the time period (Figure 32). Two participants thought that the average size had decreased. One current fisher described them as '*plentiful*", but of no commercial interest given the small mesh size required to catch numbers, which also resulted in a high level of bycatch.

Another species not targeted commercially was piper (or garfish). Some participants commented that they didn't really see or catch this species as "*they don't enter the estuaries, not fished that often*", but another thought piper were increasing in numbers and can now be caught from the beach. No change in abundance of 'baitfish' was noted by the four participants who scored this category (Figure 33), with one commenting that he had caught "*baskets full of sprat*" all his life.

Single participant observations were recorded for some species: a 30% decline in kingfish was reported since the 1940s by one fisher, and a 40% decline for eels and whitebait; both drops were attributed to a loss of habitat and fishing pressure.

Commercial shark fisheries

School Shark

School shark (or tope) were previously an important summer fishery in the Kaipara, supplying the lucrative Australian market (Figure 34). Two of the participants interviewed came from the Scott family, which has commercially fished the harbour for as long as any other family. Their fathers and grandfathers were commercial fishers before them, targeting flounder and mullet in the winter, and tope in the summer for their fins, liver and flesh. The fishing company, set up by the previous generation of Scott brothers was based in Helensville, and in the shark season (October to March), the deep channels from Shelly Beach up to South Head were targeted with longlines, including the Tauhoa Channel. The fishery was based on females coming into the harbour "*in their thousands*" to pup, and several participants (26, 27, 1, 2) commented on the absence of males, and could track the development of the embryos over the following months. Other participants (29, 18, 13) also identified 'The Heads', as well as off Taporapora, Fitzgerald Bank, Pouto Point and Bushy Point as shark fishing grounds. In the inner estuaries, areas such as Hargreaves Bay and the deep holes of the Oruawharo River up to Port Albert were also targeted for school shark (1, 2, 29, 30). In the northern Kaipara, participant 12 recounted that there were "*tons of sharks down near the Lighthouse*" (at Poutu Point) and remembered watching a fisher in a 26 ft boat pulling up a longline with a "five footer" on every hook.

Although some believed abundance had not changed, others thought there had been a decline in abundance due to heavy fishing pressure prior to the quota system being introduced (Figure 35). One participant (2) recalled being able to catch small school sharks in the Kaipara River in the 1940s, but that over time they have had to move steadily further north towards the harbour entrance to find adult sharks. However, prior to quota being introduced, the demand for school shark fell due to the discovery of high mercury levels, and quota was subsequently bought up by larger companies to cover bycatch offshore. Combined with the set net ban on the coast, there has been far less fishing pressure on this species inside the harbour, and nearly all participants interviewed commented on the current high abundance (6, 7, 28, 27, 30, 1, 11). One participant (1) described "*a huge influx of sharks in the summer, so many you can walk on them*", and several commented on them being a nuisance bycatch (11, 27), especially on baited lines (7, 29); "*if you go out snapper fishing in the summer, you can't put a line down without getting absolutely trashed…they always spoil our fishing*", "*there can be 50 at a time surrounding the boat*", "*a damn curse*". Others talked about the sharks moving in large packs as they chased flounder and damaging fishing gear set further inside the harbour.

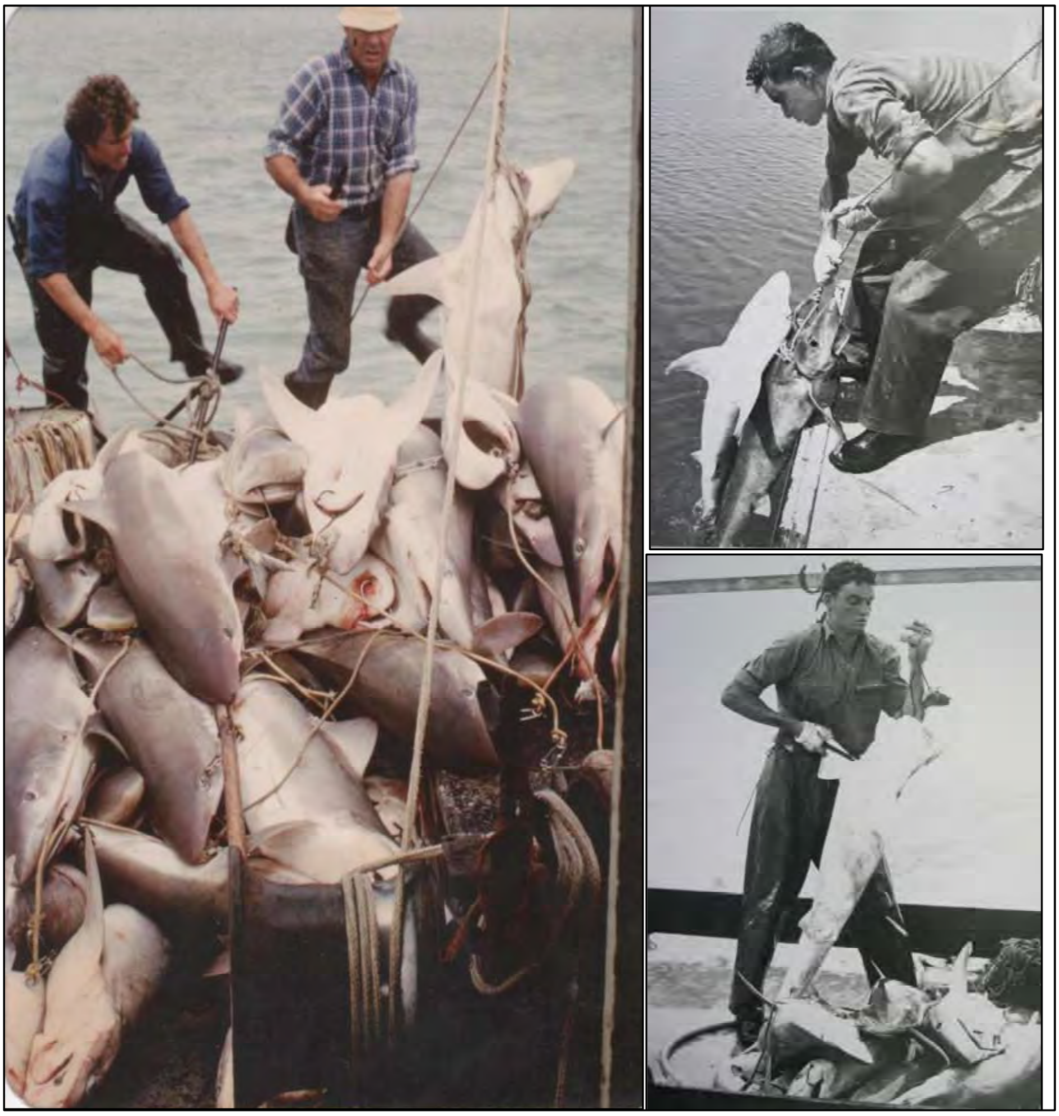

Figure 34: Shark fishing in the Kaipara Harbour. a) Ray & Gary Scott stacking a catch of school shark; b, c, Ron Hopkins shark fishing in the 1960s. (Source: a, T. Scott; b,c, Hellensville Museum).

Rig

Unlike school shark, rig were regarded as a nuisance in earlier decades (1, 2). Flounder nets could fill up with rig "*within an hour… they broke their backs and threw them back overboard*". On occasions the nets would fill up as fast as they could be cleaned and re-set and one participant recalled a fellow fisher cleaning the nets three times over and still continuing to catch rig. Similar to school sharks, these sharks move into the harbour in spring summer; the males are observed first, followed by females. In some areas (e.g. off South Head and Te Kawau Point in the Kaipara River channel), large (4 ft long), pregnant females would be common and the nets would be so heavy they could hardly be lifted (1). In the “*early days*”, there were parts of the harbour that would be avoided during the summer pupping season because of the high abundance of rig, along with snapper, parore and trevally (e.g. the Kawau Parua Inlet). The tonnages of these bycatch species were just too great and these fish were not considered valuable. Those with recollections from the 1970s also remembered “*zillions*” of rig “*coming charging into the shallow waters*” to pup and they could be found all over the harbour. However, once this species became of commercial value, it was heavily targeted, including pregnant females, and several participants thought numbers declined from the 1980s (1, 14, 5). One commented on the high level of wastage from nets left overnight, which would result in “*wall to wall rig, including juveniles*”. These fish would be spoilt and have to be discarded. Key areas for rig fishers included off South Head in Kaipara channel, Pouto Point, the Funnel, the deeper channels and holes of the Otamatea and Oruawharo rivers and Gardener’s Flats (Central South Kaipara Shallows) (5, 14, 21, 27, 29). One deep hole off Oruawharo Heads also used to have a good green-lipped mussel bed, although the mussels were no longer there (30). Recent declines in the number of boats targeting this species was perceived to have resulted in increased abundance by some, with fishers able to rotate between sites and avoid pupping females.

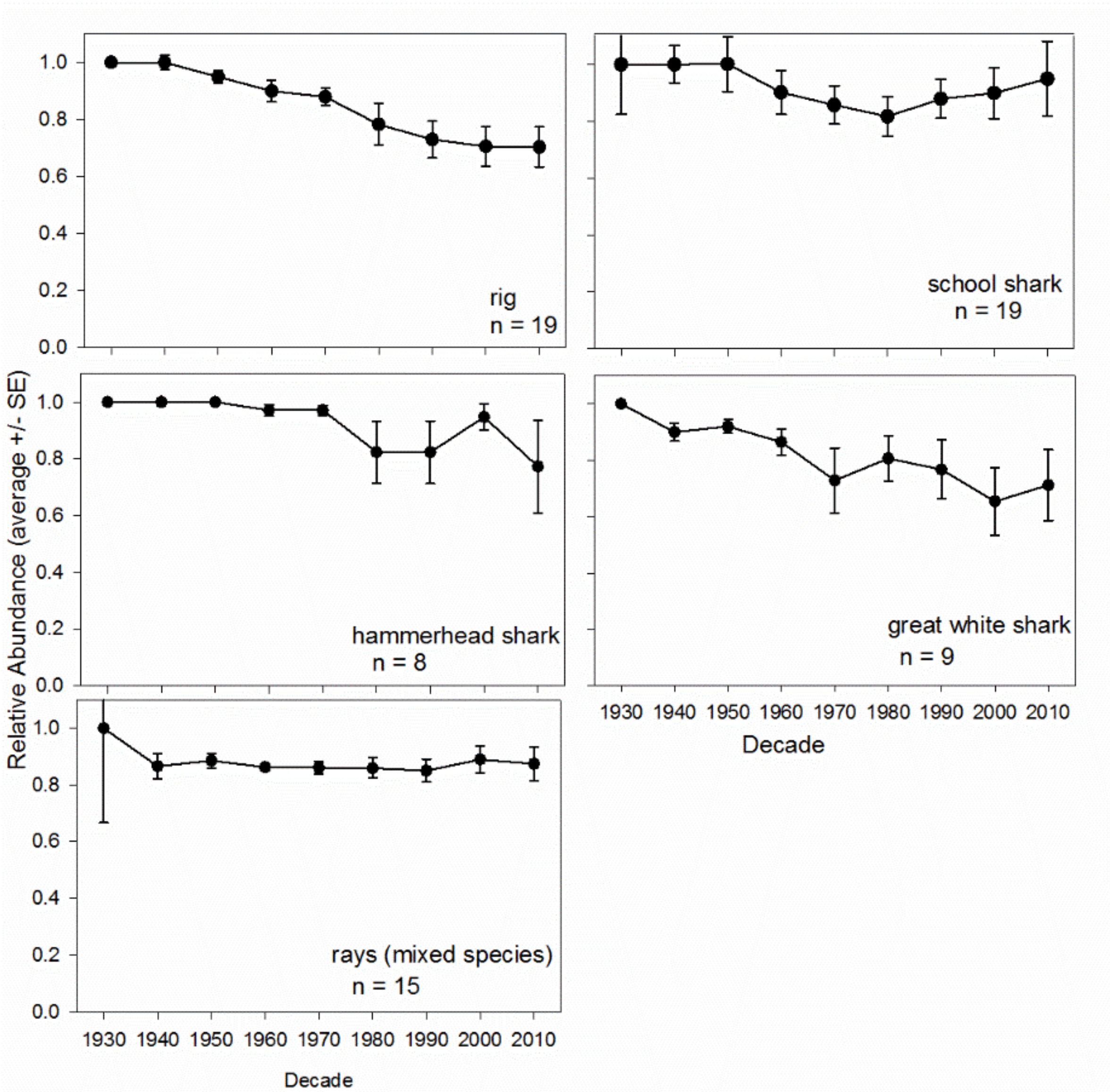

Figure 35: Changes in relative abundance of elasmobranch species in the Kaipara Harbour, based on the memories of long-term residents of the harbour.

Hammerhead shark

Most catches of hammerheads were juveniles, which were mainly encountered in summer (14, 30, 29, 5, 9). One participant (30), commented that he hadn't seen a school of hammerheads since the early 1940s and 1950s when he was a child, but that he caught "*a lot of little ones about 30% of the year and thought they were breeding somewhere*". Areas where juveniles (40 to 60 cm) were caught included Whakapirau Wharf and deeper water in Arapaoa River, the Funnel (5, 14), Shelly Beach (11) and Subritzky Channel sandbanks. Adults (ranging from 1.8 m to 3.0 m) were occasionally seen and caught near the harbour entrance (8, 9, 29).

Great White Shark

White pointers (Figure 36) were thought to come and go from the harbour, with most believing they were still present and sometimes resident. Along with other larger sharks such as bronze whalers and mako sharks, white pointers were more often encountered in the summer when they moved into the harbour to prey on the smaller school sharks and rig. One participant recalled a shot of 500 hooks where every school shark (around 5 ft long) caught had been bitten clean off just behind the eyes. White pointers would regularly hang around boats at a site called "The Gutter" off Opahekeheke Island (South Kaipara) when they were discarding fish that there was no market for, such as rig. The sharks would circle and sometimes even attack the boats (2). Sometimes these sharks became entangled in static nets. Several participants had caught white pointers off Bushy Point (29, 27), Matich Bay and Tauhara Creek (27). Large sharks (longer than 10 ft) have also been observed or caught off Pouto Point (13, 11) on longline gear, and one participant has encountered white pointers at the Graveyard taking snapper off hand lines as they were retrieved (2). Another participant recalled several incidences over the years of some very large fish, one maybe 30 ft long, being wrapped up in fishing line in 5 Fathom Channel; the girth of this shark was wider than a meter and the tail was "*wider*" than 13 ft. Another 15 to 18 ft shark caught in Tapora Channel was weighed in at Helensville at 1.5 t, and one was caught at the north end of the Kaipara River which was 3.7 m long (2). Although most sightings were in the entrance and northern parts of the harbour, there were stories of large sharks thought to be white pointers that were encountered in the upper reaches, such as off Page Point in the Arapaoa River (31), and in Hargreaves Bay, where a large (12–15 ft) shark had leapt out of the water in front of a fishing boat. One participant recalled a "*resident*" great white in the Whakaki River in the 1970s (5), and another resident shark, 'Punahiri Jack' used to cruise up and down the bays along the north Kaipara peninsula and children weren't allowed in the water (7). Several commented that most or all of the white pointers caught in the harbour were females (13, 11, 27), with one commenting that females entered the harbour in winter to pup (13).

Most participants felt that there was no change in numbers of white pointers, but some believed there had been a decline due to recreational targeting and 'trophy' fishing, with Bushy Point mentioned as a popular site by multiple participants.

Figure 36: Left) Vic Harrison (6 ft) standing behind two Great White sharks caught within the harbour; Middle) Len Scott with 13 ft White Great mid-late 1950s caught off the 'Olga'; Right) Jack Siminovish with shark (likely to be a Great White). (Source: respectively, B. Searle, Ray Scott, and Helensville Museum).

Other rays

Rays, which included skates, sting rays and especially eagle rays, were described as "*plentiful*", "*heaps*", "*getting worse*", "*all over the place*", "*millions of them*", "*out of control.*", "*Sting rays...oh, god there are hundreds*". Commercial set net fishers considered rays to be a nuisance, which got tangled up and damaged their nets (12, 14, 31). Eagle rays were associated with mud flats and sand banks in shallow waters (1, 14, 27), although sting rays were found more often in the deeper channels (1, 31). The sandy bays from Pouto Point to Kelly's Bay, especially north of Tauhara, were areas where they were particularly abundant, and "*great flocks*" of eagle rays have been observed in the inner harbour. One participant (14) had seen a large ray with a 2 m wing span off Pahi Beach (31). They are thought to breed in the harbour (25) where both adults (up to 2 m) and juveniles were observed (31, 27, 26, 25). Several participants have observed orca feeding on rays (9, 14, 11, 30), and large sharks such as bronze whalers and seven gill sharks may also prey on these species (31). Not all participants believed that the abundance of all rays had increased (Figure 35), with one commenting that skates and sting rays "*have dwindled over time*", and another (1) believed that gillnetting had caused a decline in numbers.

Other sharks

Bronze whaler numbers were not thought to have changed in abundance by most participants, although one recalled this species being regularly caught off Pahi and believed that numbers were now depleted (21). They were believed to be more common at the Lighthouse (North Head), sometimes entering estuaries such as Tauhara and Okaro Creek at high tides. Few participants recorded observations about mako sharks, but one (9) thought that this species was more common prior to the 1950s, when large (about 6 m) adults were often spotted as far north as Okaro Creek (these possibly may have been great whites given their size, authors). In later years there have been fewer sightings, with only the occasional individual seen at North Head.

3.3 LEK Summary

The lifetimes of observation shared by the interviewees collectively told a story of fundamental changes to the Kaipara Harbour's environment, habitats and fisheries species, extending back to the 1930s (Figure 37). There were also references to the recollections of previous generations that suggest that substantial changes had already occurred by the 1930s. The concept of shifting baselines, where each generation has a different view of what is natural (in reality being diminished each generation), is now well accepted (Jackson et al. 2001a, b). ‘Modern’ ecological science and the associated collection of robust empirical data-sets has only occurred over the past few decades, with usually very limited scientific data-sets being available before that. Most data comes from harvest records, log-books, and other ‘non-scientific’ sources. The data and observations captured here for the Kaipara Harbour clearly illustrate the value of LEK.

The interviewee’s accounts and associated relative abundance scores showed that the Kaipara Harbours overall seafloor environment became muddier (in particular in the upper reaches and arms), with some increase in suspended sediments also noted. Associated with this were some changes in water colour (i.e., less blue, more brown) and a reduction in water clarity. The abundance of many key biogenic habitat formers (horse mussels, rock oysters, sponges, green-lipped mussels, and seagrass) declined substantially, along with the annual landings of those that were harvested. Conversely, the coverage of mangroves increased, along with NIS biogenic species such as Asian date mussels, Pacific oysters, and red algae (probably *Gracilaria* sp.). Associated with these expansions were increased sedimentation, narrowing and shallowing of upper harbour channels (presumably also resulting in less tidal prism and tidal flow), and the loss of some flounder fishing grounds. A number of interviewees associated these changes with changes in land use practises, including forestry and livestock farming. Populations of harvested shellfish also declined substantially (pipi, cockles, scallops, oysters and mussels), and were lost from a number of areas where they had previously been abundant, including areas where harvesting was popular (e.g. “*Pipiland*”, once a highly regarded recreational gathering area, “*now covered in mud and silt*”).

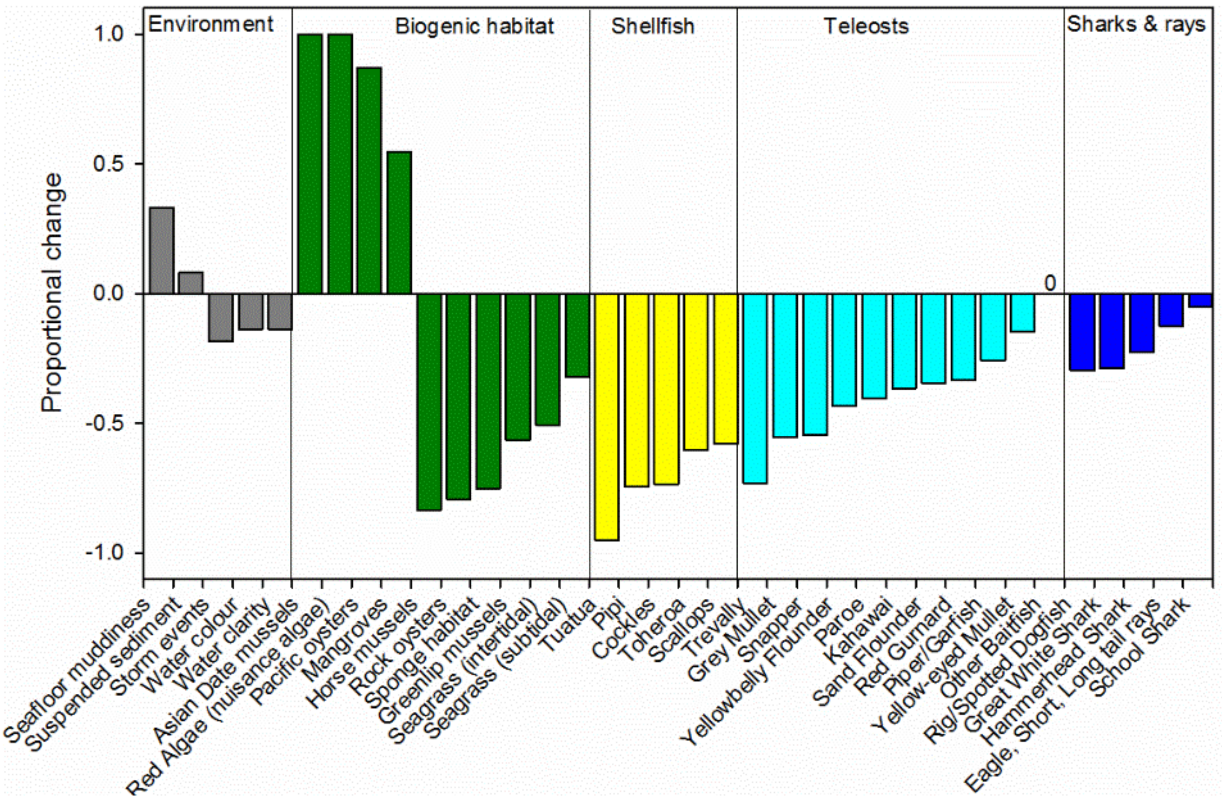

Figure 37: Changes in relative abundance/extent (both increases and decreases) of environmental parameters, biogenic habitats and species in the Kaipara Harbour from recollections of long-time residents of the harbour.

Substantial declines were universally reported in the abundance of teleosts (bony fish) and elasmobranchs (sharks), (Figure 37). Declines in average fish size were also reported for some fisheries (e.g. snapper, flounder). These declines were attributed to several factors, including over-fishing/poor fishing practises in the harbour, increased commercial trawling on the adjacent open coast, and environmental changes in the harbour. Harbour range retractions were also observed for a number of species, especially in the upper areas and arms of the harbour (e.g. for snapper and trevally), where such fish used to be regularly caught in good numbers and of good size. Interviewees also described juvenile fish dynamics in the harbour, which were very similar to independent research findings (see Section 4), such as [the appearance of small snapper (4–5 cm) in summer when they "*come pouring into the harbour*" between January and March, and appearing in all habitats right up into the upper reaches of the harbour, and then disappearing once there was "*a cold snap*" or the temperature dropped in April / May]. Other interviewee observations suggested dynamics not yet seen by researchers [in the spring, juvenile gurnard were abundant; "*if nets are left overnight can catch 100 juvenile gurnard …get huge numbers…about the size of your thumb or finger*]; [The (red gurnard) adults had been found to prey on crabs and juvenile fish such as flounder, stargazer and snapper].

A number of interviewees reported that some forms of fish behaviour are no longer exhibited by the harbour's fish populations. For instance, a number of interviewees commented on the phenomena of snapper feeding in large numbers in water so shallow that their tails would be visible above the surface, or they could be heard feeding on shellfish [e.g., "*acres of snapper tails sticking out of the water*" (in 14–18 inches of water) as the fish fed on the Kaipara flats (Southern Kaipara), around 100 m from shore (with an average size of around 8 to 10 lb; large enough for tails to stick out of the water)]. One interviewee recalled [using number 8 wire to catch snapper off the beach by walking into water and wrapping the wire around their tail, and flicking onto the beach]. Others recalled flounder behaviour not seen today [recalled seeing and playing with numerous "*very large*" flounder in the shallows as a child]; ["*couldn't set foot on a beach without upsetting a flounder and could literally lift them out of the water at the beach, they were that docile"]*. Such accounts do not match contemporary observations of these species today, yet these behaviours were once common enough to be regularly observed by people (for similar accounts on the east coast for snapper, see table 4 of Parsons et al. 2009). The existence of different "*behavioural morphs*" in fish populations (and invertebrates) is now accepted, including some individuals being bolder and some shyer, as part of different behaviour repertoires. For example, Biro & Post (2008) found that rainbow trout (*Oncorhynchus mykiss*) with bold personality traits were more vulnerable to harvesting by gill net than fish with shy personality traits. In terms of snapper, Parsons et al. (2009) postulated that '*if these fish* (i.e. snapper often visually observed in shallow water on the east coast] *represented an element of the snapper population with "bolder" behaviours, then they may have been more vulnerable to fishing selection, and thus may now have been largely suppressed or eliminated from present-day populations (either phenotypically or genetically). Alternatively, the abundance of snapper may have been sufficiently high at these times that curious behaviour may have been required to ensure enough resources were gathered to survive*".

The habitat associations of scallops also appear to have changed. A number of interviewees commented on a consistent association between seagrass meadows and abundant scallop beds, allowing people to gather them by hand. Such an association is not seen in the harbour today, even though scallop beds and subtidal seagrass are still present (e.g. subtidal seagrass sampling by Morrison et al., in revision) beam trawl sampling observations, no mention by Kelly 2009). A similar phenomenon was noted in historical accounts of scallops and seagrass in Whangarei Harbour (Morrison 2003).

More broadly, seagrass meadows appeared to have historically held considerable numbers of fish [Fishers avoided "*the grasslands*", as "*there were tonnes and tonnes of snapper and parore, which would destroy the net*."]. Fishers commented on parore once being very common, but being heavily fished down as a market developed, and being relatively uncommon today (although the numerical score only suggests a 45% decline in abundance). This effect has been seen in other harvested species (e.g. Sáenz-Arroyo et al. 2006), where once abundant species are considered by current scientists and others to be naturally ‘rare species’ (as they are unaware of the shifting baseline). While commercial parore catches are still taken in the Kaipara Harbour (about 10 t per year, see Figure 18), we suggest that this species has been fished down to a point where it is now a relatively minor component of the harbour’s fish assemblages. Perhaps worryingly, juveniles have seldom been captured in small fish surveys of the Kaipara Harbour, despite the sampling of some of their favoured juvenile nursery habitats (mangroves, subtidal seagrass) (as shown for the east coast, Morrison 1990, Morrison et al. 2014, in revision). As parore are a relatively long lived species (about 40 years, Gillanders et al. 2012), it may be that parore populations are in decline, with fishery catches now being sustained by adult fish from a range of adult age classes (5 to more than 40 years), with little or no new recruitment occurring (note: this is speculative only; however only two juveniles were caught during extensive seagrass and other habitat sampling in 2013, see following sections).

In conclusion, these LEK interviews help document what the Kaipara Harbour was like historically, and what has been lost from the ecosystem over the last 80 years. While changes will also have occurred before the 1930s, and the system was not in a natural ‘pristine’ state at that time (i.e. as it was before human occupation, which means back to pre-1300 AD), the narrative and associated numerical scores provide a fundamentally better indication of ‘baseline environmental states’ than that provided by contemporary research. While the harbour will never be able to be fully restored back to its original state, these findings allow natural resource managers, iwi and local communities, land owners, researchers and others with an interest in the harbour to set management objectives and targets for the future, which reflect its historical state.

4. RECENT EMPIRICAL STUDIES

4.1 Fringing habitats (salt marsh and mangroves)

Mangroves occupy a significant area within the Kaipara Harbour, comprising 19% of the approximately 407 km^2 intertidal area. Recent GIS analysis of historical aerial photography revealed an 11% increase in their spatial extent from 6845 ha in 1966/1977 to 7615 ha in 2002/2007 (Figure 38; Table 3), (Swales et al. 2011). This estimate includes the effects of a large scale reclamation works that reduced the total mangrove area undertaken in the southern Kaipara. All of the net increase in mangrove habitat has occurred in the Northland half of the Kaipara Harbour, with the total area increasing by 41% (1977–2002), with the Whaketu mangrove forest increasing by a sizeable 53% (Figure 38; Table 3). More modest increases (about 15%), were recorded for areas such as Oruawharo River, Central Kaipara and Kaipara Flats. By comparison, the extent of mangrove forests in the southern arm of the Kaipara, which contains the largest area of mangroves (about 25%, see Figure 38), has not changed appreciably since 1966/1977 (Swales et al. 2011).

Table 3: Summary of recent historical changes and present area in mangrove and salt marsh habitat in the Kaipara Harbour. Habitat areas (hectares) are given for the most recent data (2002/2007). The rate of habitat change is given as an average percentage per year: 1977–2002 (Northland Region) and 1966–1997/2000 (Auckland Region). (*1966 photography covers South Kaipara, Omokoiti and South Head compartments). Source: Swales et al. (2011). [1]Auckland region areas, all other areas fall in Northland; the boundary falls along the middle of the Oruawharo River.

Compartment	Mangrove			Salt marsh		
	Area (ha)	Area (% total)	Habitat change (% yr^{-1})	Area (ha)	Area (% total)	Habitat change (% yr^{-1})
North Kaipara	386.7	5.1	-	145.2	22.0	-
Whakatu	334.6	4.4	2.1	71.5	10.8	0.2
North Head	64.2	0.8	-	24.7	3.8	-
Arapaoa	836.7	11	1.5	42.2	6.4	0.0
Otamatea	314.8	4.1	1.4	28	4.3	4.5
Oruawharo[1]	898.7	11.8	0.6	35.3	5.4	1.3
Whakaki	118.1	1.6	1.1	5.7	0.9	3.4
Central Kaipara[1]	588.1	7.7	0.7	-	-	-
Tauhoa–Hoteo[1]	1313.7	17.3	0.2	66.2	10.0	0.0
Kaipara Flats[1]	390.9	5.1	0.5	34.7	5.3	0.0
South Head[1]	13.3	0.2	0.2	5.3	0.8	-
Omokoiti Flats[1]	380.1	5.0	-0.7	40.8	6.2	-0.1
South Kaipara[1]	1974.9	25.9	-1.2	159.9	24.3	-0.3
Total area (ha)	7614.8			659.5		

By contrast, over the same time period the total coverage of salt-marsh habitat has reduced by 3.6%, from an estimated 684.3 ha in 1966/1977 to 659.5 ha in 2002/2007, with the majority of this reduction (31%) occurring in the Auckland region (southern harbour) due to tidal flat reclamation (Figure 39; Table 3). Conversely, salt-marsh habitat has increased by 48% since the mid-1970s in the northern Kaipara (Swales et al. 2011). Loss of salt-marsh habitat has historically been due to reclamation and the expansion of mangrove forests landward, although mangroves typically favour expansion onto bare intertidal flats (Morrisey et al. 2010). Data for mixed mangrove and salt-marsh habitat in the Auckland region (southern Kaipara only), reveals a substantial reduction from 417 ha (1966/1977) to 212 ha in 2007, primarily because of reclamation in the southern arm of the harbour and on the Omokoiti intertidal flats, rather than because of mangrove expansion (Swales et al. 2011).

In addition to recent comparisons of historical aerial photos providing quantitative insights into recent environmental changes within the harbour (including mangrove expansion), anecdotal and historical photos of settlers dating back to the 1860s (Section 2) suggest that periods of rapid expansion of mangrove habitat also occurred prior to the 1940s (see also Ferrar 1935). Historical surveys (Ferrar 1934) suggest that the extensive south Kaipara mangrove forest had reached maturity by the 1930s and has altered little since then. Fine scale change maps (by each compartment) along with associated estimates of change can be found in Swales et al. (2011).

Figure 38: Summary of mangrove habitat in the Kaipara Harbour by compartment: yellow text) percentage of mangrove-forest habitat in each compartment (2002 Northland, 2007 Auckland); and blue/red text) average annual change in mangrove-habitat area (% per year) since 1966/1977. Note: the 1966 data apply only to the South Kaipara and Omokoiti compartments. (Source: Swales et al. 2011).

Figure 39: Summary of salt marsh habitat in the Kaipara Harbour by compartment: yellow text) percentage of salt-marsh habitat in each compartment (2002 Northland, 2007 Auckland); blue/red text) average annual change in salt-marsh habitat area (per cent per year) since 1966/1977. Note: the 1966 data apply only to the South Kaipara and Omokoiti compartments. (Source: Swales et al. 2011).

4.2 Sediments and bathymetry

The 6400 km^2 land area of the Kaipara Harbour catchment drains almost half of the Northland Peninsula (Figure 40a) (Swales et al. 2011). The harbour's catchment geology is predominantly Cretaceous-Miocene age basement of inter-bedded sandstones and siltstones (New Zealand Geological Survey 1972). Fine sediments and poor drainage characterize the inner regions of the harbour, in the north between Ruawai and Oruawharo River, and in the southern areas between Oruawharo River and Shelly Beach (Figure 40b c). The combination of complex geology, deep soil profiles, high intensity rainfalls in conjunction with agricultural practices all contribute to the frequent and sometimes severe soil erosion experienced, particularly in the northern Kaipara (Northland Catchment Commission and Regional Water Board 1980).

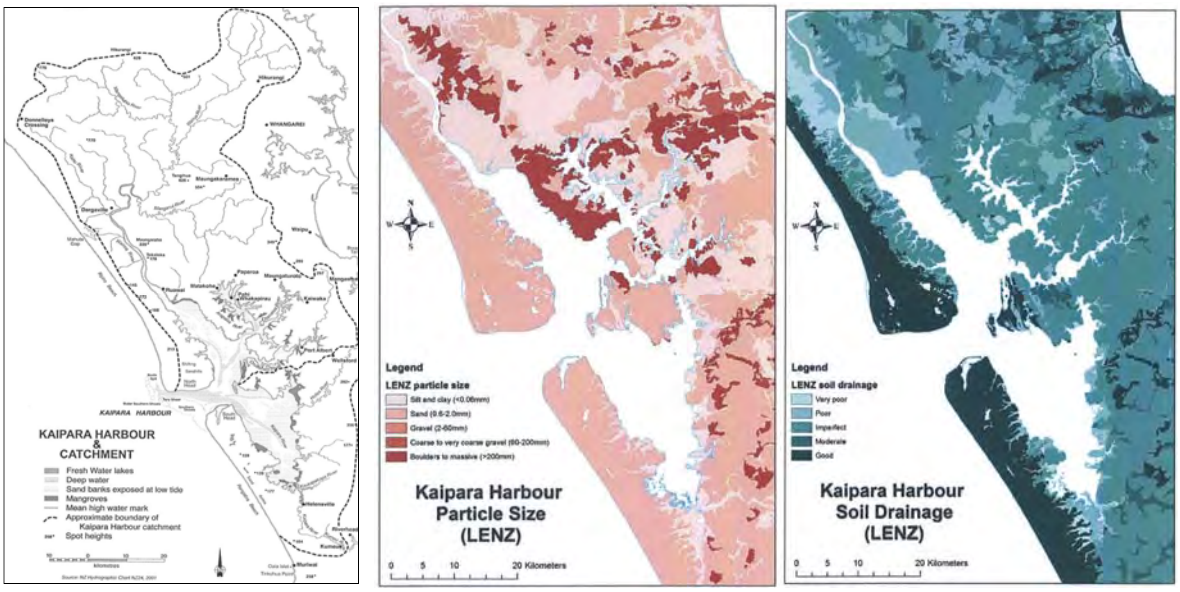

Figure 40: a) location of the northern (Northland Regional Council, NRC) and southern (Auckland Council, AC) boundaries and Kaipara Harbour catchment area. b) Sediment particle size for the Kaipara Harbour catchment, c) Soil drainage for the Kaipara Harbour catchment. (Source: Land Environments New Zealand; Haggitt et al. 2008).

The northern Kaipara Harbour is dominated by discharge from the 3900 km^2 Wairoa catchment. The low lying alluvial flats bordering the Wairoa Estuary are predominantly pastoral farming. By contrast, the largely rural catchments of the southern Kaipara Harbour cover an area of only 270 km^2, i.e., 7% of the total catchment area (Reeve et al. 2009). Land use comprises a mixture of agriculture, horticulture, production forestry and increasing numbers of small farm blocks (Biddy & Webster-Brown 2005, P. Yardley, pers. comm.). Detailed information on surficial-sediment composition has been documented for the southern Kaipara Harbour by Hewitt & Funnell (2005), as part of a benthic-habitat mapping study undertaken for the ARC (now AC). The mud content of bed sediments was found to vary from less than 2% on the lower-middle intertidal flats (e.g. Kaipara Flats, Omokoiti Flats, and the flats flanking Tapora Island) to greater than 50% on the upper intertidal flats south of Shelly Beach, Tauhoa Creek and Oruawharo River (Figure 41).

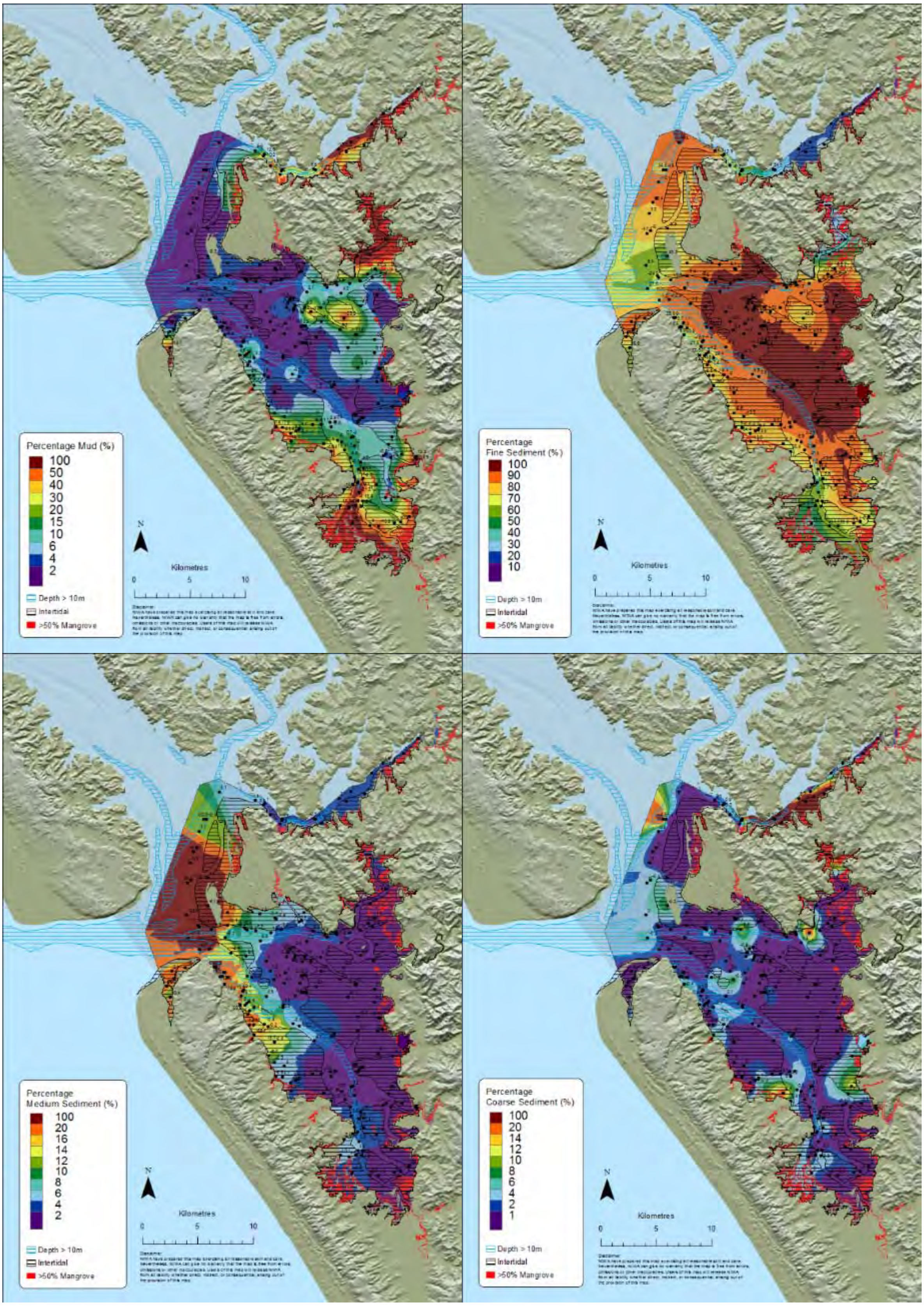

Figure 41: Interpolated plots of sediment particle size (upper left) mud; (upper right) fine sediments; (lower left) medium sediments; (lower right) coarse sediments, for the southern Kaipara Harbour. (Source: figure 5 from Hewitt & Funnell 2005).

While surficial sediments within mangrove and salt-marsh habitats were not sampled in the Hewitt & Funnell survey, prior research and field observations by NIWA concluded that these areas are primary sinks for terrigenous muds in the Kaipara Harbour (Swales et al. 2011). In the more exposed areas of the southern harbour, firm packed rippled sand predominated.

The northern Kaipara Harbour follows similar broad-scale trends in sediment distribution, with a lower percentage of intertidal flats (Haggitt et al. 2008). However, coarser sediments are distributed further into the northern branch of the harbour than in the southern, particularly on the eastern coast (Brockbank 1984, Hume et al. 2003a, b, Hewitt & Funnell 2005). The lower deposition of muds on the intertidal flats (e.g. Wairoa River flats) is thought to be a result of waves and/or strong currents re-working the sediments (Swales et al. 2011). Coarser sediments are found towards the entrance of the harbour, and in channels in faster current areas. Prior studies have documented the extremely dynamic nature of the entrance area, with large scale movement of sediments and of the positions of sandbanks and channels (Hume et al. 2003a, b). Strong tidal currents, coupled with extreme wind and wave events makes documenting the physical processes of this area challenging. However, the seabed is thought to be comprised of scoured mudstone or shell-lagged compact sand, while other areas are characterized by mega-ripples and sand-waves (Hume et al. 2003a, b, Hewitt & Funnell 2005, Haggitt et al. 2008).

Aside from the entrance and main navigation channels, the bathymetry of the harbour is poorly mapped, especially for the large shallow subtidal areas flanking the main channels in the southern Kaipara Harbour (see Section 6.3 for aerial photography which illustrates this well). Haggitt et al. (2008) presented a general digital bathymetry model for the harbour, which is reproduced here (Figure 42).

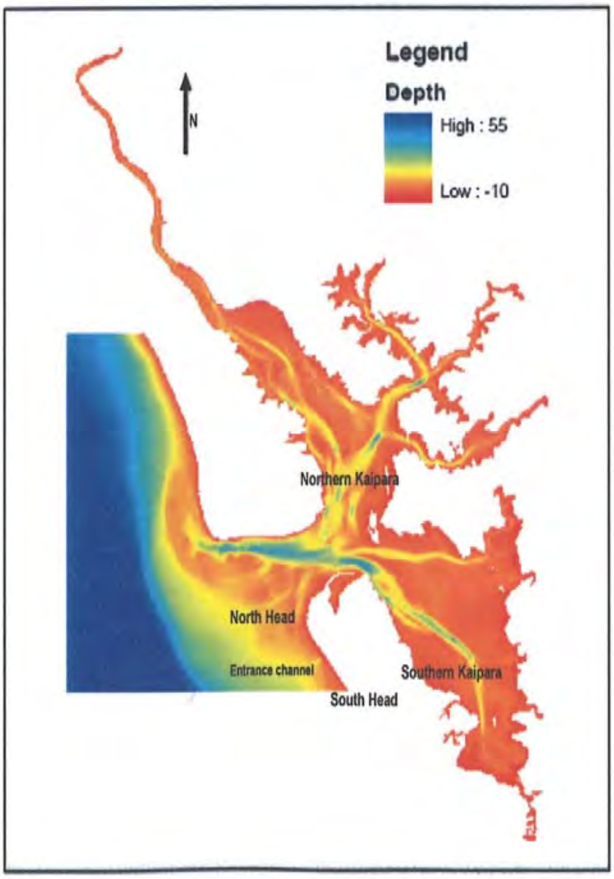

Figure 42: Bathymetry grid of the Kaipara Harbour showing depths to 55 m. (Source: Haggitt et al. 2008).

4.3 Benthic communities

Surveys of marine benthic communities in the harbour have been limited and have largely centred on the southern Kaipara. These include a comprehensive State of the Environment Report of the South Kaipara by Hewitt & Funnell (2005), in addition to consent monitoring reports (i.e., Grace 1995–2004), mangrove benthos (Morrisey et al. 2007, Lowe 2013), and seagrass surveys (Lowe 2013, Morrison et al. in review b). Resource consent research has also been undertaken for aquaculture development and possible environmental effects (various private reports), while macro-algal diversity has also been recently assessed by Neill et al. (2012). The Otamatea sub-estuary has also been mapped as part of the national monitoring program on estuaries (Robertson et al. 2002). For the following sections, the reader is referred to Figure 1 to help with geographic placing of area and site names

Southern Kaipara

Many areas of the southern Kaipara show high taxonomic diversity at both the species and order level, despite high current velocities and susceptibility to wind and ocean swell generated waves. A number of organisms are large and long-lived, with some species (e.g. sponges, ascidians, bryozoans, hydroids and pipis), commonly associated with pristine environments (Hewitt & Funnell 2005). Intertidal communities were dominated by deposit feeding polychaetes, with a number of bivalve and gastropod communities also occurring. Hewitt & Funnell (2005) identified fifteen different community types in intertidal soft sediment habitats, six of which were dominated by bivalves such as *Macomona* (wedge shells) *Austrovenus* (cockles) and *Musculista* (date mussels) (see table 3, figure 6 in Hewitt & Funnell 2005). Mangrove communities were generally characterized by infaunal species, with lower densities and diversity recorded compared to other habitats such as seagrass (Hewitt & Funnell 2005, Morrisey et al. 2007, Lowe 2013).

