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Intertidal habitat mapping for ecosystem goods and services: Waikato estuaries

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Executive summary

In January 2013, Waikato Regional Council (WRC) contracted the National Institute of Water and Atmospheric Research (NIWA), to develop rapid assessment techniques for mapping of intertidal habitats associated with the provision of ecosystem goods and services. Assessment techniques were successfully trialled for mapping the intertidal area of Tairua Estuary. This report documents the application and adaptation of the habitat mapping methodology for thirteen estuaries and harbours within the Waikato Region: Otahu River, Whangamata Harbour, Wharekawa Harbour, Purangi River, Whitianga Harbour, Whangapoua Harbour, Kennedy Bay, Waikawau Bay, Port Charles, Colville Bay, Coromandel Harbour, Te Kouma Harbour and Manaia Harbour.

Field based observations of intertidal areas in each of the thirteen study locations were undertaken to rapidly identify habitat characteristics linked to the provisioning of ecosystem goods and services. As much of the intertidal area in each estuary that could feasibly be covered given spring low tides was covered. Handheld global positioning systems (GPS) were used to demark boundaries between habitats, and geo-referenced photographs were collected inside each habitat type. All data were processed and converted into GIS map layers. Sediment information from each study location was also detailed for each habitat polygon using five broad categories (mud, sand, shell-hash, sandy mud/muddy sand mixture, and gravel mixture). Sediments were classified based on visual observations, textural analysis and sinking depth underfoot. Sediment samples were collected from each estuary for quantitative verification at a later date.

There were three habitats defined by the characteristics/dominance of the flora: seagrass, mangroves and pneumatophores (the aerial roots of mangroves). There were 12 habitats defined by characteristics/dominance of the fauna: cockles, pipi, cockles and pipi, Wedge shell (*Macomona)*, oysters, crustacean burrows, crabs and cockles, tubeworms and cockles, snails (*Amphibola)*, ‘low density deposit feeders’ (our baseline/LD deposit feeding community composition), ‘mounds and pits’ (similarly dominated by deposit feeders but featuring a distinct surface topography) and ‘low fauna’ (where macrofauna were extremely sparse). Habitat heterogeneity of each category is indicated in the accessory data provided for each estuary.

1 Introduction

In January 2013, Waikato Regional Council (WRC) contracted the National Institute of Water and Atmospheric Research (NIWA), to develop rapid assessment techniques for mapping of intertidal habitats associated with the provision of ecosystem goods and services. Ecosystem goods and services are defined as ‘the direct and indirect benefits that mankind receives or values from natural or semi-natural habitats’ and include the provision of food and raw materials, waste treatment, processing and storage, disturbance prevention, sediment retention, water filtration and regulation, nutrient regulation, gas and climate regulation, habitat structure and cultural services such as spiritual heritage and leisure and recreation (Townsend *et al.* 2010).

The rapid assessment techniques trialled in Tairua estuary (i.e., the methods of mapping and the repeatability and precision of the results described in Needham *et al.* 2013) appeared promising, thus further work was commissioned by WRC to apply these techniques in a greater number of estuaries in the Waikato Region. This report documents the application and adaptation of the habitat mapping methodology to these other estuaries (Figure 1-1). The report includes:

- Descriptions of habitats consistent with ecosystem goods and services. As the mapping techniques were being expanded to new areas, this occasionally required the inclusion of new habitat types and amendments to the criteria used to categorise habitats.
- Information on sediment type. Each habitat was assigned to one and only one of the following 5 sediment categories based on visual and textural observations: mud, sand, shell-hash, sandy mud/muddy sand mixture, and gravel mixture.
- A review of the repeatability and precision of maps produced.
- An overview of current and future threats for the various harbours and estuaries.

In addition to this report, all of the geo-tagged digital images collected during fieldwork, GIS shape files of habitats and the accompanying metadata are being provided to WRC. NIWA also collected sediment samples from numerous sites in each estuary for the purposes of sediment layer verification at a later date.