The subtidal community was dominated by variable densities of sand dollars (*Fellaster*), or a sand dollar/gastropod mix (Figure 43, 44). Epifaunal species, including sponges, ascidians, bryozoans and mussels occurred mainly along the channel banks, at central moderate depth subtidal areas, and in the main channel area near South Head. Additionally, hydroids were found at considerable distances up the arms of the Oruawharo, Tauhoa, and Kaipara rivers. Although many of the taxa and habitats recorded in the southern Kaipara are ubiquitous throughout the Auckland region, Hewitt & Funnell (2005) considered some subtidal fauna unique in terms of their co-associations. These included high numbers of the tube-building worms *Owenia*, *Macroclymenella*, *Euchone* and *Phoronids* found in the shallow subtidal area of the main southern harbour (Hewitt & Funnell 2005); as well as the presence of subtidal seagrass meadows, considered to be a ‘rare’ habitat within New Zealand (Turner & Schwarz 2006, Schwarz et al. 2006).

Species analysis revealed that the major intertidal habitat types (mud, sand, seagrass, and mangroves) supported significantly different assemblages. Lower numbers of taxa were observed in mangrove habitats and muddy areas, relative to sandy sediments, with the lowest diversity recorded within dense mangroves (see figures 7 and 14 in Hewitt & Funnell 2005). Seagrass meadows were found to have similar communities to bare sand habitats (with respect to macro-invertebrates over 1 mm). Given these significant spatial differences between the types of fauna/communities recorded, Hewitt & Funnell (2005) divided the region into seven intertidal and eight subtidal areas (Figure 44; Table 4). In the subtidal area, the high current (H) and shallow subtidal areas (S) were significantly different to all other areas.

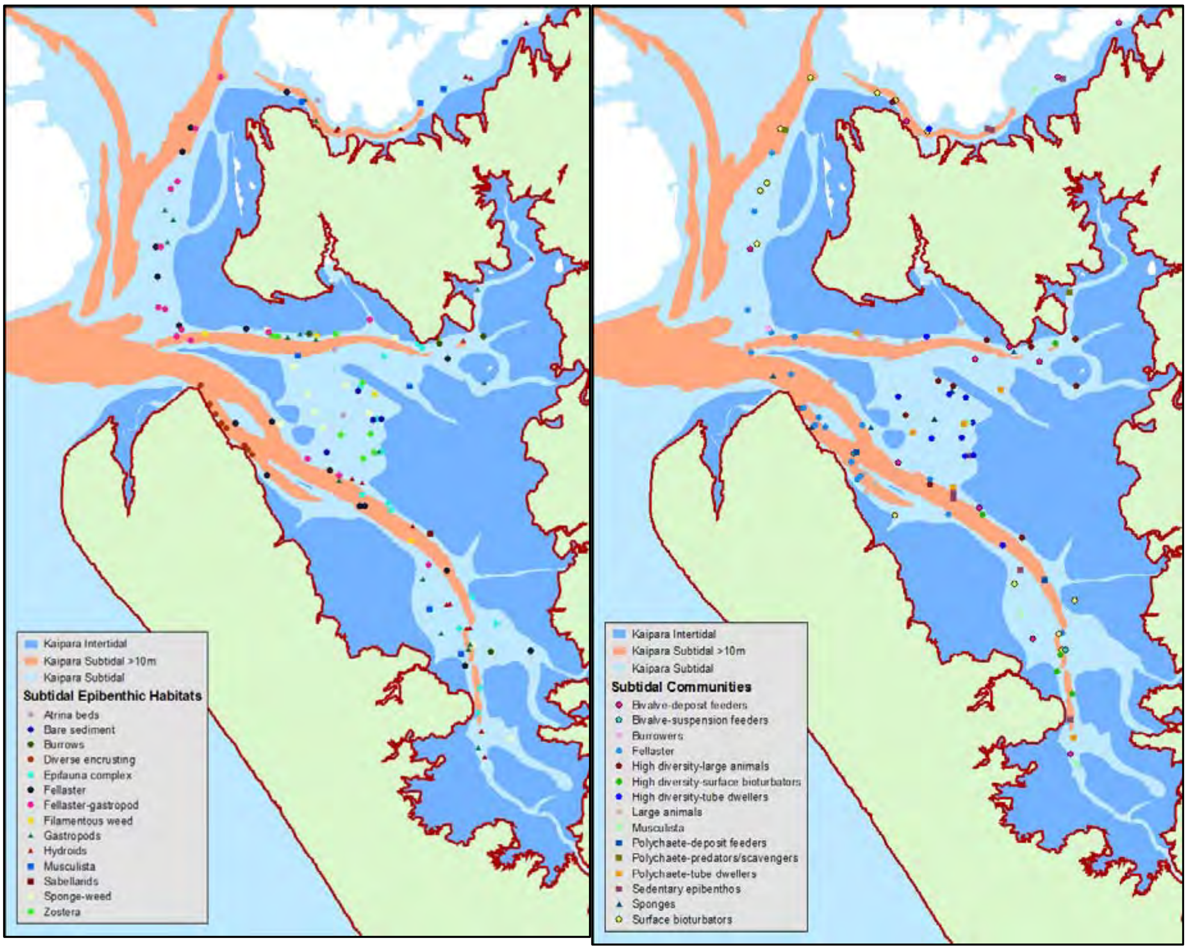

Figure 43: a) Assignment of Hewitt & Funnell subtidal sampling benthic sampling sites to categories for a) subtidal epibenthic habitats (bare sediments, and various biogenic habitat types, and b) subtidal communities (dominant species and/or functional classes). (Source: Hewitt & Funnell 2005).

Figure 44: General habitat areas of the southern Kaipara Harbour, as assigned by Hewitt & Funnell (2005). Descriptions of each are given in Table 4. The northern area ends halfway across the Oruawharo River, which is part of the northern boundary of the Auckland Council area. (Source: figure 12 from Hewitt & Funnell 2005).

A recent macro-algae survey of the southern Kaipara Harbour by Neill et al. (2012) found 43 algal taxa (see appendix 5 and figure 3 in Neill et al. 2012), with 24 taxa collected by dredge, 5 taxa from intertidal quadrats, and 26 taxa opportunistically from two intertidal sites (Karaka Point and Shelly Beach). Analysis revealed that assemblages were quite distinct between the two intertidal sites and from those collected by dredge from the subtidal. Diversity indices did not reach an asymptote suggesting that there is higher macroalgae diversity in the harbour than that detected. NIS species collected included *Gracilaria* sp, *Polysiphonia sertularioides*, *Solieria* sp, and *Ulva pertusa* (Neill et al. 2012).

Table 4. Habitat and ecological descriptions of the Southern Kaipara. (Source: Hewitt & Funnell 2005).

Area U (upper Kaipara River arm area)

Five main habitat types: mangroves of varying densities, unvegetated intertidal mudflats/sandflats and a small area of intertidal *Zostera* (seagrass), and subtidal muds. Mangroves all dominated by burrowing animals; mud communities, variable comprised of deposit-feeding bivalves, polychaetes, surface bioturbators, tube dwellers and polychaete predators/scavengers; *Zostera* supported a *Macamona* community; sand areas also had *Macamona* community, deposit feeding polychaetes, bivalves *Austrovenus* and tube dwellers; subtidal comprised of four ecological community types, being deposit feeding bivalves, tube dwellers, sedentary epifauna and surface bioturbators.

Area T (Tauhoa arm)

Tauhoa arm had a similar range of intertidal habitat types to the upper Kaipara River arm, including seagrass and mangroves. The inner subtidal area had finer sediments and was shallower (less than 7 m) than the outer, with a more diverse range of communities (deposit-feeding bivalves, surface bioturbators, tube-dwellers, predatory/scavenging polychaetes, large fauna, and invasives). Lower subtidal area characterized by burrowing, tube dwellers, and large fauna communities. Both areas frequently had high order diversity.

Area S (shallow subtidal between Kaipara River and Tauhoa arms)

One of the most diverse areas, with mainly fine sand sediments with a number of ecological communities (deposit feeding bivalves, sedentary epibenthos, sponges, tube-dwellers, large fauna, surface bioturbators, and invasives).

Area E (eastern intertidal)

Muddy areas were dominated by tube-dwellers. The *Zostera* communities were very variable, dominated by *Austrovenus*, *Macamona*, deposit-feeding polychaetes, tube dwellers, polychaete predators/scavengers or surface bioturbators, and varying from high to moderate diversity. Sand areas were also variable, ranging from *Austrovenus*, *Macamona*, polychaetes, tube dwellers to surface bioturbators, although diversity was generally lower than seagrass.

Area W (western intertidal)

Mangroves on the western side of the Kaipara River arm. Muddy areas supported *Austrovenus, Macomona* and tube dweller communities. *Zostera* dominated by Austrovenus and *Macomona*, while sand supported a number of different communities (suspension-feeding bivalves, deposit-feeding polychaetes, tube dwellers, polychaete predators/scavengers, surface bioturbators and *Macomona* dominated; frequently high diversity.

Area M (middle subtidal area of the Kaipara River arm)

Generally low diversity, with sandy muds to fine sands. Ecological communities varied from suspension feeding bivalves, tube dwellers, surface bioturbators, large fauna and *Fellaster* dominating. High current area by South Head very diverse, comprising steep rock walls, rubble habitat and sandy channel bottom. Highly diverse communities on the rock walls and rubble. *Fellaster*, surface bioturbators, sedentary epifaunal communities common.

South Head area

Very diverse high current area, with steep rock walls, rubble habitat, and sandy channel bottom. Apart from the highly diverse rock wall and rubble communities, *Fellaster*, surface bioturbators, and sedentary epifaunal communities were common.

Area I (Waionui Inlet intertidal)

Mangroves present, no *Zostera*. Unvegetated mud communities dominated by deposit-feeding polychaetes, also found in the sandy areas. Other sandy communities dominated by *Austrovenus* and surface bioturbators.

Areas Ex and H (Entrance subtidal and intertidal respectively)

Three main habitats opposite the mouth were intertidal *Zostera*, sand and subtidal sand. *Zostera* dominated by a mix of large animals and dead cockle shells common. Intertidal sand area community’s variable, with *Macomona*, tube dwellers, surface bioturbators, deposit-feeding bivalves and polychaete predators/scavengers dominating. Subtidal communities predominantly *Fellaster* and surface bioturbating gastropods.

Oruawharo arm (northern Kaipara)

Zostera not observed. Mangrove communities different from other mangrove areas, with small deposit-feeding bivalve (*Arthritica*) and polychaete predators/scavengers or deposit feeding bivalves. Sandy mud areas were dominated by *Austrovenus*, often with *Macomona*. Subtidal areas mainly muddy comprised of deposit-feeding bivalves, sedentary epifauna and *Fellaster* dominated communities. Further towards mouth, increasing numbers of surface bioturbators, tube dwellers and communities dominated by large fauna.

Area T (north-eastern intertidal)

No information provided.

Northern Harbour

While this region is less well studied than the southern Kaipara (Haggitt et al. 2008), several benthic surveys have been undertaken in discrete arms e.g. Otamatea river (Poynter 1992, cited in Haggitt et al. 2008, Robertson et al. 2002), and Port Albert mangroves (Morrisey et al. 2007, Lowe 2013). Vegetated intertidal habitats include extensive mangroves and salt marshes, intertidal mud and sand flats, shallow subtidal flats, deep high-flow channels and rocky reefs and cliffs (Gibbs et al. 2012). Results across these various studies suggest that the dominant taxa indicate a degraded environment.

Wairoa Arm

The eastern coastal areas of the Wairoa arm are typified by extensive intertidal sand and mudflats, with numerous muddy embayments between Werewere Point and Paraoanui Point. Little information on the benthic communities is available. Subtidal mussel beds occur adjacent to Pareotaunga Point, however their spatial extent is unknown (Haggitt et al. 2008). Asian date mussels were also collected from beam trawls within the more northern sector of this arm (see Section 4.10; subtidal beam trawl survey).

Arapaoa Arm

Numerous embayments, rocky headlands and extensive intertidal mudflats characterize the Arapaoa River arm. Species associations originally documented by Morton & Miller (1968) have been commonly observed throughout the area (Haggitt et al. 2008). These associations include oysters dominating the upper shore, whilst common gastropod fauna are present on the mudflats (e.g., *Xymene plebius, Zeacumantus lutulentus* and *Cominella glandiformis*). The Chilean oyster (*Tiostrea chilensis*) has also been recorded within the Pahi Bank area (Jeffs et al. 1993). Oyster reserves also occur between Wakiti and Tahupo Creek, and between Te Kopua Point and Waipako (see Section 4.4, also Haggitt et al. 2008). Extensive Asian date mussel beds are also present in the lower arm reaches (see Section 4.10).

Otamatea Arm – including Whakaki River

These areas are typified by muddy embayments and intertidal mudflats, with many creeks draining into Otamatea River (e.g., Kaiwaka River, Awaroa, Takahoa creeks) and into the Whakai River (e.g., Paki Creek, Stony Creek) (Haggitt et al. 2008). Otamatea is typical of many northern areas, with a catchment dominated by highly erodible beds of marine sedimentary sandstone, mudstone and limestone soils with extensive agricultural development (i.e., about 80% used for dairying, beef and sheep farming). Substrata at all three sites contained high mud content, with whole sediment samples recording elevated nutrient (nitrogen and phosphorous) concentrations compared with other reference estuaries in the study (see appendix C3 in Robertson et al. 2002). Benthic fauna was dominated by infaunal species (deposit-feeding polychaetes) with the addition of gastropods at the lower harbour site. Wide belts of rock oyster reefs were also noted along the hard shore (i.e. grey limestone) in site maps (see figure A2 in Robertson et al. 2002).

Benthic fauna collected from mangroves within the Oruawharo River / Port Albert arm as part of a North Island mangrove survey (see Section 4.6), generally revealed modest numbers of predominantly deposit-feeding infaunal polychaetes and infaunal amphipods, along with high abundances of the small gastropod *Potamopyrgus antipodarum* at one lower harbour site relative to the other Kaipara Harbour mangrove sites assessed.

4.4 Rock oyster reserves (northern Kaipara)

Rock oyster beds were once common in the Kaipara Harbour and elsewhere in northern New Zealand, and supported both customary and commercial fisheries, althrough the history of this fishery in the Kaipara has been fraught with social and biological issues (see Section 2, and chapter 10 of Makey 2010). Some areas were set aside in the past as “Māori oyster reserves”, including six locations in the Kaipara Harbour. Oyster densities were mapped at five locations in 2007, following concerns that these beds were in poor health and in decline. Using a low-flying (30–50 m) helicopter, the broad-scale extent of oysters was mapped using a geo-referenced video. Oyster abundances were assessed on a five point scale (table 1 of Kelly 2009), ranging from small low density patches (less than 5 m across), up to more extensive dense oyster beds (more than 25 m across). A Geographic Information System (GIS) was used to generate a 25 × 25 m resolution grid across all of the survey sites, with each grid cell being assigned an abundance value (1 to 5) based on the aerial survey data (see Kelly 2009) (Figure 45a). One of the five sites (Wakaiti to Tahapo Creek Oyster Reserve) was also visited on foot to gain quantitative estimates of oyster abundance and cover (using the same 1–5 rank scale), with empirical sampling within a randomly selected sub-set of the 25 × 25 m aerial data grid cells, stratified by abundance rank (1 to 5). Overall there was a good correspondence between the aerial and ground data abundance estimates, although some interpretation issues arose from the presence of large numbers of dead shells in several ‘rank 5’ cells, which were not detectable as dead from the air (the ground survey counted live oysters only). These field estimates were used to scale the aerial density class information up to total oyster numbers.

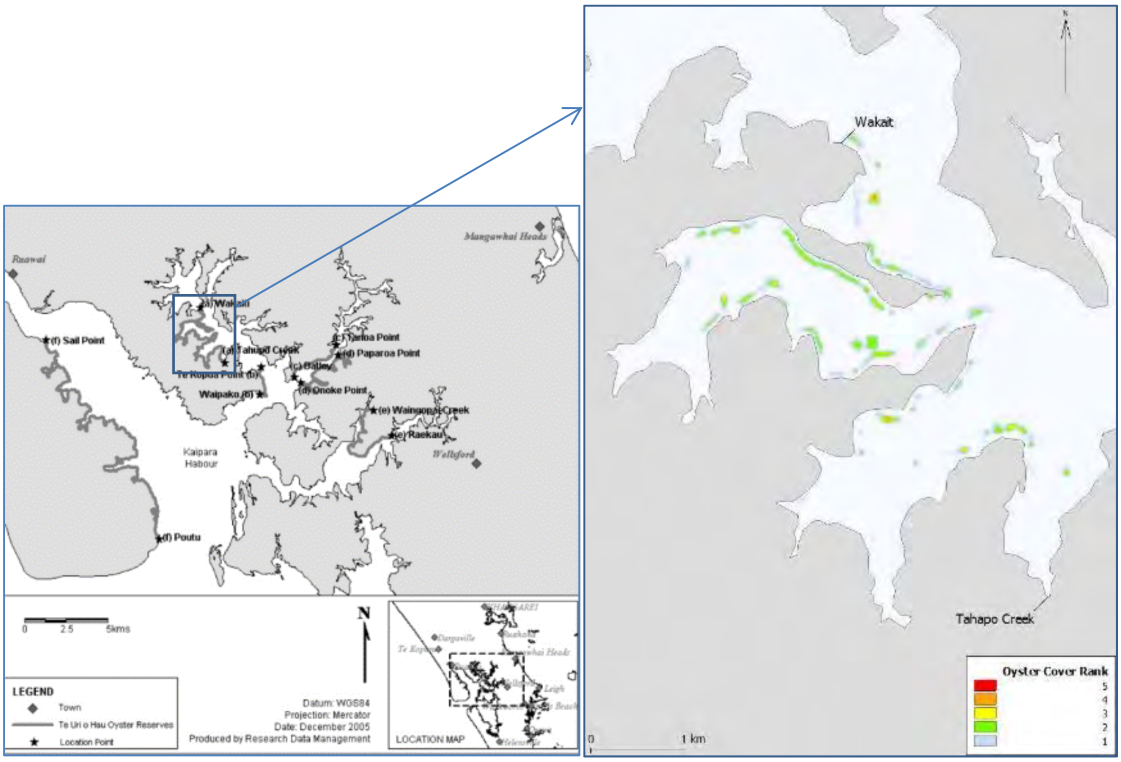

Figure 45a: Location of the six oyster reserves in the Kaipara Harbour (left) (Source: Annex Two of Ministry of Fisheries 2005; and abundance contours for oyster beds in Wakaiti to Tahupo Creek (right). (Source: figure 3 from Kelly 2009).

Figure 45b: Examples of intertidal oyster reefs in Kaipara Harbour; one on rocky reef, one on reef and mud, one on mud. (Source: Shane Kelly, Coast & Catchment Ltd).

Pacific oysters (Figure 45b) were the most commonly observed oyster species in all of the ground surveyed cells, while rock oysters were only found in 27% of the cells. While the two species overlapped, rock oysters extended further up the shore than Pacific oysters, and conversely Pacific oysters extended further down the shore than rock oysters. Oysters were attached to a variety of structures including mangroves, boulders, reefs, and man-made structures (largely abandoned oyster farms), as well as mud. While Pacific oysters were found on a wide ranges of substrates, rock oysters occurred at a higher frequency in clean or muddy reef grid cells, and at lower frequencies in mud or clean boulder grid cells (the latter thought to be an artefact of such boulders being found below the tidal range of rock oysters). An estimated 22.4 M oysters (95% confidence limits 18.2 to 26.9 M) were present in the Wakaiti to Tahapo Creek Oyster Reserve. Isolated areas within this, and the Waingopae Creek to Raekau Oyster Reserve, were found to hold ‘hotspots’ of oyster abundance, but at least some of these contained large numbers of dead oysters. This was consistent with recent mass mortalities information as described by local kaumatua, with an associated significant reduction in the number of oysters available for harvesting (Kelly 2009).

4.5 Scallop beds

Scallop beds were historically abundant in many areas of the harbour (see Section 2.3). Commercial scallop fishing was closed in 1986, and since then there has been a recreational and customary take fishery only. Following concerns of resource depletion, this recreational fishery was closed in 2005. To assess the state of scallop beds, research surveys using paired recreational dredges were carried out in 2007 (Walshe & Holdsworth 2007) and 2009 (Kelly 2010). The 2007 survey reported that the fishery was based on two main beds which produced relatively high catch rates, located north of Shelly Beach and opposite Tinopai, as well as a number of secondary areas which produced moderate to low catch rates. The two main beds were well known to local fishers, and had been extensively fished historically (Kelly 2010, Section 3). The survey strata used in 2007 and 2009 were based on known or expected areas of scallop habitat, with random stations allocated within and across strata. Issues were found with the 2007 station allocations, which appeared to be clumped, creating some issues in analysis in 2009, in terms of comparing trends across surveys. Kelly (2010) describes the survey sampling design and data analysis, which is not discussed further here. Of note was that the survey used recreational dredges which have a mesh size of 65–70 mm mesh, that the efficiency of these dredges is unknown (how many scallops are captured from all of the scallops the dredge passes over), and that size selectivity will be operating (e.g. most small scallops will not be sampled). Catch data were scaled to catch per unit area, and plotted to show bed locations, with the 0.025 scallops.m^{-2} contour (approximately 4 scallops per tow) used as an arbitrary lower threshold to define bed margins (Figure 46). Both the 2007 and 2009 surveys found scallops to be patchily distributed around the harbour, and within the strata surveyed (e.g., in 2009 no scallops were obtained from 57.6% of the stations sampled). In the southern Kaipara, a relatively large, high density scallop bed was located on the eastern side of the Kaipara River channel, north of Shelly Beach, along with a smaller, less dense, bed of scallops in Tauhoa Channel. In the northern Kaipara, another large, high density, bed occurred on the southern side of the Otamatea Channel, opposite Tinopai (Kelly 2010). Smaller, less dense, beds of scallops were located in in the Oruawharo and Arapaoa rivers. Scallops were also obtained from scattered stations outside these main beds (Kelly 2010). Overall, comparison of the two surveys “*suggested that the total number of legal scallops declined between 2007 and 2009, primarily due to fewer numbers within the larger size classes, including legally harvestable scallops. Those losses were mainly attributed to lower numbers of large scallops in beds within the southernmost strata (Shelly Beach and Inner Kaipara River). However, that conclusion must be treated cautiously because stations within the southern strata displayed a high level of clumping in 2007. Concentrating stations in areas with high scallop densities would lead to population numbers being overestimated. Size frequency estimates could also be biased if the spatial distribution of scallops varies among size classes.*” (Kelly 2010).

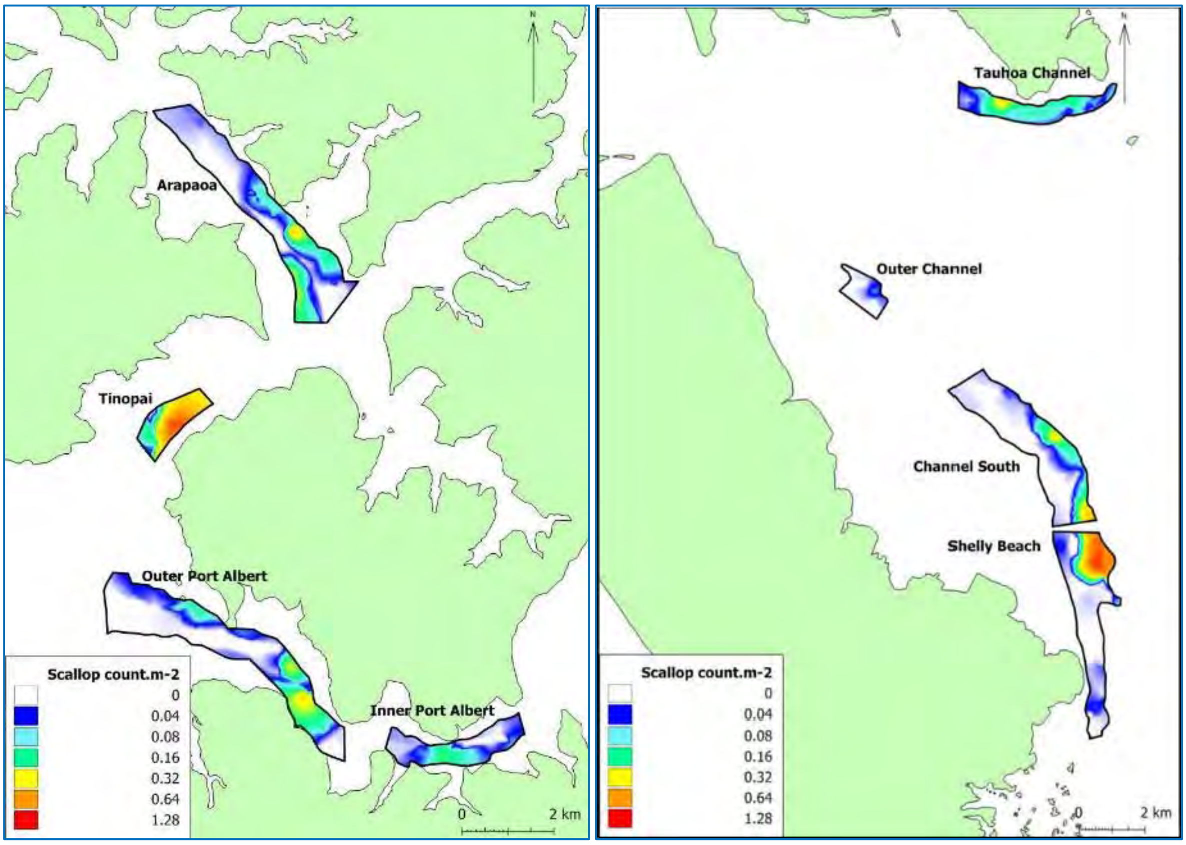

Figure 46: Scallop distribution in the a) northern and, b) southern strata based on kriging of the 2009 scallop catch (count.m^{-2}). (Source: figure 5 from Kelly 2010).

4.6 Juvenile / small fish in mangrove forests

As part of the FRST (now MBIE) "*Fish usage of estuarine and coastal habitats*" programme, a northern New Zealand 'small fish in mangroves' survey was undertaken in March–April 2004. This was in response to strong societal concerns and debate about ecological and other values associated with mangrove forests, relative to the loss of social amenities resulting from the expansion of this vegetation throughout many estuaries. This work is reported on in several documents, the most comprehensive being Morrisey et al. (2007); but also see Morrisey et al. (2010) and Lowe (2013). Eight estuaries were sampled (including the Kaipara), with each estuary being allocated 6 sample stations (12 in Rangaunu given its perceived level of 'pristineness'). Within an estuary, stations were placed to encompass as wide an environmental gradient as possible, from the lowest seaward extent of the forest, to the highest reach navigable by small boat (Figure 47a). At each station, a single fine mesh fyke net (9 mm thick braid mesh) was set parallel to the forest edge, with its wings touching the mangrove trees and the codend set in slightly deeper water next to the forest edge. Once the tide cleared the codend entrance (i.e., the entire net was exposed), the catch was removed, and the net then left to fish overnight throughout another tidal cycle. Catches (high-to-low day, and high-to-low night) were combined to give an overall sample of the number of fish leaving per 14.5 m of forest edge (net width) tidally over a 24-hour period. All fish caught were sorted, identified to species level, and measured (fork length) down to the nearest millimetre. The diet (stomach contents) of all fish collected were examined except when more than 12 individuals of a species were collected, when a subset of 10 animals was randomly sampled, ranging in size from smallest to the largest. Fish stomachs were preserved in the field. Stomach contents were identified to species or genus level under a dissecting microscope. A range of environmental variables were measured concurrently in the field at the time of fish sampling. These included water depth and clarity (Secchi), total suspended sediments (TSS), distance to the nearest subtidal channel, sediment grain size, organic carbon and mangrove characteristics (tree height, basal diameter and density, sapling/seedling densities, and width of the pneumatophore zone. For a full report and discussion of this sampling programme the reader is referred to Morrisey et al. (2007). Here we focus on the Kaipara Harbour in particular, with reference as appropriate to findings from the other estuaries sampled (the Manukau Harbour, and five east coast estuaries).

The west coast estuaries (Kaipara and Manukau) had mangrove forests characterised by larger, more complex mangrove trees (Figure 47b), along with high TSS, lower water clarities, higher organic carbon levels and finer sediment grain sizes (mud). By contrast, the majority of east coast sites were comprised of smaller, less complex mangrove trees, higher water clarities and larger sediment grain sizes (i.e. sand).

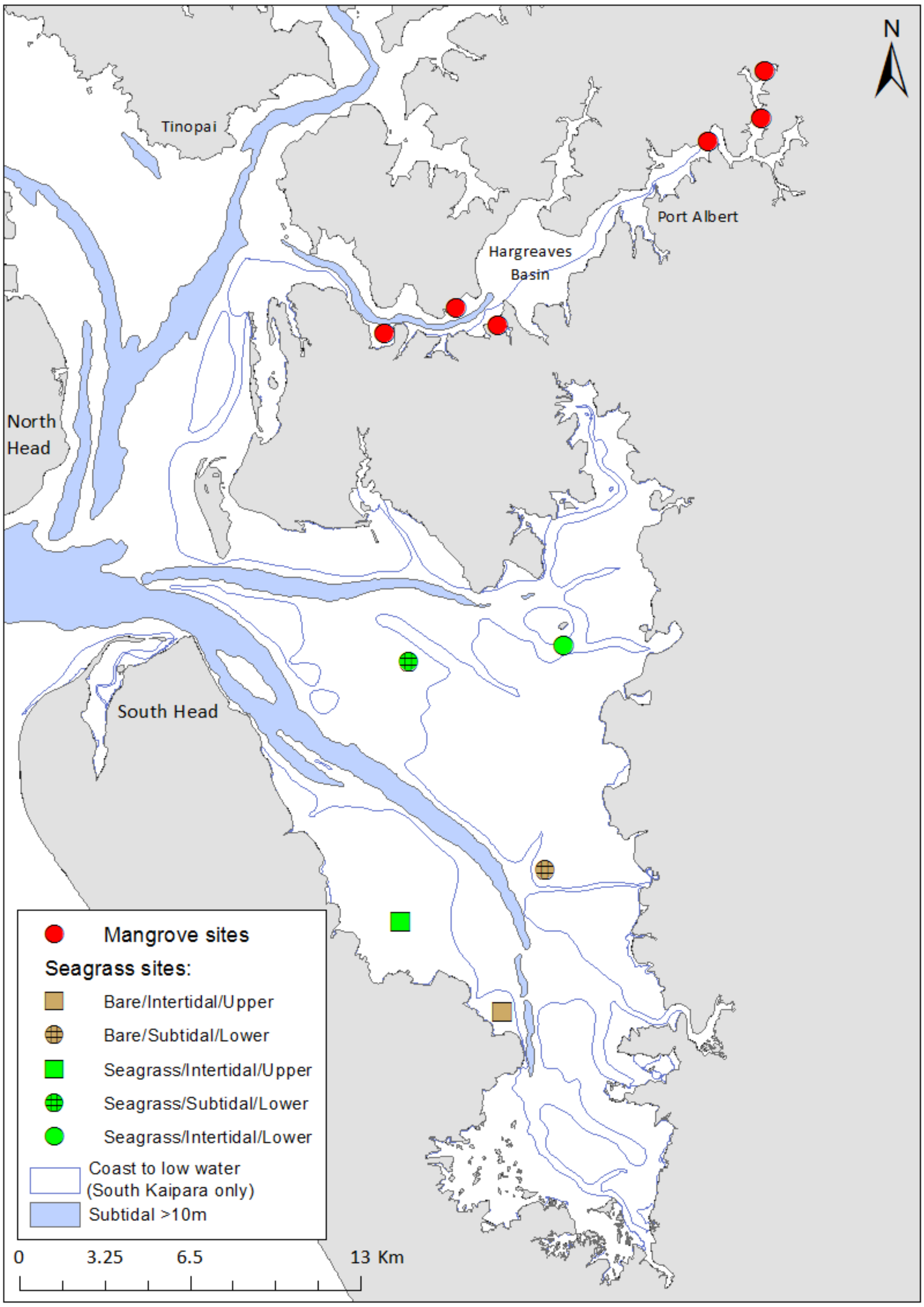

Figure 47a: Sampling locations for surveys of both the small fish in mangroves and seagrass surveys carried out in the Southern Kaipara.

Figure 47b: Example of a large (about 6–8 m height) mangrove tree being measured within a random 10 × 10 m sampling plot as part of fish sampling work, southern Hargreaves Basin, Kaipara Harbour. (Source: M.L., NIWA).

Overall, 19 species of fish were collected with fish assemblages dominated by juveniles (98%) (e.g., Figure 48), of which 88% were small semi-pelagic schooling species, which included mullets, pilchards and smelt (Table 5). Four species dominated the catch (92%), comprising yellow-eyed mullet, grey mullet, estuarine triplefin and pilchard (Table 5). Other demersal species were also caught in lower numbers, including short-finned eels, parore, sand flounder and yellow-belly flounder. Occasional individuals of another nine species were also caught, including snapper and kahawai. Comparison of day/night catches revealed variable catches with most grey mullet, and all but one of the short-finned eels, being caught overnight. Total fish catch rates varied across the eight estuaries, ranging from 121 ± 25 (s.e.) to 751 ± 305 individuals per set (Kaipara 149 ± 55), while species richness ranged from 4.6 ± 0.3 to 8.3 ± 0.8 s.e. (Kaipara 5.3 ± 0.5). Individual statistical tests were completed for total abundance, species richness, and individual species densities; while some significant differences were found between harbours, overall no clear trends were evident, and so are not reported on further here. With the exception of grey mullet, short-finned eels and parore (all in the QMS), no other commercial species were commonly found in mangrove habitats. Grey mullet were only common in the west coast estuaries, short-finned eels were found on both coasts, and parore almost exclusively on the east coast (only two juveniles sampled from the west coast, in Manukau Harbour). The Kaipara Harbour samples had moderate juvenile grey mullet densities (25.2 ± 18.0 per 14.5 m net set, with most fish coming from one site), along with the highest densities of short-finned eels recorded (10.5 ± 2.5), although these measurements are based on a single survey, with no replication over time. The other two species present in some numbers were juvenile yellow-eyed mullet (84.8 ± 28.8), which were ubiquitous across all of the different estuaries mangrove forests sampled (Kaipara having the second lowest densities, just above the Manukau Harbour), and juvenile anchovies (a species whose main abundance is thought to occur in the pelagic environment of the deeper open channels, with their occurrence in the mangrove zone being just the fringe of their distribution).

Table 5: Average mangrove fyke net sampling summaries by harbour and species. Densities are expressed as mean (± s.e.) number of individuals per 14.5 m net set (day and night catch combined). Kaip, Kaipara; Manu, Manukau; Rang, Rangaunu; Mang, Mangawhai; Mahu, Mahurangi; Wait, Waitemata; Wang, Whangapoua; Taur, Tauranga. Kaipara Harbour mangrove catch values are grey back-grounded. Source: Morrisey et al. (2007).

Scientific name	Common name	Kaip	Manu	Rang	Mang	Mahu	Wait	Whang	Taur
Aldrichetta forsteri	Yellow-eyed mullet	84.8 (28.8)	234.5 (104.8)	55.1 (17.4)	112.5 (47.4)	340.6 (100.0)	482.7 (193.2)	342.1 (92.3)	183.4 (53.2)
Mugil cephalus	Grey mullet	24.2 (18.0)	473.1 (298.7)	1.6 (1.3)	–	0.3 (0.2)	0.2 (0.1)	0.5 (0.5)	0.6 (0.4)
Grahamina nigripenne	Estuarine triplefin	0.3 (0.2)	2.5 (2.1)	40.9 (11.2)	2.3 (1.2)	92.5 (50.4)	4.8 (2.2)	1.8 (1.0)	0.2 (0.2)
Sardinops neopilchardus	Pilchard	–	1.5 (1.3)	–	58.5 (58.5)	47.0 (47.0)	–	–	–
Retropinna retropinna	Smelt	0.3 (0.3)	17.7 (6.5)	10.9 (7.0)	–	12.0 (3.9)	2.3 (1.6)	–	12.2 (9.2)
Anguilla australis	Short-finned eel	10.5 (2.5)	2.8 (1.0)	5.0 (3.3)	5.3 (3.9)	7.2 (2.2)	3.5 (1.5)	4.5 (1.4)	6.8 (2.7)
Engraulis australis	Anchovy	24.8 (24.0)	0.3 (0.3)	1.5 (1.2)	0.5 (0.5)	2.0 (0.9)	0.5 (0.5)	1.0 (1.0)	–
Rhombosolea plebeia	Sand flounder	1.2 (0.8)	4.7 (3.2)	1.7 (0.5)	0.3 (0.2)	14.7 (9.0)	1.0 (0.6)	0.7 (0.4)	0.4 (0.4)
Girella tricuspidata	Parore	–	0.7 (0.6)	1.3 (0.5)	2.3 (0.9)	1.8 (0.9)	0.2 (0.1)	11.7 (8.7)	0.4 (0.2)
Rhombosolea leporina	Yellow-bellied flounder	1.5 (0.5)	9.0 (5.0)	–	0.2 (0.1)	3.2 (1.5)	3.2 (1.3)	0.8 (0.4)	0.2 (0.2)
Favonigobius exquisitus	Exquisite goby	1.2 (0.8)	0.7 (0.4)	2.8 (0.7)	1.0 (0.5)	1.7 (1.0)	0.8 (0.4)	0.2 (0.1)	–
Grahamina capito	Mottled triplefin	–	3.2 (3.1)	–	0.2 (0.1)	1.0 (0.8)	–	0.3 (0.3)	0.2 (0.2)
Arenigobious bifrenatus	Bridled goby	–	–	–	–	1.3 (0.9)	–	–	–
Hyporhamphus ihi	Garfish	0.5 (0.5)	–	0.2 (0.1)	–	0.2 (0.2)	–	–	–
Sprattus sprattus	Sprat	–	–	0.2 (0.2)	–	–	–	–	0.4 (0.4)
Trachurus novaezealandiae	Jack mackerel	–	–	0.2 (0.1)	–	–	–	0.2 (0.1)	–
Pagrus auratus	Snapper	–	–	0.2 (0.1)	–	0.2 (0.1)	–	–	–
Notolabrus celidotus	Spotty	–	–	0.2 (0.1)	–	–	–	–	–
Arripis trutta	Kahawai	–	–	–	–	–	–	0.2 (0.1)	–
Total species		10	11	13	9	14	9	12	9

Across the full estuary data set, multivariate analysis (ANOSIM) revealed that mangrove fish assemblages were significantly different between the east and west coast estuaries (Morrisey et al. 2007), with differences driven more by large variations in the relative abundance of a few species than by differences in the species pool present. Abundances of individual species varied in response to environmental variables. For example, grey mullet (west coast only) and yellow belly flounder were strongly associated with higher TSS; yellow-eyed mullet were positively associated with increasing distance from the sea; parore (east coast only) were positively associated with higher water clarities, and short-finned eels were positively associated with three dimensional mangrove structure. These results suggest that habitat quality and geographical setting of mangrove forests influence the fish assemblages they support, and that it is not just the presence of mangroves *per se* that should be taken into account when assessing (fish) habitat values.

The value of mangroves for fish species is usually explained in terms of 1) refuge from predation amongst prop roots/pneumatophores and 2) elevated foraging opportunities resulting from higher prey abundances. However, these views are primarily a result of studies in tropical mangrove forests, which tend to have much greater mangrove species diversity and structural complexity (including complex buttress roots) than their temperate counterparts, along with some areas remaining permanently submerged throughout the tidal cycle. In New Zealand, provision of refuge for small fish within mangrove forests may be limited due to *Avicennia marina*'s structurally low complexity, aerial roots (pneumatophores), and their lower growing range extending to only the half tidal range, meaning that fish are forced to leave mangrove habitats during low tides (both day and night). Sampling by Lowe (2013) of the benthos of a subset of the mangrove sampling stations reported on here (including three Kaipara stations) found the benthic invertebrate fauna to be dominated by small infaunal deposit feeders. These species collectively provided only low abundance, species diversity, biomass and productivity values, which in turn limited their potential to provide foraging opportunities for small fish, especially when compared to other estuarine habitats such as seagrass (see figures 4.13, 4.14, and tables 4.22a, b, in Lowe 2013). Overall, molluscs and crustaceans were rare, as seen in other studies (e.g., Morrisey et al. 2003, Ellis et al. 2004, Alfaro 2006). Benthic biomass and productivity were low when compared to subtidal seagrass habitats in the southern Kaipara (see figures 4.13; 4.14 in Lowe 2013, also Table 8 this report). Of the four harbour systems assessed for mangrove productivity by Lowe (2013), Kaipara Harbour (Oruawharo River) ranked second: Manukau (Pahurehure Inlet) 59.08±29.82, Kaipara 34.36±9.75, Rangaunu 23.38±7.77, Mahurangi 16.86±5.35 (units are milligrams of Ash Free Dry Weight per metre per year).

Quantification of the associated fish guts sampled found that those fish species found in high abundances within the mangrove forests (e.g. yellow-eyed, grey mullet, and anchovy) were feeding on food resources common throughout the estuary (i.e. zooplankton; comprising 87% of total gut prey density), and/or on food types common in mangrove forests and the associated seafloor (i.e. fine algae/detritus).

Collectively, these results agreed with the overall findings of Morrisey et al. (2010), whose global review of temperate mangrove functionality and ecology concluded that they play only a modest role as juvenile fish nurseries.

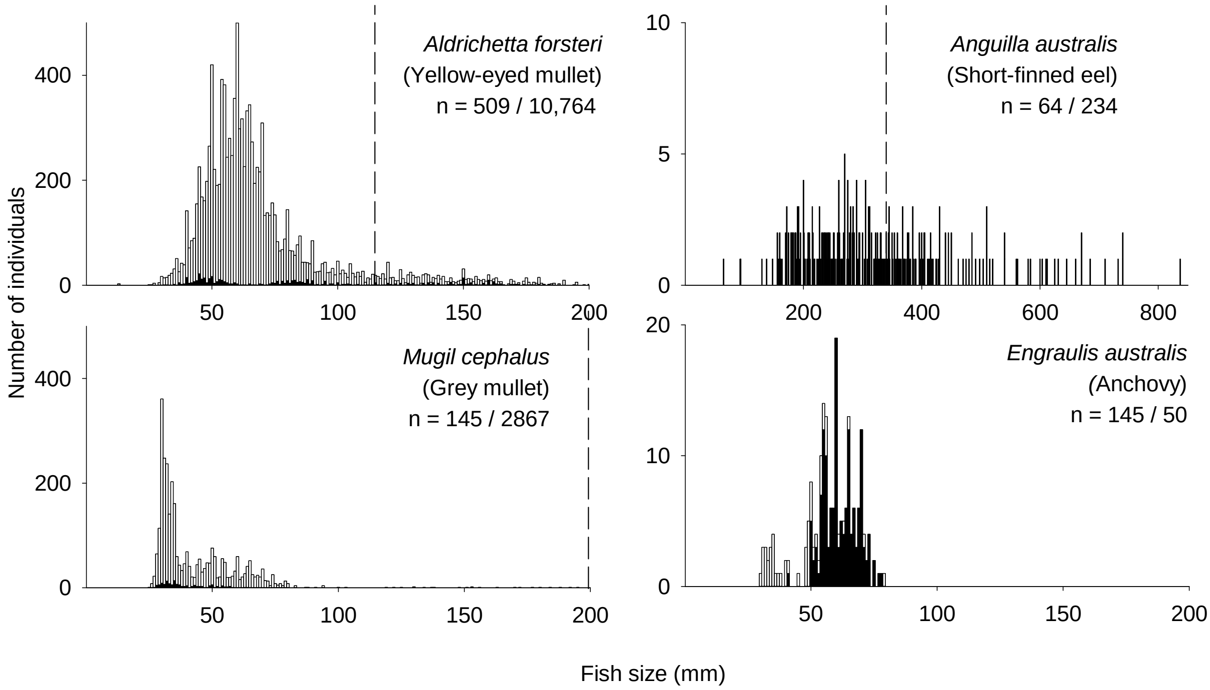

Figure 48: Length frequencies of the four most abundant species sampled in Kaipara mangrove forests. Dotted vertical lines denote length at maturity where known (see Hurst et al. 2000). Black shading denotes fish from the Kaipara Harbour, white shading denotes individuals from the other seven harbours (bars are stacked) (n; number of fish caught in the Kaipara Harbour / sum of individuals from the other seven harbours). (Source: modified from Morrisey et al. 2007).

4.7 Fish assemblages on intertidal flats

The Kaipara Harbour was one of sixty-eight estuaries sampled as part of a national estuarine fish survey (Francis et al. 2005, 2011) undertaken as part of the "*Fish usage of estuarine and coastal habitats*" programme. Sampling was undertaken during low tides, when fish had left the intertidal flats and were aggregated in the immediate adjacent subtidal areas. Earlier work in the Manukau Harbour had shown that low tide sampling resulted in higher fish species richness and abundance than high tide sampling (Morrison et al. 2002). An 11 m wide beach seine, with 9 mm mesh, 2.3 m drop, and a 4 m long codend, was used to sample small fishes adjacent to the shoreline. Two people deployed and retrieved the net, which fished a width of about 9 m. The net was extended parallel to the shoreline in chest-deep water, and then hauled straight to the shore. Hauling speeds depended on the nature of the sea bottom; firm sand allowed a slow walking speed, while soft muds associated with upper harbour sites produced a slower speed due to 'bogging' of the net. For a number of low tide shots it was necessary to sieve the catch through the net to extract fish from large volumes of semi-liquid mud scraped from the seafloor. On average, about 432 m^2 was sampled by each beach seine tow (9 m wide by 48 m tow), with tows starting in water depths of about 1.3 m, although some tows at sites with very gentle slopes were much longer (up to 220 m). Tows were spread across the harbour system, with the objective of encompassing as wide a range of environmental gradients as possible. Fish were retrieved from the net, larger individuals of species such as grey mullet and flounders measured and released alive, and the rest of the catch bagged, and frozen on return to the shore. At a later date, samples were thawed, and fish sorted by species, counted, and measured down to the nearest millimetre (fork length). Catches of individual species exceeding 100 fish per tow were subsampled, with least 50 fish or 25% of the catch measured.

A series of environmental variables were measured at each station: water depth at the start of the tow, salinity, water temperature, water clarity (Secchi disc), substrate type (as a category), and whether vegetation (seagrass, algae, mangroves) was present at or immediately adjacent to the tow. Distance towed and time of tow was also recorded, and a ‘distance-up-harbour’ variable was subsequently calculated (Distlabel), being the distance from the harbour mouth towards the upper end of the harbour at which the station was located, expressed as a percentage (possible range 0–100). These data are analysed and reported on in aggregate across the set of harbours sampled, as the objective of the research was to quantify broad scale patterns across New Zealand estuaries, rather than to describe any particular estuary in fine detail. Francis et al. (2005) reported on the initial 25 northern New Zealand estuaries, while Francis et al. (2011) reported on the full nation-wide 68 harbour data set, inclusive of the original 25 estuaries sampled.

National scale harbour comparisons of fish assemblages

At the scale of the northern North Island (25 harbours), 34 species were caught; 21 in more than 2% of stations, with the four most common species being caught in more than 50% of stations; being yellow-eyed mullet, exquisite goby, sand flounder and specked sole (Francis et al. 2005). Using both ordination (correspondence analysis) and clustering approaches, two main species assemblages were identified;

- Assemblage 1 – exquisite goby, sand flounder, specked soles, yellow-belly flounder, grey mullet, mottled triplefin and red gurnard.
- Assemblage 2 – yellow-eyed mullet, spotty, snapper, trevally and parore.

The occurrence and relative abundance of the twelve most common species, and species richness, were also modelled with a series of General Additive Models (GAMs), using all of, or subsets of, the nineteen predictor variables. These included the environmental variables measured at each site as well as a number of physical environment variables estimated at a harbour level such as: Estuary type (coastal bay, drowned valley, tidal lagoon), Tideflow (ratio of spring tidal prism to total estuary flow), Riverflow (ratio of river inflow to total estuary volume), a shoreline complexity index and Catchtemp (annual mean terrestrial catchment temperature). In addition to these physical variables, three location variables were used; Harbour, Latitude and Coast (i.e. east or west). Both descriptive (using various different subsets of the predictor variables) and predictive (using only those variables that would be available for un-sampled harbours) models were developed, their validity being tested using GRASP (Gravitational Radiation Analysis & Simulation Package) routines to compare predicted and observed values, both from the original dataset and from a separate 6-harbour dataset, where five of the harbours had not been sampled previously. The performance of the GAM models varied widely; descriptive models performed well for relative abundance of exquisite goby, estuarine triplefin, smelt and sand goby, poorly for yellow-eyed mullet and sand flounder, and for the remaining six species, the descriptive models described the data well, but performed poorly under cross validation. This was possibly due to a small number of high catch stations strongly influencing the predictor variables. Table 6 shows the variables that were selected in the GAM “Environment” model for each of the twelve species and species richness (note that this includes all samples, not just those of the Kaipara). Water clarity was most frequently selected (for 10 out of 12 species), followed by, in descending order; *Salinity* > *Distpercent* = *Time* = *Tiderange* > *Substratum* = *Depth* = *Riverflow*. Overall, *Clarity*, *Salinity*, and *Riverflow* were the most useful of the variables available for describing the abundance of harbour fish species. These were key variables for distinguishing fish from the different assemblages, with species from the first group associated with turbid, muddy upper reaches of harbours often with complex coastlines (exquisite goby, sand flounder, specked soles, yellow-belly flounder, grey mullet, triplefin and red gurnard), while those from the second group were associated with more saline, deeper waters with seagrass present (yellow-eyed mullet, spotty, snapper, trevally and parore).

Francis et al. (2011) examined the national scale dataset, and reported that 51 species were sampled (this includes the 34 sampled in the 25 northern estuaries). The reader is directed to this paper for more detail on the analyses and findings (much of which are not directly relevant to the Kaipara Harbour). However, Boosted Regression Tree (BRT) models applied to this national data set showed that, within estuaries, fish species richness increased towards the head of the estuary, as water clarity declined and substrate became muddier (Francis et al. 2011). This trend was also seen in the Kaipara Harbour beam trawl and video surveys (Sections 4.10 and 4.11).

Table 6: Variables selected in GAM (*Environment* Model 3 of Francis et al. 2005) showing the nature of the relationship between each continuous variable, or the level of each categorical variable, and fish abundance or species richness. Species are arranged by descending frequency of occurrence within assemblages (U indicates an un-associated species). Blank cells indicate non-significant variables. Shading indicates the three variables, or more if some are tied for importance, (and their associated levels) contributing most to each model. Also shown (last two columns) are the number of times each variable was selected in the best fit model, and the number of times it was selected in the top three variables. –, negative; +, positive; 0, intermediate; ∩, unimodal with intermediate optimum; ∪, bimodal with low and high optima; ?, indeterminate. As an example, (juvenile) grey mullet (MCE) would be interpreted: as having positive associations with mangroves nearby, tidal lagoons, seagrass present, warmer water temperatures, being further up the harbour (Distpercent), tide range (due to its higher west coast densities relative to the east coast), and catchment temperature (being a warm-temperate species); and having negative associations with water clarity, salinity, and tidal flow (being found in the mid to upper reaches of estuaries). Species codes are FEX, exquisite goby; RPL, sand flounder, PLA, speckled sole; RLE, yellow-belly flounder; MCE, grey mullet; AFO, yellow-eyed mullet; NCE, spotty; PAU, snapper; EUA, anchovy; FLE sand goby, ; RRE, smelt, GNI, estuarine triple-fin. (Source: Francis et al. 2005). (Note: codes used are not standard MPI species codes).

		Species														
Variable	Levels	FEX	RPL	PLA	RLE	MCE	AFO	NCE	PAU	EAU	FLE	RRE	GNI	Rich-ness	Times selected	Times in top three
Assemblage		1	1	1	1	1	2	2	2	U	U	U	U			
Substratum	Soft mud	+		+	+					–			+	0	6	1
	Firm mud	+		–	+					0			+	+	6	1
	Sandy mud	+		0	+					+			+	+	6	1
	Sand	–		0	–					0			–	–	6	1
Vegetation	None	0			0	0		0	0						5	1
	Mangroves nearby	–			0	+		0	–						5	1
	Seagrass nearby	–			–	0		0	0						5	1
	Seagrass present	+			0	+		+	+						5	1
Depth							+		+		–	∪	+	+	6	3
Salinity		+			–	–	+	+	+	+		–			8	5
Clarity		–	–	–		–		∪	+	–	+	–	–	–	11	6
Temperature		–	+	∪		+					–				5	2
Distpercent		+			+	+		+	∩	∪				+	7	0
Towdist		–		–				–				–	–		5	4
Time		–			∪	–			∩	∪		∪		–	7	2
Type	Coastal bay	+				0	–						–		4	2
	Drowned valley	–				0	+						+		4	2
	Tidal lagoon	+				+	–						–		4	2
Tideflow			∩			–				∪		∩			4	2
Riverflow			–	–						–		?	–	–	6	6
Complexity		+	+	+							–				4	1
Area							–	–		–			–		4	2
Tiderange		–				+		–	?		–		∪	–	7	2
Catchtemp					?	+						+			3	0

Kaipara Harbour fish assemblages

Within the Kaipara Harbour, forty beach seine stations were sampled in 2001, and a further seven stations in 2003. A total of 22 species were caught over the sand and mud flats, although only four species were caught in more than 50% of the samples. The small fish assemblage was dominated by exquisite goby, juvenile yellow-eyed and grey mullet, as well as juveniles of three flatfish species; speckled sole, sand flounder and yellow-belly flounder. Figure 49 gives the mean overall catch rate for all species caught.

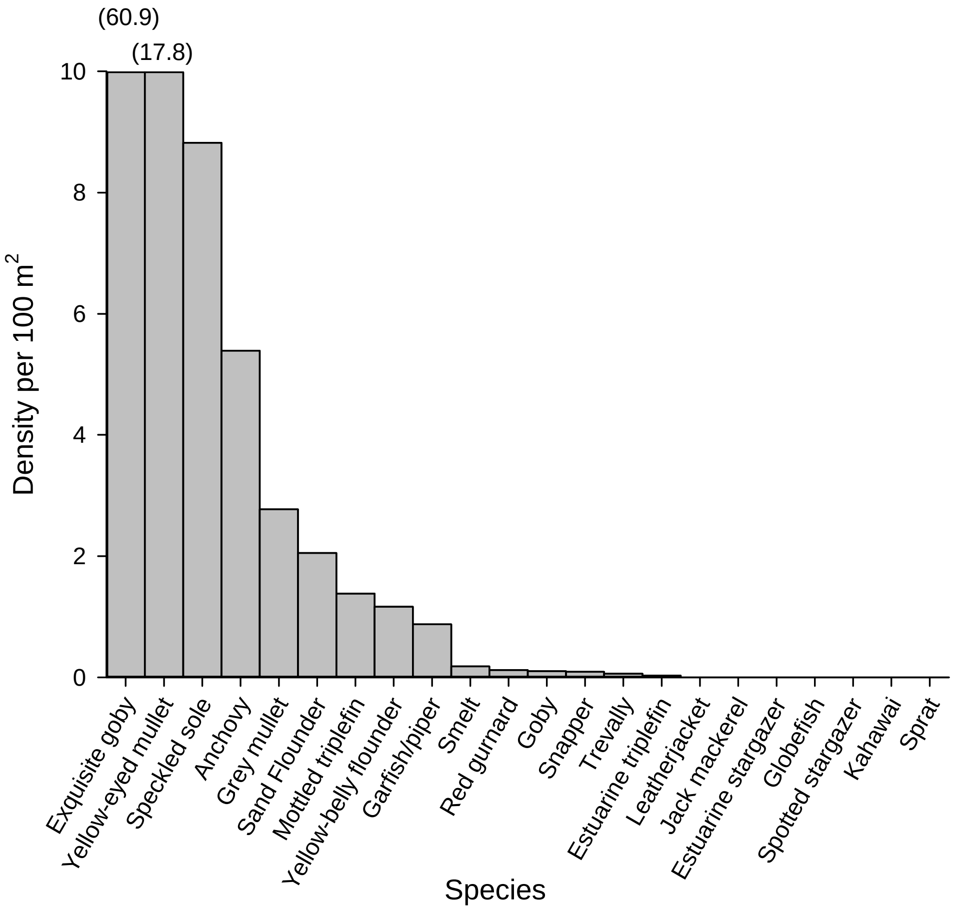

Figure 49: Mean catch rates (density per 100 m^2) for finfish species caught in the Kaipara Harbour beach seines. Note that to maximise display, the graph is capped at a maximum density value of 10. Exquisite goby densities were six times this value, and yellow-eyed mullet two times (values given in brackets).

Figure 50 compares the mean catch rates of the eight most abundant species across three substrate groups; mud (includes hard and soft mud categories), muddy sand, and sand. A number of species were more abundant on muddy/muddy sand substrates (exquisite goby, grey mullet and mottled triplefin), while others were more cosmopolitan in their substrate associations (yellow-eyed mullet, speckled sole, anchovy, and sand flounder). With the exception of mottled exquisite gobies and triple-fins, most individuals sampled were juvenile life stages, including ‘0+” individuals (less than 1 year old) (yellow-eyed mullet (40–80 mm), speckled sole, anchovy, grey mullet (20–30 mm), and yellow-belly flounder (30–120 mm), as well as 1+ or older juveniles for some species (yellow-eyed mullet 100–150 mm, grey mullet 90–250 mm, and yellow-belly flounder 120–280 mm). Length frequencies of the different species were similar across the three substrate classes (where they occurred) (not presented), with the exception of mottled triple-fins and yellow-eyed mullet, where larger individuals were associated with the sandy mud and sand relative to mud substrates (Figure 51).

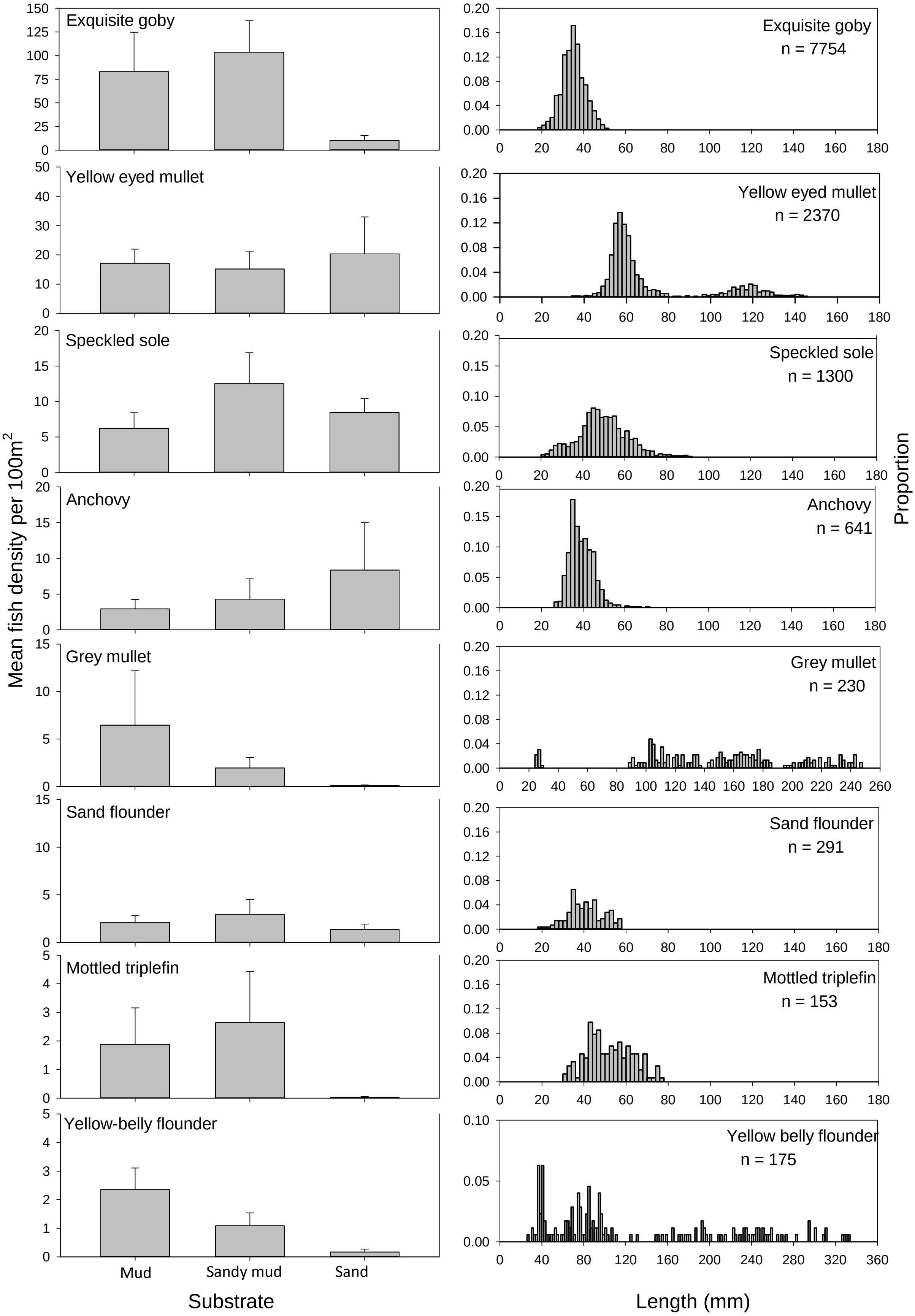

Figure 50: Mean catch rate (+/- s.e.) and length frequencies for the eight species most commonly caught by beach seines, across three substrate categories. Fork length was measured for yellow eye mullet, anchovy and grey mullet, total length for the remainder. Note that the y axis density scales vary.

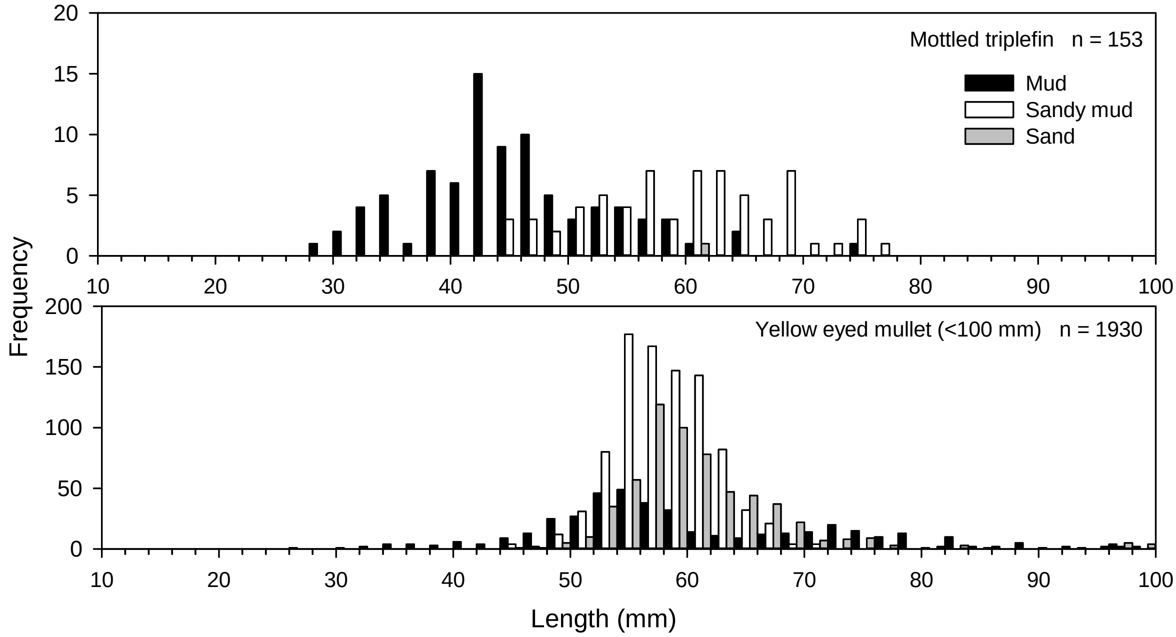

Figure 51: Length frequency by substrate type for mottled triplefins and yellow-eyed mullet (<100 mm presented only). Note that the y axis scales vary.

A nMDS ordination (implemented in Primer 6) of fourth root transformed fish assemblage data shows sand stations clustering to the left-hand side of the plot, with mud and sandy mud stations clustered towards the right (Figure 52). Pairwise ANOSIM tests between the three substrate groups indicated a significant difference between fish assemblages found on sand and mud ($R = 0.151$, $P < 0.002$) and between sand and sandymud substrates ($R = 0.125$, $P < 0.023$).

The DISTLM routine was used to perform a dbRDA (distance based redundancy analysis) multivariate regression between the fish assemblage and continuous environmental variables. Using a selection routine based on the Akaike Information Criteria (AIC), the model with the lowest AIC value incorporated Clarity (Pseudo f = 5.3227, $P< 0.001$), Depth (Pseudo f = 1.9888, $P< 0.066$) and “Distlabel” (distance from harbour entrance as a proportion of total harbour arm length) (Pseudo f = 4.3773, $P< 0.001$), but not temperature or salinity. This model is visualized in Figure 53. The first two axes capture just over 90% of the fitted variation, but less than 20% of the total variation in the data. The first axis relates to water clarity, and accounts for most of the variance overall. Intertidal/immediate subtidal fish assemblages in the Kaipara were strongly influenced by location in the harbour in relation to distance from the entrance, freshwater input, and water clarity, which is a similar finding to that of the national beach seine survey (Francis et al. 2005, 2011). Species such as exquisite goby, yellow belly and sand flounder and grey mullet were found in higher abundance in the inner, turbid parts of the harbour, while species such as yellow-eyed mullet, snapper and trevally were more likely to occur at mid harbour stations with higher water clarity (see Figure 54). (NB: snapper and trevally catch rates were very modest, while juvenile parore and spotty are rarely sampled in the Kaipara Harbour or other west coast harbours).

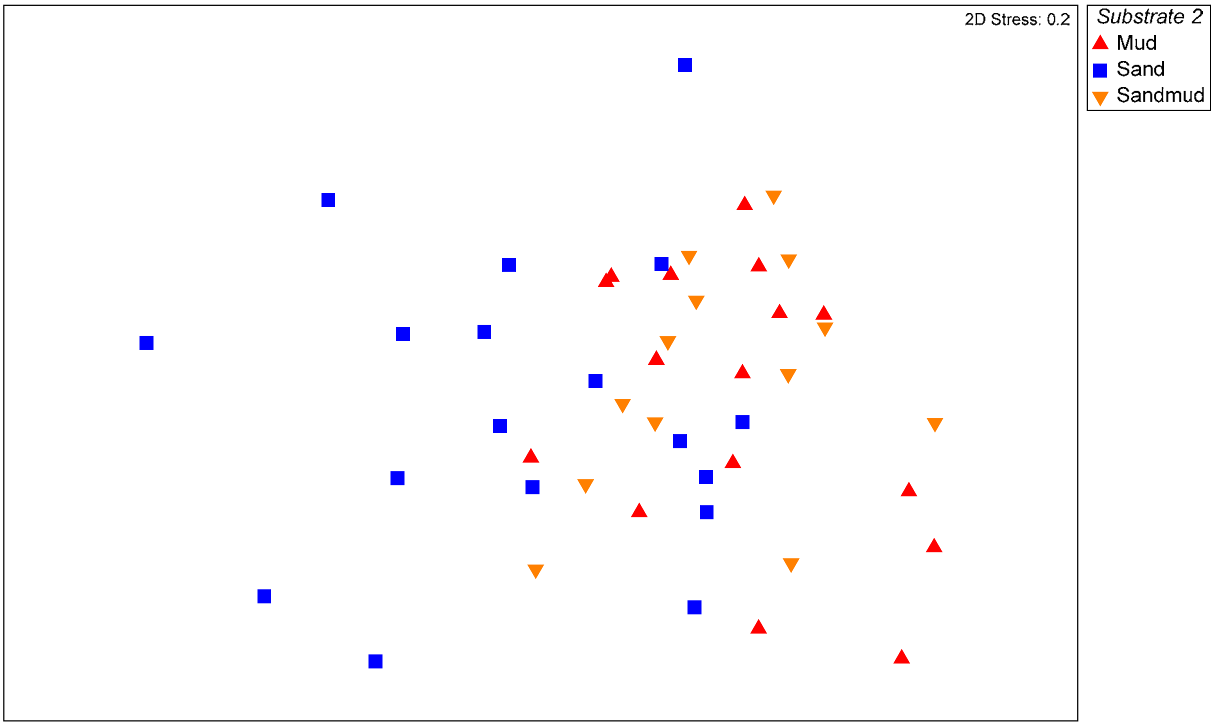

Figure 52: nMDS ordination of Kaipara Harbour fish beach seine data, for three substrate types (soft and hard mud categories combined).

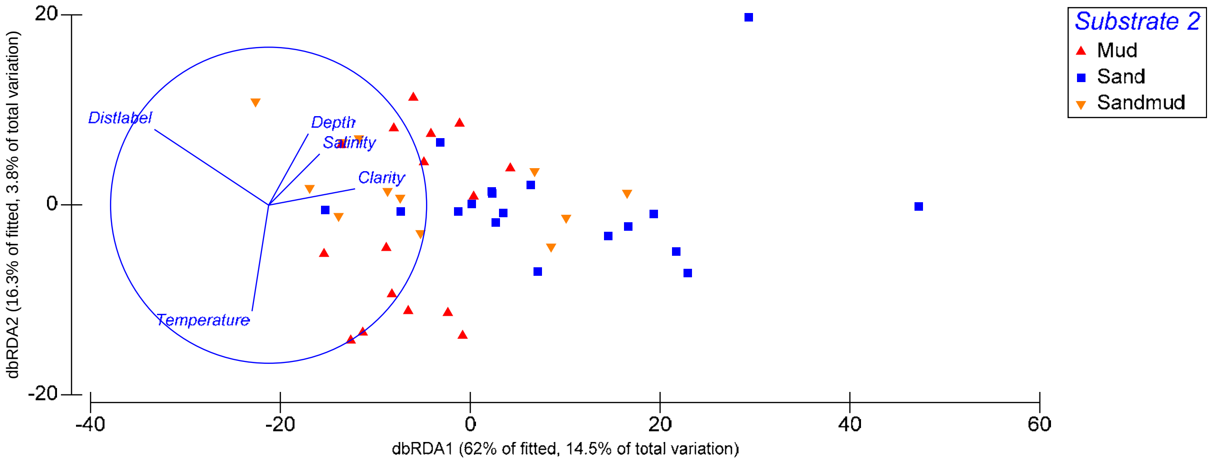

Figure 53: dbRDA ordination for the fitted model showing patterns of important environmental variables with fish assemblage data from the Kaipara Harbour beach seine survey. Each point represents a station, colour-coded by substrate type.

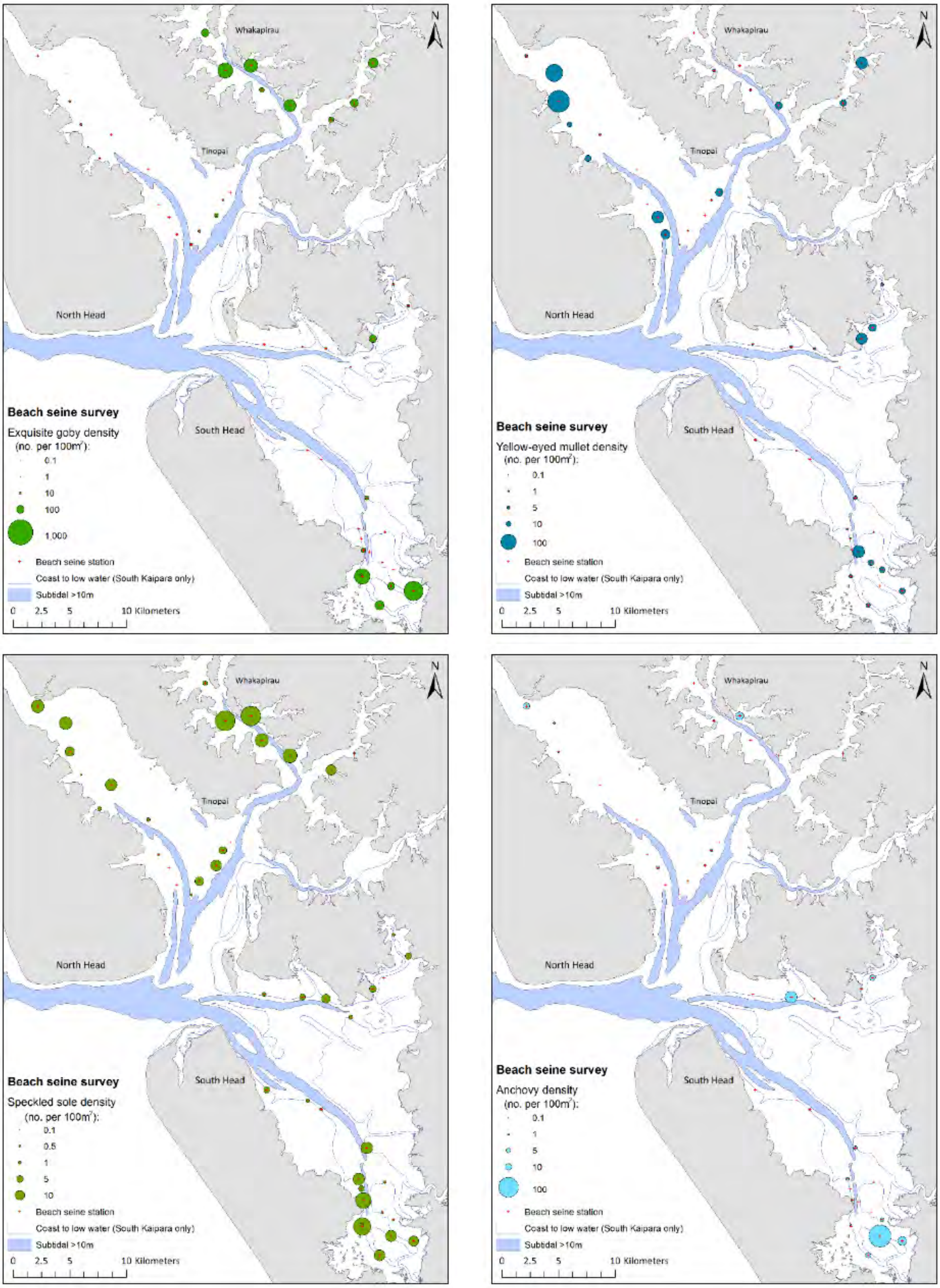

Figure 54: Estimated densities (no. per 100 m^2) and distribution of exquisite goby (top left), yellow-eyed mullet (top right), speckled sole (lower left) and anchovy in intertidal beach seine samples in the Kaipara Harbour. Symbols are proportionally scaled to density and are different for each species.

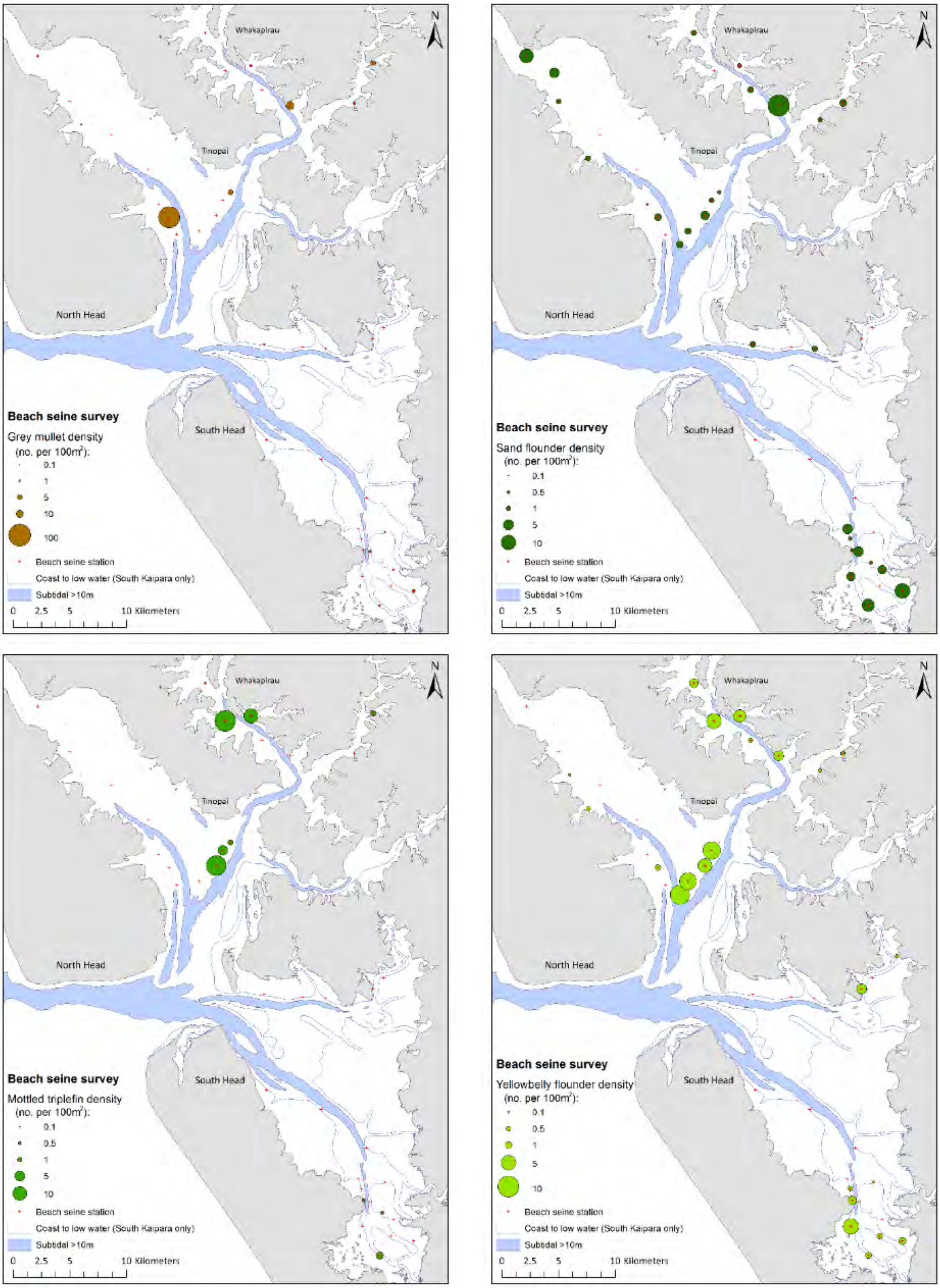

Figure 54 (cont): Estimated densities (no. per 100 m²) and distribution of grey mullet (juveniles) (top left), sand flounder (top right), mottled triplefin (lower left) and yellow belly flounder (lower right) in intertidal beach seine samples in the Kaipara Harbour. Symbols are proportionally scaled to density and are different for each species.

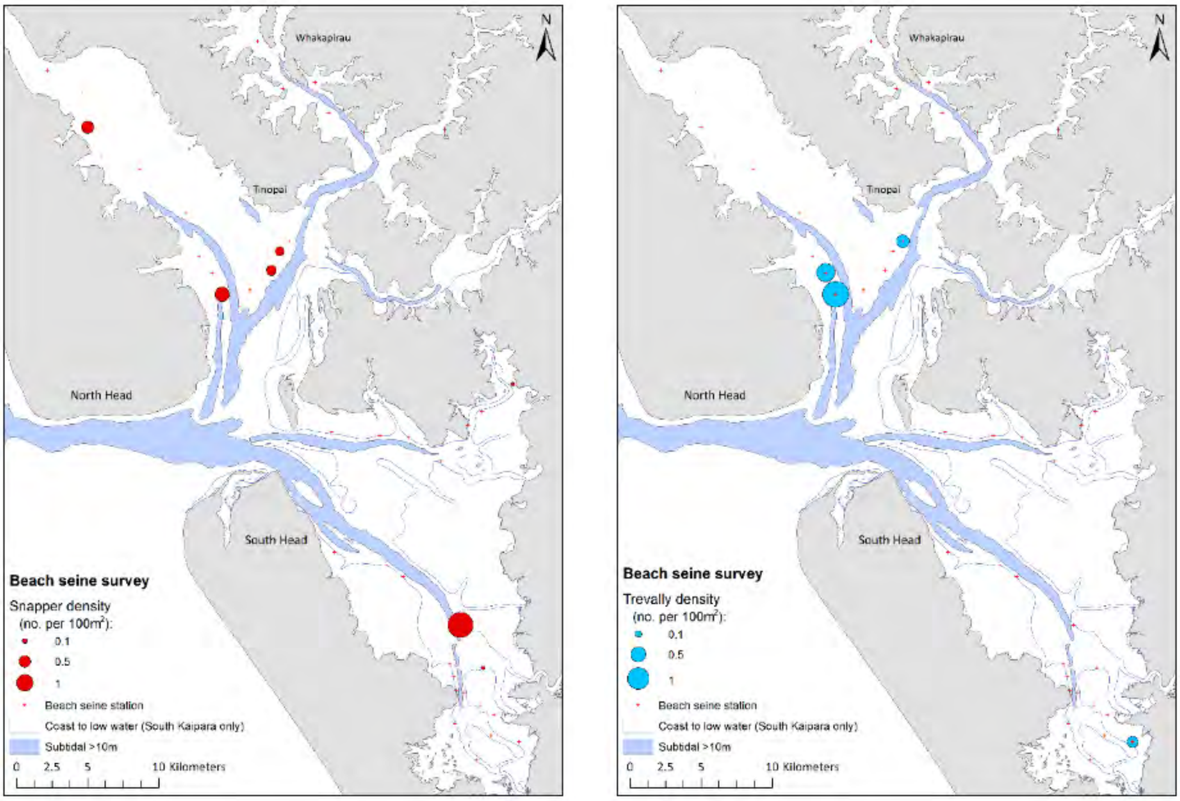

Figure 54 (cont): Estimated densities (no. per 100 m^2) and distribution of juvenile snapper and trevally in intertidal beach seine samples in the Kaipara Harbour. Symbols are proportionally scaled to density and are different for each species.

4.8 Seagrass meadows

As part of the MPI ZBD200408 "*National Seagrass Meadows*" programme, the southern Kaipara Harbour was sampled at five habitat locations (upper harbour, one intertidal seagrass and one bare site; lower harbour, one intertidal seagrass, one subtidal seagrass, one bare substrate) (Figure 47a) (Morrison et al. in review b, see also Lowe 2013). Sites were sampled by beach seines (same nets as reported in Section 4.6) over low tides in March–April 2006, but in contrast to other beach seine sampling, tows were made along the immediate subtidal, for a distance of 50 m (as opposed to being towed straight up the shore). This change was made to increase the ground covered, and make hauls next to intertidal banks match as closely as possible hauls well away from shorelines (subtidal stations). Four replicate hauls were made at each site, with at least 50 m between each haul. Fish were kept and processed as described in Section 4.7 (above). Gut samples were also taken and processed as described by Lowe (2013). Four strip transects (50 × 2 m) and nine infaunal cores (13 cm diameter, 15 cm deep) were also collected (four of which were ultimately processed), with five seagrass blade lengths being measured from each core to estimate canopy height. The full sampling programme is reported by Morrison et al., in revision, but for the purposes of this report we focus on the Kaipara Harbour data only.

Table 7: Densities per 100 m^2 [± s.e.] of fish species sampled. Species are ranked in deceasing order of density based on the subtidal seagrass values. The two intertidal seagrass sites are denoted as A and B. (Source: data re-worked from Morrison et al., in revision).

Species	Upper		Lower		
	Intertidal		Intertidal	Subtidal	
	Bare	Seagrass	Seagrass	Seagrass	Bare
Exquisite goby	0.44 [0.4]	35.44 [17.6]	58.93 [28.2]	9.52 [3.3]	3.56 [0.6]
Garfish	–	2.22 [2.2]	–	6.14 [2.9]	0.44 [0.3]
Snapper	–	0.22 [0.2]	–	5.18 [1.0]	0.61 [0.2]
Trevally	–	0.56 [0.3]	0.67 [0.2]	4.49 [1.7]	0.06 [0.1]
Mottled triplefin	–	–	0.06 [0.1]	3.25 [1.3]	0.22 [0.2]
Speckled sole	7.67 [6.2]	0.50 [0.4]	6.39 [3.9]	0.22 [0.1]	0.89 [0.5]
Speckled pipefish	–	0.11 [0.1]	–	0.10 [0.1]	–
Sand goby	0.61 [0.5]	2.44 [0.7]	0.17 [0.1]	0.08 [0.05]	–
Kahawai	0.11 [0.1]	1.33 [0.6]	1.06 [1.0]	0.06 [0.1]	0.06 [0.1]
Spotty	–	–	–	0.06 [0.1]	–
Sand flounder	9.89 [1.9]	3.50 [1.2]	1.44 [0.6]	–	0.06 [0.1]
Yellow-belly flounder	2.11 [2.5]	0.78 [0.3]	0.33 [0.2]	–	0.06 [0.1]
Black pipefish	–	0.06 [0.1]	0.17 [0.1]	–	0.06 [0.1]
Yellow-eyed mullet	106.95 [43.0]	176.77 [28.6]	12.67 [3.2]	–	–
Grey mullet	0.06 [0.1]	10.17 [3.4]	1.11 [0.5]	–	–
Gurnard	0.06 [0.1]	–	0.06 [0.1]	–	–
Parore	–	–	0.06 [0.1]	–	–
Jack mackerel	–	0.06 [0.1]	–	–	–
Anchovy	2.06 [2.1]	0.67 [0.5]	–	–	8.72 [3.7]
Species Richness	5.50 [0.6]	11.00 [1.1]	8.00 [0.9]	6.80 [0.9]	5.50 [0.6]
Overall Fish Density	129.95 [49.6]	234.80 [35.4]	83.09 [33.4]	29.10 [5.8]	14.72 [3.8]

Nineteen species were caught in all (Table 7). The subtidal seagrass meadow site was numerically dominated by five species; exquisite goby, garfish, snapper, trevally, and mottled triple-fin; these species were only found in low abundances at the nearby bare subtidal site (with the exception of exquisite gobies). Yellow-eyed mullet were notably absent from the subtidal seagrass site. All of the snapper (5.18 ± 1.0) and trevally (4.49 ± 1.7) were juveniles (Figure 55), as were many of the garfish. The intertidal habitats were dominated by yellow-eyed mullet, exquisite gobies (effectively intertidal seagrass only), sand flounder (bare site dominant), and speckled sole (bare site, and one of the seagrass sites). Unexpectedly, numbers of very small juvenile grey mullet were also found in association with the lower edges of intertidal seagrass (10.2 ± 3.4; 1.1 ± 0.5), suggesting the possibility that this habitat type may be used as an initial settlement substrate for this species. Modest densities of small juvenile kahawai were also present (1.33 ± 0.6; 1.06 ± 1.0); but the initial settlement preferences of this species are unknown. Species richness (numbers of species per tow) was similar across all of the habitats, while total number of individuals was higher for the intertidal habitats, driven by the high densities of yellow-bellied flounder and exquisite gobies present. From these data, we conclude that the Kaipara Harbour subtidal seagrass meadows provide a nursery role for snapper, trevally and garfish, while the lower edge of intertidal seagrass provides a nursery role for juvenile grey mullet and kahawai (as very small juveniles). These findings are strongly supported by more recent extensive fish-seagrass survey work (see Section 5 of this report), which is in the early stages of being written up (timing falls outside this current report).

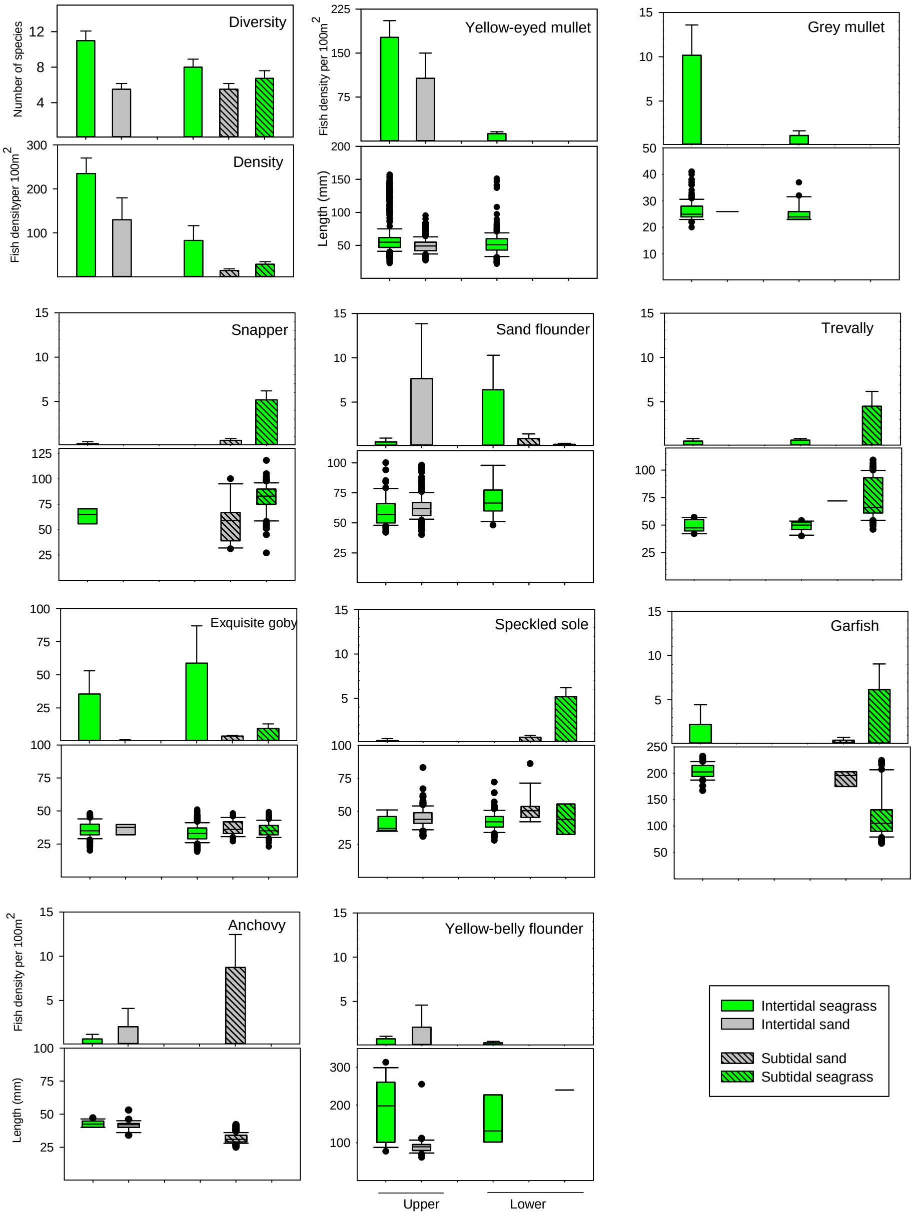

Figure 55: Average species richness and total abundance per tow, by habitat category (two top left graphs); and average density per 100 m^2 and fish length box plots per habitat category (all other graphs, arranged as a pair per species). Note that y axis scales vary.

Higher densities, biomass and productivity of benthic macrofauna (1–5.6 mm) were recorded from the lower subtidal seagrass sites (see figure 4.13, 4.14 in Lowe 2013), characterized by longer blade lengths, increased density and coverage than for intertidal sites. Gut analysis revealed that dietary breadth generally reflected benthic biodiversity. Higher prey diversities were recorded from those fish species occupying more structurally complex biogenic structure viz. subtidal seagrass (e.g. snapper 51 taxa). Diets of those species highly associated with seagrass (e.g. snapper, trevally) were dominated by gammaridean amphipods (35–73% of total gut biomass), whilst individuals collected over sand consumed larger proportions of infaunal species. Within the Kaipara Harbour, the proportion (biomass) of gammarid amphipods consumed within subtidal seagrass meadows was 89%, the highest recorded for the northern region (Lowe 2013). A comparison of secondary productivity between habitats and areas is given in Table 8. There was no difference between intertidal seagrass and 'bare' habitat, while subtidal seagrass was about 67–79% more productive. These values were less than half of those seen for the same habitats on the east coast (Table 8).

Table 8: Estimated seagrass secondary production productivities for Kaipara and two other northern New Zealand location, from Lowe (2013) and Morrison et al., in revision, calculated using the method of Edgar (1990). Units are milligrams of Ash Free Dry Weight per metre per year.