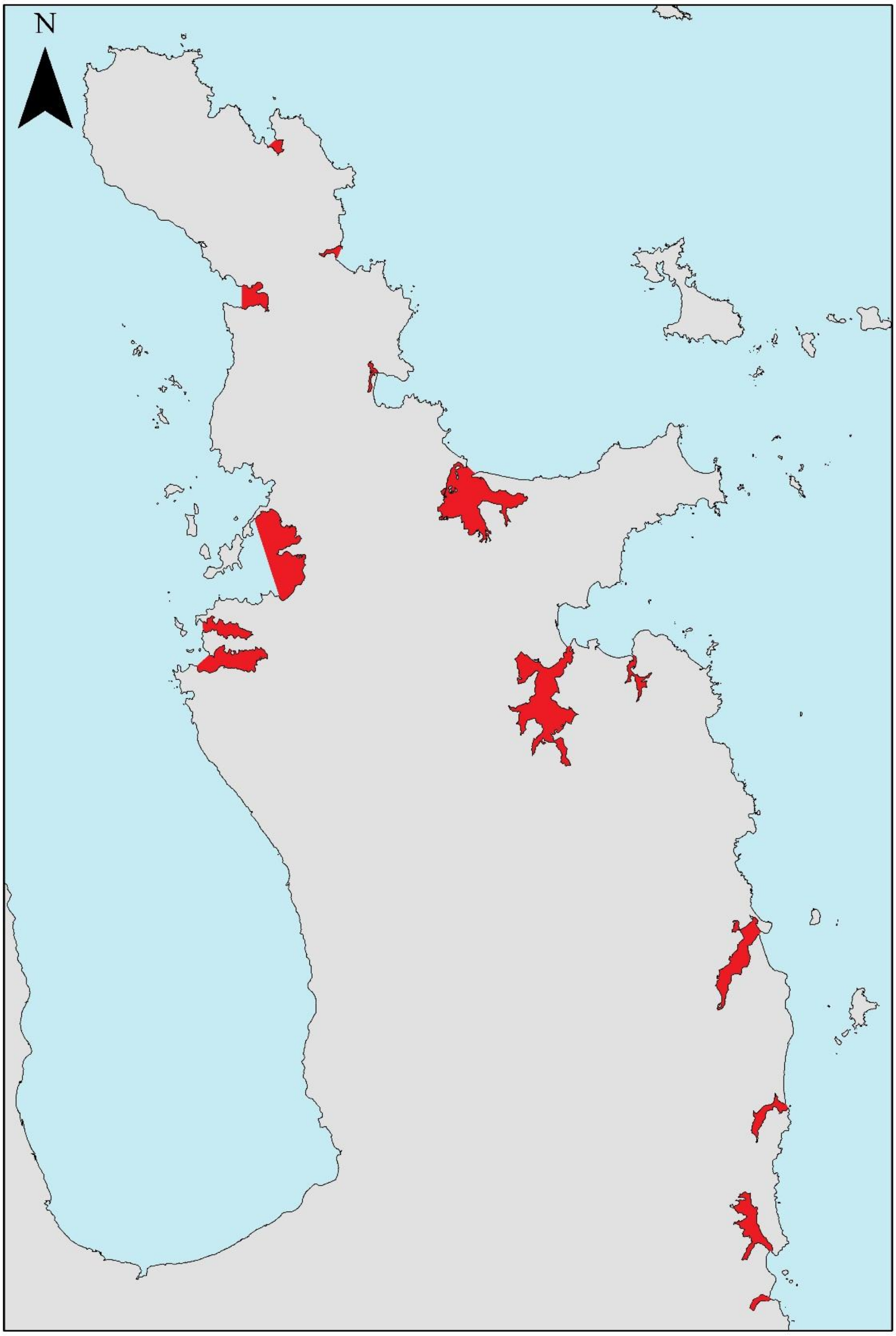


Figure 1-1: Map showing the estuaries and harbours (red) covered for intertidal habitat mapping. Starting bottom right and working in an anticlockwise direction around the Coromandel Peninsula, the locations were: Otahu River, Whangamata Harbour, Wharekawa Harbour, Tairua Estuary (studied previously), Purangi River, Whitianga Harbour, Whangapoua Harbour, Kennedy Bay, Waikawau Bay, Port Charles, Colville Bay, Coromandel Harbour, Te Kouma Harbour and Manaia Harbour.