Harbour	Habitat	Productivity	
		Mg	s.e.
Rangaunu intertidal	Sand	13.6	3.1
Rangaunu intertidal	Seagrass	162.5	13.9
Rangaunu Subtidal	Seagrass	310.4	39.2
Kaipara intertidal	Sand	65.6	10.9
Kaipara intertidal	Seagrass	70.3	19.4
Kaipara subtidal	seagrass	117.2	23.3
Bay of Islands subtidal	Sand	63.6	21.4
Bay of Islands subtidal	Seagrass	258.0	48.9

4.9 Inner estuaries; grey mullet sampling

A current project is assessing grey mullet otolith chemistry as a potential tool for addressing stock structure issues. This project (GMU2009–01) sampled 88 estuaries across GMU 1 in the 2010 year, including the Kaipara Harbour (15 sites). Grey mullet is known to be heavily reliant (obligate) on estuarine environments during its early juvenile life-stages in the New Zealand context. Each site was searched on foot or by boat for promising habitat features (e.g. the subtidal adjacent to small water streams entering the main channel), and visual signs of juvenile grey mullet feeding at the water surface. Where fish were sighted they were targeted using one of three sampling methods; small mesh beach seines, throw nets, and large fine mesh dip nets. Where there were no visual signs, beach seines were primarily used to systematically tow for fish at the site. As field sampling was a mixture of different gear types, targeted and haphazard 'blind' tows, it was not possible to compare catch rates across sites, and hence the unstandardized metrics of sampling effort. Total catches are given in Figure 56a as a semi-quantitative proxy for true abundance. Juvenile grey mullet were present across all of the sites searched, usually in muddy tidal channels proximate to mangrove forests. Highest catches of grey mullet came from the muddy, turbid inner estuaries (Arapaoa and Oruawharo rivers), with lowest catches from more sandy substrate sites such as Te Waro Point and Okaro Creek, in the northern part of the harbour. Most fish were 20–60 mm in length forming the 0+ cohort which was the sampling age target, along with a second smaller 1+ cohort of fish 9–13 cm in length (Figure 56b). Finer scale examination of size frequencies between the northern harbour, eastern arms (Arapaoa, Otamatea and Oruawharo), and southern harbour (including the Tauhoa and Kaukapakapa rivers) found limited size differences in the 0+ cohort (median length 3.9 cm in southern and eastern areas, and 4.3 cm in the northern harbour) (Figure 56c).

These observations match with what we know about the life history of this species from previous sampling work. At, or immediately following settlement, very small fish (20–50 mm) are strongly associated with habitat types such as mangrove forests and intertidal seagrass meadows (see sections 4.6 and 4.7), where they may form dense tightly packed schools that migrate with the tidal cycles, or can be found at low tides sheltering in tidal pools and very small water streamlets on steeper mud-banks (M.M., pers. obs., Manukau Harbour). With increasing size the density of these very small fish falls greatly (C. Walsh, Stock Monitoring Services, pers. comm.) presumably from predation or other mortality influences. As juveniles increase in size (50–150 mm), they move out from the more limited upper harbour mangrove areas to the often turbid, muddy tidal flats (see Section 4.7), then to the general harbour system including some sandier areas, with the adults eventually becoming widely distributed, both within and between estuaries (Morrison et al. 2002, Francis et al. 2005, Morrisey et al. 2007, Morrison et al. 2014). The Kaipara Harbour, along with other west coast estuaries such as the Hokianga and Manukau harbours, returned relatively high densities of juvenile grey mullet during sampling, in line with much of the commercial catch also coming from these harbours.

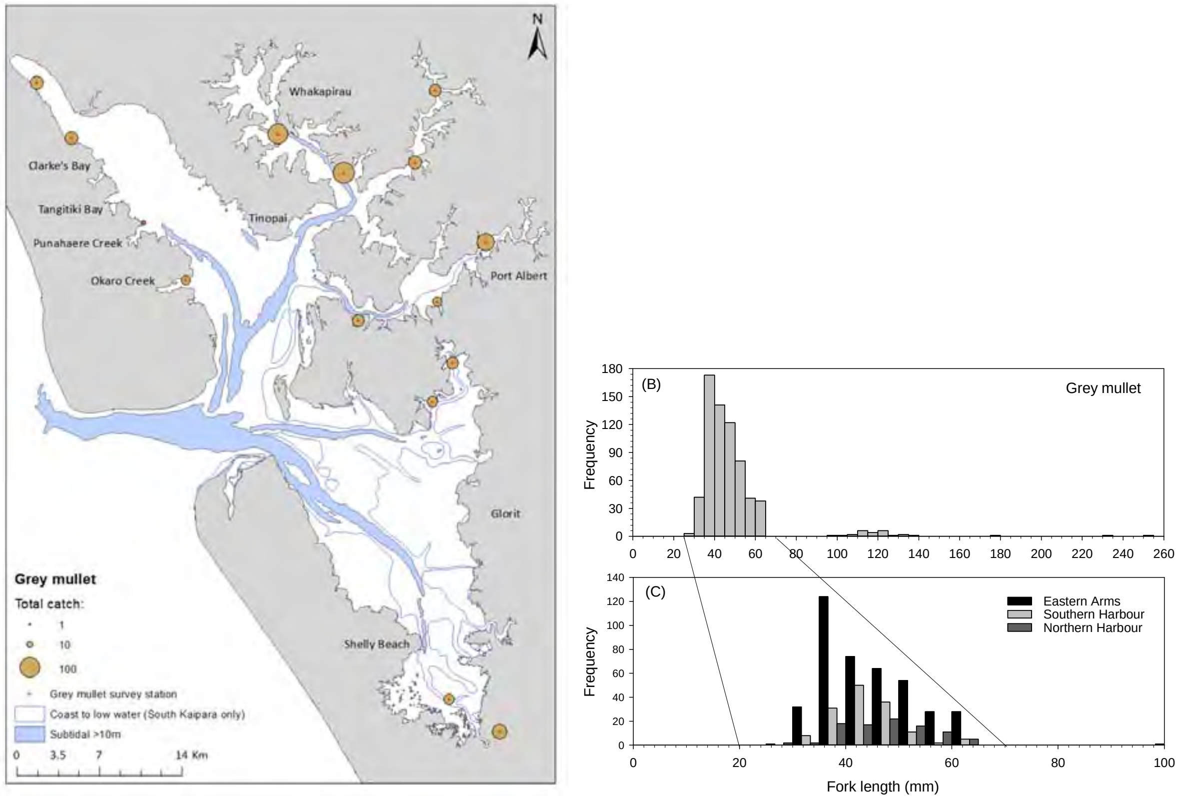

Figure 56: a) Location and size of grey mullet catches from targeted beach seines, throw and dip nets within the Kaipara Harbour. Symbols are proportionally scaled to catch size; b) length frequency distribution for all grey mullet sampled in the Kaipara harbour; and c) separated by region for the length range 20–70 mm.

4.10 Subtidal channels; Beam trawl survey

Beam trawl methodology

As part of the MBIE-funded programme "*Coastal Conservation Management*", the small benthic associated fishes occurring in the subtidal channels of the full Kaipara Harbour were sampled by beam trawl, based on the design of Hamer et al. (1998). The trawl consisted of a 4.0 m beam, from which a 3.0 m wide net was suspended, with a 6.0 m deep cod-end made of 9 mm coarse mesh braid. Stations were assigned across four broad areas; the harbour entrance (EN), Northern harbour (NH), including the Wairoa River arm, Southern harbour (SH), including Kaipara and Tauhoa River arms, and the "Eastern Arms" (EA), comprising the Arapaoa, Otamatea and Oruawharo Rivers (see Figure 57, 58). Stations included channel floors, banks, and shallow subtidal flats, assigned based on information from the nautical chart (noting that these charts do not show shallow areas well). Tows were made along the depth contours for a duration of four minutes, at a maximum speed of 1.5–2 knots, measured from the time when the warp came up hard on the trawl, to when hauling in commenced. Start and end point coordinates, and associated water depths were recorded. The average distance towed was 295 m, although the true distance towed across the seafloor will have been slightly greater due to the lag between commencing hauling, and the trawl lifting clear of the seafloor. A 5:1 warp-to-depth ratio was used in water depths of less than 10 m, reducing to 4:1 in deeper waters (maximum depth 25 m). Sampling was undertaken within a 2.5 hour window either side of high tide. The catch was sorted to species level, and fork lengths were measured down to the nearest mm. The biogenic bycatch was measured either volumetrically (L) or numerically counted, depending on its form. A suite of environmental variables were measured concurrently at each site. Water clarity was measured using a 25 cm black-and-white Secchi disc. Water parameters including turbidity (NTU), temperature, salinity, pH, and dissolved oxygen were also collected using a Horiba U10 multi-probe.

A total of 176 beam trawls were successfully completed. Water clarity (as measured from the surface using a Secchi disc) was around 1 to 2.5 m for most of the harbour, with measurements being made during a period of settled weather with little or no rain. Water clarity was higher in the northern harbour, the harbour entrance, and the lower southern harbour, but was slightly reduced in the eastern arms (Arapaoa, Otamamtea, and Oruawharo rivers), and the upper southern harbour (Kaipara River) (Figure 57). Total suspended sediment (TSS) measurements were made from a water sample taken about one metre above the seafloor. These TSS measurements showed a generally inverse spatial pattern to water clarity as measured by Secchi disc; although some higher values were recorded at harbour entrance stations, probably as a result of bottom sediment re-suspension by strong tidal currents (Figure 57).

Distribution and densities of fish species

The overall fish catch was composed of 30 fish species, totalling 6228 individuals (Table 9). The three most abundant species were exquisite goby, anchovy and snapper, which made up almost 90% of the total catch, and were caught at 53, 44 and 52% of the stations respectively. Total fish catch rates were highest in the Oruawharo River, where several stations caught over 800 fish in total (EA 4 and EA 8), mainly driven by exquisite gobies densities (Figure 58a). Exquisite gobies were caught down to 25 m water depth throughout the wider harbour (Figure 58a), with higher catches in the upper harbour areas and relatively consistent presence in the southern subtidal seagrass meadows area (note that at the time of survey (2010), no maps were available of subtidal seagrass distribution). Fish sizes ranged from 20–54 mm, encompassing the adult size range for this species (Figure 59). Smaller juveniles were not present during the seasonal time period sampled (October/November). Anchovy catches were largely dominated by juveniles (20–60 mm; Figure 59), with individual catch rates being relatively low for this schooling pelagic species. The density estimates presented here are likely to be very conservative as anchovies of the size encountered often pass through the net meshes. In addition their ‘vertical availability’ to this sampling method is unknown (i.e. their vertical distribution may extend well up into the water column, resulting in the net only sampling part of the fishes vertical distribution whilst on the seabed, but also potentially encountering them during shooting and hauling). Adult anchovy have not been encountered in any estuarine fish sampling work known to the authors. In this survey, its distribution was patchy, being notably absent from the northern harbour and the Arapaoa River, but with several larger catches in the Oruawharo River, along with one station in the Otamatea River, found at uniformly low densities in the mid harbour east area, and present at some stations along the subtidal arms of the southern harbour (Figure 58a).

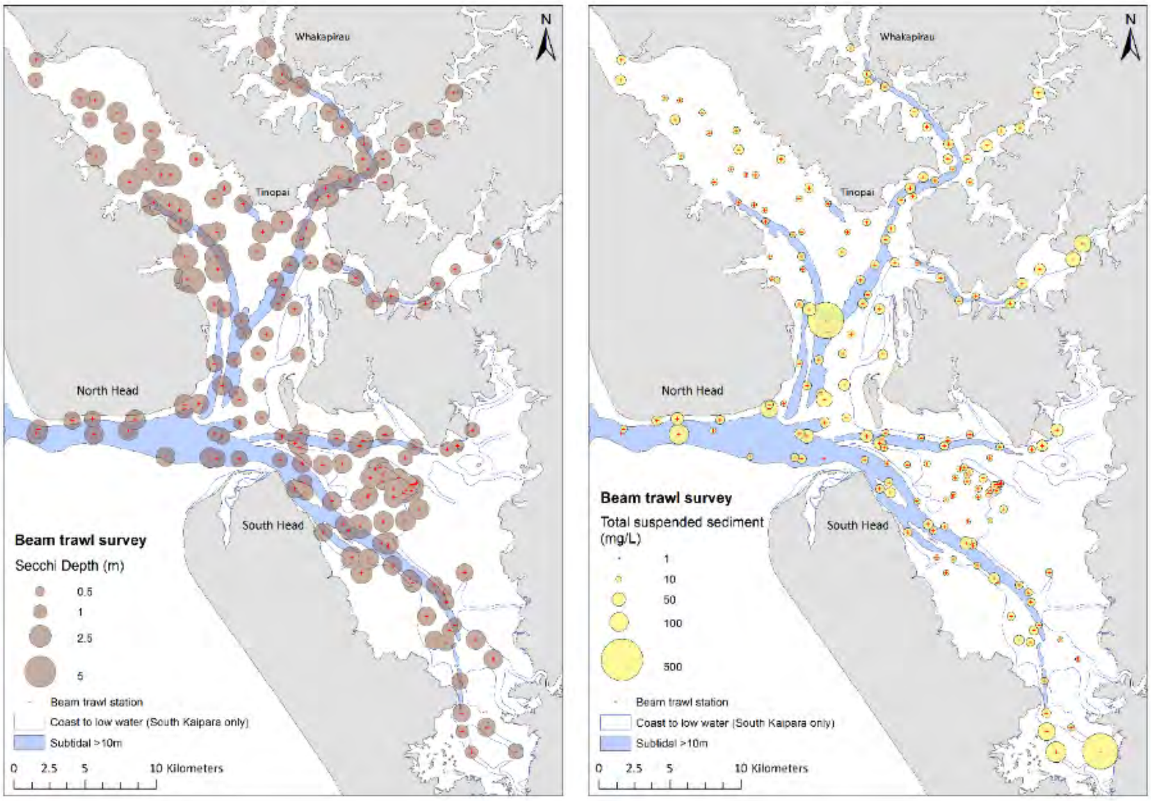

Figure 57: Water clarity (left), total suspended solids (right), recorded at beam trawl stations in the Kaipara Harbour. Symbols are proportionally scaled and are different for each map.

The third most commonly caught species was snapper, which occurred at 52% of the stations surveyed. Most catches were composed of 0+ fish, which ranged from about 40 to 100 mm (Figure 59). A few larger fish were caught in the 100 to 200 mm range, but beam trawling is very poor at sampling snapper larger than 100 mm (Morrison & Carbines 2006). Snapper were consistently caught more often in the lower to mid southern harbour, with several relatively larger catches around the subtidal seagrass meadows, as well as one large catch adjacent to the 'Concrete Blinker' (Figure 58a). Snapper were also caught in the three eastern harbour river arms, even as far up as Pahi. Fish were far less common in the entrance (only two fish) and northern harbour, with most being caught along the western channel side (Figure 58a). Across all stations (including zero catches, and some subtidal seagrass shots, overall snapper density per 100 m^2 was 0.299 ± 0.052 s.e. The higher density tows were either less than 5 m deep, or between 10 and 20 m deep (Figure 60).

Initially seagrass associated juveniles are known to move from very shallow habitats (0–2 m low water) in April–May into deeper areas (i.e. the beam trawl areas), joining other juvenile snapper which had directly recruited into deeper water habitats. Examination of the snapper size frequencies by the three broad harbour areas found little apparent difference (Figure 61); however when length frequencies were plotted by water depth, there was a clear progression of increasing fish size with depth (Figure 61), although only a few fish were sampled from greater than 20 m water depth. This is taken to be an ontogenetic shift from shallow to deeper water with increasing size.

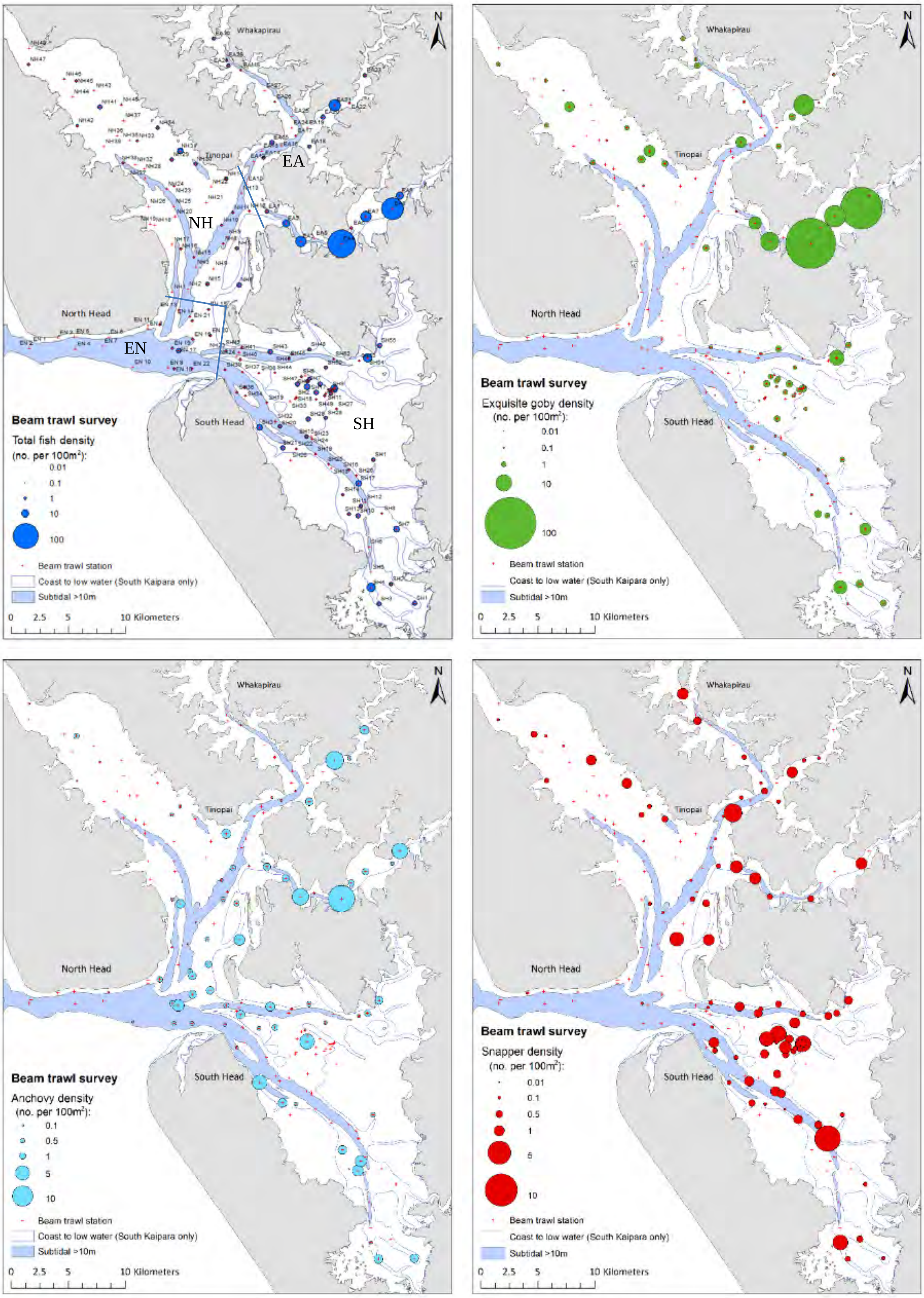

Figure 58a: Estimated densities (no. per 100 m^2) and distribution of all fish (top left) along with station labels and strata areas, exquisite goby (top right), anchovy (lower left) and juvenile snapper (lower right), caught in the subtidal beam trawl survey of the Kaipara Harbour. Symbols are proportionally scaled to density and are different for each species.

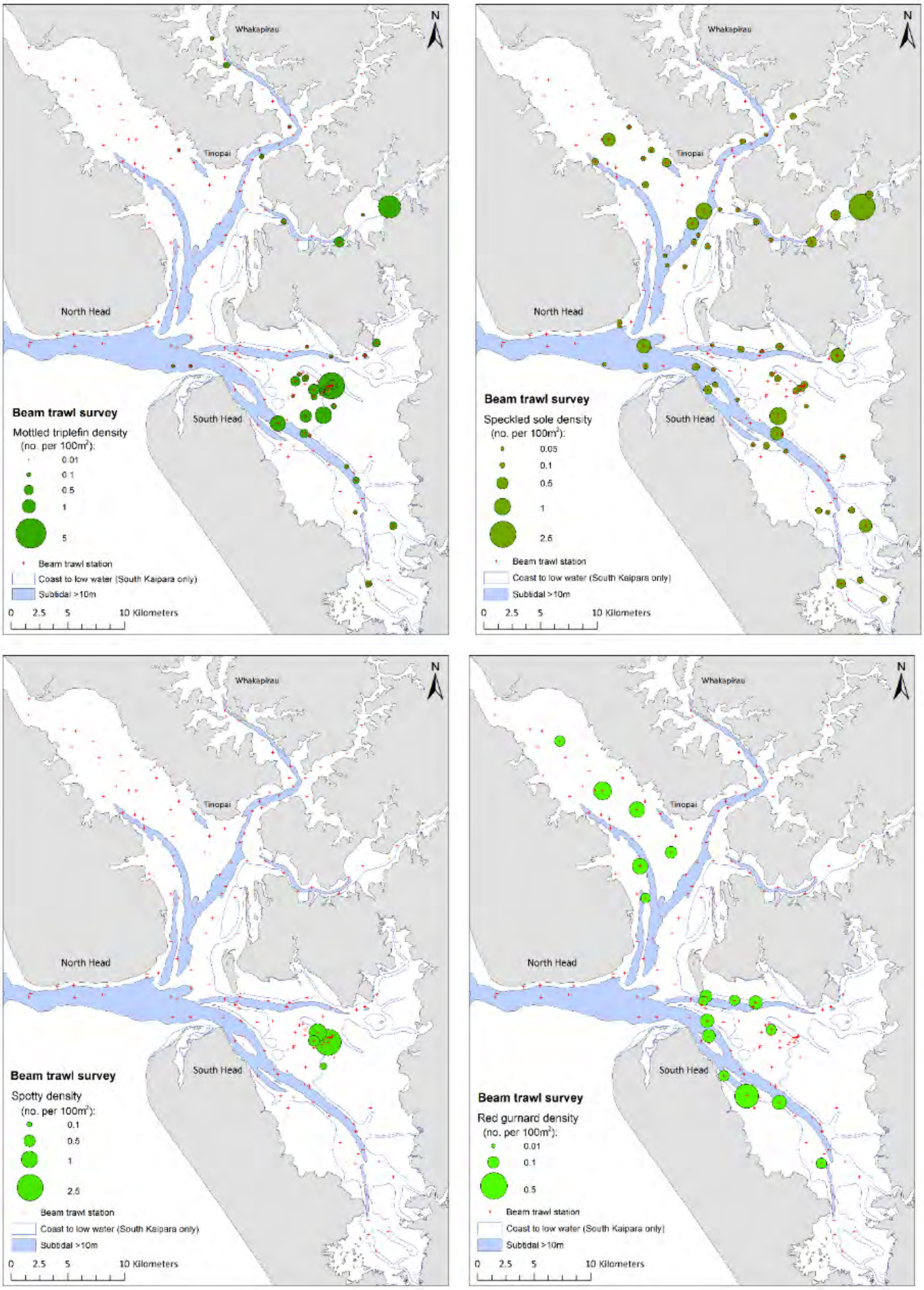

Figure 58 (cont.) b: Estimated densities (no. per 100 m^2) and distribution of mottled triplefin (top left), speckled sole (top right), spotty (lower left) and juvenile red gurnard (lower right), caught in the subtidal beam trawl survey of the Kaipara Harbour. Symbols are proportionally scaled to density and are different for each species.

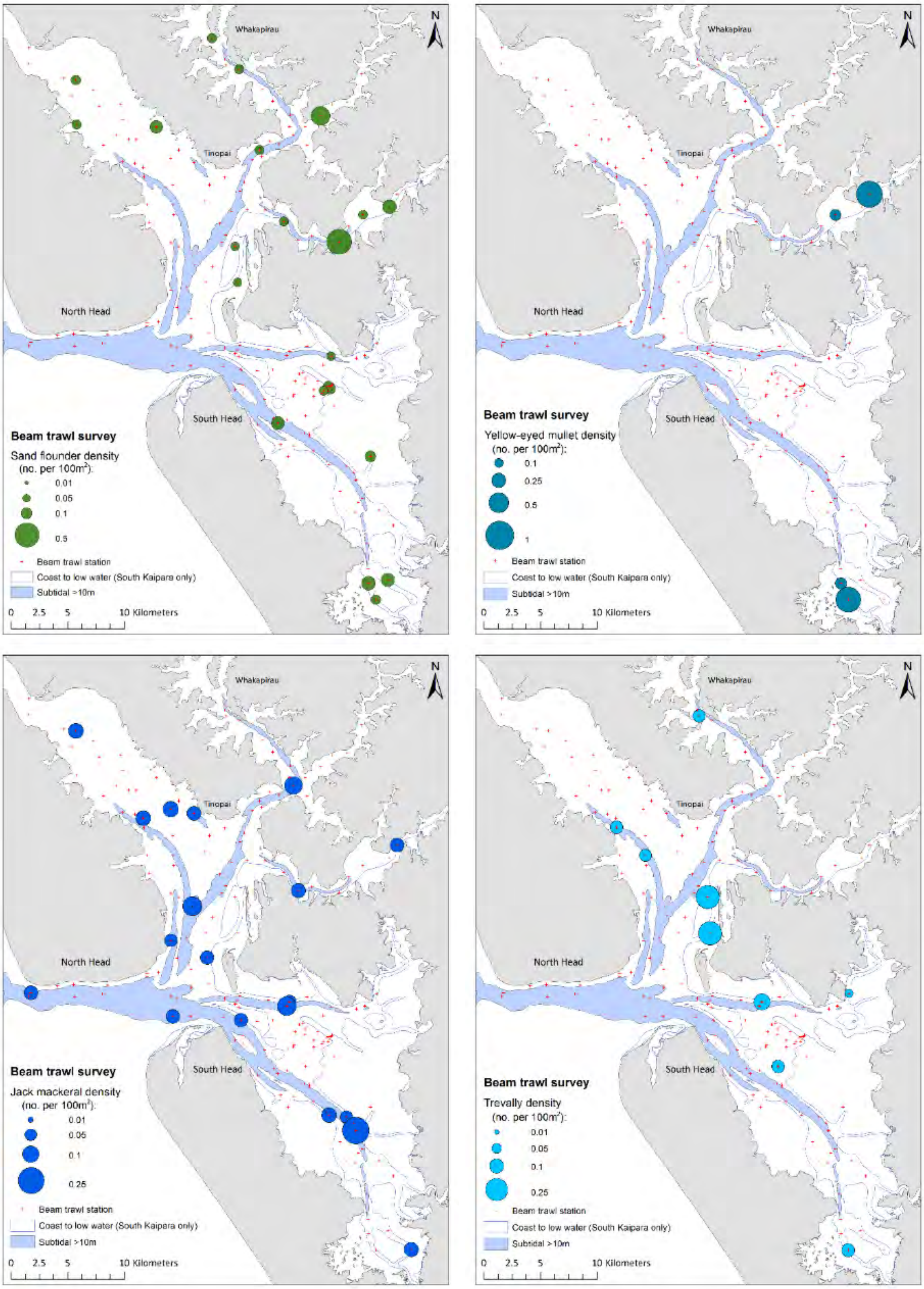

Figure 58 (cont) c: Estimated densities (no. per 100 m^2) and distribution of sand flounder (top left), yellow-eyed mullet (top right), jack mackerel (lower left) and juvenile trevally (lower right), caught in the subtidal beam trawl survey of the Kaipara Harbour. Symbols are proportionally scaled to density and are different for each species.

Table 9: List of species caught during the subtidal beam trawl survey of the Kaipara Harbour with total numbers, overall catch percentage, density per 100 m^{2}, % occurrence across tow's, and length range (mm) for all species caught.

Common name	Scientific name	Total count	Proportion of catch	No. per 100 m^2	% Occ.	Length range (mm)
Exquisite sand goby	*Favonigobius exquisites*	3 383	54.35%	1.339	53.45%	17–62
Anchovy	*Engraulis australis*	1 396	22.43%	0.553	44.25%	16–99
Snapper	*Pagrus auratus*	756	12.14%	0.299	52.30%	27–190
Mottled triplefin	*Grahamina capito*	216	3.47%	0.086	22.99%	33–93
Speckled sole	*Peltorhamphus latus*	211	3.39%	0.084	35.63%	24–118
Spotty	*Notolabrus celidotus*	71	1.14%	0.028	3.45%	73–143
Gurnard	*Chelidonichthys kumu*	35	0.56%	0.014	9.77%	20–125
Sand flounder	*Rhombosolea plebeia*	32	0.51%	0.013	12.64%	37–196
Yellow-eyed mullet	*Aldrichetta forsteri*	25	0.40%	0.003	2.30%	107–211
Jack mackerel	*Trachurus novaezelandiae*	23	0.37%	0.009	10.92%	18–318
Trevally	*Pseudocaranx dentex*	16	0.26%	0.006	4.60%	35–328
Slender sprat	*Sprattus antipodum*	8	0.13%	0.003	2.30%	45–59
Yellow belly flounder	*Rhombosolea leporina*	7	0.11%	0.001	2.87%	135–261
Speckled pipefish	*Leptonotus elevatus*	6	0.10%	0.002	2.30%	105–156
Black pipefish	*Stigmatophora nigra*	5	0.08%	0.002	2.30%	63–98
Longsnout pipefish	*Leptonotus norae*	4	0.06%	0.002	1.72%	71–126
Opalfish	*Hemerocoetes spp.*	4	0.06%	0.002	1.15%	64–126
Short finned eel	*Anguilla australis*	3	0.05%	0.001	0.57%	186–293
Crested flounder	*Lophonectes gallus*	3	0.05%	0.001	1.15%	99–124
Snake eel	*Ophisurus serpens*	3	0.05%	0.001	1.72%	292–425
Red cod	*Pseudophycis bachus*	3	0.05%	0.001	1.15%	103–174
Estuary stargazer	*Leptoscopus macropygus*	3	0.05%	0.001	1.15%	66–197
Clingfish	*Gobiesocidae (Family)*	2	0.03%	0.001	1.15%	26–32
Garfish	*Hyporhamphus ihi*	2	0.03%	0.001	1.15%	70–89
Silver conger eel	*Gnathophis habenatus*	2	0.03%	0.001	1.15%	117–145
Seahorse	*Hippocampus abdominalis*	2	0.03%	0.001	1.15%	106–130
Northern bastard cod	*Pseudophycis breviuscula*	1	0.02%	<0.001	0.57%	123
Crested blenny	*Parablennius laticlavius*	1	0.02%	<0.001	0.57%	27
Parore	*Girella tricuspidata*	1	0.02%	<0.001	0.57%	342
Sandfish	*Gonorynchus forsteri*	1	0.02%	<0.001	0.57%	104

Mottled triplefin occurred at scattered stations in the eastern arms (Figure 58b), including one larger catch station just east of Hargreaves Basin, but most of the larger catches were made around the southern harbour's subtidal seagrass area, along with a few individuals sampled from further up the subtidal channels. Fish sizes ranged from 33 to 93 mm, with most individuals being mature adults (Figure 59).

Speckled sole ranged in size from 24 to 118 mm, and were largely juveniles (Figure 59). Catches were made throughout the harbour (Figure 58b), with the larger catches being made in both the subtidal channels and the shallow subtidal flats. Notably, no individuals were captured from the upper half of the northern harbour, or from the Arapaoa River. The biggest catch (2.5 fish per 100 m^2) was made at a station just east of Hargreaves Basin.

Spotties were rare in the harbour, and all individuals caught came from the southern harbour subtidal seagrass area (Figure 58b), with a size range from 73–143 mm (large juveniles and small adults) (Figure 59). As with a number of other species, juveniles of this species first appear around early January, so the juveniles caught would have probably been around 9–10 months old.

Red gurnard (all juveniles 20–125 m, 2–20 m water depth) were never common in the harbour (maximum density 0.2 per 100 m^2), occurring in the lower to mid areas of the northern and southern harbours (Figure 58b).

Sand flounder (37–196 mm, all juveniles, 1.5–30 m water depth) were also uncommon, occurring sporadically in the mid to upper harbour areas (Figure 58c). This is not surprising, as the juveniles of this species are predominately found across the intertidal flats during high tide periods, dropping down to the immediate low tide mark when the tide recedes (Morrison et al. 2002). While there is an ontogenetic shift down the channel bank sides with increasing fish size, and occasionally there may be larger juvenile density 'hotspots' in the subtidal channels (see Lowe 2013 for a Manukau Harbour example), juveniles occur largely outside the beam trawl survey area. Adults are relatively rare in estuaries, with most fish migrating out into coastal waters (e.g., Colman et al. 1976).

Yellow-eyed mullet (107–211 mm) were only caught at five upper harbour stations (Figure 58c) with this species known to be very poorly sampled by small beam trawls (Morrison & Carbines 2006).

Jack mackerel were more widespread, but again are poorly sampled by beam trawl, with a maximum catch rate of only 0.2 fish per 100 m^2 (Figure 58c).

Trevally were also rarely sampled (n=16, size range 35–328 mm, maximum catch rate 0.1 per 100 m^2), and were largely confined to mid-harbour channel (1–16 m depth) stations. This species has been sampled at much higher densities as smaller fish in the subtidal seagrass meadows using beach seines; at average densities of 4.49 (± 1.7) per 100 m^2, and comparative beam trawling and fish potting in the Manukau Harbour have shown that larger juvenile trevally can actively avoid capture by beam trawl (M.M., & M.L., unpubl. data).

Catch rates for the remaining 19 species were too low to inform any meaningful interpretation of the data.

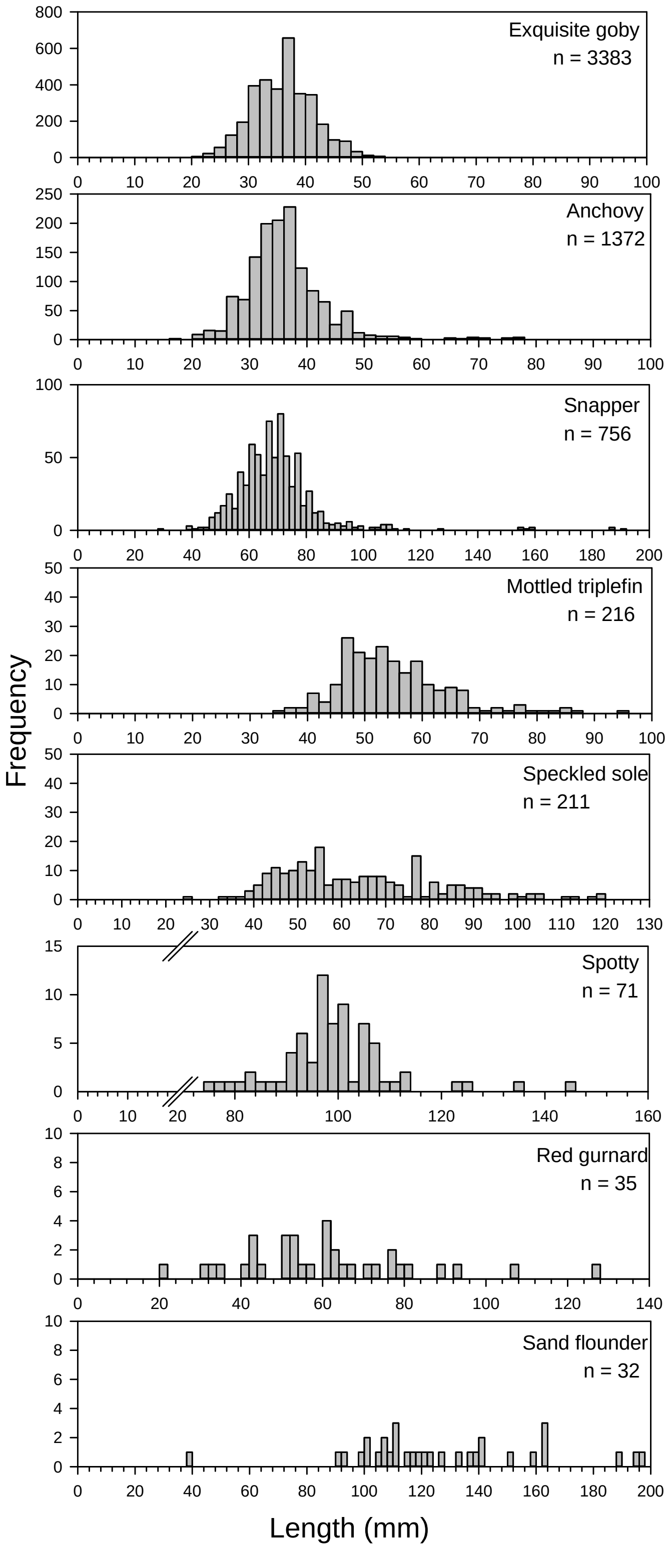

Figure 59: Length frequency for the top eight most abundant species sampled in the beam trawl survey. Note that both the x and y axis scales differ for different species.

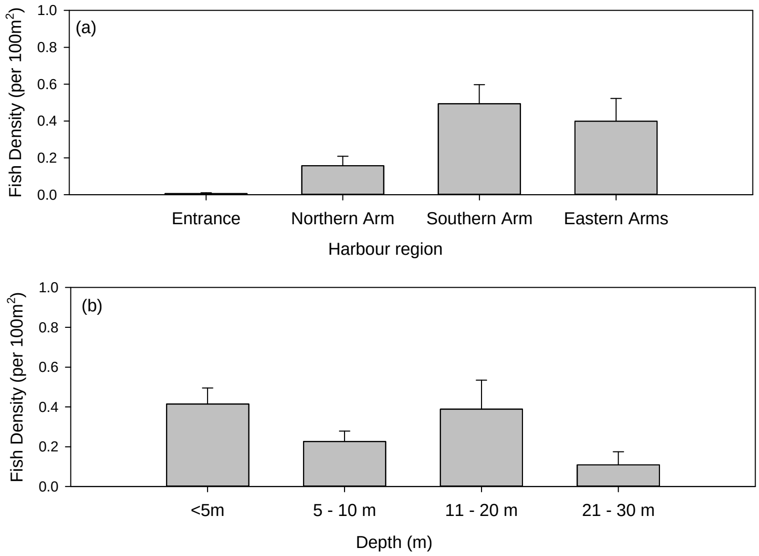

Figure 60: Mean snapper densities per 100 m^2 (± s.e.) by harbour area (a), and depth category (b).

Variation in fish densities with biogenic habitat occurrence

The bycatch was also quantified for each beam trawl tow (Figure 62). Although not a precise measure of organism density or volume (e.g., when passing over horse mussel patches only a few individuals may be dislodged and captured) bycatch does provide an idea of what is present, and how frequently it occurs. Horse mussels were relatively rare in the harbour (as noted by Hewitt & Funnell 2005), and were caught at four lower harbour stations in the southern harbour (1–10 per tow), and at one station off Tinopai in the north (one individual) (Figure 63a). (Note: low densities (estimated about 1 per 10 m^2) of small individuals (about 15–20 cm) were commonly seen in the subtidal seagrass meadow area in dropped video footage as part of the remote sensing ground-truth work reported later in this report,). Algae (all forms combined) was also relatively uncommon, although two stations in the southern harbour returned about 10 litre volume each. A few stations in the eastern arms also returned algae (Figure 63a). The 'native' bryozoan bycatch (all forms summed, overall small volumes only) was restricted to the northern side of the entrance, extending about 7 km along the main subtidal channel, as well as at one station in the southern subtidal seagrass area. Seagrass bycatch was recorded in the mid to lower southern harbour only (up to 10 litres per tow) and was a mixture of in situ seagrass being removed, and seagrass 'drift' (it was not possible to separate the two) (Figure 63a).

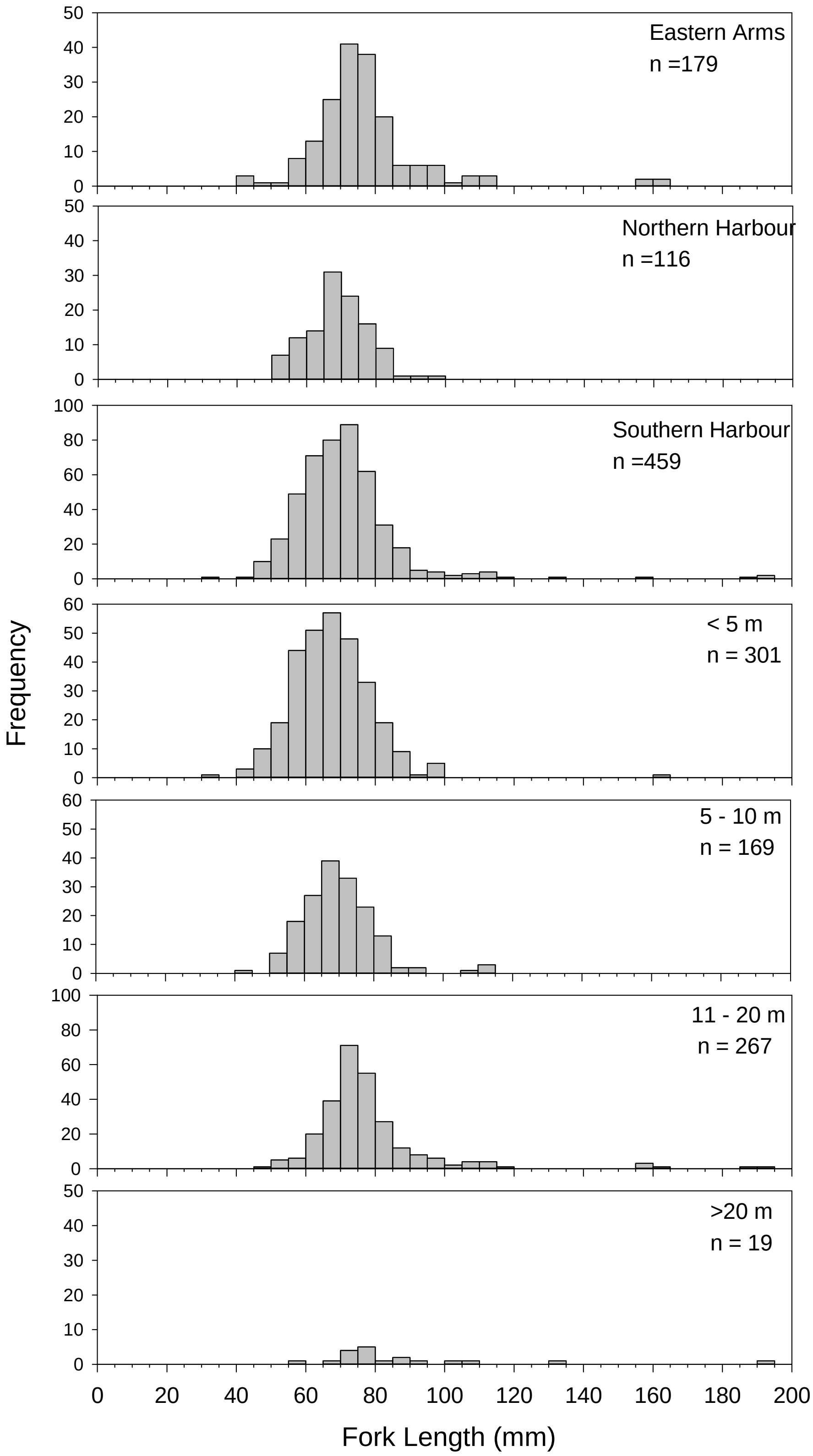

Figure 61: Snapper length frequencies by harbour region (top three) and by depth band (lower three). Note that y axis scales differ.

Figure 62: Examples of bycatch caught in the beam trawl survey of the Kaipara Harbour; a) sponge (*Callyspongi*a sp.) growing on a horse mussel; b) shown with assorted fish catch for that station; c) catch being sorted on deck; d) mixed bycatch from a tow in the southern harbour.

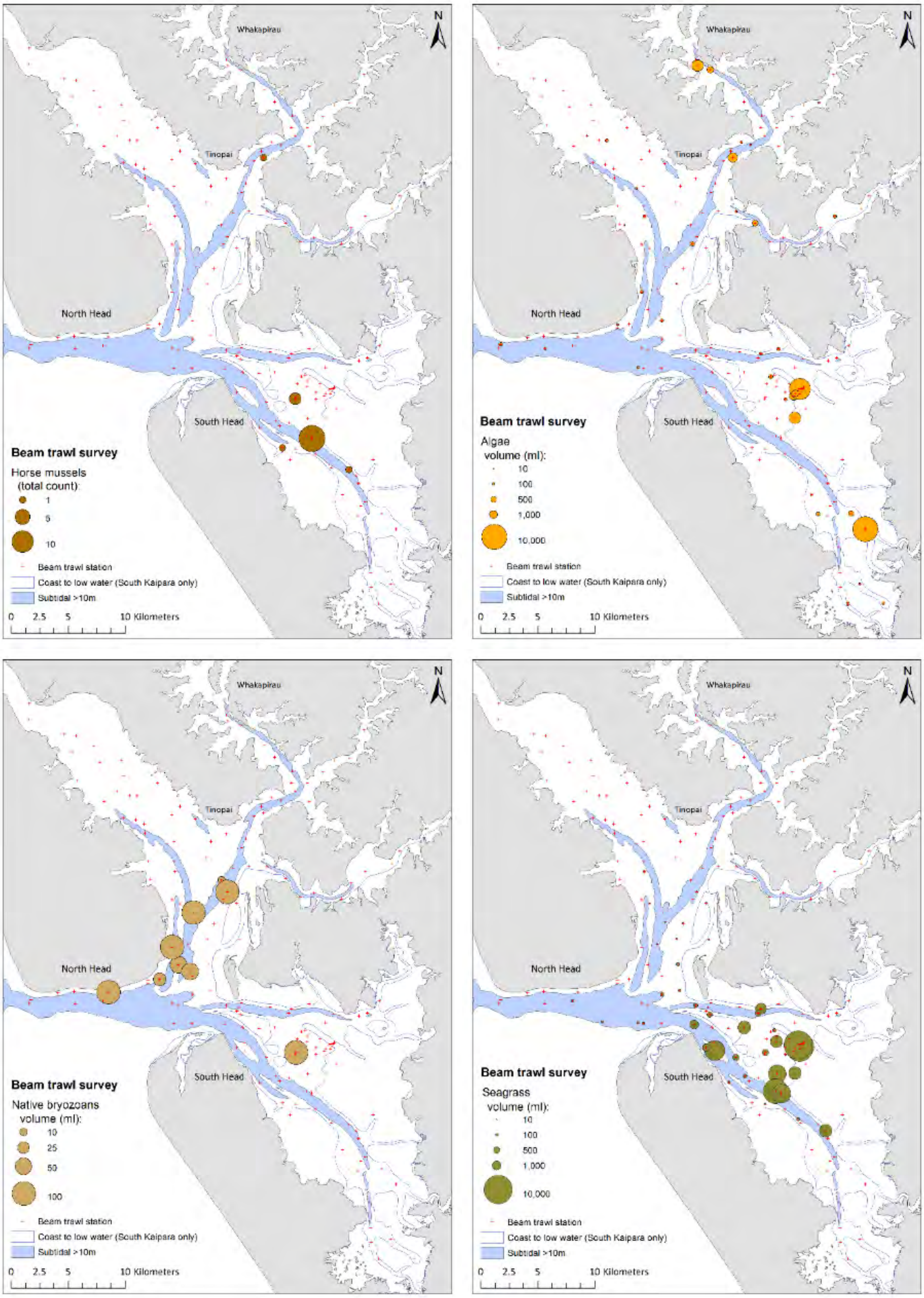

Figure 63a: Occurrence of bycatch sampled in the beam trawl survey of the Kaipara Harbour. Symbols are proportionally scaled to relative densities and are different for each species.

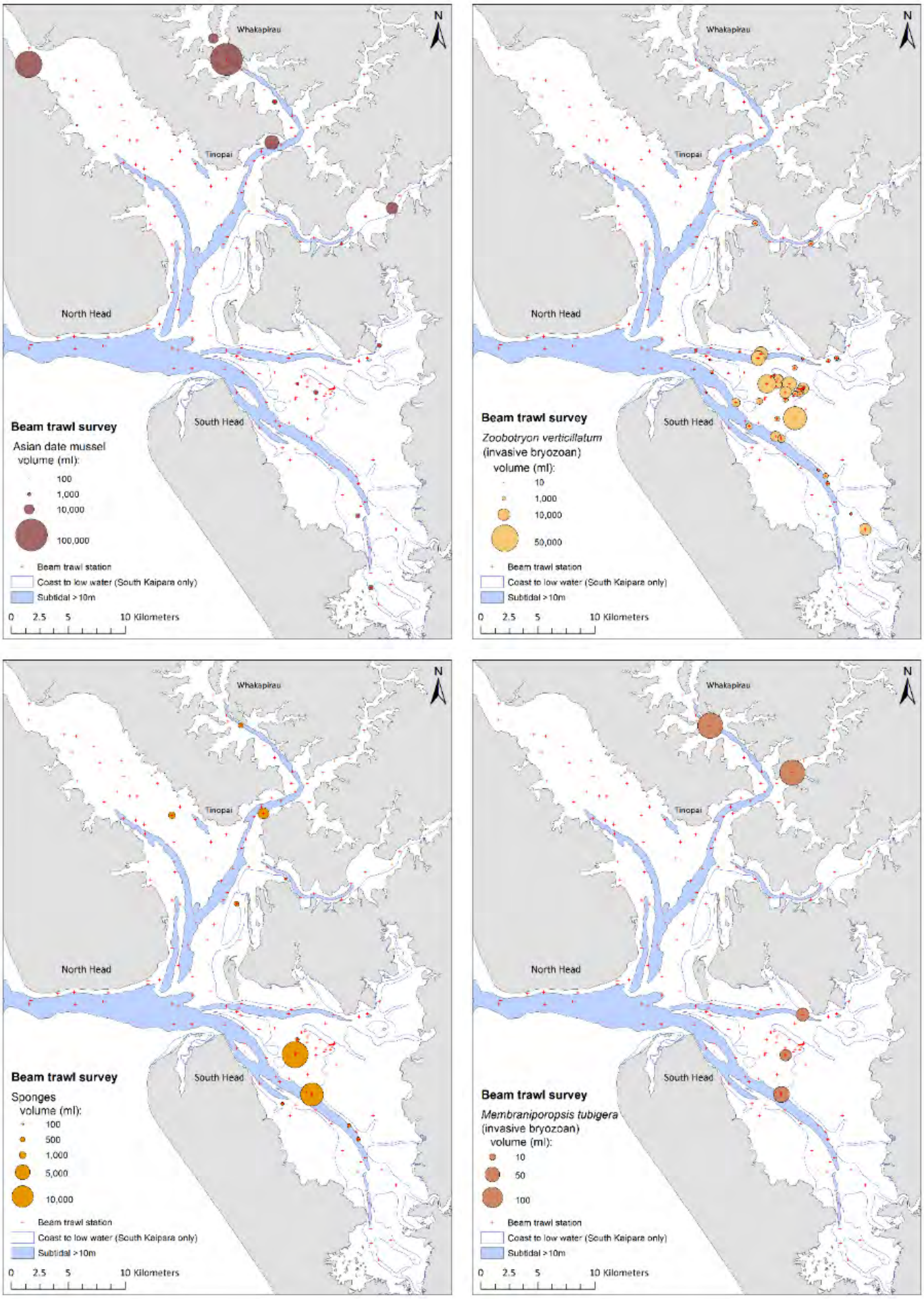

Figure 63b cont: Occurrence of bycatch sampled in the beam trawl survey of the Kaipara Harbour. Symbols are proportionally scaled to relative densities and are different for each species.

Sponges were rare, with two larger volumes taken from the mid southern harbour (up to 10 L), and smaller volumes from five stations in the northern portion of the harbour (Figure 63b). Three NIS biogenic habitat forming species were encountered. Asian date mussels were found at relatively few stations, but larger catches (up to 100 L) were made south of Pahi in the Arapaoa River, at the entrance to the Wairoa River, in the Funnel, and east of Hargreaves Basin. In the southern harbour Asian date mussels were caught in low volumes (about 1 L) at five stations (Figure 63b). The NIS bryozoan *Membraniporopsis tubigera* (see Section 5), previously reported in 2001 as a major pest to net fishers, was present in low volumes (0.1 L) at two stations in the eastern arms, as well as at three stations in the lower southern harbour (about 0.05 L) (Figure 63b). In contrast, a second NIS bryozoan (*Zoobotryon verticillatum*), was more common, occurring up to a maximum of 50 L in the lower southern harbour (Figure 63b). This bryozoan was most prevalent in the subtidal seagrass area, but also occurred in the surrounding subtidal channels, and as far up the harbour as just north-east of Shelly Beach.

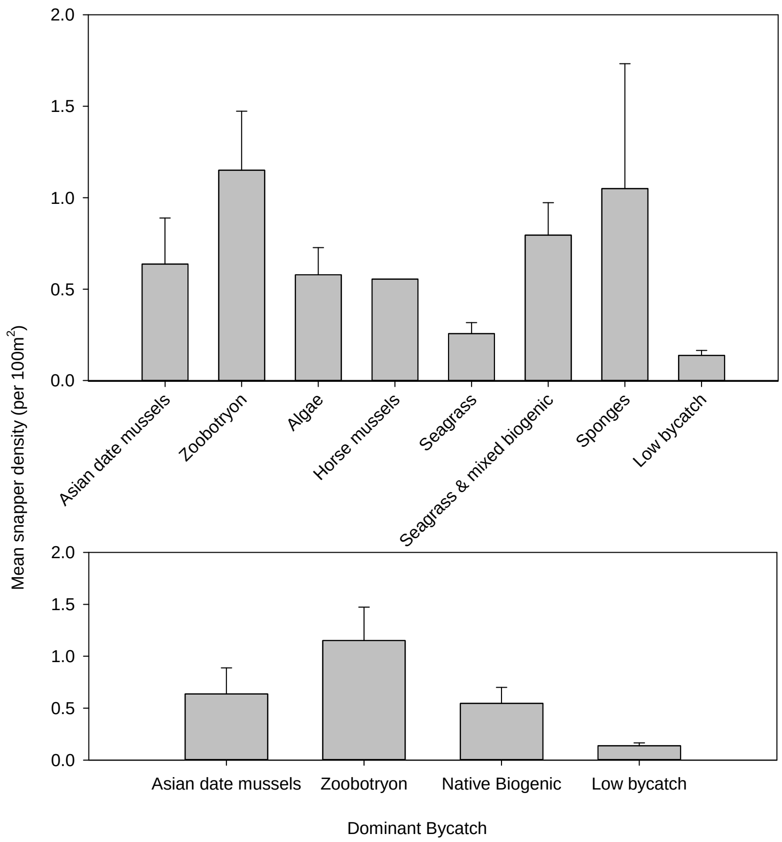

Figure 64: Average density of snapper (number per 100 m^2) in hauls characterized by the dominant bycatch (where volumes were 1 litre or greater). Remaining hauls were grouped as "low" bycatch.

To look at the potential relationships between juvenile snapper densities and the presence of three-dimensional biogenic habitats on the seafloor, each station was assigned to its dominant (over 1 L) bycatch categories, and average catch rates of juvenile snapper were calculated (Figure 64). The highest juvenile snapper catch rates were associated with *Zoobotryon verticillatum* and sponge classes, followed by seagrass and mixed biogenic, Asian date mussels, and algae. The lowest catches were associated with seagrass (noting that much of this was drift, being sampled from subtidal channel depths too deep for seagrass growth), and the 'low' bycatch class (i.e. no bycatch of over 1 L). Collapsing of all of the 'native' species down to one combined class, showed that stations where *Zoobotryon verticillatum* was dominant held the highest juvenile snapper densities at 1.15 fish per 100 m^2 (n = 20, s.e. = 0.323), compared to 0.55 where bycatch was composed mainly of native biogenic habitat formers (n = 19, s.e. = 0.153) and 0.13 (n = 127, s.e. = 0.0272) where low volumes or no bycatch was recorded. These results show that the biogenic habitat structure on the seafloor is associated with higher densities of juvenile snapper in the Kaipara Harbour. Further discussion of this and its ecological, fisheries, and management implications is presented in Section 7 of this report.

4.11 Subtidal channels and shallow banks; towed underwater video survey

Towed video methodology

Also as part of the MBIE-funded programme "*Coastal Conservation Management*", 81 of the 190 stations sampled by beam trawl were then surveyed by towed video. A towed camera (Morrison & Carbines 2006) was used to count sleeping fish and quantify their habitat associations, and to more broadly quantify the habitats that occur in the Kaipara Harbour. It is assumed that for most fish species day and night habitat usage are similar, with for instance, estuarine snapper being shown by acoustic tracking to be resident at small spatial scales over periods of weeks to months (Hartill et al. 2003). Stations were stratified by the same harbour areas, and encompassed the same range of depths and topography classes (channel floors, channel banks, shallow subtidal flats, and the intertidal – with the last class having only low sampling effort assigned), but also targeted beam trawl stations where high juvenile snapper catches and / or biogenic sea floor habitat structure had been recorded. Several additional stations were added, targeting known/likely areas of rocky reef and green-lipped mussel beds which could not be sampled by beam trawl. These included known areas of "foul" around South Kaipara Head, along the Pouto Peninsula (North Head), off Old Man's Nose (Orongo Pt), off Mussel Rock (west of Tinopai), and green-lipped mussel beds in the harbour entrance.

All camera work was carried out on board the 14 m wooden launch, *Shamrock II*, working at night between the hours of darkness from 1700 to 0500. The underwater image system "*Coast-cam*" consisted of a video camera, a stills camera, and a RBR TDR-2050 temperature logger mounted on a lightweight frame (1200 × 760 × 580 mm). The Tritech Typhoon colour zoom video camera was lit by underwater LEDs, and a pair of scaling lasers were used to measure object size and transect width. The stills camera system was made up of a 12 Megapixel Canon 450D digital SLR camera which fired two 580EX2 flashes, all held in custom made underwater housings. This stills camera system also had a pair of scaling lasers. An umbilical cable to the surface provided power and control to the optical and lighting systems, and also relayed real-time video footage to a Sony Mini DV video recorder with overlaid environmental data from a Horito GPT-50 video titler. Vessel position and water depth data were captured on a laptop by the Ocean Floor Observation Protocol software (OFOP; http://ofop.texel.com).

At each station, the camera was towed along a 400 m transect, at 0.3 to 1.0 m above the seabed, depending on weather conditions, tidal strength and water clarity. The optimum tow speed was 1 knot over the seafloor, as higher speeds led to blurred video imagery and reduced definition of objects. The camera sites in the upper reaches of the harbour were surveyed during the top half of the incoming tides, and sites closer to the entrance were sampled on the turn of the tide to ensure that there was sufficient depth to deploy the camera system. Poor water visibility was a constant problem, and the initial survey planned for March 2011 was deferred for several months in the hope that water conditions would improve. Despite this, conditions were never particularly good, with the survey charter skipper commenting that this was as bad as he had seen it. Turbidity was the limiting factor, determining how far the survey extended up into the upper reaches of harbour.

Video was successfully captured and analysed from 67 transects. Each transect was reviewed and information recorded about the primary substrate type, presence of secondary substrates and biogenic habitat formers. Table 10 lists the habitat variables considered. Where the substrate and/or habitat formers changed mid transect, the GPS position of this change was noted from the video display. All fish observed were identified and measured, where possible.

Table 10: Habitat descriptors used in video analysis.

Primary Substrate	Secondary substrate	Biogenic habitat formers
Mud	Shell grit, rubble, hash	Macroalgae
Sandy mud	Cobbles	Horse mussels
Muddy Sand	Boulders	Seagrass
Sand	Patch Reef	Sponges
Shell armour		
Bedrock / Reef		

Fish species diversity and densities are presented in relation to harbour area, broad habitat class, and depth categories. Habitat types were defined based on the combinations of primary and secondary substrates and biogenic habitat formers observed in the video using the descriptors in Table 10. The habitat classes that were apparent in the data were as follows:

- Bare soft sediment: includes mud, sandy mud and muddy sand and sand.
- Soft sediment with shell debris: including shell hash, shell grit and shell rubble.
- Soft sediment with seagrass beds.
- Soft sediment with sponges (underlying substrate may also include shell hash).
- Soft sediment with macroalgae (underlying substrate may also include shell hash / grit, boulders and shell armour and sponges were also present in some sections).
- Hard substrates: including reef, patch reef, boulders and cobbles (i.e., areas where hard substrate was patchy and interspersed with soft sediment).

The seafloor areas covered by each transect (and habitat segments within transects where present) were estimated using GPS co-ordinates (as recorded in OFOP), and the average transect width measurements, as estimated using the laser scale. Using these area swept estimates, fish densities were calculated and expressed as standardised densities per 100 m^2 (by transect, or by habitat segment within transect).

Distribution of habitats and fish species within the harbour

A total of 17 fish species were identified from the video transects (Figure 65) made throughout the Kaipara Harbour (Table 11). The most abundant fish species was snapper, seen in 44% of transects, followed by jack mackerel observed in nearly 30%. These species were found in all areas of the harbour, with highest observed densities for both being in the southern harbour around the Concrete Blinker (snapper) and on the shallows off Kakarai Flats (jack mackerel) (Figure 66). Anchovy, kahawai and sweep were seen in smaller numbers, with the remaining species seen in fewer than 2% of transects (less than 10 individuals total). A number of sharks were unable to be identified, but in most cases were likely to be either juvenile school shark or rig. A single unidentified eel was thought to be a snake-eel.

In the entrance area, 11 stations were completed across and along the northern edge of the deep channel, and just outside the entrance, ranging in depth from 3–27 m. The fast current speeds experienced during these transects made full analysis of the video difficult (especially EN1 and EN2 just outside the entrance – see Figure 65). Most transects were over seafloors of bare rippled muddy sand; but at two sites boulders, patch reef and green-lipped mussels were observed (EN5 and EN 6, just off the coast between North Head and Kaipara Head). The average fish density observed in this area was lowest of the four areas, at 0.8 fish per 100 m^2 (n = 59), with six species observed in total. Jack mackerel was the most commonly observed species, followed by snapper and sweep (the latter observed in a group over patch reef), as well as trevally, kahawai, grey mullet, red gurnard, sand flounder, and northern bastard cod. The low density estimate does not fit with this area being a popular recreational fishing spot (see Figure 22), and it is possible that the high currents affect the number of fish sleeping in this area, with fish moving into this area daily from adjacent areas.

In the Northern Harbour area, there were 19 stations spread across the channels, banks and shallows, with seafloors dominated by bare muddy sand and sand substrates, in depths ranging from 1.5–23 m. Patches of sand dollars, heart urchins and infaunal burrows were observed. Some inshore foul/reef sites were sampled off Te Hakono Bay, consisting of patches of cobbles and bedrock, with horse mussels, brown algae and the yellow rock-boring sponge *Cliona celata* associated with this substrate (NHL1 and 2, see Figure 65). Snapper, jack mackerel and kahawai were the most commonly observed species of the 11 detected in this area. The average fish density was 0.9 fish per 100 m^{-2} (n=102).

In the Southern Harbour area, 29 stations were spread across the Kaipara and Tauhoa river channels, and adjacent banks and flats, with depths ranging from 2–39 m. As with the Northern Harbour area, muddy sand was the dominant substrate, particularly in the channels, with patches of shell hash and sand dollars. Around the Concrete Blinker, relatively high numbers of snapper were associated with shell hash, macroalgae and sponges (SH 16, SH17, SHA1 and SH26, see Figure 65). In the central shallows (2.5–8 m water depth) off the Kakarai Flats, secondary structure including shell debris, seagrass, sponges, macroalgae and horse mussels was frequently present. Patch reef and cobble habitat was observed off South Head (SHN1). A total of 16 species were identified, including eagle rays and a number of shark species. Snapper and jack mackerel were again the most common species, with this area having the highest fish densities of the four harbour areas sampled, at 1.5 fish per 100 m^2 (n= 228).

Table 11: Species observed on towed video transects in the Kaipara Harbour, with total number observed, percentage of transects where species were observed and estimated density. *, jack mackerel are presumed to be *Trachurus novaezealandiae*.

Common name	Scientific name	Total count	% Occurrence in tows	Fish density per 100 m^2
Snapper	*Pagrus auratus*	200	44.74	0.52
Jack mackerel	*Trachurus novaezelandiae**	127	28.41	0.33
Anchovy	*Engraulis australis*	37	8.28	0.10
Kahawai	*Arripis trutta*	19	4.25	0.05
Sweep	*Scorpis lineolatus*	11	2.46	0.03
Silver conger eel	*Gnathophis habenatus*	8	1.79	0.02
Grey mullet	*Mugil cephalus*	6	1.34	0.02
Trevally	*Pseudocaranx dentex*	4	0.89	0.01
Shark (Unid.)		4	0.89	0.01
Gurnard	*Chelidonichthys kumu*	3	0.67	0.01
Flatfish (Unid.)		3	0.67	0.01
Eagle ray	*Myliobatis tenuicaudatus*	3	0.67	0.01
Stingray	*Dasyatis* sp.	3	0.67	0.01
Sand flounder	*Rhombosolea plebeia*	2	0.45	0.01
School shark	*Galeorhinus galeus*	2	0.45	0.01
Lizardfish	*Synodus* sp.	1	0.22	0.00
Nth Bastard Cod	*Pseudophycis breviuscula*	1	0.22	0.00
Red mullet	*Upeneichthys lineatus*	1	0.22	0.00
Spotty	*Notolabrus celidotus*	1	0.22	0.00
Eels (Unid.)		1	0.22	0.00
Fish (Unid.)		10	2.24	0.03
Totals		447	100.00	1.13

In the Eastern Arms, 8 stations were sampled at the entrance of the Arapoa, Otamatea and Oruawharo river arms, in depths ranging from 2–37 m (the deepest station being in the "The Funnel"). Channel floors were dominated by bare muddy sand substrate, with sponges observed in the Otamatea River between Te Whau and Pakurangi Points (The Funnel). Several areas of reef habitat were observed in the shallows; opposite Schnapper Point in the Oruawharo (EA3) and between Batley and Te Hoanga Points in the Otamatea River (EA20). Only six species were observed in these transects, with an overall density of 1.2 fish per 100 m^{-2} (n=58). Similar to the other parts of the harbour, snapper and jack mackerel were the dominant species observed.

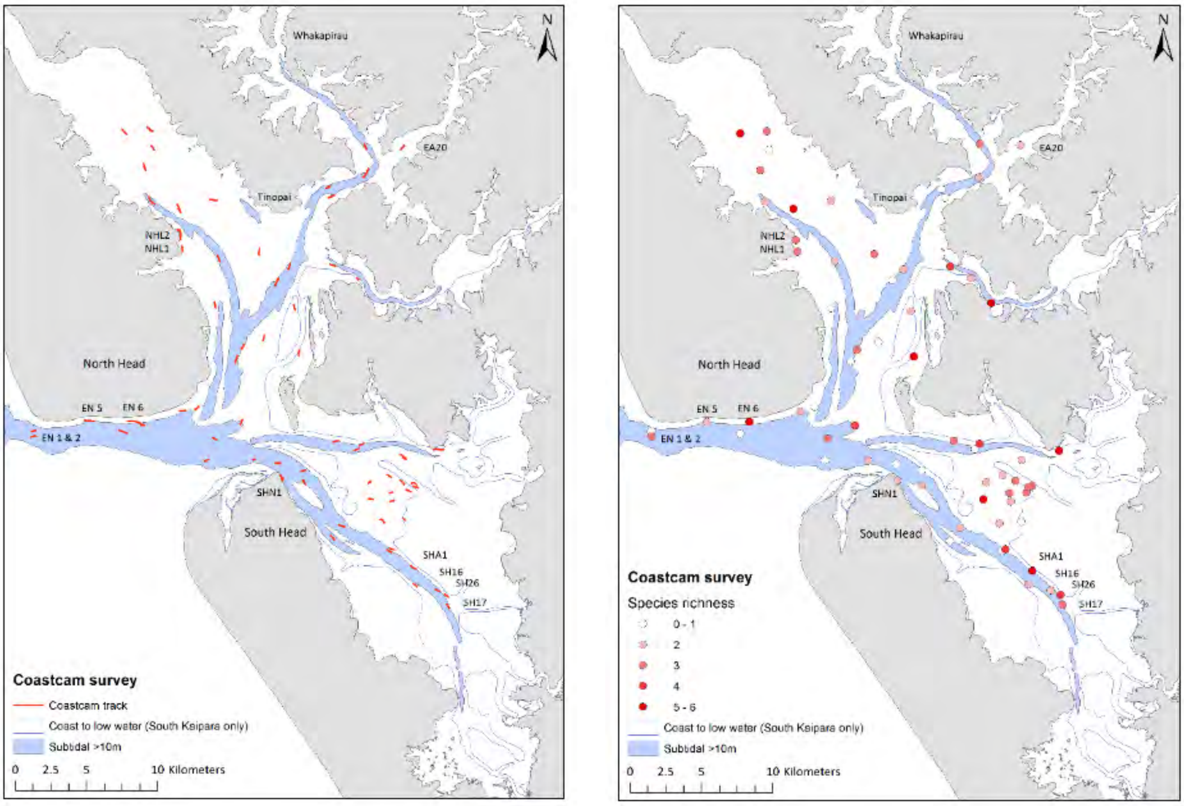

Figure 65: Coastcam video transect stations in the Kaipara Harbour (left) and species richness (right). Stations referred to in the text, where biogenic habitat was encountered are labelled.

Association of fish with biogenic habitat, as observed by video

Using the broad habitat types previously defined, individual habitat segments were grouped together, and species richness, total fish mean density, and mean density of snapper estimated. Table 12 gives a summary of the sampling effort and total area sampled for each habitat category along with species richness and observed fish densities. Bare soft sediment was the most extensively sampled habitat category, observed in 44 out of 67 stations and making up nearly 60% of the area sampled. Soft sediment with shell debris was also frequently observed. Structured habitats were less common, making up less than 20% of the area sampled. Out of the 17 species identified, 13 were observed on the bare sediment, as well as an unidentified shark likely to be either school shark or rig (eagle ray, sweep and red mullet were not observed with this seafloor type) (Table 12). Fewer species were observed associated with other habitats, but the numbers of all but snapper and jack mackerel are too low to draw any conclusions. These two most commonly observed species were counted in all habitat categories.

Table 12: Habitat types observed on the Coast-cam video, and associated observations of fish populations. The number of stations where different habitat types were observed is given, with the number of transect segments classed as each habitat category in brackets. Average densities (across all habitat segments), for all fish, and snapper specifically are given [± s.e.].

Habitat type	Station count [Habitat segments]	Area (m^2)	% of Total Area	Depth range (m)	Fish count	Average density per 100m^2 [s.e.]	Species count	SNA count	SNA average density [s.e.]
Bare soft sediment (mud / sand)	44 [52]	23 696	58.9	2–37	221	1.17 [0.2]	14	76	0.44 [0.2]
Soft sediment with shell debris	20 [24]	9 048	22.5	2–39	78	1.76 [0.5]	9	28	0.94 [0.4]
Soft sediment with seagrass	4 [9]	1 451	3.6	1.7– 3	14	1.19 [0.4]	3	4	0.13 [0.1]
Soft sediment with sponges	7 [7]	2 690	6.7	5– 37	28	1.03 [0.5]	5	20	0.69 [0.4]
Soft sediment with macroalgae	10 [14]	2 317	5.8	3– 23	78	3.97 [0.6]	9	50	2.26 [0.6]
Boulder, bedrock, reef, patch reef, cobbles	8 [11]	942	2.3	3–15	25	3.78 [1]	5	20	2.65 [0.9]
Soft sediment with Horse mussel beds	1 [1]	80	0.2	8–10	3	-	2	2	-

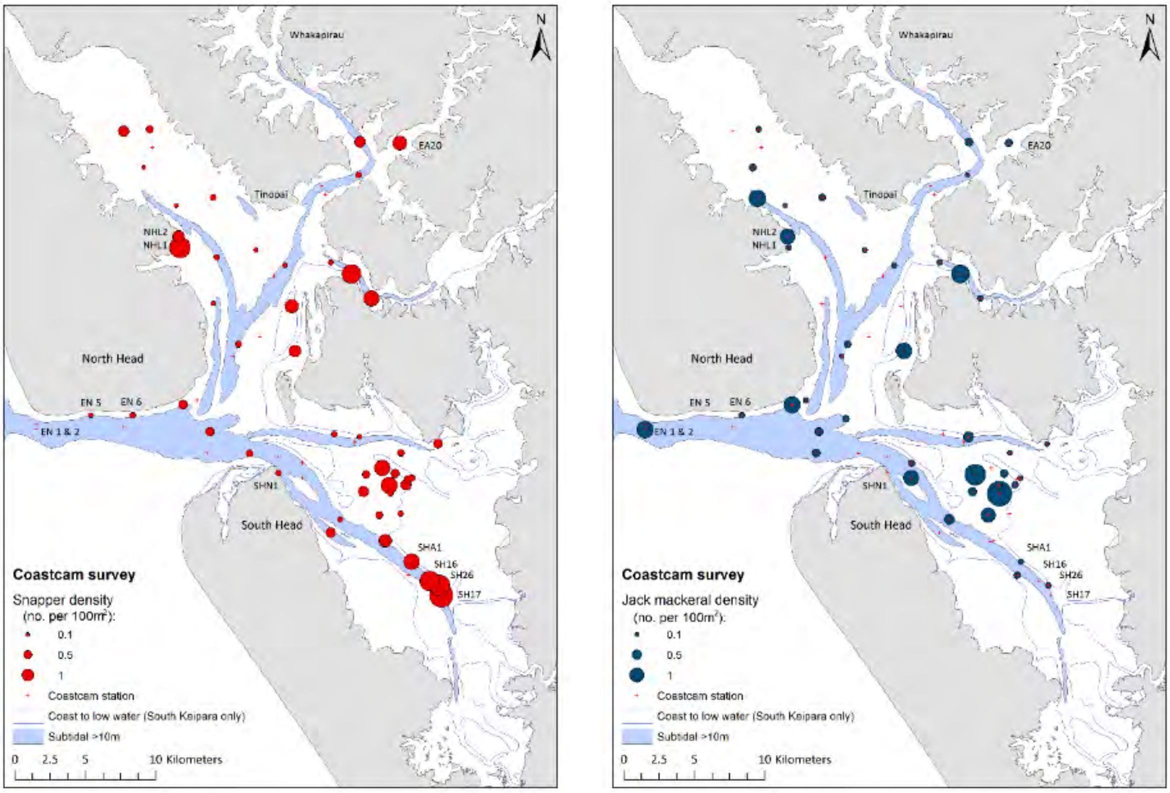

Figure 66: Maps showing estimated densities (no. per 100 m^2) and distribution of snapper (left) and jack mackerel (right) observed on the Coastcam video transects in the Kaipara Harbour. Symbols are proportionally scaled to density and are different for each species.

Figure 67 presents the mean density of all fish observed, and snapper separately, estimated from all habitat segments for six out of the seven habitat categories. Total fish densities, and snapper densities were higher on structured habitat, particularly reefs, boulders / cobbles and areas of macroalgae (Table 12 and Figure 67). Densities of snapper were lowest over the shallow seagrass, although sampling was not at the time of year to observe the smaller 0+ year class (under 9 cm), which is known to utilize this habitat type during the summer months (see Section 4.8). Only one small area of horse mussel habitat was sampled, with only three fish observed, which is not shown in Figure 67.

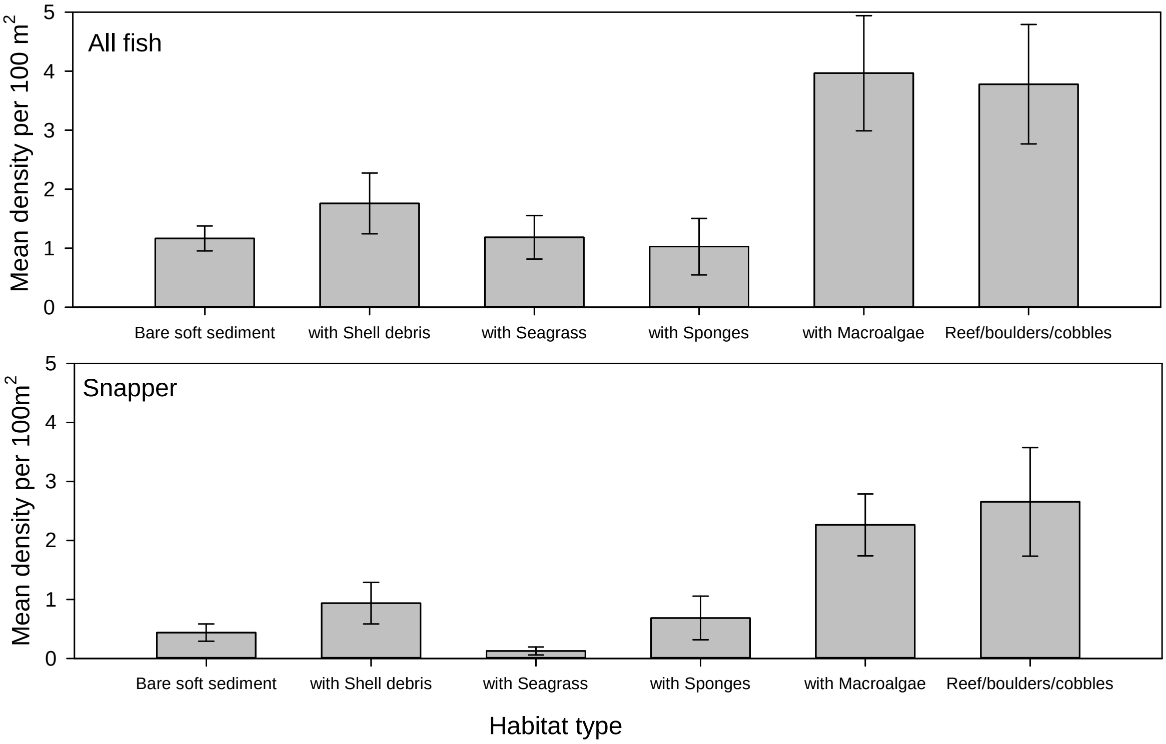

Figure 67: Density (no. per 100 m^2) of a) all fish observed, and b) snapper; by substrate / habitat type. Bare sediment includes all mud, sand and sandy mud combinations.

Estimated snapper lengths ranged from 6–45 cm, with a median length of 18 cm, but several modal size classes were apparent, representing a range of year classes, from 0+ up to 2–3 years old, along with a small number of adult fish. Length frequencies from each of the six habitat classes are given in Figure 68. The main modal class (17–20 cm, probably 2+ fish) was present across all of the habitat classes, but smaller fish (less than 10 cm) were observed mainly over soft sediment, with and without shell debris, and where macroalgae was present. No obvious differences were apparent between the four harbour areas, or with depth, and so plots of these are not presented here.

Overall, the fish assemblages observed by this survey method were modest relative to other methods, such as beach seine and beam trawl. While jack mackerel were detected, they are known to often show attraction to lights at night, and are usually found in the water column rather than on the seafloor proper (i.e., they may occur above the camera's field of view). Therefore, the density estimates reported here should be viewed as indicative only. Snapper are more amenable to this method, and occurred through the harbour. The timing of this survey work (September–October) fell within a seasonal period when juvenile 0+ snapper have left shallower habitats, such as subtidal seagrass (which they usually leave by April–May); and also when larger snapper have moved offshore, including out of estuaries, into deeper coastal waters. The relatively few adult snapper (over 25 cm) observed can probably be regarded as resident fish in the harbour. The low densities recorded will not reflect adult densities found over the summer period, when migratory snapper (including 'school snapper') move seasonally into estuaries and shallow coastal waters. Whether sharks and other elasmobranches are able to detect the lights/electrical fields cast out by the towed video gear is unknown, and it is possible that some species are able to avoid visual detection.

The video survey showed that much of the Kaipara Harbour seafloor was composed of relatively featureless sand and muddy sand, with structured habitat areas covering around 18% of the seafloor surveyed (note: that biogenic and other elements contributing to these ‘structured habitats’ were themselves patchy within their broad habitat classes). More turbid waters in the upper reaches of the harbour could not be assessed using this towed video method. Snapper and other species were more common over seafloors with forms of structured habitats.

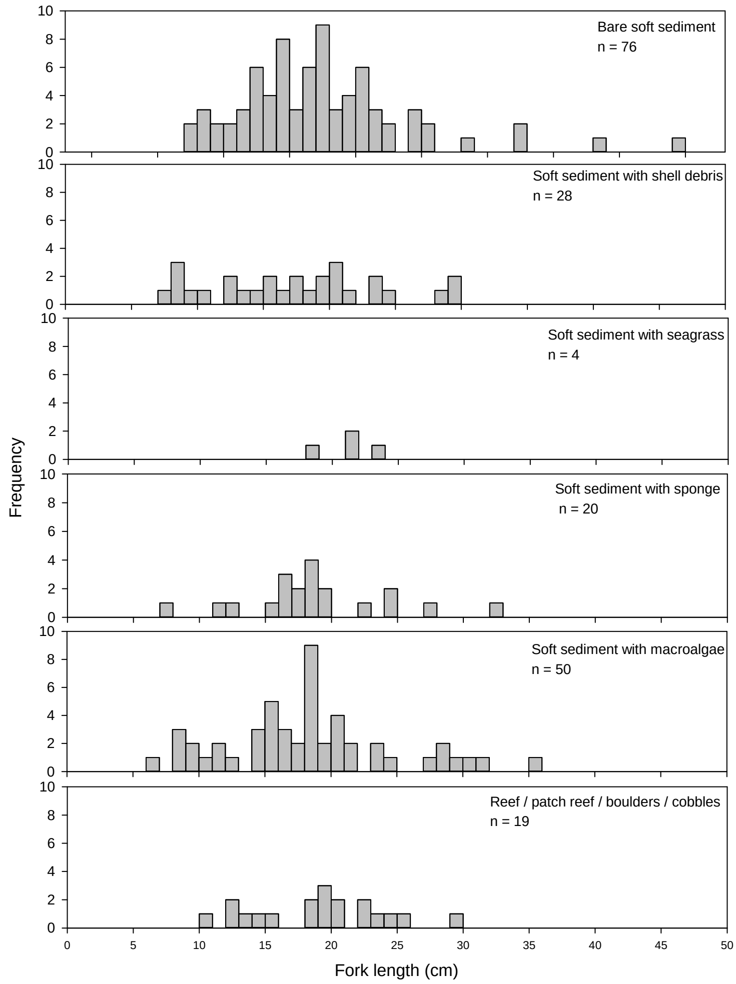

Figure 68: Length frequency of snapper observed on video transects grouped by habitat category.

4.12 Subtidal channels of inner estuaries; set net survey of larger fish

The Arapaoa and Oruawharo Rivers in the Kaipara Harbour were surveyed as part of a national study of potential rig (*Mustelus lenticulatus)* nursery grounds in 2011 (Francis et al. 2012). The survey was carried out between February and March to coincide with the occurrence of recently pupped rig in the harbours and estuaries. Nets were constructed from 0.5 mm diameter monofilament nylon, with a stretched mesh size of 3 inches (76 mm), 30 meshes deep, 60 m long and anchored at each end with a 12–24 kg weight. In each river, six nets were set simultaneously at randomly selected stations over two consecutive days. Stations on the second day were geographically interspersed among the stations completed on the first day, so that approximately the same overall survey area was covered on both days.

The target depth range was 1.5–3.0 m at low tide, so station locations were chosen after calculating depth at low tide from the echosounder depth and the tide state determined from tide tables. This ensured that the nets remained submerged at low tide (with the floats at the surface) at even the shallow end of the tidal range, while avoiding the centres of main channels. Acoustic tagging data indicate that rig are most active around dusk and dawn (M. Francis, unpubl. data), and nets were set to cover the dusk–night–dawn period and a soak time of at least one hour of daylight either side of this period. Nets were set parallel to shore or along the direction of a channel.

Environmental data were collected at each station; spot measurements of temperature, salinity, and turbidity were recorded, and a sample of surface sediment was collected from the seabed using an Ekman dredge. Sediment was classified subjectively on a 6-point scale: mud, sandy mud, muddy, sand, sand, sand and shell, and shell. All fish caught were identified and measured to the nearest whole centimetre below fork length (FL, if they have a forked tail) or total length (TL).

In the Kaipara sets, soak times ranged from 19–26 hours, and site depths ranged from 2.6–4.3 m. Most stations were set on mud or sandy mud, with only 2 stations classed as sand. The catch composition was dominated by grey mullet (*Mugil cephalus*), snapper (*Pagrus auratus*) and rig, with smaller quantities of other species, including school shark (*Galeorhinus galeus*) and kahawai (*Arripis trutta*). As well as the 11 species recorded in Table 13, spotty (*Notolabrus celidotus*) and trevally (*Pseudocaranx dentex*) were caught in foul hauls that were not included in the final analysis.

Table 13: Total catch from 6 set nets each in the Arapoa and Oruawharo Rivers, Kaipara Harbour.

Common name	Species	Arapaoa River	Oruawharo River	Total
Grey mullet	*Mugil cephalus*	477	474	951
Snapper	*Pagrus auratus*	434	308	742
Rig	*Mustelus lenticulatus*	329	146	475
School shark	*Galeorhinus galeus*	54	23	77
Kahawai	*Arripis trutta*	22	14	36
Red gurnard	*Chelidonichthys kumu*	2	33	35
Sand flounder	*Rhombosolea plebeia*	10	7	17
Jack mackerel	*Trachurus novaezelandiae*	1	2	3
Hammerhead shark	*Sphyrna zygaena*	2	1	3
Yellow-eyed mullet	*Aldrichetta forsteri*	1	2	3
Parore	*Girella tricuspidata*	1	1	2
Totals		1 333	1 011	2 344

Snapper was the most commonly caught species caught in the national survey, with highest numbers caught in the western coast harbours of the North Island (Francis et al. 2012). Within the Kaipara Harbour, snapper catches ranged from 3 fish (off Ngaupiko Point at the entrance of the Arapaoa river) to 92 (off the Pahi peninsula, Figure 69), with a size range of 14–41 cm and a modal peak at 18–19 cm, and a second smaller mode at 23–24 cm (Figure 70). Fish caught in this survey were not aged, but these modes likely represented 2+ and 3+ age classes (Francis et al. 2012). Figure 71 shows length frequency plotted by substrate type, which suggests that proportionally more fish greater than 20 cm were caught on sandy or muddy sand sediment (28–31%), compared to 8–16% on mud and sandy mud.

Grey mullet were the second most numerous species in the national survey, being most abundant on the west coast of the North Island, and were not caught in the South Island harbours. Within the Kaipara Harbour, fish size ranged from 19–42 cm, with a modal peak at 31–33 cm, likely representing a mix of sub-adult and mature fish (Figure 70). Very few grey mullet were caught in 2 sets on sandy substrates (Figure 71).

Juvenile rig were abundant in the harbour (Figure 69), compared to other harbours surveyed nationally (Francis et al. 2012). The 0+ class was defined by Francis et al. (2012) as those less than 46 cm in length, and this class dominated the catch in all North Island harbours, including the Kaipara (Figure 70). There were also 1+ rig present in the Oruawharo River, as well as a smaller number of sub-adults (60–80 cm). The survey identified the Kaipara Harbour as likely to be the most important nursery area in New Zealand for rig, with juvenile abundances being greatest within muddy turbid parts of the harbour, with an associated significant freshwater input.

Other species caught included school sharks, with a single juvenile mode at 43–45 cm (1+ fish as per Francis & Mulligan 1998). Red gurnard were caught across all of the substrates sampled, and including one ‘large’ catch of 20 fish at station 11 at the entrance of the Oruawharo River off Motukumara Point. Fish ranged in size from 18–43 cm, with a modal peak around 36–38 cm. Kahawai were present as several size classes (although numbers were modest, n = 41) at 15–17 cm, 25–30 cm, and 33–51 cm modes. Three juvenile hammerhead sharks were also caught (56, 76 and 85 cm length).

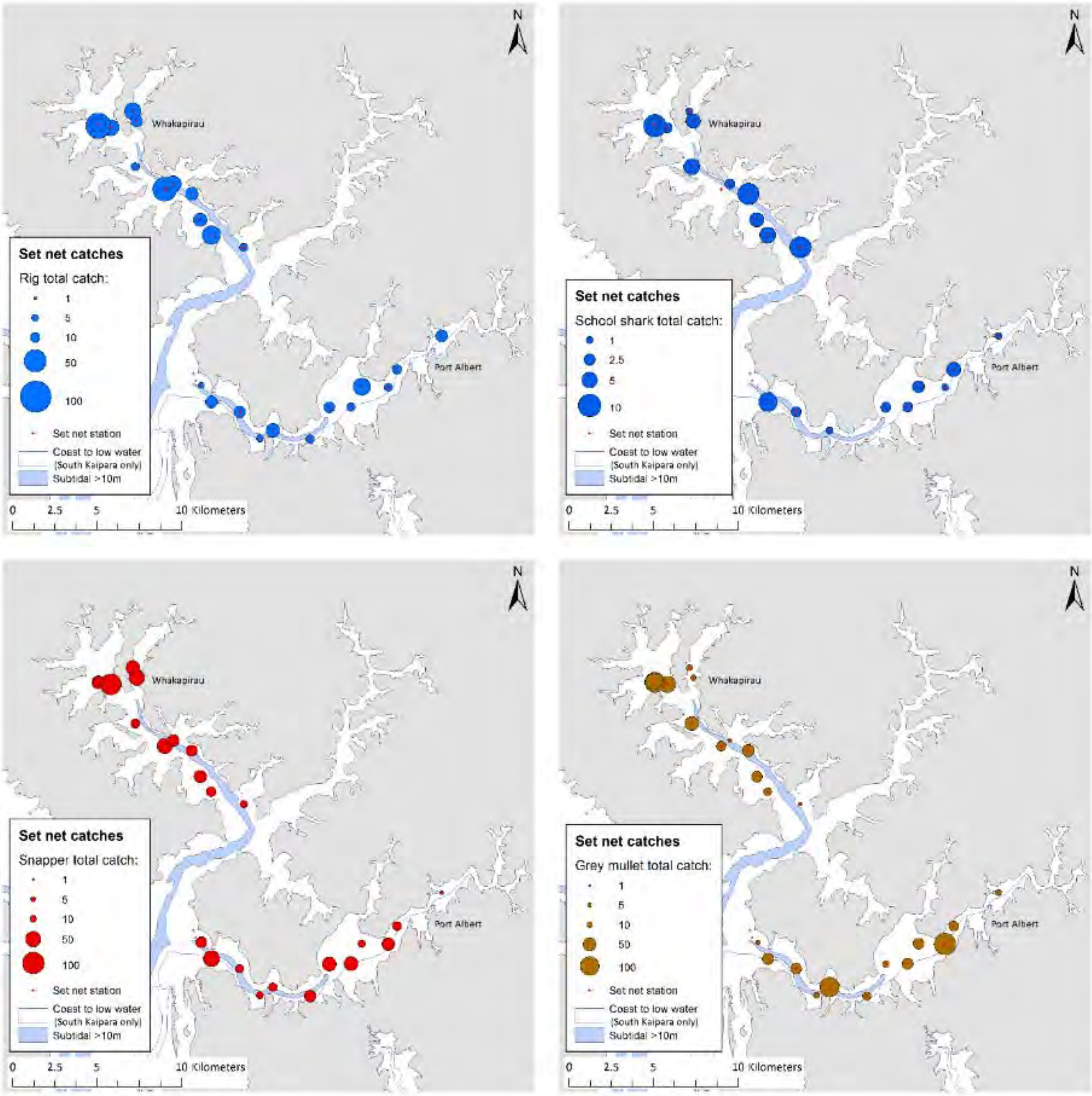

Figure 69: Total catches from set nets in the Otamatea and Oruawharo rivers for four of the most common species. Symbols are proportionally scaled to density and are different for each species.

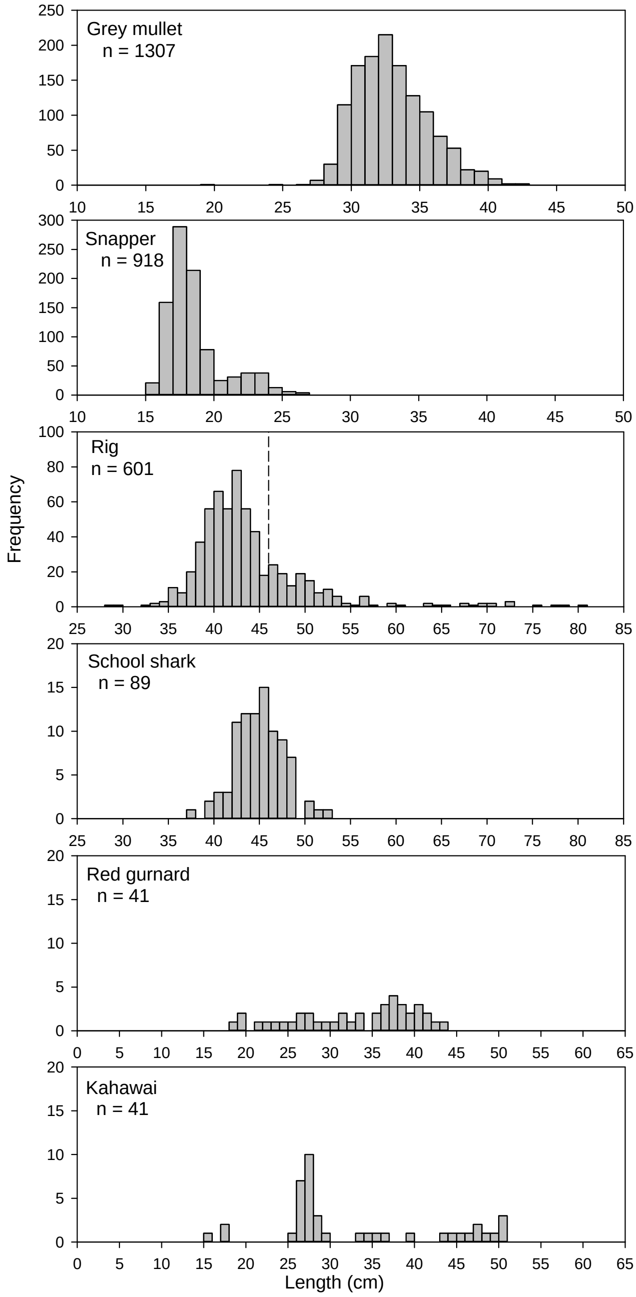

Figure 70: Length frequencies for snapper, grey mullet and rig plotted for all sets across all four substrate types combined. The dashed line represents the length below which rig were considered to be young of the year. Note that x and y axis scales change between species.

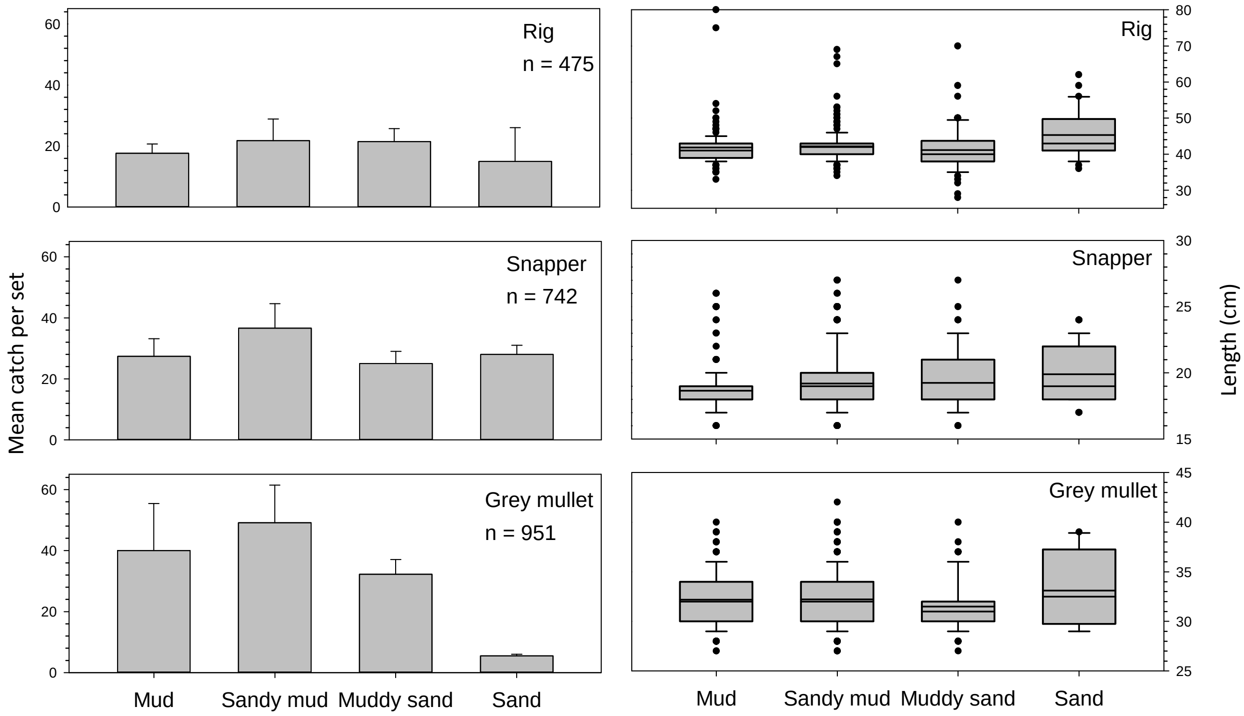

Figure 71: Mean total catch and s.e. for the three most common species caught in set nets (left) and length range (right) by substrate type.

5. THREATS AND STRESSORS

5.1 Land-based stressors

Recent sedimentation within the harbour

Sediment accumulation rates (SAR) within the harbour have recently been estimated from cores collected from 18 sites located in six harbours/estuaries using the radioisotopes ^{210}Pb and ^{137}Cs (Swales et al. 2011). Radioisotope data can be used to generate accurate 'sediment clocks' based on the known constant rate of decay. The average ^{210}Pb SAR estimated for the Kaipara Harbour was 6.7 mm yr^{-1} (s.e. 1.9 mm yr^{-1}) which is considerably higher than those for other North Island estuaries (Figure 72). However, the harbour average was considered to be skewed by high SAR values recorded at two of the sites, i.e. KAI-2 (Kaipara River entrance, 30 mm yr^{-1}), and KAI-16 (Hoteo, 21 mm yr^{-1}). Data for KAI-2 suggested that high sedimentation was a result of lateral shifts in the channel rather than to increased sediment load. The values for Hoteo were not considered representative of conditions in the main body of the harbour, although similar rates were obtained from Auckland's tidal creeks over the past 50 years (20 to 30 mm yr^{-1}). Exclusion of these two sites gives a harbour average SAR of 4.0 mm yr^{-1} (s.e. 0.6 mm yr^{-1}) which is comparable to sedimentation rates in Auckland estuaries. Notably, these sedimentation rates are up to three times higher than other North Island estuaries and coastal embayments for which robust data are available (Swales et al. 2011).

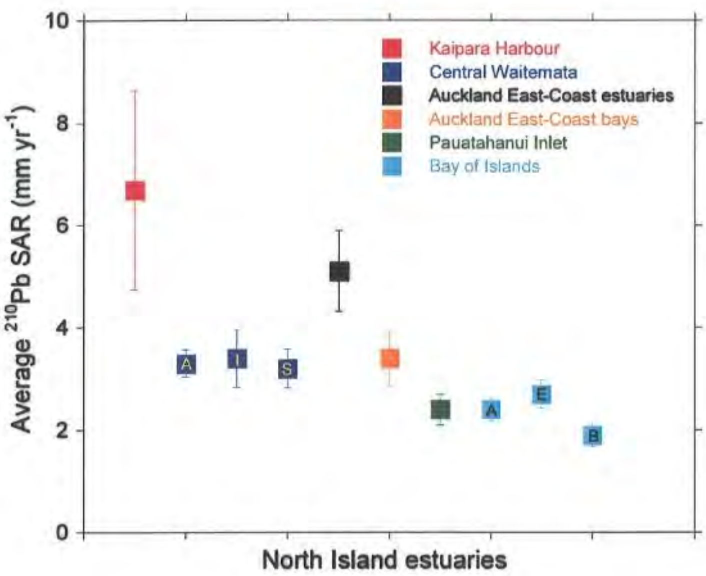

Figure 72: Comparison of average ^{210}Pb based sediment accumulation rates (SAR) in North Island estuaries (±s.e.). For (A): all data; (l): intertidal sites; (S): subtidal sites; (E): estuaries; (B): coastal embayment's; total number of cores = 85. (Source: Swales et al. 2011).

Sediment dispersion within the harbour

Recent survey data suggests that long term deposition of fine muds is occurring: on the intertidal flats in the southern Kaipara, near the Hoteo River; in large tidal rivers (e.g. Arapaoa), the creeks of the northern Kaipara, vegetated intertidal habitats, and on intertidal flats with limited wave fetch (Figure 73), (Swales et al. 2011). Field observations suggest that mud is accumulating in the mangrove forests (e.g. at Whaketu – 365 ha) and the salt marshes that fringe the Kaipara Harbour, at a faster rate than that measured on the intertidal flats (Swales et al. 2011). Notably, there has been little deposition of muds on the large intertidal flats (e.g. Wairoa River flats; Kaipara Flats) and tidal channels due to wave action and/or strong currents reworking the sediment deposits.

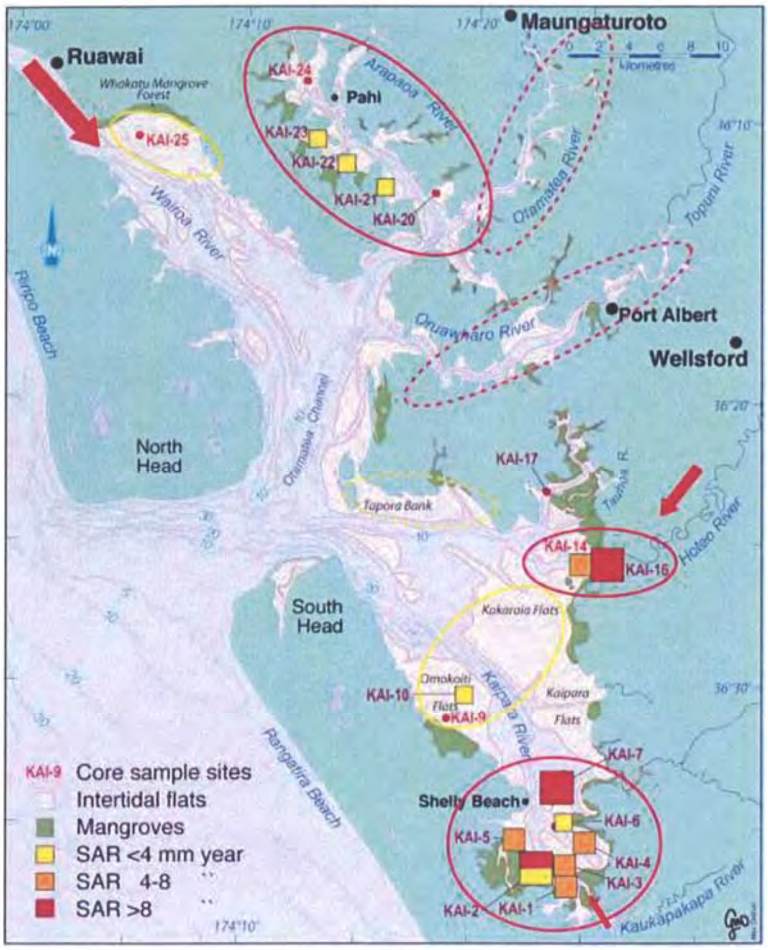

Figure 73: Summary of sedimentation and fine sediment fate in the Kaipara Harbour and location of core sites. Red ellipses denote long term fine sediment sinks, yellow ellipses denote temporary sinks, dotted ellipses denote inferred sediment sinks, and red arrows represent the relative size of catchment sediment inputs. (Source: Swales et al. 2011).

Sediment origin and river inflows

The greatest source of sediment into the Kaipara Harbour is from the Wairoa River, which drains over 60% of the total Kaipara Harbour catchment. Its mean annual flow is 10 times greater than the annual flows of both the Kaipara and Kaukapakapa Rivers (estimated from NIWA's Water Resources Explorer NZ Model; WRENZ 2007). The Wairoa River also carries more than 20 times the volume of the Kaipara and Kaukapakapa Rivers, given mean annual flood events and more than 40 times the maximum flood flow. The majority of sediment entering the harbour does so during flood events (Gibbs et al. 2012). Compound specific stable isotope (CSSI) analysis reveals that the spatial distribution of fine sediments from the Wairoa River are found throughout almost the entire harbour (Figure 74), with sediments being deposited in the southern Kaipara, predominantly along the western shore as far south as Shelly Beach (Gibbs et al. 2012).

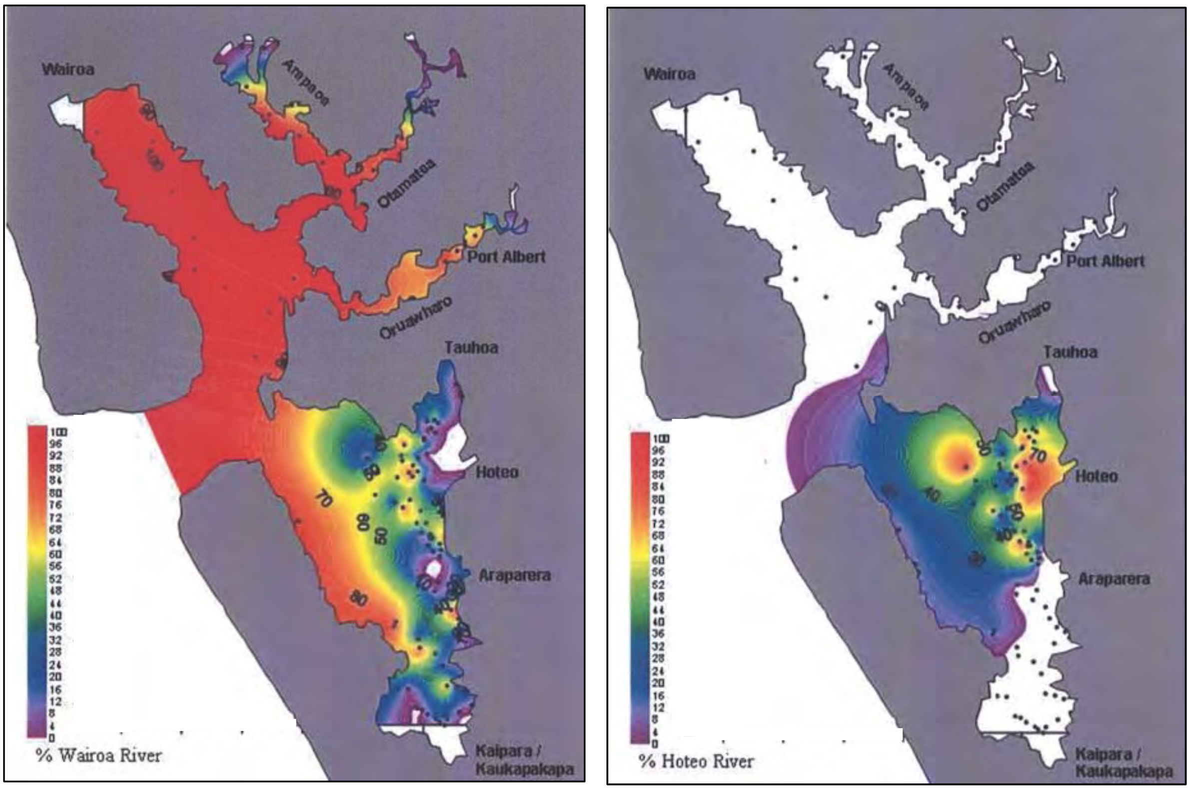

Figure 74: a) dispersion of sediment derived from the Wairoa River and b) Hotea River across the Kaipara Harbour, displayed as percentages. Gibbs et al. (2012) note that the pattern is indicative rather than absolute and is subject to the plotting software package interpolation between the limited number of data points. Uncertainty is typically plus or minus less than 5% on each sample point. (Source: Gibbs et al. 2012).

There appears to be a high degree of connectivity between the northern and southern arms of the harbour. The primary mechanism of sediment delivery is thought to be via tidal advection of silt plumes from the Wairoa River to the southern Kaipara and into both basins of the harbour over successive ebb and flood tides (Swales et al. 2011).

By contrast, fine sediments discharged from the Hoteo River system (which has a larger flow and higher sediment loads than the other northern Kaipara side arms), are primarily deposited on the Kakaraia Flats, close to the river mouth, with patchy deposition on lower intertidal flats (Figure 74). Contribution along the western shoreline at South Kaipara Head is minor (less than 10%). Equally, the Arapaoa and Otamatea Rivers, and the Oruawhero River arm contribute relatively small amounts of sediments, with distribution constrained within the respective arms (see figures 3-8; 3-9 in Gibbs et al. 2012). The Kaipara and Kaukapakapa River system dispersion patterns also suggest that sediment deposition occurs close to the source i.e. on the intertidal flats within the southern Kaipara (see figure 3-12 in Swales et al. 2011).

Composition of sediments

Sediments within the harbour can be derived from many sources including river inflows, coastal and harbour sediment deposits. To ascertain the contribution of each sediment source to the sample, compound specific stable isotope analysis (CSSI) utilizing a mixing model (i.e. IsoSource; Phillips & Gregg, 2003) was employed by Gibbs et al. (2012). The degree of natural abundance enrichment of bulk δ^{13}C (carbon) and δ^{15}N (nitrogen) values, would suggest that most of the sediment deposited in the main body of the Kaipara Harbour came from terrigenous rather than from marine sources (Figure 75). Isotope signatures also indicated that enrichment occurred along the shorelines of the Hoteo and Araparera Rivers, which may be associated with land drainage and the development of dairying in this area (Gibbs et al. 2012). By comparison, sediments in the Arapaoa, Oamatea and Oruawharo River channels were consistent with sediments originating from rolling pasture associated with sheep and beef farming and less intensive dairy farming. Highly depleted δ^{13}C values (-25‰ to -28‰) recorded from the head of Otamatea and Oruawharo River channels indicated runoff from forestry which is consistent with the high country land use on the east of these rivers (Gibbs et al. 2012). Similar depleted values were recorded at the head of the northern Kaipara and along the eastern shores associated with blocks of pine forest behind mangrove forests. Bulk δ^{15}N values showed similar and consistent patterns of sediments originating from agricultural/farmland.

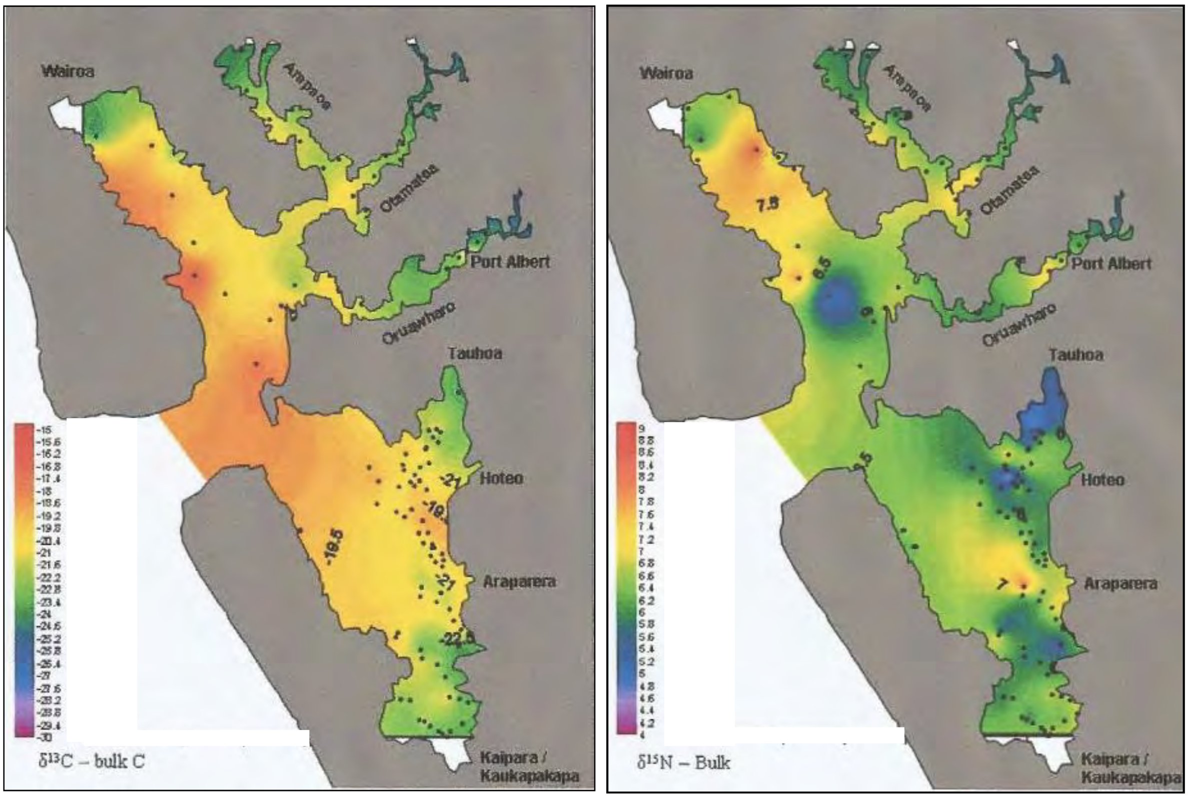

Figure 75: Bulk δ^{13}C (left) and bulk δ^{15}N (right) distribution within the harbour, as an indicator of marine versus terrestrial origins. (Source: Gibbs et al. 2012).

In summary, both historical and current data suggest that changes within the catchment of the Kaipara Harbour has resulted in increased levels of sedimentation (Swales et al. 2011, Gibbs et al. 2012).

Water quality

Since 2009, the Northland Regional Council (NRC) has undertaken monthly monitoring at nine sites in the northern harbour; Wairoa River (Five Fathom Channel and Burgess Island), Arapaoa, upper Otamatea and Oruawharo Rivers (NRC 2013). A range of water quality parameters are measured, including temperature; salinity, pH, chlorophyll *a*, dissolved oxygen, turbidity, total suspended solids, nitrate, nitrite, ammonium, phosphate, enterococci and faecal coliform levels. The Auckland Council (AC) has also monitored seven sites spread across the southern arm of the Kaipara over the same time period (see NRC 2012 and AC 2013 for details of stations).

At the northern sites, nutrient concentrations frequently exceeded the Australia and New Zealand Environment and Conservation Council (ANZECC) guidelines (see ANZECC (2000) for guideline levels). Over 90% of samples were within guidelines for *Enterococci* bacteria and dissolved oxygen. However, nutrient levels were high with 99% of samples exceeding the ANZECC guidelines for dissolved reactive phosphorous, 44% for ammonia, and 55% for nitrate-nitrite nitrogen. Highest concentrations generally occurred in the upper reaches of the different arms, (e.g. Oruawharo River;

Wahiwaka Creek (Otamatea River); Kapua Point (Arapaoa River); Burgess Island (the Wairoa arm)), while lowest concentrations were detected in the outer Five Fathom and Otamatea Channel sites (NRC, 2012).

The Auckland Council (AC) report card for the seven southern Kaipara sites is based on a Water Quality Index developed by the Canadian Council of Ministers for the Environment (CCME) in 2001 (see Water Quality Index Table 1.0; CCME 2001). Overall water quality has been ranked as 'fair' over the past three years. The latest rankings for 2012, however, show a decline in status for five out of seven of the sites monitored. The overall ranking is predominately due to the poor water quality found at the Makarau Estuary, at Shelly Beach and the Kaipara River (which recorded the highest concentrations of suspended sediments; turbidity and typically one of the nutrients e.g. total phosphorous, nitrate + nitrite nitrogen, ammoniacal nitrogen), combined with results from sites closer to the mouth of the harbour which were ranked "excellent" to "good" (Table 14) (Walker & Vaughan 2013a, b). Such high nutrient concentrations can lead to eutrophication resulting in enhanced biomass of phytoplankton, epiphytes, macroalgae, and TSS/turbidity. This can lead to shading and smothering of plants such as seagrass and the benthic community (Morrison et al. 2009). Anecdotal reports suggest that the incidence of algal blooms is increasing in the northern Kaipara (P. Yardley, pers. comm.).

Table 14. Auckland Council water quality index and water quality class for the southern Kaipara Harbour sites monitored. (CCME index ranges between 0–100, with 100 equalling excellent water; 70–90=Good; 50–70= Fair; ≤ 50= poor water quality) (Source: Walker 2012; Walker & Vaughan 2013a & b; AC 2013, unpublished data).

Site		2009		2010		2011		2012
Kaipara Heads	93.5	Excellent	67.8	Fair	61.3	Fair	48.6	Poor
Tauhoa Channel	93.5	Excellent	74.1	Fair	80.7	Good	67.9	Fair
Hotea River mouth	73.7	Fair	73.2	Fair	60.6	Fair	54.6	Poor
Omokoiti Beacon	87.1	Good	66.9	Fair	87.1	Good	55.0	Poor
Makarau Estuary	72	Fair	65.6	Fair	60.9	Fair	53.9	Poor
Shelly Beach	66.4	Fair	72.1	Fair	67.3	Fair	67.3	Fair
Kaipara River	53.8	Poor	56.6	Poor	49.5	Poor	43.3	Poor

5.2 Marine-based Stressors

Non-indigenous species (NIS)

At least 20 non-indigenous species have been recorded from the Kaipara, as well as two toxin forming dinoflagellate species, *Alexandrium ostenfeldii* and *Gymnodinium catenatum*, considered cryptogenic in New Zealand (Inglis et al. 2010).

Bryozoans

Bryozoans are some of the most common marine fouling organisms, whose arrival has been facilitated largely via boat hull fouling or ballast. The presence of at least five NIS bryozoans has been documented in the Kaipara Harbour. These include *Zoobotryon verticillatum*, present in New Zealand since the 1960s (Gordon & Matawari 1992), and *Membraniporopsis tubigera*, a small foliaceous (calcified erect structure) species first discovered in New Zealand by local fishers in 2001 (Gordon et al. 2006, see Figure 76) (as well as *Conopeum seurati*, *Anguinella palmate*, and *Bowerbankia gracilis* (Inglis et al. 2010)) . *M. tubigera* became so abundant within the harbour over the austral summer of 2001–02 that local fishers reported that set nets for flounder were clogged with drifting colonies, negatively affecting catches. This bryozoan was also found in snapper stomachs (L. Harrison, pers. comm.; cited in Gordon et al. 2006). However, there have been subsequent reports of sudden population decreases, with only modest sightings recorded since then (2010, M.L, pers. obs.).

The bryozoan *Zoobotryon verticillatum* grows into large, bushy colonies often 20 to 30 cm in diameter. Young colonies are usually transparent, becoming dirty white in appearance with age and growth. This species can grow rapidly under optimal conditions (water temperatures of at least 22°C) forming large aggregations capable of clogging fishing nets, and potentially excluding other sessile organisms (GSID, 2013). *Z. verticillatum* is usually found on hard surfaces (e.g. rocks, pilings, boat hulls) or as an epibiont on shells (Inglis et al. 2005). However, under ideal growing conditions it has been observed on underwater video, detached from the substratum and drifting like tumbleweed forming large aggregations in some areas of the southern Kaipara, Rangaunu and Parengarenga Harbours (M.L., pers. obs.). International research suggests that this species can reduce the level of light reaching seagrass blades, in addition to weighing blades down, and causing canopy collapse while proliferating in summer (Sewell 1996; cited in Wong & Vercaemer 2012; Williams 2007). Only a few organisms such as nudibranchs (sea-slugs) are known to feed directly on the zooids, given that *Z. verticillatum* colonies produce bromo-alkaloids, which are a class of chemical compounds related to drugs like nicotine, morphine and cocaine. It is thought that these secondary metabolites protect the colony by discouraging predation and preventing settlement of other organisms (Hill 2001).

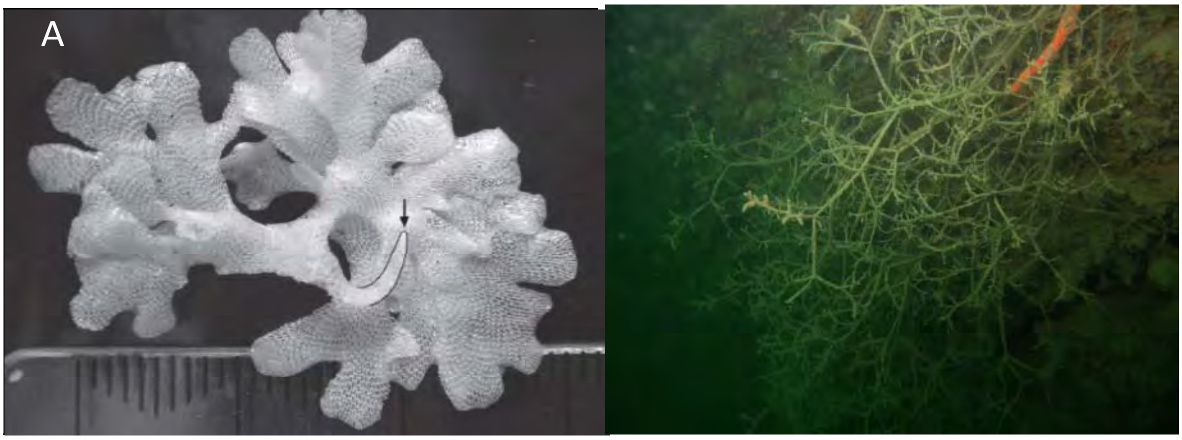

Figure 76. NIS bryozoan species. Left) a frond of *Membraniporopsis tubigera* from Poutu Beach, North Head, Kaipara; Right) *Zoobotryon verticillatum – "which can form 'curtains' up to 1.5 m in length when growing from marina pontoons in the Waitemata Harbour"* (M. Smith, pers. comm.). The size of this colony is about 50 cm. (Source: a) D. Gordon, NIWA; b) C. Middleton, NIWA).

Bed/reef forming bivalves

The Asian date mussel (*Arcuatula* (previously *Musculista*) *senhousia*) (Figure 77) is an opportunistic species that was first detected in New Zealand in the 1970s. It is a prime example of a species that modifies native habitats. In soft sediments it settles in very dense patches, sometimes numbering more than 16 000 individuals per square metre (Creese et al. 1997). Date mussels produce byssal threads which coalesce once densities reach over 1500 m^{-2} to form a continuous mat over the sediment surface (GSID 2013). At large scales, these dense mats trap fines, creating a silty layer that can alter the local physical environment and competitively inhibit macro invertebrate assemblages such as native bivalve species (Creese et al. 1997, Hayward et al. 2008) and polychaete tubeworm densities (Hewitt & Funnell 2005). At smaller scales, however, the mussel can benefit certain biota (Reusch & Williams 1998, GSID 2013).

Within the southern Kaipara, increased trapping of fine sediment within the mats has resulted in mud 'hummocks' ranging from 20 cm to 1.5 m high (M. Morrison, pers. obs.). It has been suggested that the large amounts of organic matter deposited by the mussel can also result in the accumulation of toxic metabolites such as sulphides (observed in the Kaipara) which can have adverse effects on seagrass growth (GSID 2013). Juvenile mussels in San Diego have also been reported to settle onto seagrass (*Z. marina*) in sufficient densities to weigh down the leaf canopy (Sewell 1996; cited in Reusch & Williams 1998), in addition to inhibiting rhizome growth, particularly where seagrass meadows are sparse and patchy (Reusch & Williams 1998). This has management implications given that many of Kaipara's meadows are irregular and patchy in distribution, especially the subtidal seagrass which is especially important as nursery habitat for snapper, trevally, and other species. Initial research in the Tamaki Estuary suggested that the impacts of Asian date mussel were largely local and ephemeral due to the mussel beds breaking up when the shellfish die after about two years (Creese et al. 1997). However, more recent work has shown Asian date mussels to have spread and become dominant in some areas, favouring some species and disadvantaging others (Hayward et al. 2008, Lohrer et al. 2008) Within the Kaipara, anecdotal and quantitative evidence suggests that the Asian date mussel is now widely distributed throughout both the northern (i.e. the Wairoa arm) and southern arms of the harbour (Hewitt & Funnell 2005, Haggitt et al. 2008, M.L., M.M., unpubl. data 2010–2013).

Figure 77: Left) Asian date mussel (*Arcuatula senhousia*), with few byssus threads shown; Right) Extensive Asian date mussel bed in Tamaki Strait, inner Hauraki Gulf, about 10 m water depth, June 2008. (Source: a) Ministry for Primary Industries; b) J. Williams, NIWA).

The Pacific oyster (*Crassostrea gigas*) was probably introduced into New Zealand in the 1960s (Cranfield et al. 1998) and has successfully out-competed the native oyster. Large oyster reefs can form on intertidal flats due to the propensity of larvae to settle on the shells of adults. The extensive oyster/mud reefs or mounds that form can subsequently alter local hydrodynamic conditions and sediment transport (Swales et al. 2011). Oyster reefs can persist for decades, with new recruits growing on the remnants of a prior cohort. Within the Kaipara, large numbers of such oyster reefs are present on the intertidal flats adjoining the Whakatu mangrove forest (Swales et al. 2008). The reduced wave exposure/and or increased surface elevation associated with growth of the oyster reefs, can also facilitate mangrove seedling settlement (Chapman & Ronaldson 1958). Reefs such as this can ultimately be buried by the rapidly accumulating mud as the mangrove forests expand (e.g. Firth of Thames, Swales et al. 2011).

Spartina (cord-grass)

Spartina species such as *Spartina alterniflora* (Figure 78) were introduced into the Kaipara Harbour in the 1950s (Shaw & Gosling 1997) in conjunction with the promotion of reclamation of tidal flats for agriculture; for protection of low lying shorelines from wave erosion, and to provide areas for stock grazing. However, *Spartina* marshes alter sediment budgets by promoting mud deposition of up to tens of millimetres per year (Swales et al. 2005b, Hayward et al. 2008). *Spartina* is also capable of colonising intertidal flats down to mean tide level, spreading more rapidly than mangroves due to their ability to spread asexually through radial extension of rhizomes. It forms dense mats and can grow up to 1.5 m high (NRC 2012). Its spread can lead to the exclusion of native intertidal plants such as *Sarcocornia* spp. and seagrass, reducing feeding grounds for fish species and exacerbating flooding (Hayward et al. 2008 – note that this is based on overseas research). Due to ongoing concerns of the environmental effects of *Spartina* spp. on estuarine environments, eradication programs have been instigated by regional councils and the Department of Conservation since the mid-1990s (Swales et al. 2011).

Figure 78: Example of the introduced saltmarsh species *Spartina alterniflora* in New Zealand. Photograph taken 12th February 2011, Te Kapa Inlet, Mahurangi Harbour, Auckland. (Source: Richard Taylor, Leigh Marine Laboratory, University of Auckland).

Mantid shrimp

The Japanese mantis shrimp (*Oratosquilla oratoria*) (Figure 79) first appeared in fishing nets in early 2010, with its pathway into the harbour unknown. To date, specimens captured have been mature adults, (around 15 cm length) and are considered to be about two and a half to three years old (Ahyong 2010). Their wide range in Kaipara suggests that they have been present for some years. Recent anecdotal reports, particularly from flounder fishers, reveal that ‘hundreds’ are now being caught in flounder nets. These shrimps have also been found in the stomachs of snapper, kahawai and juvenile rig (Getzlaff 2012, P. Yardley, pers. comm.). The species is 2–3 times larger than its native congeners, and burrows in soft sediments. Where abundant, it is an important bioturbator. It is an important commercial species in Japan, living in areas that have already been disturbed and degraded (Ahyong 2010), as well as being a valuable component of mixed crustacean fisheries in other regions where it has successfully invaded (e.g. parts of temperate Australia). As yet, nothing is known of the impacts of *O. oratoria* in New Zealand. However, there is some concern from local flounder fisherman that the poor catches recorded this year may be partially a result of predation on juveniles by the mantis shrimps.

Figure 79: Introduced mantis shrimp (*Oratosquilla oratoria*) collected in the southern Kaipara in 2010 (15 cm). (Source: Ahyong 2010).

Direct and indirect effects of fishing

Current evidence suggests that Kaipara fish stocks are coming under increasing pressure, with some species showing significant signs of decline (e.g., snapper), with localised depletion occurring in some areas for some species such as flounder (KHSFG 2003: note, this reference is over ten years old, so may not match the 2014 situation). There is anecdotal evidence of inefficient fishing practices leading to increased juvenile mortality and bycatch (e.g., KHSFG 2003; P. Yardley, pers. comm.). Historically, flounder fishing was carried out by 'stalling', a practice unique to the Kaipara (see Figure 33) whereby nets of about 550 m in length were run out at high tide, and fish were collected once the immense tidal flow had ebbed. Nets were comprised of thick cotton mesh which allowed the juveniles *"to hit them and bounce off*' (T. Scott, pers. comm.). The advent of fine nylon nets in the 1960s resulted in a higher incidence of capture for both juvenile flounder and snapper (P. Yardley, pers. Comm.). Up to 915 m of net are sometimes run out, with tie downs every 7 m (these pull the float line and ground line together) which trap the flounder in a pocket. Additionally, nets are sometimes left in the water for extended periods (Third 2013b). Current day fishing practices are outside the scope of this report, but the reader is referred to KHSFG (2003).

Fisheries impacts also include the removal of important biogenic habitat forming species (some of them being target species) such as horse and green-lipped mussels, sponges, red algae, bryozoans ascidians and other species (see Morrison et al. 2014), through being scraped off the seafloor by fishing gear. Some of these impacts in the Kaipara Harbour are now largely historical, such as the commercial dredging for green-lipped mussels across the 'Graveyard' harbour entrance, where up to 14 commercial dredges worked the area at the fisheries peak during the early 1980s (Third 2013b). However, recreational dredging for mussels still occurs periodically in the Wairoa Arm of the harbour, adjacent to Pareotaunga Point (Haggitt et al. 2008). Other fisheries interactions are ongoing, such as the removal of attached epifauna from the seafloor through contact with set nets and fishing lines.

Sand mining

Currently, the major sand extraction site is located on the Tapora and Fitzgerald Banks, undertaken by Winstone Aggregates Ltd (see Section 2.1) Further scoping has been undertaken for extraction covering 20 000 ha, adjacent to the Kaipara Heads, which includes the ebb tidal delta (Figure 80), (Haggitt et al. 2008). There is currently some uncertainty concerning the volume of sand being deposited in the Tapora area relative to the amounts being extracted. Given that this area encompasses the flood delta, it has the potential to significantly alter the local bathymetry, thereby modifying hydrodynamics (i.e., current velocities and wave conditions) and sediment transport into both the northern and southern arms of the harbour. This could result in flow on effects to the benthic communities including destruction of shellfish beds, alteration of fishing grounds and acceleration of shoreline erosion (Haggitt et al. 2008). Temporary increases in turbidity associated with sand extraction could be expected. However, given its location in an extremely dynamic area of the harbour, the environmental effects of dredging are probably minimal.

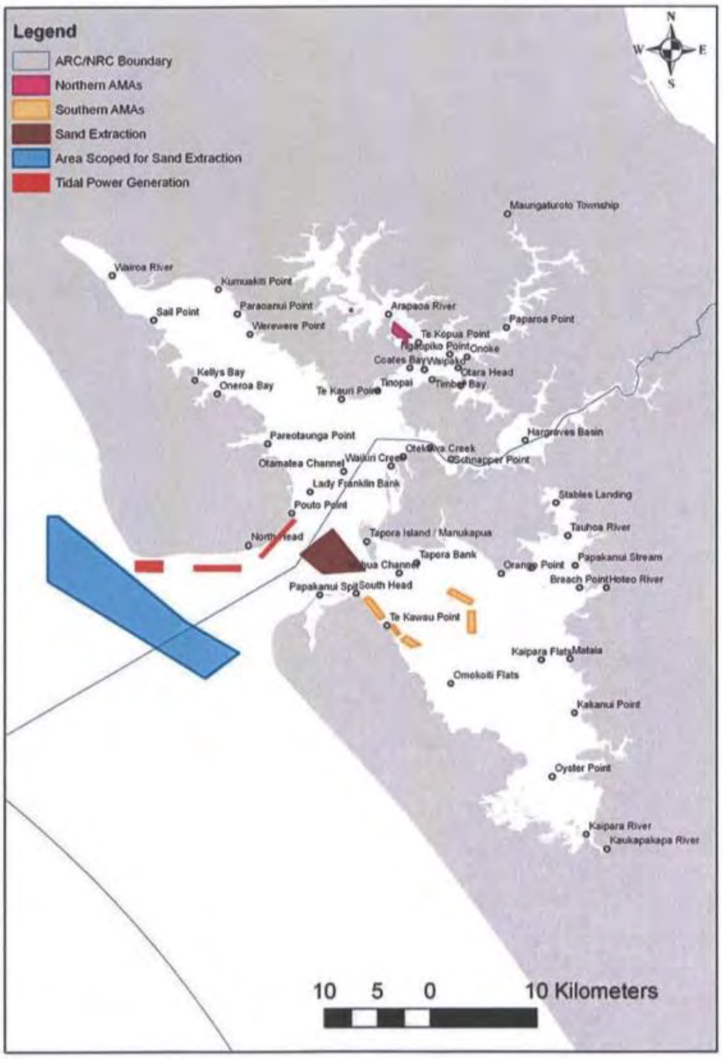

Figure 80: Current sand mining areas within the Kaipara, and those scoped for future extraction; Crest Energy proposed tidal turbine sites; and the original Aquaculture Management Areas (AMAs). The southern Kaipara leases have since been abandoned or declined consent (J. Dollimore; Biomarine, pers. comm.) and Crest Energy have decided not to proceed with the proposed installation of tidal turbines. (Source: Haggitt et al. 2008).

Power generation

The proposed marine tidal power development by Crest Energy (Figure 80) to install 200 turbines at the harbour entrance, although approved in 2011, was subject to baseline monitoring for three years to gather sufficient species and site specific information for a staged impact assessment, including the movement patterns and habitat use of fish before installation began. During the consent process, the potential impacts of collision, electromagnetic fields, noise and habitat loss were considered for marine fish and mammals (Francis 2009, 2010). Mitigation of potential impacts was identified for high ambient noise, non-continuous operation and the nature of the noise patterns (steady rise and fall rather than pulsed or sudden loud noises) and eventual habituation. However, Crest Energy has recently announced that the project has been put on hold for the foreseeable future due to the uncertainty over the electricity market (i.e., possible future Tiwai Point closure) and the partial privatisation of New Zealand power companies (Doesburg 2013).

Aquaculture

Aquaculture in the Kaipara Harbour has included rock oysters (see Section 2), Pacific oysters, and green-lipped mussels. Given the devastating mortalities on oyster spat and adult oysters as a result of the OsHB micro variant virus in 2010, some of the former southern aquaculture leases have been abandoned, while others have been declined permission to proceed following council hearings (J. Dollimore, Biomarine; pers. comm.). However, future intensive aquaculture could affect some areas of the harbour, particularly the southern areas with high species diversity (Hewitt & Funnell 2005) and seagrass meadows (but see Bulmer et al. 2012). Impacts of oyster farming on the marine environment include modifying water clarity and both the suspended and benthic sediments (see review Forrest et al. 2009; cited in Bulmer et al. 2012). This may be a result of deposition of organic material (faecal material) beneath farms, and accumulation of shells, both living and dead, and associated biota (Grange & Cole 1997, Christensen et al. 2003) and shading. This can potentially have detrimental effects on the density and diversity of benthos; sediment quality, nutrient cycling and productivity of benthic phytoplankton (Haggitt et al. 2008). Localised depletion of phytoplankton, due to the intensive filter feeding capabilities of high numbers of oysters and mussels, has also been cited as an effect. Conversely, other studies have shown higher concentrations of phytoplankton within the mussel farms due to the increased ammonium excreted by the mussels (Ogilvie et al. 2000). Recent work assessing the impacts of the BioMarine open water oyster farm (hanging baskets rather than the traditional stick and rack system), found only a very limited shading effect on the subtidal seagrass present, limited to shading directly under the basket lines. Overall, seagrass cover increased in both the farm and four sequentially adjacent control sites over the three year period of the study (Bulmer et al. 2012). Aquaculture is also recognized as a significant potential source of NIS species, which has resulted in strict controls being put in place by Biosecurity New Zealand both in the Kaipara harbour and nationally, in collaboration with the aquaculture industry.

5.3 Climate change

Climate change is expected to change the rate and intensity of many natural processes to which organisms are adapted. For example, sedimentation rates are predicted to increase in the future, while increasing water temperatures are already allowing many warmer water species to move their distributional range southwards in the Southern Hemisphere (and vice versa in the north), while colder water species are being reduced in their range. Seasonal activity patterns of species are also changing, such as time of spawning, and migration patterns. As such, the effects of climate change are many, and there will be interactions arising from some of these changes, that may be surprises to marine resource managers. New Zealand’s terrain is predominantly mountainous and hilly with 50% of the land mass at slopes of more than 28°, with many areas (including the Kaipara), composed of highly erodible soft siltstones/mudstones (Hicks et al. 2000, Morrison et al. 2009). This, coupled with high conversion rates of native forest to pasture for intensive agriculture (notable in the northern Kaipara Harbour) has substantially increased the susceptibility of slopes to landslides (Glade 2003, Gibbs et al. 2012, Figure 81). New Zealand’s inputs of sediments to the coastal zone are now especially high by world standards, approaching almost 1% of total world sediment yields (Robertson & Stevens 2006, Morrison et al. 2009). With the majority of sediments entering New Zealand estuaries during flood events (Hicks et al. 2000, Robertson & Stevens 2006, Oldman et al. 2009, Swales et al. 2011), the predicted increase in frequency and intensity of extreme weather events, including heavy rainfall and wave climates (west coast) associated with climate change, is likely to increase levels of sedimentation within both freshwater and marine environments (Fowler & Hennessey 1995, Thrush et al. 2004, Willis et al. 2007, Morrison et al. 2009).

Increased sedimentation can produce a wide range of biological effects, both from deposition of fine sediments on the seafloor, and as suspended sediments in the water column. Ongoing re-suspension and deposition events (e.g. by storms and fishing gear) may shift sediments between these two states. The effect of degradation of water quality is also well documented, leading to reduced seagrass coverage due to enhanced biomass of phytoplankton, epiphytes, macroalgae, and Total Suspended Sediments (TSS), shading and smothering seagrass. Elevated levels of TSS have been shown to reduce the diversity and abundance of both pelagic and benthic invertebrate prey (e.g., for juvenile fish) in both freshwater and estuarine systems (Quinn et al. 1992, Harding et al. 2000, see various reviews: Lloyd 1987, Newcombe & MacDonald 1991, Bash et al. 2001, Berry et al. 2003, Gibbs & Hewitt 2004, Thrush et al. 2004, Morrison et al. 2009) by abrading, clogging and smothering organisms; reducing interstitial spaces; and reducing food supply and quality through increased light attenuation and hence aquatic algae and plant productivity. Elevated suspended sediments have also been shown to increase fish mortality and cause sub lethal responses including reductions in feeding rates (reduced visibility of pelagic prey), changes in type and/or ratio of prey consumed, reduced growth, reduced fish density, avoidance of suspended sediments, along with physiological changes including changes in blood physiology and gill structure, increased respiration and cough responses and increased susceptibility to diseases (Newcombe & MacDonald 1991, Kerr 1995, Morrison et al. 2009). Recent survey and empirical work by Lowe (2013) has demonstrated such effects on juvenile snapper (50–90 mm). Experimental tank treatments of increasing TSS loads found effects including higher weight loss, increased mortality rates, significant increases in gill damage (epithelial hyperplasia and fusion of the gill lamellae) which impaired respiratory function, increased gulping and coughing at the water surface, higher respiration rates and decreased activity, consistent with the effects of anoxia. A field survey of seven northern estuaries, including the Kaipara (fish collected adjacent to the concrete 'blinker' in the southern Kaipara), found juvenile snapper to have significantly lower condition indices (body weight relative to fish length) in the more impacted estuaries, which include the Kaipara (characterised by higher TSS and catchment urbanisation) (Lowe 2013).

Also unknown but of concern is the potential impacts of changes on the seasonal biology of many species, including spawning triggers and seasons, and migratory behaviour. Arguably these are poorly known for most if not all estuarine and coastal finfish fisheries species in New Zealand (Morrison et al. 2014), as well as most invertebrates. This also holds for all of the other species in the ecosystem on which they interact, including prey and predators, and more broadly, diseases and pathogens.

Figure 81: Left) stock grazing (beef) on steep land in the northern Kaipara is often associated with localised erosion, Right) silt laden storm water plume discharging from the Hoteo River mouth on the ebb tide on 22nd March 2011. The valuable subtidal seagrass meadows (as juvenile fish nurseries) of the southern Kaipara lie between this river mouth, and the southern Kaipara peninsula which can be seen in the background (harbour in the background to the right). (Source: Gibbs et al. (2012), photographs M. Pritchard & M. Gibbs respectively, NIWA).

Increased deposition of suspended sediments can also adversely affect species which form 'biogenic' habitats, many of which provide important fisheries habitat functions (Morrison et al. 2009, 2014, in revision, in press). New Zealand examples of the declines of such habitats include horse mussels (*Atrina zealandica*) (Ellis et al. 2002, Norkko et al. 2002, Hewitt & Pilditch 2004, Lohrer et al. 2004, 2006a), sponges (Lohrer et al. 2006b), green-lipped mussels (Morrison et al. 2003), and seagrass meadows (Short & Neckles 1999, Park 1999, Inglis 2003 Turner & Schwarz 2006, Morrison et al. 2009, in revision, Matheson et al. 2010). As an example Tauranga Harbour lost an estimated 90% of its subtidal seagrass beds between 1959 and 1996 (Park 1999), with potential additional early losses having occurred prior to 1959. Internationally, seagrass meadows are regarded as sensitive indicators of water quality, being particularly vulnerable to water quality degradation (i.e. sedimentation/eutrophication), and are often referred to as 'coastal canaries' (McKenzie & Yoshida 2009). Increasing sedimentation with future climate change would be expected to exacerbate such issues. Paradoxically, increasing deposition of fine muds has seen New Zealand's mangrove forests (*Avicennia marina*) rapidly expanding in the upper North Island in general (Schwarz 2003), with for example, the inner Firth of Thames mangrove forest expanding seaward by an average of 20 metres a year over the last 50 years (Morrisey et al. 2007, Swales et al. 2007, Willis et al. 2007). However, rising levels are expected to place mangrove forests under increasing threat as their tidal range is contracted against shore-lines (see below).

Elevations in sea level are predicted to have a negative impact on seagrass growth, present day distributions and abundances (Orth et al. 2006, Wong & Vercaemer 2012). An experimental study by Short et al. (1995) revealed that an increase in water depth by 50 cm (expected change to 2070 in Australia) reduced light available to the seagrass canopy by 50%, reducing growth and productivity of *Zostera marina* (a sister species to New Zealand's seagrass species *Zostera mulleri*) by about 40%. As the amount of available light reduces (via increasing depth and turbidity), those seagrass areas growing at their maximum depths, i.e., subtidal meadows (valuable juvenile fish nurseries) will retract first with a shoreward shift in location (Waycott et al. 2007). If habitat availability is limited by barriers such as mangroves and unsuitable sediments, seagrass loss is inevitable. Additionally, the expected storm surges and elevated winds are likely to increase erosion of shorelines and re suspend sediments, thereby exacerbating turbidity levels in conjunction with destabilisation and dislodgment of seagrass (Cabaco et al. 2007, cited in Connolly 2009). Rising water temperatures would also lead to heat stress for temperate seagrass meadows, whilst leading to the increased incidence of fouling invertebrate blooms and canopy collapse (e.g. zoobotryon) (Williams 2007). Warming temperatures would also allow animals having planktonic larvae to extend their ranges, thereby enhancing the establishment of introduced marine species (Carlton 2000, cited in Williams 2007) which might compete with or graze on seagrass. Moreover, it is suggested that increasing temperatures may cause temperate species such as *Zostera* to contract globally; with no expansion pole-ward possible in New Zealand, as seagrass already occurs in the southernmost estuary of Stewart Island (Cook Inlet, M.M., pers. obs.), and the sub-Antarctic Islands have little in the way of sheltered estuaries. It is not clear whether this effect would be sufficient to displace seagrass from the north of New Zealand, or even to reduce its resilience; as so many predictions for the future have yet to be tested.

Conversely, increased concentrations of carbon dioxide in the atmosphere and increasing temperatures may lead to increased photosynthesis and growth of mangroves, with subsequent expansion of their geographical range to higher latitudes (i.e., southwards). Within New Zealand, this would be dependent upon the propagule's successfully reaching more southern habitats (Morrisey et al. 2007). Nevertheless, rising sea levels may reduce mangrove distribution on the shoreline as the lower parts of the estuary are flooded more frequently or permanently submerged. This may be exacerbated by the increased erosion of the lower shoreline by storm surges. However, if sedimentation rates are high, this might mitigate sea level rise with a net effect of reduction in the rate of seaward mangrove spread. Where sedimentation rates do not keep pace, rising sea level may reduce the width of the mangrove zone or cause migration upshore, with inner zones being flooded more frequently (Morrisey et al. 2007).

6. MONITORING HABITATS OF SIGNIFICANCE TO FISHERIES

6.1 Selection of habitats and remote sensing approach

In the New Zealand context, remote sensing and mapping of marine (fisheries) coastal habitats are at a relatively early stage of development and implementation. Given its small size, "in-country" remote sensing technologies for marine habitat mapping are limited to single and multi-beam sonars, side-scan sonar, and aerial photography. In addition to these approaches, a range of satellite based sensor systems pass over New Zealand on a regular basis, from which data can be purchased through a variety of overseas data sellers. These satellite based technologies in particular are developing rapidly, with increasing spatial resolution and spectral processing abilities, but are not yet at the stage of replacing aircraft mounted aerial imaging for finer-scale resolution work.

In the estuarine and coastal zone (defined as extending to the edge of the continental shelf, at about 200 m water depth), aerial photography is usually used for the mapping of shorelines, the intertidal, and sometimes the immediate shallow subtidal area. Beyond these very shallow areas where light penetrates the water column sufficiently, vessel mounted acoustic systems are used, including side-scan sonar (encompassing water depths from very shallow down to about 50 m, depending on the system), and multibeam sonar, which can operate out to the thousands of metres depth. These remote sensing approaches do not map the same habitat components: aerial photography maps surface cover including vegetation but provides no depth information; side scan sonar provides good detail on surface sediments and their bed-forms, and harder biogenic surface features such as horse mussels and bryozoan mounds but does not provide depth information; and multibeam sonar provides comprehensive three dimensional topographic (depth) information, and a measure of bottom ‘hardness’ as a proxy for sediment type, but gives no direct measure of biological features. In addition, not all ecological habitats and features are detectable by remote sensing, regardless of what method is used. Therefore, the choice of the appropriate remote sensing approach/s needs to be matched to the mapping objectives of any given project, and what can be meaningfully detected and mapped. There are also a number of ‘scale’ issues that need to be considered (see discussion).

No remote sensing method directly determines the identity of any quantified geological or ecological features/habitats, and it is necessary to do ‘ground-truthing’ to assign true identities. This involves selecting a number of points within the surveyed area, which collectively cover all of the features of interest, which are then visited, viewed, and assigned true identities. The most common ground-truthing methods are drop video and still cameras, which allow analysts to view the seafloor directly to assign habitat identities.

The Kaipara Harbour presents several challenges for remote sensing, which are common to many shallow water systems. The most limiting factor for vessel deployed sensors (e.g. side-scan and multibeam sonars) is very shallow water depths, which in particular limit the mapping footprint of multibeam sonar, where the swathe mapping width is proportional to water depth (about 4× water depth). Survey vessel access and navigation can also be difficult, especially where the seafloor topography is three-dimensional, subject to strong tidal regimes, and/or swell exposure (e.g. Morrison et al. 2010). Previous work in the southern Kaipara Harbour using single beam (QTC View) and side-scan sonars has produced imagery/data which is plagued by artefacts and difficult to interpret meaningfully (Hewitt & Funnell 2005). These authors concluded that “*much of the differentiation* [between seafloor types detected by QTC] *was between different degrees of wave and current disturbance in sandy sediments. Because of this a high degree of concordance between the acoustic data and the fauna and flora was not observed*”. Light-based remote sensing technologies (e.g. aerial photography and other aircraft borne spectral band detection devices such as CASI) also have their limitations, including turbid waters limiting light penetration through the water column, surface glare from sunlight, and rough sea surfaces impairing image interpretation.

Objective 3 of this project called for the identification of critical fisheries habitat in the Kaipara Harbour, to allow for the “*Design and implement* [ation of] *cost-effective habitat mapping and monitoring surveys of habitats of particular significance for fisheries management in the Kaipara Harbour*”. Following on from the findings of Objectives 1 and 2, along with our knowledge from other work streams (Morrison et al. in revision) and previous reviews (Turner & Schwarz 2006, Morrison et al. 2014, in press), we selected ‘subtidal seagrass’ as the critical ‘fisheries’ habitat to focus on. This was discussed with MPI and confirmed (passing through a ‘decision gate’, as specified in the original project proposal). A short description of why this habitat was chosen is given below.

Recent work has shown that the Kaipara Harbour (and its habitats) is likely to provide the majority of juvenile recruits to the adjacent west coast North Island snapper stock (SNA 8) (Morrison et al. 2009). Within the harbour, small fish assemblage sampling across a range of habitat types (see Objective 1) has shown that subtidal seagrass meadows hold comparatively very high densities of juvenile snapper and trevally, as well as other fish species. This association also holds for subtidal seagrass meadows in other estuaries such as Parengarenga and Rangaunu on the East Northland coast, and in Te Rawhiti Strait, Bay of Islands (Morrison et al. 2009, in review b; Lowe 2013; M.M., & M.L., unpubl. data). Subtidal seagrass habitats in the Kaipara Harbour are effectively limited to the southern half of the harbour, apart from a few possible small discrete patches further north towards the Tinopai arms of the Kaipara.

Both intertidal and subtidal seagrass are ‘map-able’ using aerial photography, as shown by several New Zealand studies (e.g. Park 1999, Hartill et al. 2000, Fyfe 2003, Matheson et al. 2010), as well as many international studies. Subtidal seagrass is a relatively ‘rare’ habitat in New Zealand, with seagrass physiologists viewing it as essentially an inter-tidal plant requiring high light levels, with the ability to extend into subtidal areas where the water clarity is sufficiently high to permit photosynthesis (Turner & Schwarz 2003). The subtidal (and intertidal) extents of seagrass beds in New Zealand have undergone large declines over time scales dating back to at least the late 1930s (see accounts in Inglis 2003) in New Zealand, although quantitative records are limited to only a few harbours, and rarely extend further back in time than the 1940s. Significant changes may have occurred before the 1940s (Inglis 2003, Turner & Schwarz 2003, Schwarz et al. 2006), although there is some anecdotal evidence of possible recovery in some northern New Zealand areas and/or some longer time scale abundance cycles/oscillations. This includes the Kaipara Harbour, where seagrass was (putatively) much less common in the early 2000s, but has since increased in extent. This included observations as part of aquaculture impact assessments (late 1990/early 2000s) and relatively recent fish-sampling surveys (e.g. 2003, 2005, 2013), as well as reports from local fishers and aquaculturists. Subtidal seagrass has also re-appeared in Whangarei Harbour, where since 2008 around 3.5 km^2 of subtidal seagrass (as dense patches) has become established (D. Parsons, pers. comm.).

Other potential habitats in the southern Kaipara were also considered when deciding which habitats should be mapped. Mangrove forests are common in the Kaipara Harbour, and have increased in spatial extent over time. Previous fish sampling of mangrove forests has shown that mangroves provide important juvenile nursery habitats for grey mullet, short-finned eels, and parore (the latter on the east coast only). Short-finned eels were found to respond (positively) to structural complexity (number of trees, saplings, and recruits), while juvenile grey mullet were positively associated with higher suspended sediment loads and muddy substrates, and parore to clearer waters and sandier substrates (Morrisey et al. 2007, 2010). Given the available funding for Objective 3, and the lower economic ‘value’ of these species, as well as the increasing spatial extent of mangroves over time (see Swales et al. 2011), mangroves were not selected for mapping. However, after the first mapping run, it was decided that aerial coverage of the full southern Kaipara Harbour and its habitats (above and beyond that of the critical habitats targeted in the ENV200907 project) would be very useful, and additional funds from the MBIE programme “Coastal Conservation Management” (CCM) were used to extend the overall extent of the photography to cover: the intertidal flats flanking the subtidal seagrass banks and channels of the southern Kaipara, the upper harbour area south-east of Shelly Beach, and the various mangrove lined tidal channels to the north-east, east and south of the main body of the southern harbour arm. These areas have subsequently been assessed and mapped for intertidal seagrass, Asian date mussel beds, and associated low red algal canopies. While mangrove forests were captured and are readily identifiable in the imagery, they were not digitally mapped as part of this current project.

Deeper subtidal habitats were also considered in the critical habitat selection process, in particular green-lipped mussel and horse mussel beds. Dense green-lipped mussel patches are readily distinguishable from reef and soft sediment habitats, using acoustic ‘signatures’ collected with a single beam sonar and processing using the acoustics processing software package QTC View (Morrison et al. 2010). Extensive green-lipped mussel beds occur on low-lying rock throughout much of the northern side of the entrance to the Kaipara, extending from the shallow subtidal down to water depths of about 30 m. However, their potential value as habitat for small fish assemblages is effectively unknown, although the limited sampling of this habitat by towed video camera and by beam trawl suggests that any small fish habitat value is probably modest at best in this specific environmental setting (exposure to heavy seas, exceedingly strong tidal currents, and the presence of large predatory fish). Horse mussels are also found in the Kaipara Harbour, with their presence as bycatch in beam trawl samples being positively associated with catch rates of juvenile snapper and trevally (e.g. Morrison et al. 2009, Section 4.10). Horse mussel densities on the Kaipara Harbour seafloor seem to be relatively low (as noted by Hewitt & Funnell 2005, as bycatch during beam trawl sampling, and in the drop camera remote sensing work), and do not form the large dense beds often seen in estuaries and shallow embayment's on the adjacent east coast, and more broadly around New Zealand (Morrison et al. 2014). Dense horse mussel beds are detectable and can be mapped using side-scan sonar. Hewitt & Funnell (2005) did not identify any horse mussel beds in the southern Kaipara Harbour using side-scan sonar in the main channel area. Given the expected absence of dense horse mussel beds and the logistical limitations and cost of deploying side-scan sonar in very shallow waters, this method was not adopted here.

6.2 Habitat survey methodology

Target area selection for aerial data capture

The known areas of subtidal seagrass (the primary target for mapping) both prior to, and subsequent to this present project, in the southern Kaipara Harbour are all located in the central lower harbour region, across a series of largely subtidal shallow sand banks with some intertidal components. These subtidal banks are separated by areas of shallow water from the extensive intertidal flats in the surrounding harbour area, which grade up to the high tide mark. In many areas these intertidal flats support extensive intertidal seagrass meadows and mangrove forests towards the upper part of the tidal range. The remainder of the southern Kaipara Harbour is composed of extensive upper harbour inlets and riverine systems along the north-eastern, western, and southern extents of the southern Kaipara which are lined with mangroves.

Initially a mapping footprint was selected that covered the central lower south Kaipara Harbour, extending up the main harbour body to just north of Shelly Beach. This footprint covered the known subtidal seagrass meadows, as well as potential areas where subtidal seagrass might conceivably grow in the future (bare sandy subtidal banks). During this first mapping run on 3 May 2012, not all of the target 'tiles' (individual photographs) were captured, and a second mapping run was needed to complete these. At this time, it was decided to increase the overall proposed imagery footprint to cover the entire southern Kaipara, to maximise its potential use into the future beyond just the primary habitat target of subtidal seagrass. The additional costs incurred by this survey expansion were covered by the MBIE 'Coastal Conservation Management' programme. Due to issues of weather, tides, plane and camera availability this second mapping run was significantly delayed, and eventually completed in the following seasonal mapping window, on 9 January 2013.

Aerial survey design

New Zealand Aerial Mapping Ltd (NZAM) was subcontracted to undertake Red/Blue/Green (RGB) and near infrared (IR) aerial photography over the southern Kaipara Harbour. All of the aerial photography and post-processing of the raw imagery was undertaken by NZAM. The aerial photography was flown to provide a pixel resolution of 0.2 m, at low water, given suitable lighting, cloud free and calm sea conditions. Geo-positioning was provided by DGPS and IMU (Inertial Measurement Units) data generated by a Vexcel UCX camera system. In addition, several survey control points around the outside of the extent were used to tighten up the aerial triangulation providing accuracy within ± 1.0 m. The photo imagery was photogrammetrically ortho-rectified, and delivered to NIWA as TIFF/TFW tiles to NZTM 1:2000.

Aerial image processing

Seagrass patches can be identified as distinct features in the sea bottom by looking at variations in the radiance detected in aerial or satellite imagery. This of course relies on atmospheric, water column and sea bottom conditions to be right to distinguish the feature in question from the entire spectrum of objects that lie in the sea bottom. To facilitate this we used false colour Infrared Images (RGBI), tuned to the spectral bands of vegetation, to highlight and distinguish these habitats from non-vegetated areas.

Colour images, mapped at 1:2000 scale (NZTM2000), with a resolution of 0.2 m were obtained from NZAM as tiles in TIF/TFW format. The total coverage extent was 180 km^2. The photo tiles (each 1.5 km^2) were initially combined into one large layer with the aim to globally classify these for the whole extent. This was found to be impossible, however, because of variations in colour and lighting, possibly due to differences in water depth, turbidity and sea bottom surface composition across the range of tiles. Given this, it was decided to process each tile separately.

Image analysis was used to “extract” the outlines of seagrass patches. We used the specialist remote sensing software ENVI (from ITT Visual Information Solutions). A technique called “Feature Extraction” was used. This involves an object based approach (as opposed to a pixel based one) whereby features of interest are identified based on spectral colour and brightness, as well as the “texture” (i.e., degree of pixel to pixel variability) in the vicinity of the feature.

The analysis proceeded in three steps. First, image-processing software was used to separate out the “seagrass” patches based on their spectral and textural characteristics. This involved the visual selection of a “training set”, which was then used by the software to segment, merge and compute parameters for those features. Next a supervised classification was performed, and contiguous areas converted to polygons and exported, together with attributes such as “class” and area, to a shape file. Lastly, the “class” attribute was used to filter out “non-seagrass” patches that formed the rest of the polygons, and exported to the shape file.

Extent and accuracy of patch extraction was affected by water clarity, depth, and ability to distinguish between different patch types, including mussel beds and sediment patches. This is often the case in deeper water, where the imagery becomes “noisier” and consequently more difficult to classify. In such cases, image classification was augmented with manual digitisation of patches. Due to sun-glare issues in some eastern tiles, manual digitising was also required for much of the intertidal seagrass on the eastern side of the harbour.

The final step in the process was the amalgamation of all tile derived patch polygons into a single layer. This step also allowed the merging of edge patches (contiguous but separated by tiles), and the manual removal or addition of unclassified patches. The shape file was then imported into a GIS (ArcGis10). While beyond the scope of the present project, metrics such as area and perimeter can also be calculated and assigned to each patch. Associated GIS packages, such as FRAGSTATS, can then be used quantify the seagrass patchwork, by calculating metrics such as the perimeter to area ratio to determine shape, proximity between patches, diversity, patch type or uniqueness, connectivity and other measures. Such analyses are planned as part of the MBIE CCM project on the juvenile and small fish assemblages associated with the habitats mapped in this current project.

Ground-truthing approach

Ground-truth field data was collected to help assign habitat identities to the object polygons generated by the image processing. For each provisional habitat type (biotope) present (i.e., seagrass, date mussels with associated red algae, bare substrate, unknown), replicate sites were selected both across and within different habitat patches across the southern Kaipara Harbour aerial photography extent. Two field methods were used to assign habitat identities to the object polygons.

For the first method, at each site a small video camera attached to a triangle frame with scale bar was lowered to the seafloor, and the imagery assessed in real time through a surface feed to a monitor. With the camera viewing the seafloor, the boat was allowed to drift with wind and tide for up to two minutes, while the video observer noted the dominant habitat type and any associated flora and fauna. This was undertaken about three hours each side of low tide, to maximise light penetration through the often turbid water to the seafloor. One hundred and thirty three sites (133) were assessed during this method over a three day time period (10–12 October 2012). Following this, issues of poor weather, lack of good tidal time windows, and staff and boat availability did not permit further data to be collected; and additional ground-truthing was left to the start of 2013.

As part of the MBIE funded “Coastal Conservation Management” programme, an extensive fish habitat survey (in particular of subtidal seagrass meadows) of the southern Kaipara Harbour was carried out in early 2013. While this survey was undertaken outside the time scope of this current report (i.e. the survey work has only recently been completed, and sample processing and analysis is now in progress), the initial field data collected are used here to further inform the ground-truthing process. In the fish-habitat survey, the aerial imagery was used to assign fish sampling sites across the various putative habitat polygons and areas identified in the southern Kaipara Harbour. One hundred and fifty one sites (151) were sampled during this survey between late February and April in 2013. Sites were assigned within large discrete ‘sampling blocks’; both to accommodate the existence of discontinuous subtidal seagrass meadows across different subtidal banks separated by deeper water channels; and to maximise actual sampling time given the vessel (sampling) time lost in transit between sites across large spatial scales between the numerous banks and bars of the southern Kaipara Harbour.

At each sampling site, a ‘sampling ramp’ was deployed from the side of an oyster barge onto the site, and a fine mesh beach set from the barge using 50 m warps. A small inflatable boat was used to run out the first warp, deploy the net parallel to the barge, and then deploy the second warp back to the barge. The net was then hauled by people on foot back to the barge and up the sampling ramp, providing a fish assemblage sample from a known areal extent. At the same time, various environmental variables were recorded, both for the water column, and the seafloor, including a visual assessment of which habitat/s were present. Sampling for this work was largely carried out across low tidal windows for all lower intertidal and immediately subtidal habitats. The effective maximum water depth sampling limit was around 1.4/1.6 m, depending on the height of the people hauling the net. Some additional high tide sampling of upper intertidal habitats was also undertaken to assess the fish that utilised these habitats during the high tide.

For both the video camera drop and beach seine ramp data, each site was assigned a primary habitat type with an associated spatial position, and these were plotted over the habitat polygons generated by the aerial image processing. A table of % correct habitat classification by remote sensing, based on the ground-truthing data, was assembled.

6.3 Results

A mosiaced image of the southern Kaipara Harbour aerial imagery, and then with the the ground-truth stations added, is given in Figures 82 and 83 respectively.

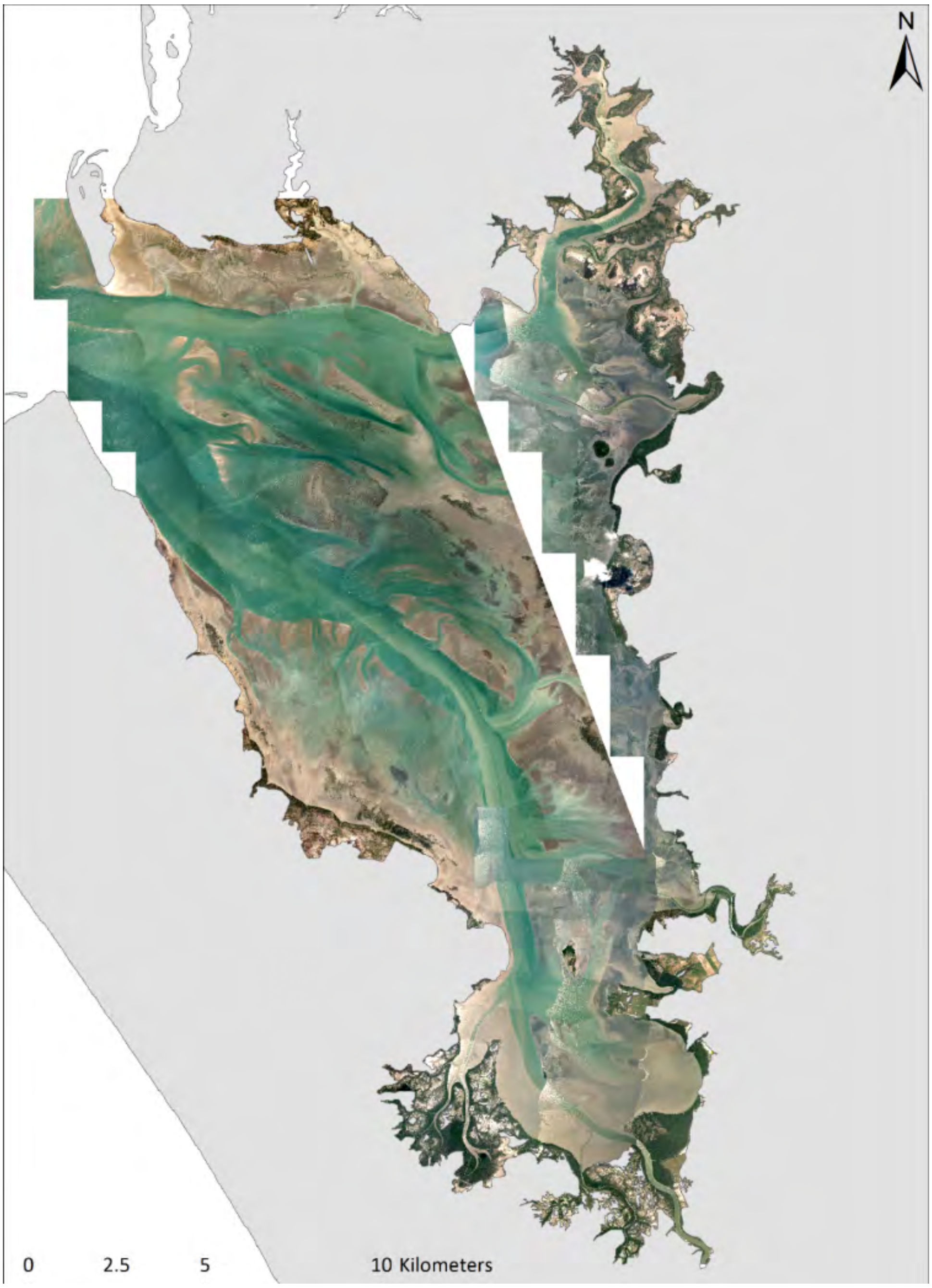

Figure 82: Raw photo imagery (RBG) as provided by NZAM. Both mapping runs are shown: the white areas in the image are covered by the second aerial run, but are excluded here as the two image series visually 'clash' strongly when displayed simultaneously. Soft sediment intertidal and shallow subtidal areas appear as pale colours, while the channels as various shades of blue/green, along with some sediment plumes. Most of the 'shade changes' seen are artefacts from the stitching together of many separate image tiles, including in many cases the 'best' parts of individual tiles where multiple images overlap. Note the relative bathymetric complexity of the central harbour bank areas, as well the extensive shallow subtidal areas to the west, east and southern side of the harbour.

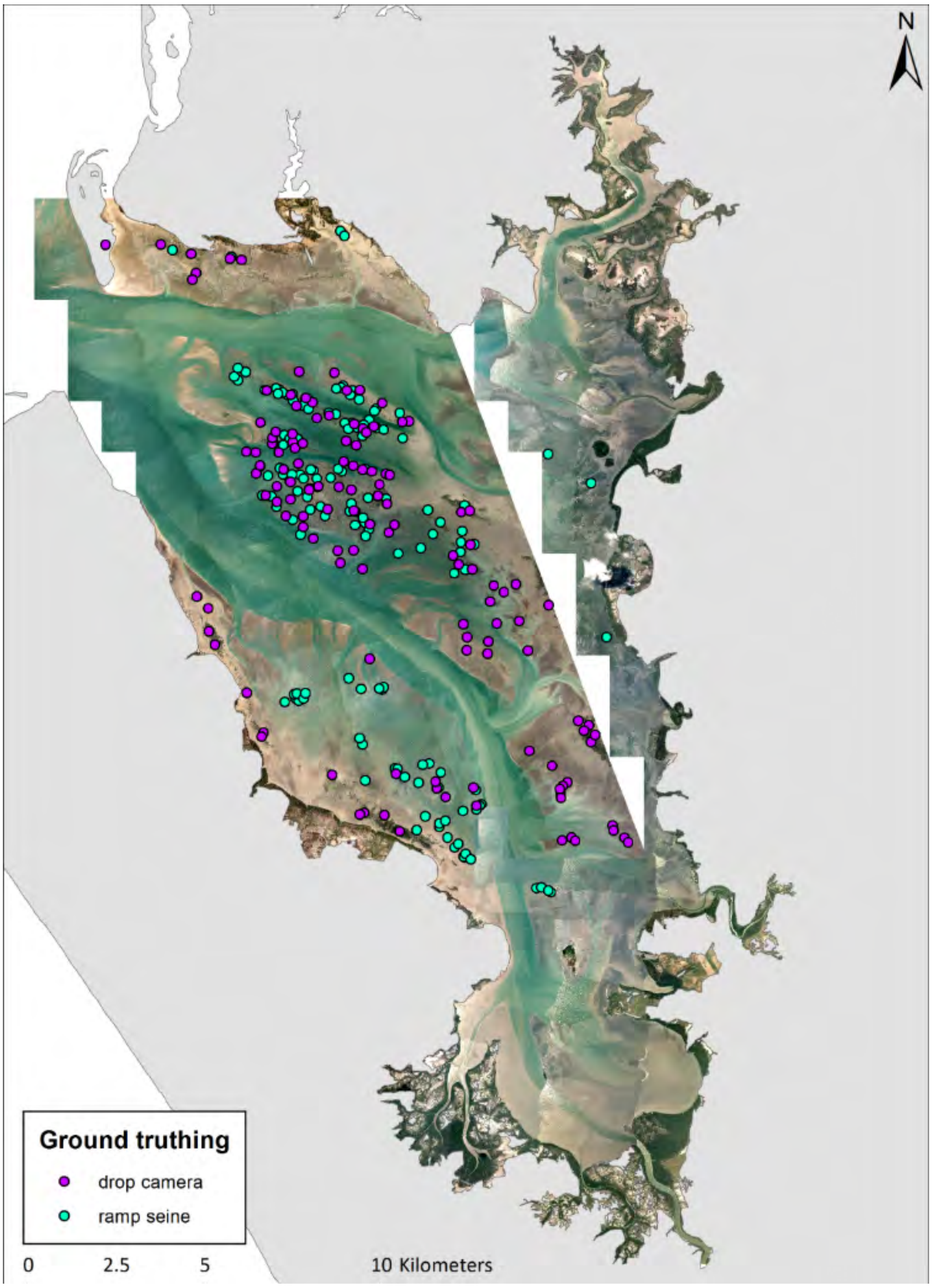

Figure 83: Overlay of the ground-truthing sites, as collected over high tides by drop camera, and both high and low tides by beach ramp seine sampling (only the start points are shown here, given the scale of the map).

Ground-truthing

Ground-truthing confirmed three primary habitat types: seagrass (both intertidal and subtidal); Asian date mussel beds (often with accompanying over-lying red algae as various degrees of 'secondary' cover), and bare sediments (ranging from soft muds to hard sands) (Figures 84–86). These three primary ground-truth habitats matched very well to the (putative) habitats initially identified on the aerial imagery with classification accuracy rates ranging from 93.4% (bare sediments), to 97.1% (Asian date mussels) and 97.4% (intertidal and subtidal seagrass) (Table 15).

Table 15: Remote sensing classification accuracy rates for the three primary habitat types. Numbers in brackets are the number of ground-truth samples collected.

True habitat type	Remote sensing class		
	Seagrass	Asian date mussels	Bare sediments
Seagrass	97.4 % (150)	–	2.6% (4)
Asian date mussels	–	97.1% (66)	2.9% (2)
Bare sediments	4.9% (3)	1.6% (1)	93.4% (57)

Misclassification rates were low, ranging from 1.6% to 4.9% depending on class. Seagrass (intertidal/subtidal) habitats were never misclassified as Asian date mussels, nor were Asian date mussels ever misclassified as seagrass. Misclassifications were always with bare sediment for these two classes, and vice versa. There are several probable reasons for this. Firstly, there was a significant time delay between the aerial imagery capture, and the undertaking of the two ground-truthing approaches. For biogenic (living) habitats, significant change is possible over relatively short time periods. This means that seagrass may have gone missing from sites where it was present at the time of aerial imagery capture by the time of ground-truthing, and vice versa it may have appeared in areas where it was absent at the time of image capture. Evidence of sand movement smothering some seagrass areas (largely the edges of extensive meadows) were evident at some sites. The hummock bed forms characteristic of subtidal seagrass presence in this harbour (resulting from its ability to trap sediments) were also seen at a number of sites without seagrass, suggesting the loss of seagrass cover from these areas. These bed forms persist for some (unknown) time after the loss of seagrass. Secondly, there are almost certainly detection threshold differences, as well as scaling differences, between the aerial imagery and the ground-truthing. Essentially the remote sensing approaches were binary, either classifying a habitat as being present or absent. In reality, seagrass cover can range from a very dense 100% seafloor cover, through to very short 'wispy' blade tufts, with the full spectrum in-between; as well as the related spectrum of patch sizes mosaics between seagrass and bare sediments. We do not know at what threshold the remote sensing ceases to detect seagrass at low coverage or IR intensities. Conversely, ground-truthing using video cameras can detect the presence of seagrass down to individual blades, and at fine spatial scales (one to tens of metres), so has a much finer detection threshold than inferred from the IR signatures. A similar situation holds for the Asian date mussels, where the IR and RBG signatures are likely to be at least partially driven by their often associated canopies of foliose red macro-algae, and potentially microscopic algal forms as well, growing on the byssus threads. These issues, while mentioned here, did not significantly affect the overall successful classification rates for the imagery, and are not of great concern in this current study.

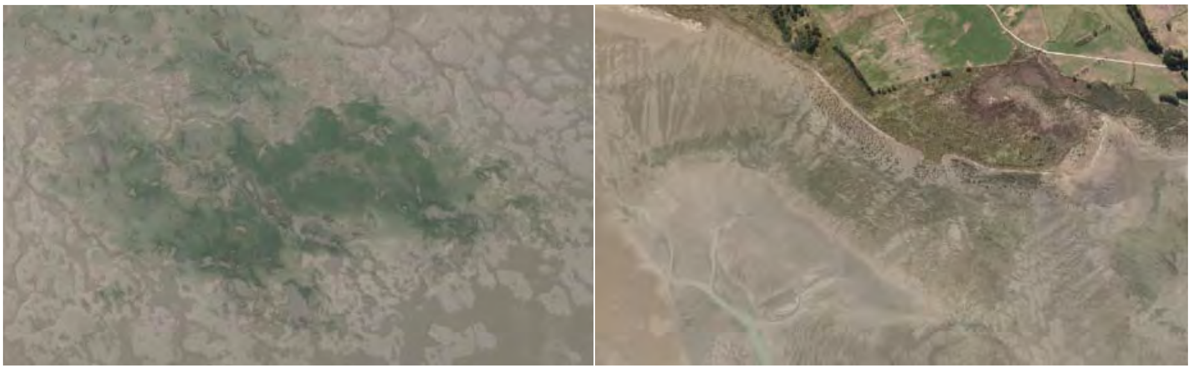

Figure 84: Examples of intertidal seagrass images. Left) dense uniform seagrass cover; Right) less dense patchier intertidal seagrass cover. Note that these two images are not to the same scale.

Figure 85: Examples of subtidal seagrass images from two different sand banks, both showing the rosette mosaics characteristic of subtidal Kaipara Harbour seagrass. Left) bank with Biomarine Ltd oyster farm in centre of image, visible as oyster basket lines, with seagrass growing under the shallower southern lines. Right) subtidal seagrass on a bank to the south of the first image; the bare circular areas contain hummocks characteristic of seagrass cover, the seagrass is suspected to have disappeared from that area. Note that these two images are not to the same scale.

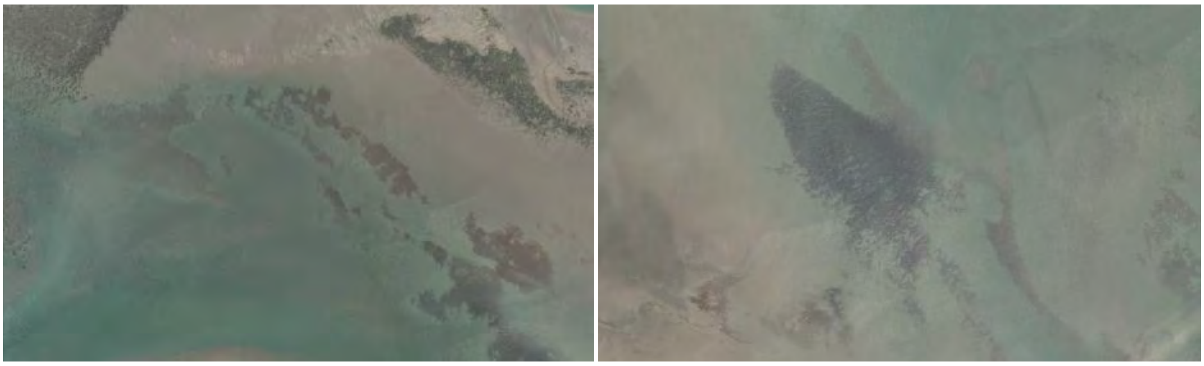

Figure 86: Examples of Asian date mussel patches. Left) large bed areas arm in centre of image occurring in a shallow water 'embayment' area, flanked by subtidal seagrass to the north-west, and intertidal seagrass meadow to the north-east. Right) a large Asian date mussel 'reef' in the central area covered by red algal canopy, surrounded by a complex of smaller Asian date mussel patches. Note that these two images are not to the same scale.

Some finer scale habitat variations were also visually identified through the ground-truthing site work. Some intertidal seagrass habitat patches in the lower bank areas were initially thought to be potentially algal turf patches, due to their extremely uniform smooth textural appearance in the raw imagery. However, ground-truth inspection found them to be dense seagrass patches, in contrast to the much sparser blade densities of subtidal seagrass patches, and intertidal seagrass areas found higher up the shore on the western, northern, and eastern shorelines.

In some of the higher intertidal shore seagrass areas, the green algal species *Ulva* (exact species not confirmed) became more common and widespread, forming patchy mats interlaced under the low seagrass canopy, as well as in patches of its own in small open spaces in the seagrass cover (Figure 87). Individuals of the fleshy algae *Codium* sp. were also often present, although in much lower densities than *Ulva* and seagrass. These small scale mosaics of varying seagrass blade density and *Ulva* coverage are likely to be factors driving the small scale colour and textual variability that can be seen within these upper shore intertidal seagrass beds (e.g., Figure 87); however overall, these areas were clearly dominated by intertidal seagrass cover.

Figure 87: Example of intertidal seagrass meadows colour and texture variations driven by differing seagrass blade densities, and the presence of secondary habitat elements of the green algae *Ulva* sp. (a sheet-forming species) and *Codium* sp. (individual erect fleshy algae). Ground truth sites (video drop camera at high tide) are shown as red circles (3).

In the subtidal seagrass areas, video drops found scattered horse mussels individuals across a number of sites assessed, albeit at densities far too low to be defined as horse mussel beds. Other habitat elements identified included low numbers of red algal species, clumps of the NIS zoobotryon, *Codium* sp. individuals, and colonial ascidians. Previous limited sampling of subtidal seagrass epifaunal assemblages in this area in 2005 also found such associations, although the (relatively limited) area sampling during that work did not hold horse mussel individuals, and the NIS zoobotryon was not well established (or perhaps even present) at that time (Morrison et al. in revision). Overall, seagrass was the dominant ground-cover in these regions.

In the Asian date mussel habitat areas, there was a variable secondary cover of low canopy red algae, which ranged from being absent at many sites, to being common as isolated individuals, to almost 100% cover at a few sites (see Figure 86 right side, Figure 88). The association of red algae with Asian date mussels was quite unexpected given previous descriptions of Asian date mussel habitat patches in east coast estuaries (e.g., Creese et al. 1997). It was not possible to assign quantitative cover values to these secondary coverages during the ground-truthing. We also suspect that these algae are ephemeral in their abundance over time (long recruiting season, fast growing and easily removed by environmental events such as heavy wave action). In some cases during ground-truthing, the water clarity was so poor (turbid) that the presence of Asian date mussels and algae was only confirmed through hand-grabs of the seafloor. At several sites, extremely high densities of small eleven-armed starfish *(Coscinasterias calamaria)* were associated with patches of Asian date mussels where most of the mussels were dead, presumably a consequence of starfish predation. At least one of these mussel beds appeared in the aerial photography with a distinctly reddish brown hue (the colour of the starfish), although it should be noted that there was a significant time delay of several or more months between aerial photography capture, and the subsequent ground-truth site visits, and these starfish are known to move reasonable distances over time.

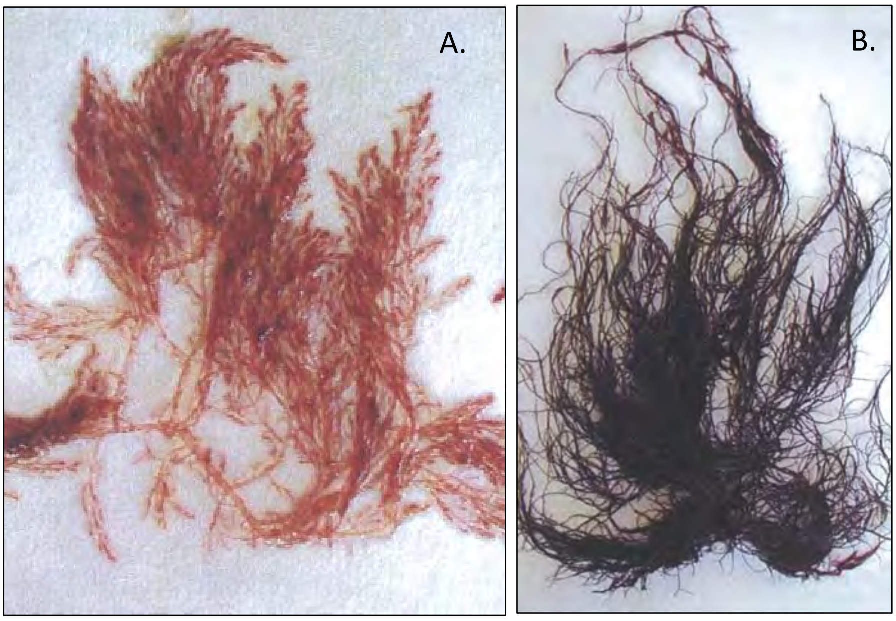

Figure 88: Images of two macro-algal species from the southern Kaipara Harbour which were often associated with Asian date mussel beds, and are (pending formal analysis) now thought to provide a nursery habitat function for juvenile snapper (in association with Asian date mussel beds), especially *Gracilaria spp.* a) *Spyridia filamentosa*, a native species common to the area, and b) *Gracilaria chilensis*, an NIS species (note, there is a native *Gracilaria* also present in the harbour, and the two species can only be distinguished with genetics (Source: Neill et al. 2012).

Mapping of the three habitat classes identified by ground-truthing

Subtidal seagrass was found to be restricted to the central bank systems of the southern Kaipara, where it was common/dominant across most of the available space from the low-tide mark to water depths of about 2–3 m (Figure 89). Subtidal seagrass beds predominantly occurred as numerous inter-connected ‘rosettes’, with the densest areas occurring as an irregular ring in the outer part of each rosette. About 10 km^2 of area was covered (note that this includes the bare components of the mosaics) (Table 16). This distribution form is known to be associated with wind-generated higher energy environments. On the deeper edges of the banks these rosettes became more dispersed, eventually disappearing with increasing water depth. The more exposed westerly banks are subject to the energy of defracted ocean swells from the entrance, and did not support seagrass habitats, but provided protection for the seagrass covered banks to the east. On the intertidal bank area forming the northern edge of the central bank system, intertidal seagrass patches were present at several places, where they formed a much denser plant cover, which was visually distinctive from the adjacent subtidal rosette forms (both in terms of being a visual shade of green, and being homogenous in texture). To the east of the central bank systems, intertidal seagrass became much more abundant, starting with large patches on the lower/outer subtidal, and then increasing in spatial extent further up the intertidal, to form very extensive intertidal meadows along the eastern shoreline of the south Kaipara. These extensive intertidal meadows were also found along the western shoreline of the south Kaipara, extending as far up the harbour as just north of Shelly Beach. A small area of intertidal seagrass was also present east of Shelly Island in the upper open reach of the southern Kaipara (Figure 89). About 10.4 km^2 of intetidal seagrass was present overall (Table 16).

An unexpected habitat (in terms of both being detected by aerial photography, and its large spatial extent in the southern Kaipara), was the presence of large low relief subtidal ‘beds’ of the NIS Asian date mussels (*Musculista senhousia*) (Table 16). The largest of these beds were found immediately to the south-east of the subtidal seagrass area, where they occupied a large shallow subtidal area as a series of simple, albeit quite large, habitat patches (Figure 89). Smaller patches were found to the north-west of the subtidal seagrass area, and to a lesser extent along the northern shoreline. Further up the harbour, numerous smaller and more convoluted beds occurred along the western side of the harbour throughout an extensive shallow water areas, as well as a shallow channel area north of Shelly Island, and just west of Shelly Island. Some Asian date mussel patches were also present west of Shelly Island, in the central upper harbour shallow water basin.

Table 16: Contributions of the different remote sensed habitats in the Southern Kaipara. Note that bare sediments are not defined as this is the 'background class' and not one of the habitats of interest *, all seagrass (intertidal and tidal). [1]Note that the division between Asian date mussels beds with and without algal cover is driven by algorithm analysis of the raw spectral data; the empirical algae cover threshold between these two classes is not known.

	Sub-class (m^2)	Total (m^2)	Area (km^2)
Seagrass* (about 10 km^2 is subtidal)		20 370 900	20.37
Asian date mussels low or no algal cover	6 640 170		
Asian date mussels high algal cover[1]	557 736		
Total Asian date mussel including red algae		7 197 906	7.20

Several issues were encountered during image collection that are reflected in this final habitat map. The most important issue was unwanted sun glare off the sea surface, which causes 'flare' in the imagery, obscuring what lies below the surface of the water, and on the exposed intertidal flats. The potential for this sampling artefact was minimised by only flying during that part of the year where sun angles were high enough to avoid such effects, and within that time period, flying within time windows of the day where sun angles were not too low. However, major issues were still encountered in some regions of the imagery, and were unable to be resolved. Habitats in these areas were manually digitised where possible; this can be seen in some of the polygons as relatively coarsely defined areas, in particular of the extensive intertidal seagrass meadows on the eastern side of the harbours. The other main issue was water turbidity/sediment plumes and associated light penetration, which was quite variable spatially and temporally. While this issue was absent from the areas mapped for subtidal seagrass habitats (expected since otherwise these plants would be unable to persist and grow), it was common in other areas of the harbour, including across much of the Asian date mussel habitat zones. Data from the beam trawling survey, as reported earlier in this document, clearly shows that date mussels can occur down to depths of at least 20 m in this harbour, although whether these occur as dense beds is unclear. Given this, the outer extents of some Asian date mussel beds would have been obscured by turbid waters, and the overall habitat extent for this species should be viewed as conservative and an underestimate of its true spatial cover in the southern Kaipara Harbour.

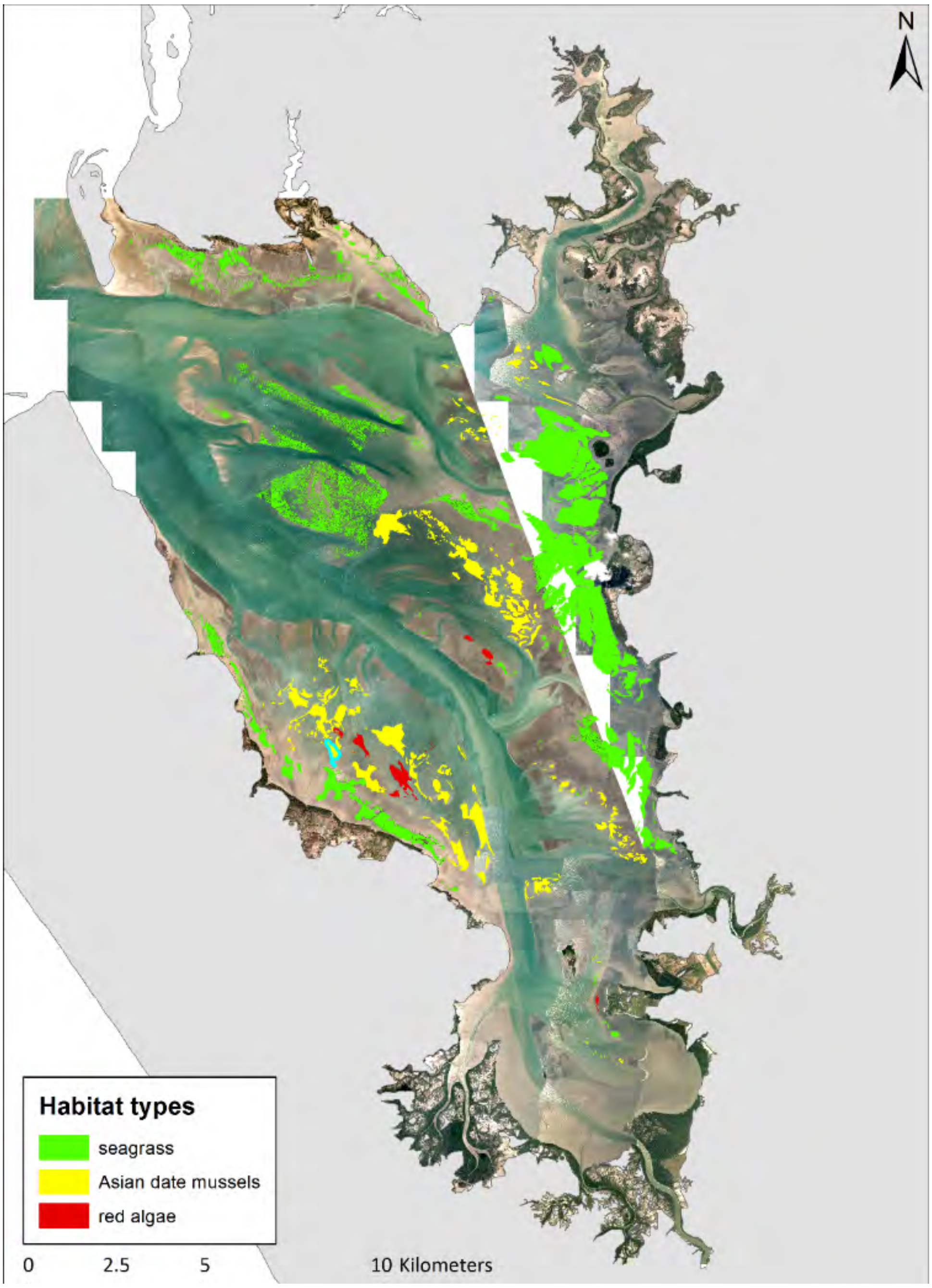

Figure 89: Final habitat polygons derived from the aerial imagery. Note that the 'red algae' polygons are a subset of the Asian date mussel habitat class; these polygons represent mussel beds with an especially heavy canopy cover (100%) of foliose red algae, but do not include all red algae growing on mussel beds. Estimates of habitat extent for seagrass and Asian date mussels are given in Table 16.

6.4 Summary and recommendations for habitat monitoring

Overall, the target habitat of subtidal seagrass meadows was reliably detected and mapped in this project using aerial photography. Ground-truthing data showed that this habitat class was readily distinguishable from the other habitat types found in the harbour using aerial photography, validating that this remote sensing approach is appropriate for seagrass mapping and monitoring over time. This habitat has been shown to consistently support high numbers of juvenile fish in northern New Zealand, especially snapper. While no formal definition(s) of '*habitats of particular significance for* *fisheries management*" exist in New Zealand policy regulations (i.e. via agencies such as MPI, DOC, EPA and so on), from a science perspective these habitats largely meet the formal nursery habitat requirements of Beck et al. (2001), although more empirical work remains to be done (Morrison et al., in press). The aerial mapping found that about 10 km^2 of subtidal seagrass (measured as the collective area of the rosette mosaics, which includes bare sediment components) was present in the southern Kaipara in 2012, arranged as complex mosaics of rosettes across four largely subtidal sand banks in the central lower harbour region. Patches of intertidal seagrass also occurred where these banks become intertidal, but were less common and widespread than the adjacent subtidal seagrass.

The maps produced from this project have been used by the Auckland Council in their draft unitary plan to zone these subtidal seagrass meadows as an "Ecologically Significant Area" (ESA). Of particular note with respect to perceived localised threats to subtidal seagrass, the subtidal seagrass habitat also extended under the shallow southern end of the Bio-marine Ltd oyster farm (see Figure 85). Monitoring of subtidal seagrass under this farm and in four adjacent contiguous control zones has found that the cover of seagrass has increased in recent years (Bulmer et al. 2012). During Auckland Council hearings (where the initial oyster farm application was declined), and a subsequent Environment Court case (where the oyster farm application was approved with strict monitoring provisions), one of the arguments (and arguably the key argument) was whether subtidal seagrass would be adversely affected by the presence and operation of the farm. Peer-reviewed empirical evidence now shows only a very limited effect directly under the actual basket lines, as predicted (Bulman et al. 2012), More broadly, overall subtidal seagrass cover in the southern Kaipara Harbour has also increased since the early 2000s (see Section 1).

The aerial mapping also revealed the widespread occurrence of another biogenic habitat type; beds/reefs of Asian date mussels. This small mussel species (15–25 mm) is a NIS, and uses byssus threads to form densely packed 'carpets' of mussels which can cover 100% of the seafloor, often raised up as low beds or mounds. Given this seafloor dominance, and its filter-feeding of the water column, its overall influence on the harbour system may be very substantial. According to the LEK accounts, it first arrived in the Kaipara Harbour sometime in the 1990s, and has been reported as a problem since then, rapidly increasing in abundance. The aerial photography imagery clearly delineated these beds in shallow waters, showing them as discrete polygon objects with sharp boundaries. Bed shapes ranged from broadly rectangular through to elongated low ridges, and variegated patches. In the infra-red imagery, they returned 'red' coloured spectra, driven by the range of epifloral foliose red algae often growing on them, with microscopic algae possibly also having been present (not visible in field ground-truthing). Ground-truthing of a number of the Asian date mussel beds showed this algal association to range from completely absent, through to heavily canopied reefs, with at least two to three algal species being present. Identification of some limited red algae samples (from several sites) identified the presence of: *Spyridia filamentosa*, which is native to this area, and often washes up in large quantities as drift weed; *Gracilaria*; either *G. chilensis* and/or an NIS species as yet unnamed; and *Vaucheria* sp. (along with some colonial diatoms and probably *Cladophora*, *Chaetomorpha*, *Rhizoclonium*), which consolidates sediment in patches and can be locally abundant (pers. comm., Wendy Nelson, algal taxonomist, Science Programme Leader, NIWA Wellington).

Some Asian date mussel beds were also covered in large numbers of the predatory starfish *C. calamaria* (eleven-armed starfish), whose dull rusty brown colouring appeared to influence the normal RBG imagery spectra at some sites, where starfish cover was visually estimated at 50% or more. These starfish often form dense feeding aggregations or fronts across bed-forming bivalve prey species (including pipis *Paphies australis*, dog cockles *Tucetona laticosta*, and the morning star *Tawera spissa*), and it is suspected that they may have been responsible for some observed Asian mussel beds being formed of in situ recently dead mussels (note: it is not possible to distinguish live from dead mussels using aerial photography).

The topography of the mussel beds themselves ranged from very low and flat, through to highly mounded bed mosaics, with estimated individual mound heights of 1–1.5 m, which were often extensive (tens of metres across) and undulating (also described by some LEK participants). All of these beds were subtidal, with the more mounded beds being in slightly deeper water depths. This species extended deeper than the depth range covered by the aerial photography, with live Asian date clumps coming up in the beam trawl sampling down to at least 20 m (it has also been observed in the Tamaki Strait, inner Hauraki Gulf, as extensive carpeting beds in 10–15 m water depth, M.M., pers, obs.). Ground-truthing data showed that these beds could be reliably identified and mapped using aerial photography, within the constraints of water clarity. Some of the upper harbour beds were likely to have only partially been mapped, with their lower extent extending out into water depths where water turbidity was too high for light penetration. Two separate flying events were completed during this work, and it was apparent that where some limited spatial overlap occurred between the two events in the upper harbour region, that some mussel beds could be seen in one set of images (where the water clarity was much better), but not in the other (where turbidity plumes were noticeably present). Both sets of images were combined to create the best final maps. Given the extensive and dense nature of these reefs, their raised profile off the seafloor and associated sharp boundary edges, and their almost certainly different acoustic returns relative to bare sediments, it is likely that these habitats could be effectively mapped in deeper waters using either side-scan or multibeam sonars (although they were not reported by Hewitt & Funnell 2005; possibly because such beds were not present at the time, or because their acoustic mapping work was limited to water depths beyond those where such reefs occurred).

Collectively, these habitat types (subtidal/intertidal seagrass, and Asian date mussel beds, with varying degrees of secondary red algae cover) were not only readily separated from each other in their remote sensing appearance, but also spatially, with no overlap in their distributions. This strongly implies either competitive exclusion interactions (probably unlikely in this context given the presence of large areas of ‘available’ bare sediment); or fundamental differences in their preferred environmental conditions. The most likely drivers for subtidal seagrass presence are the combination of sufficient water clarity, sandier substrates, shelter from strong wave action, and possibly moderate water current speeds. Intertidal seagrass was largely confined to the mid to upper regions of the intertidal, which may have been a consequences of the frequent occurence of turbid fringes in the lower tidal areas due to wind/wave actions, and associated turbidity plumes. Date mussel beds were confined to shallow subtidal areas, especially in regions where extensive sheltered/semi-sheltered waters were available, which were usually associated with muddier substrates and turbid waters. These areas also experienced strong tidal current flows, which are presumably necessary to provide sufficient food sources for these very dense filter-feeding bivalves. Collectively, these patterns and associated environmental observations suggest that the optimal environmental conditions for these species could be readily modelled and used in a predictive sense to run ‘what-if’ scenarios of what future habitat change trajectories might occur. A word of caution here however is that NIS species may sometimes be introduced into a system and operate relatively benignly for a number of years, until some threshold is reached, at which time their impact on endemic ecosystems may alter radically. Such dynamics are not well documented nor understood at present.

The choice of aerial photography limited the maximum water depth of habitats sampled to about 3–4 metres, with this lower limit being set by the water clarity condition in the southern Kaipara Harbour. In general, water clarity over time can be quite variable across the harbour both as a whole and in individual areas, with known drivers being heavy rainfall events with associated sediment plumes, water column phytoplankton blooms, and wind-drive sediment re-suspension across shallow inter-tidal and subtidal flats. Problems were encountered in getting the right conditions for flying, in terms of both environment (suitable low tides, no cloud cover, low wind speeds, no recent rainfall events, right time of day and year), and working in with other operational demands on the sub-contactor (e.g., combining other mapping work in the same flight, or avoiding plane and equipment clashes with other operations). Despite two flight missions being carefully scheduled and executed, some sun glare issues remained in the final imagery, limiting some of the automated post-processing possible for some sub-areas. Fortunately, these issues were largely restricted to the intertidal areas of the western side of the survey area, and did not affect the ‘critical’ subtidal seagrass habitat areas. Such problems are not fully avoidable by aerial photography (nor other light based methods such as satellite sensors), and can only be mitigated by careful survey planning and an allowance for image capture over as long a potential season as possible. Subsequent ground-truthing also needs to be completed as soon as possible, to minimise the risk of habitat changes occurring between the time of imagery capture and ground-truthing being confounded with the degree of correct habitat classification achieved.

6.5 Linking habitat mapping to fisheries values

Subsequent to the habitat mapping component reported here, and outside of the scope of this report, NIWA has successfully completed a large scale juvenile/small fish survey of the southern Kaipara Harbour based on the aerial habitat imagery. This work was funded under the MBIE Coastal Conservation management (CCM) programme; as outlined earlier the 151 stations sampled were used to augment the ground-truthing replication in this report. Fish sample processing and analysis are still in progress, but field observations are briefly reported here. Large numbers of juvenile snapper were captured in close association with the subtidal seagrass meadows across all four banks holding this habitat, as well as juvenile trevally, spotty, black pipefish, triple-fins and a number of other species. Sampling of 'bare' substrates immediately adjacent to and/or between seagrass patches returned few or none of these species. In the same field season (February–April 2013), similar sampling of the extensive subtidal seagrass beds of Parengarenga and Rangaunu harbours also showed these fundamental fish–habitat associations, with the sampling design in those harbours being aided by the use of satellite imagery of seagrass and other habitats. This further confirmed the fundamental wide-spread occurrence of this fish-subtidal seagrass association in northern New Zealand, in particular for juvenile snapper. As expected, intertidal seagrass meadows held relatively few fish (Morrison et al., in revision), and those species caught were either small general pelagics (juvenile anchovies) or larger wide-ranging adults of species such as eagle rays.

A number of the Asian date mussel beds were also sampled, and unexpectedly high densities of juvenile snapper were found at several sites where the date mussels were covered with foliose red algal canopy. In contrast, few juvenile snapper were found in association with Asian date mussel reefs without associated dense algae. While these fish data have yet to be formally analysed, the juvenile snapper counts made in the field were directly comparable with the highest densities seen from the subtidal seagrass meadow areas. This is a significant finding, and suggests that these habitats, based on an NIS species secondarily colonised by native algae (and possibly an NIS *Gracilaria* sp, also), may be providing a snapper nursery function comparable with the 'best' endemic biogenic species based habitat (i.e. subtidal seagrass). We note here that juvenile snapper (and juveniles of other fisheries species such as trevally and parore) are not obligate on subtidal seagrass as their only biogenic habitat nursery. Juvenile snapper appear to respond to three-dimensional structure rather than specific habitat identities, with more complex three dimensional structure holding larger juvenile densities, as shown by artificial seagrass experiments using a range of seagrass blade densities (constructed from plastic ornamental plants; Morrison et al. unpubl.).

Once these data are analysed and written up, a more detailed picture will emerge of how specific fish species are responding to habitat structure in the Kaipara Harbour, measured at both patch and landscape levels (specifically with respect to subtidal seagrass and Asian date mussel habitats). In turn, these can be functionally mapped back onto the habitat maps provided here, so that they can be used to give fisheries and other managers greater insight into management actions and policies required to maintain and perhaps enhance ongoing fisheries support functions.

7. GENERAL DISCUSSION

7.1 The past

The intertwined environmental and human histories of the Kaipara Harbour show that the harbour has changed considerably; in the past there were substantially larger fish populations and bigger individual fish sizes, sandier habitats and clearer waters extending into the upper arms/reaches of the harbour, more extensive habitats of seagrass, green-lipped mussels and rock oysters, deeper and wider upper channels, and far less extensive mangrove forests. Some species also exhibited behaviours and habitat associations no longer apparent today, such as large schools of large snapper feeding in very shallow waters, and very large schools of parore and scallop beds in association with seagrass meadows. NIS species were also largely (if not completely) absent, though undocumented introductions from wooden sailing ships cannot be discounted. Settlement in the region by Māori probably led to human–induced changes in the harbour, based on evidence elsewhere, including burning of woodlands with associated increased sedimentation, and the localised impacts of harvesting of finfish and invertebrate food species. European settlement brought full scale harvesting of timber and flax, pastoral farming and other land based industries, and commercial fishing. As with all of coastal New Zealand, fishing pressure continued to increase with an increasing human domestic population and the development of overseas markets, while land based uses resulted in fundamental changes to processes such as the rates of sediment and nutrient run-off from the land. These cascaded through into impacts on the marine environment, some of them profound, of which we still have only a basic and fragmented understanding of today with respect to impacts on coastal fisheries (Morrison et al. 2009). Heavy fishing of estuarine and coastal fish populations greatly reduced their abundances and their length and age composition, as the larger and older cohorts were fished down. These reductions are an expected outcome of fisheries management but a lack of management controls in the past pushed local populations down to levels below those now considered optimal for sustainable fisheries' yields. Fishing pressure reduced following the introduction of the QMS, and the abundance of many species may have increased, though not necessarily to the levels desired by all parties. A full discussion of these issues is outside the scope of this report but we note that any substantive fishing of populations by definition means that overall fish populations will be reduced. Implicit in this conclusion is the fact that earlier fish population abundances reported by observers were closer to those of an unfished system, and a return to those population levels cannot be achieved while substantive fish removals and ongoing environmental degradation are still occurring. Substantial reductions in the carrying capacity of the environment have also probably occurred; driven by the loss of important nursery habitats (for some species) such as subtidal seagrass, horse mussels and other biogenic habitats, a change from sandy clear water to muddy turbid waters in sheltered water areas, and shifts in predator and prey populations and distributions. The historical and contemporary environmental issues identified for the Kaipara Harbour are not unique to this estuary, and are being faced by local communities and resource managers around New Zealand. Intensification of land use and climate change are predicted to interactively further increase the severity of impacts into the future, both from land-based inputs (e.g. sediment and nutrients), and marine effects (e.g., more intense and frequent storm events with associated wave regimes).

7.2 The present day

The contemporary Kaipara Harbour supports valuable commercial, recreational, and customary fisheries, both directly in the harbour (e.g., yellow-belly and sand flounder, grey mullet, rig, kahawai, and snapper), and by providing fish nurseries from which juvenile fish move out into adjacent coastal fisheries (e.g., snapper, trevally, sand flounder, rig, school shark, and probably kahawai). There is potentially also a dynamic interchange of some fisheries species to and from other estuarine systems such as the Hokianga, Manukau and Waikato River (e.g. tagged grey mullet individuals have moved between the Waikato River and Manukau Harbour; a tagged adult yellow belly flounder from the Manukau Harbour was caught in the Kaipara Harbour: see Morrison et al. 2014), as well as seasonal adult fish migrations between the coastal zone and the harbour for most fisheries species found in the harbour (Morrison et al. 2014). Observations by LEK participants also suggest the existence of both migratory and resident behavioural morphs for some species (e.g. snapper, grey mullet, and kahawai).

Research sampling in mangrove forests found higher densities of juvenile grey mullet and short-finned eels relative to other habitats, and these species can probably be defined as using mangrove forests as nursery habitats (Morrisey et al. 2007, 2010). Sampling of the bare intertidal/immediate subtidal bare sediments of the harbour returned a range of juvenile and small fishes, with abundances increasing up the harbour in association with muddy, more turbid environments, as occurs in other estuaries (Morrison et al. 2002, Francis et al. 2005, 2011). While dominated by non-commercial fish species such as exquisite gobies, yellow-eyed mullet and speckled sole, the fisheries species of (juvenile) yellow-belly and sand flounder were also relatively common, with these areas (including the intertidal flats when water covered) being used as nurseries (Morrison et al. 2002). Few juvenile flounder were caught by beam trawling in subtidal channels and shallow flat areas. These patterns are consistent with those detected by seasonal sampling in the Manukau Harbour, where sand and yellow-belly flounder recruit into very shallow waters and then display an ontogenetic shift with increasing size down the sides of the channel banks (Morrison et al. 2007, Lowe 2013). With increasing size, yellow-belly flounder retain their association with muddy estuarine seafloors, but have also been fished for on the adjacent coast's surf zones. Adult sand flounder (dab) are less commonly caught in estuaries relative to yellow-belly flounders, and have been shown through tagging to move out into the coastal zone as adults (Colman 1978, the Canterbury Bight).

Limited sampling of seagrass meadows in the Kaipara in 2006 found that subtidal seagrass supported comparatively high densities of juvenile snapper and trevally (0+, under 90 mm), with densities of 5.18 ± 1.0, and 4.49 ±1.7 per 100 m^2 respectively. This association has also been reported from a number of other northern New Zealand estuaries, though densities vary widely by area, with the highest average site density being recorded from Rangaunu Harbour, at 161 snapper per 100 m^2 (Morrison et al., in revision). Recent (March–April 2013) extensive sampling of the Kaipara's subtidal seagrass meadows found similarly high densities of juvenile snapper and trevally as in 2006, occurring across the full extent of the sampled subtidal meadows (about 10 km^2). Field observations also suggest that the smallest snapper were found in the shallowest subtidal seagrass habitats, with average fish size increasing with water depth (across approximately 4 m depth range sampled). In situ video cameras detected juvenile snapper swimming in loose low density schools, while juvenile trevally tended to move in larger, more closely aggregated schools. Both species were observed to be feeding on passing zooplankton. Dietary analyses from the 2006 survey found that snapper prey heavily on small gammarid amphipods living on the seagrass, as well as passing zooplankton (Lowe 2013). The two main processes thought to be driving small fish usage of three-dimensional habitats are shelter from predators, and higher prey availability. These subtidal seagrass meadows and others (e.g. Parengarenga, Rangaunu, Tairua, Whangapoua and Great Mercury Island), all tend to occur in higher current areas with clearer waters, allowing small fishes to visually pick out passing zooplankton. Experiments with artificial seagrass plants show that fish densities of a number of species (including juvenile snapper, trevally, spotties and parore, and small adult fish such as triple-fins and pipefish) increased with increasing blade densities, to combined densities of over 1000 individuals per 3 m^2 unit (Morrison et al. unpubl. data). Based on these surveys and experiments, we conclude that subtidal seagrass provides a very valuable nursery habitat for these species, with upper fish density limits possibly determined by the availability of food.

Sampling of intertidal seagrass meadows in the Kaipara Harbour did not capture juvenile snapper and trevally juveniles, however unexpectedly very small juvenile grey mullet, and to a lesser extent kahawai, were associated with the lower fringes of these habitats. This association has not been seen in other estuarine systems. We suggest that these species may use such habitats when initially settling from the water column, but then soon move off to other habitat types, as intertidal seagrass provides shelter and food only when the tide is in, and has shorter blade lengths than subtidal seagrass, so probably provides protection for very small fish only.

Sampling of the subtidal channels for juvenile and small fish by beam trawl, and the deployment of a towed camera system at night to count larger sleeping fishes, found an assemblage dominated by juvenile and sub-adult snapper, and juvenile jack mackerel. Juvenile snapper (0+) were captured throughout the harbour by the beam trawl, but were most often caught in tows with associated bycatches of habitat forming species such as NIS bryozoans and date mussels, sponges, horse mussels, red algae and hydroids). Notably, several of these species were NIS, which suggests that interactions between native and exotic species are not always negative.

Both biogenic structure and juvenile snapper were less common in the northern Kaipara, which we suggest is due to flood events with associated suspended sediment and freshwater flows from the Wairoa River. Few juvenile trevally were caught by the beam trawl, but these fish would probably have grown beyond the size at which they were vulnerable to this fishing gear, at the time of year that this survey took place. Similar work in the Manukau over the same seasonal period (in a different year) caught no trevally in the beam trawl, but numbers in the 10–20 individuals range per small baited fish pot at the same sites. Previous limited beam trawling in 2003 did capture small trevally in the Kaipara Harbour, as well as the seven other west coast estuaries sampled, but that sampling was earlier in the year, when juvenile trevally were much smaller. The towed camera system detected larger snapper (mostly larger juveniles/sub adults) throughout the harbour; as with the beam trawl sampling, higher densities were associated with more structured seafloor habitats. Legal sized snapper (over 26 cm) were relatively uncommon, but environmentally driven delays of the survey meant that this camera survey was carried out in the colder months of the year, when most adult snapper are believed to have migrated out of estuaries and the coastal zone, into deeper waters (see Compton et al. 2012 for such effects in the inner Hauraki Gulf). The few larger snapper seen were probably resident fish.

Limited gill net sampling of the upper reaches by Francis et al. (2012) caught high numbers of grey mullet, snapper and rig, with the catches of juvenile rig being the highest seen of the various harbours sampled in the North and South Islands. Based on this, and the large size of the harbour, the authors considered the Kaipara to be the most important rig nursery estuary in New Zealand. Juvenile school shark were also caught in some numbers (89), and given the historical evidence of females pupping in the harbour, the harbour is probably nationally important as a nursery for this species as well. Limited numbers of kahawai were also sampled, but only three were under 25 cm. Similarly, only low numbers of juvenile kahawai were caught in the various beam seining deployments (over bare sediment and intertidal seagrass). However, juveniles of this species are often found in clear water areas over coarse sand bottoms associated with higher wave and/or current energies (e.g. Gerring & Bradford 1998, M.M., pers. obs.). These areas were not well sampled in the Kaipara Harbour. Additionally, the low tow speed and small size of the beach seine net probably severely limits the capture of these fast moving schooling fish. We suspect significant kahawai nursery areas do exist in the harbour that have not yet been located and sampled. Conversely, juvenile red gurnard are very limited in their movement speeds, and while juveniles were captured by the beach seines and beam trawls, densities were always low. Based on similar findings from a range of estuaries, this suggests that juvenile red gurnard do not substantively use estuaries as nurseries; the juveniles caught were likely to represent the ‘fringe’ of abundant juvenile nursery areas in the open coastal zone. However, some LEK observations suggest that higher densities of juvenile red gurnard may occur in the harbour in some places at some times.

7.3 Information gaps

Our knowledge of how the Kaipara Harbour functions in terms of productivity of fisheries species fisheries species production remains scant. Most of the work reported here involved surveys to quantify size and distribution of fish species, providing an inventory of the harbour. While inferences can then be drawn about linkages between habitats through fish movement and ontogeny (e.g. juvenile snapper dispersing from subtidal seagrass beds into the wider harbour, and juvenile grey mullet moving from upper harbour mangrove areas out into the broader mudflat areas), we still know really very little about how the system functions. For instance we do not yet know what proportion of each estuarine or coastal fishery is supported by juvenile production in the harbours (and/or in some cases on the open coast), and how the different life stages, habitats and environments function together to create that production (Morrison et al. 2014). To achieve this knowledge, we need empirical measures of factors including reproductive success, egg/larval/juvenile survival and growth, and connectivity (the movement of individuals between different places or areas). Currently, we have no quantitative estimates of these factors, even at the larger collective scale of populations, beyond stock-scale growth rates and length-at-age composition data for adults of most commercially fished species. Even the most basic question of what proportion of coastal finfish populations are supported by production in the Kaipara Harbour remains unknown for all species apart from snapper, where the majority of snapper on this coast initially come from this harbour (Morrison et al. 2009). Even for that work, criticism has been made that only one year class (2003) was sampled, potentially limiting its application across different years.

Given this lack of knowledge, a number of high priority information gaps to address are discussed in the following sections. We note that these gaps are not limited to the Kaipara Harbour, and that work from other estuaries may be meaningfully applied to the harbour (and vice versa).

The functional role of individual habitats for different life history stages of fisheries species

While we now have a better understanding of fish-habitat associations for many species, we still do not know what drives these associations, i.e. what function(s) do the habitats provide fish, such as protection from predators, higher prey availability, or a trade-off between the two? The observation that species such as snapper and trevally associate with seafloor structure regardless of its nature (although densities appear to be correlated with structural complexity) suggests that these functions may be generically applied across a range of habitat types, meaning that not all need necessarily be researched. Beyond the simple presence of a given habitat, other factors may also be important, including patch size, shape, and quality; and at a larger scale, how mosaics of habitats operate together for relatively mobile species. For example, the subtidal seagrass meadows of the Kaipara are not continuous, but rather are composed of thousands of rosettes 20–50 m wide, ranging from discrete rosettes through to rosettes directly abutting and fusing into each other, spread across four separate banks. In doing so they provide a wide range of edges and interiors, and combinations of the two, which may affect small fish usage. To assess this, the 2013 beach seine ramp seagrass survey placed stations across this range of landscape features. When these data are combined with fine scale maps produced from the aerial photography, we will be able to assess whether these spatial patterns affect fish distribution and abundance (noting that the 50 × 9 m scale of the tows in itself limits the scales that can be considered). Similarly, it is not known whether other subtidal biogenic habitats are more useful to fish when they are widely distributed or clumped together across more concentrated areas. Having a better understanding of these processes will allow us to move on from the simplistic presence/absence of habitat types, to ranking the relative importance of different configurations and habitat landscapes to fish, and assigning management effort accordingly.

Density dependence

Assuming that fish actively select habitats to occupy, it has been suggested that the ‘best’ habitats fill up first, and then individuals are subsequently forced out into less optimal habitats, with implications for growth and survivorship. This implies an upper carrying threshold per unit area, which may or may not be reached over different times (seasons and years), depending on how many fish recruit, and how resources such as zooplankton or benthic amphipods (prey) vary over time. Snapper, for instance, may vary in annual recruit strength in the west coast SNA 8 stock by a factor of at least eight. Limited beam trawl sampling in the 2003 year found juvenile snapper to be very strongly associated with by-catches of biogenic structure, but the highest catch rates were still relatively modest, while very few fish were caught in tows with little or no associated biogenic by-catch. Conversely, the 2010 beam trawl survey (which sampled many more sites) while still showing strong biogenic habitat associations, also returned much higher maximum catch rates, and also recorded numbers of juvenile snapper from areas/sites with much less biogenic structure. The inference drawn is that snapper recruitment in 2010 was much higher than in 2003, suggesting that fish saturated the best quality habitats first, forcing subsequent individuals into less optimal areas. Limiting factors might be the availability of habitat structure and food supply, and/or antagonistic behaviours between fish (e.g., juvenile snapper can vary in individual dispositions from very aggressive to submissive in tank environments (M.L., pers. obs.). Addition of artificial habitat structure in New Zealand estuaries has produced significantly large increases in fish density per unit area (horse mussels and snapper, Usmar 2009; artificial seagrass and snapper, trevally, spotties, parore and others, Morrison et al., unpubl. data), which suggests that the availability of biogenic structural habitat limits the abundance of these species at small scales. However, densities of these species also appeared to reach density asymptotes at the highest seagrass blade treatments, suggesting that some other secondary factor such as food supply (zooplankton supplied by the strong tidal current) becomes limiting beyond a certain fish density, regardless of how much additional structural habitat is available. Such density-dependence mechanisms should be considered.

In addition to variable recruitment strengths across years, optimal habitat extent/availability may also vary over time. For example, if subtidal seagrass meadow habitat was reduced by 50% between two years with the same fish recruitment strength, we do not know whether fish densities would double through all fish occupying the remaining 50% habitat area; or, whether density dependence factors would arise and many of those fish would be lost or suffer negative consequences through being forced to occupy other less optimal habitats. Likewise we do not know the potential effect of substantially expanding habitats, either through natural processes or human mediation such as habitat restoration. Without understanding these (potentially) density-dependent dynamics, it is difficult to meaningfully manage the consequences of habitat change.

Connectivity (fish movement)

Fish are mobile organisms, and display a diverse range of movement behaviours, including tidal and diurnal foraging, ontogenetic habitat shifts and seasonal migrations often associated with spawning, and wandering behaviours to maximise discovery of new resources. Within species, there may also be behavioural morphs/groups, such as migratory fish versus resident fish – with one form of this being partial migration, where a proportion of the population migrates while another does not. Animal movement dynamics is a very active research field, for both terrestrial and marine systems, but there is a great deal yet to understand (see Morrison et al. 2014 for what is known with regard to New Zealand’s coastal finfish fisheries species). To manage in a way consistent with an ecosystem approach to fisheries we need to understand fish movement. In Kaipara Harbour, most of the fished finfish species undergo seasonal migrations that are recognised by fishers (see Section 3), but where they go to and come from outside the harbour remains unknown. Ongoing concerns about the impact of commercial trawling adjacent to the harbour entrance on declining fish stocks in the harbour (highlighted as a key issue in the KHSFG Fishing for the Future 2003 report) is one example of how connectivity may affect harbour fish stocks. The substantial historical fishing-down of the age and size structure of the coastal SNA 8 stock is almost certainly responsible for associated reductions in large snapper in the Kaipara Harbour, rather than just overfishing in the harbour itself. We have no understanding of how widely adult fish move between the harbour and the open coast, including to/from other estuaries such as the Hokianga and the Manukau. Similarly, there is a paucity of information on the contribution that Kaipara Harbour’s fish nurseries make to adult coastal fisheries populations (apart from one estimate for snapper), nor for the other west coast estuaries, beyond the logical inference that it is probably significant. Movement of larger juveniles and sub-adult fish between estuaries may also be significant. For example, extensive sampling of grey mullet nurseries for an otolith chemistry study found very few juvenile grey mullet in the Waikato River (M.M. et al. unpubl. data), yet adult populations in the river are substantial, suggesting that juveniles move to the Waikato River from other systems. This might conceivably include the Kaipara Harbour, given the propensity of this species for movement. The possibility of natal homing is also important. If adult fish tend to migrate back each year to their natal estuaries (or at least some proportion does), then the potential for local fisheries depletion increases, as fish are not moving and mixing to the degree assumed in stock assessments. The existence of migratory versus resident forms, and other behavioural morphs, also has implications for fisheries productivity and depletion effects, especially if these different forms are differentially vulnerable to removal by fishing (Kerr et al. 2009, Parsons et al. 2011). Snapper and kahawai were mentioned by some LEK participants as having different population groups. It was also observed by some grey mullet fishers that two forms of grey mullet were present in the harbour, one resident and the other seasonally migrating down the coast into the harbour from the north. It has been suggested that there are actually two species of grey mullet in the Kaipara Harbour (Paulin & Paul 2006).

Spawning and larval supply

Most fisheries species are thought to leave the harbour to spawn, although several LEK participants thought that mullet spawned in the upper reaches of the harbour. Where the different species' spawning aggregations occur and how larvae make their way into the harbour are unknown (at least to scientists for the former). Recent work by Sim-Smith et al. (2012b) found that snapper in the Kaipara Harbour did not spawn, but rather reabsorbed their oocytes (known as skipped spawning), while snapper from the adjacent coast showed normal reproductive cycles – so for this species at least larval supply originates from outside the harbour. Radford et al. (2012) also demonstrated that larval snapper responded positively to water which had had Kaipara seagrass soaked it in, suggesting one possible mechanism through which larval fish orientate themselves towards the Kaipara Harbour.

Effects of land-based threats and stressors, especially sedimentation

Land based effects have been comprehensively reviewed by Morrison et al. (2009), as well as specific direct impacts on juvenile snapper being shown by Lowe (2013) through a combination of field surveys and experimental tank work. What is now needed are empirical quantitative measurements of impact and change thresholds on key habitats, and their cascading effect into juvenile fish production – for instance, at what threshold of light reduction does subtidal seagrass cease to grow, and what levels of suspended sediment are sufficient to eliminate biogenic habitat formers such as horse mussels and sponges? While work on physical processes is already underway to limit annual and cumulative sediment loads to estuarine systems (including the Kaipara Harbour), the extent to which thresholds of change in habitat quality/quantity may determine fish recruitment levels is still very poorly known, and essentially unquantified.

Modelling of habitat change

Finally, the complexity of real world marine systems means that all of the above gaps cannot be viewed in isolation, but need to be linked to each other. In addition, a modelling approach is required to evaluate differing scenarios. For example, as a system becomes muddier and more turbid, as biogenic habitats are lost or reduced, and/or NIS species increase in abundance, how does the production of fisheries species change, both in the abundance and mixture of different species? Given different scenarios of mitigation or restoration, what are the predicted benefits versus costs and constraints imposed on other human activities? Models are used extensively in single-species fisheries management. However, no models yet exist in the New Zealand context for how habitats and ecosystems underpin fisheries production, and how habitat change affects fisheries production (e.g. how the loss of subtidal seagrass meadows impacts juvenile snapper and trevally numbers). Constructing a suitable model would allow for a quantitative link with fisheries models, and could be designed as a 'bolt-on' module to provide key inputs to fisheries assessments. Without such formal consideration in fisheries management, the impacts of habitat and environmental change are likely to be overlooked in establishing fishing limits and policy setting. This omission automatically gives such issues less weight, as stock assessments are the central tools in fisheries management (Armstrong & Falk-Petersen 2008). The Kaipara Harbour offers a tractable starting point for such a model, given its well defined nature, range of habitats and species, large size, and the wide range of empirical terrestrial and marine field research being directed at it.

7.4 Longer term monitoring of important fisheries habitats

One of the objectives of this research project was to suggest and implement monitoring surveys of key fisheries habitat/s. Through the use of high resolution aerial photography, subtidal seagrass meadows, which have been shown to be a critical fisheries nursery habitat in the harbour, were successfully mapped and delineated. Asian date mussel beds were also readily identified and mapped, along with the coverage of red algae on these beds – although the lower limit of this habitat extended into water depths beyond those able to be captured by aerial photography. As such, aerial photography is a suitable and readily available habitat mapping approach. We suggest that the initial maps collected in 2012 could form the start of a time series to quantify the dynamics of subtidal seagrass in the southern Kaipara Harbour. Currently little is known about the long term dynamics of subtidal (and intertidal) seagrass in New Zealand, other than that it is very susceptible to land-based activities, and that there also appear to be longer term (greater than several year) oscillations in abundance that are not linked to human impacts. The frequency of these aerial surveys could be three-yearly, with monitoring linked to the ongoing environmental water quality monitoring time series of the Auckland Council. As satellite imagery continues to improve in resolution and spectral range, this approach could also be assessed regularly to see whether such approaches might eventually replace aerial photography as a cheaper approach. In addition, with some additional ground-truthing work to assess red algae spectral signatures, Asian date mussel beds with enough algal canopy to provide a nursery function to species such as snapper could also be monitored (with the caveat of deeper water areas not being amenable to this approach). To maximise knowledge returns, ongoing juvenile and small fish sampling work should also be linked to this series, to improve our mechanistic understanding of how these species respond to changing habitat availability and quality, and ultimately how changing habitat landscapes affect overall fisheries production.

Other important fisheries habitats in the harbour include small scale patchy biogenic structures (e.g. sponges, horse mussels, bryozoans) in the channels and shallow subtidal flats. These patches are also important in helping to elevate biodiversity. Past attempts to deploy acoustic technologies in the Kaipara Harbour have been unsuccessful (Hewitt & Funnell 2005), although improving technologies may ultimately resolve these problems. Towed video arrays with both video and still cameras may be useful in monitoring such habitats over time (using a stratified random sampling design), but the area they can cover (their sampling footprint) is small relative to the potential patchiness of the target habitats, and achieving high sampling precision might be difficult. Additionally, the resources required for post-processing can be significant (especially in person-hours), and the benefits of monitoring would have to be carefully assessed against the costs required.

8. MANAGEMENT IMPLICATIONS

Without actions to protect and enhance coastal habitats we risk affecting habitats that are particulary important for maintaining healthy estuarine and coastal fisheries, which could result in declines in fisheries productivity. For example, in the Kaipara Harbour the southern subtidal seagrass meadows area is especially important as a juvenile nursery for snapper and trevally. This general area, including deeper channels, has also been identified as providing some of the most bio-diverse habitats in the harbour (Hewitt & Funnell 2005). Based on its high value as a juvenile fish nursery habitat, the Auckland Council has listed this area as an Ecologically Significant Area (ESA) in its draft unitary plan. More widely, small patches of biogenic habitat in the subtidal channel and shallow flats areas of the Kaipara Harbour are also important, in particular for juvenile snapper. We note that the wider goals of biodiversity protection also support higher protection of these habitats and environments.

Fishing itself is not the major threat to fisheries habitats in Kaipara Harbour, although damage to biogenic habitats from nets, recreational dredges and boat anchors does occur. The biggest issues arise from adjacent land-use, dominated by the impacts of sedimentation, and to a lesser extent the possibility of eutrophication, which collectively have a wide range of detrimental effects on water and seafloor health, as well as directly on fisheries species themselves and cascading effects into coastal fisheries (Morrison et al. 2009). Management of these stressors does not fall within traditional fisheries management regimes, but is primarily the responsibility of regional councils in the New Zealand context. There are significant collaborative CRI / Northland Regional Council / Auckland Council sediment erosion and transport research programmes currently under way in Kaipara Harbour catchment and the harbour itself. There are also local initiatives around tree planting and the improvement of riparian and other forms of land management. The fish/fisheries habitat work described here engages and collaborates with the IKHMG and Kaipara Research Advisory Group (KRAG), and this type of collaboration/interaction between fisheries habitat, other scientific research programmes, and management agencies and other interested groups needs to continue.

Greater heed of the connectivity of fisheries species across different habitats and areas throughout their life histories is also required (Morrison et al. 2014); this will be a challenging task for fisheries managers given the finer spatial scales needed, compared to those of traditional fisheries stock boundaries.

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APPENDIX 1

Flyer sent to out to potential participants in the Kaipara Harbour Local Ecological Knowledge Interviews.

Helping keep the Kaipara Harbour healthy – can you help?

NIWA
Taihoro Nukurangi

NIWA is currently researching the Kaipara Harbour, in particular fish populations, and the habitats fish rely on. We want to discover how the harbour's environment has changed over the years, and what effect these changes have had on fish and other species. Ultimately we want to help ensure that the Kaipara Harbour is kept healthy in perpetuity.

What is special about the Kaipara Harbour?

We know that the Kaipara Harbour is a critical part of the North Island west coast ecosystem. It contains a diverse range of habitats, as well as many species of plants, invertebrates, and fish. It is also known to hold very important nursery grounds for snapper, trevally, grey mullet, flatfish, and other fish, as well as a wide range of other species that are important as food for larger fish, birds, and mammals.

We are interested in how different habitats such as seagrass meadows, horse-mussel beds, mangrove forests and so on, support fish populations, and how human activities may affect the health and productivity of these various habitats. We are especially interested in how things in the harbour have changed over time.

What sort of things are we looking at?

We would like to build a detailed picture of what habitats and fish populations are in the Kaipara Harbour, how they function and interact, and what the likely threats are to their continuing function and health. Some of the questions we want to answer include:

- Where are different habitats found, how common or rare are they, and what fish populations are associated with them, especially juvenile fish?
- What sort of seasonal migrations and other movements do the various fish populations make? How have fish abundances and sizes changed over time?
- How have habitats changed over time? Can we pin down the reasons for any changes – for example, storms, changes in surrounding land use, or changes in fishing activities?
- How has the appearance of the harbour changed? For example, have there been changes in adjacent land use, the extent of mangroves and seagrass, areas of oysters and mussels, water clarty and seafloor 'muddiness', the amounts of logs and debris, and other interactions with the land such as large inputs of wind blown insect swarms (to name a few)?

NIWA
Taihoro Nukurangi

Can you help us?

To maximise our understanding of the Kaipara Harbour, we want to learn from local people including kaitaki, kaumatua and kuia. Local knowledge is hugely valuable, built up from years of fishing and other experiences, effectively sampling a much wider area and far more frequently than scientists are ever able to. We would like to learn from people from different areas of the Kaipara, who have long-term knowledge and experience of the harbour

Can we interview you?

We would like to conduct face-to-face interviews that will last around an hour, using nautical charts, and a variety of pictures and specimens, to help identify where different species and habitats are found in the Kaipara Harbour, and the changes to these and the wider environment that have occurred over time. You can remain anonymous if you wish, and results will be analysed and written up in an aggregated form.

Do you have any historic information about the harbour?

We would also like to gather any historical records that can help us better understand the environmental history of the harbour. These could be things like historical photographs, personal field diaries, or fishing logs. These types of records are very valuable in helping us understand how things have changed.

Please ring or email any one of the following people for further information, and/or if you would like to contribute through an interview or providing historical material:

Mark Morrison 09 375 2063 (w), m.morrison@niwa.co.nz

Catriona Stevenson 09 375 4642 (w), c.stevenson@niwa.co.nz

Leane Makey (interviews) 09 375 2050, lmakey@slingshot.co.nz

Meredith Lowe (historical records and accounts) 09 375 2050, m.lowe@niwa.co.nz

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41 Market Place, Auckland Central, 1010
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Further background

If you would like to learn more about the role of land-based effects on coastal fisheries and supporting biodiversity around New Zealand, there is a report at:

www.fish.govt.nz/en-nz/Environmental/Land-based+Effects+on+Fisheries+and+Ecosystems/NIWA+review+of+land-based+effects+on+coastal+fisheries+and+ecosystems.htm

or you can contact us directly, and we will post you out a free copy.

Results of this survey will be available on www.niwa.co.nz
Research funded by the Ministry of Fisheries and the Foundation of Research, Science and Technology.

APPENDIX 2

Participant Information Sheet

Project Title: Habitats of particular significance for fisheries management: Kaipara Harbour

PROJECT BRIEF:

Please refer to the attached flyer "*Helping keep the Kaipara Harbour healthy: can you help?*"

The purpose of this project is to learn more about the habitats, environment, and species of the Kaipara Harbour. As part of this work, we are seeking to learn about local knowledge through face-to-face interviews, and the collation of a range of historical records. Potential interviewees have been identified through word of mouth, or through roles they may hold in various local agencies and committees.

Participation is completely voluntary. The data collected will be written up as part of a comprehensive scientific report reviewing information on the Kaipara Harbour, which will also include a wide range of other data from on-the-water field surveys of fish, habitats and the general environment. This report will be made publicly available at the end of the research project, as a formally peer-reviewed scientific report.

All participants' involvement is fully confidential and anonymous, and all interview material (tapes, annotated maps etc) will be securely stored. Tape records (if permission to record is given) of interviews WILL ONLY be used by the named researchers, and will not be made available to any other parties at any stage.

Participants are able to see a copy of the information they provide upon request.

Participation in this project is voluntary, and participants have the right to withdraw their participation and any information they have provided, up to the point of formal publication of the report.

If you have any complaints or concerns about this research, please contact the Project Leader, Mark Morrison, at NIWA Auckland (contact details below). Thank you very much for your time and help in making this study possible. If you have any queries or wish to know more please contact one of the following

Mark Morrison (Project Leader) 09 375 2063 (w), m.morrison@niwa.co.nz
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