2 Methods

2.1 Derivation of habitat types

During the Tairua Estuary assessment, an inventory of habitat types typical of New Zealand estuaries and with implicit links to ecosystems services was documented (Needham *et al.* 2013). A prevalent habitat type dominated by a low to medium density deposit feeding community in muddy sand or sandy mud was assumed to be the 'baseline' and referred to as a 'low density (LD) deposit feeder' habitat. Pronounced differences away from this baseline habitat type (Table 2-1) were mapped.

Table 2-1: Derived habitats and their links to goods and service provision. HD denotes high density, LD low density.

Habitat Type	Implicit Service Links
Flora	
Seagrass	Primary production, habitat structure, sediment stability & retention
Mangroves	Primary production, carbon sequestration, gas and climate regulation, disturbance prevention, sediment stability & retention, habitat structure and coastal defence
Pneumatophores	Nutrient cycling, sediment stability
Fauna	
Tube worm mats	Sediment stability
HD Cockle or Pipi beds	Secondary productivity, cultural harvesting, waste treatment, processing and storage, carbon sequestration.
LD Deposit Feeders	Secondary productivity, cultural harvesting, waste treatment, processing and storage, carbon sequestration, sediment stability, nutrient cycling.
Amphibola	Cultural harvesting
Oysters	Biogenic habitat provision, cultural harvesting, waste treatment, sediment stability & retention
HD *Macomona*	Sediment stability
HD Crustacean burrows	Sediment stability and reworking rates, waste treatment, processing and storage, nutrient cycling, secondary productivity, habitat structure.
Mounds and pits	Secondary productivity, nutrient cycling, sediment stability habitat structure.
Low fauna	Sediment stability

2.2 Field-gear

The principal pieces of equipment used in the field were cameras and GPS units. The GPSs were Garmin GPSMAP 78SC, which enabled us to mark waypoints and describe habitat features or attributes at specific locations and also to record track boundaries demarcating the edges of habitat patches. The cameras used were the Fujifilm FinePix XP150, which provided high resolution images (14 MP) and allowed for the 'geo-tagging' of photos with GPS coordinates to facilitate the mapping analysis. Other gear included 0.25 m^2 quadrats, trowels and 2 cm internal diameter sediment corers (see section 3.2).

2.3 Field techniques

Field techniques followed those of Needham *et al.* (2013). To cover expansive intertidal flats quickly and effectively, transects were walked in a zig-zag formation to maximise the areas covered (Figure 2-1). Changes (or similarities) in habitat type were confirmed by multiple personnel and noted using waypoints. Similarly, a fan formation, whereby each individual would walk from a central point, was used to maximise coverage in long but narrow bays (Figure 2-2). Obvious boundaries between habitats were apparent for a number of the defined habitat types (for example, raised banks of shell rich sediments or mangrove patches). Where practicable, patch boundaries were walked in their entirety. Where extensive habitat regions existed (e.g., mangroves, seagrass) a section of the perimeter was walked (noted by GPS waypoints) so that this could be referenced to both the WRAPS 2012 aerial photos and existing GIS vegetation layers (both supplied by WRC). In areas where wide, expansive patches existed, two individuals walked the perimeter in opposite directions until they came together. Patches <10 m in their longest dimension were not noted on their own, due to the accuracy of the GPS units, but were amalgamated into the description of the surrounding area, or in the case of obvious vegetation, were drawn from WRAPS photos. Photographs were taken to collate information on different habitat characteristics and to cross reference each habitat type to ensure repeatability for these and future surveys.

Figure 2-1: Transects walked by two personnel in Whitianga displaying zig-zag technique for maximising the area covered.

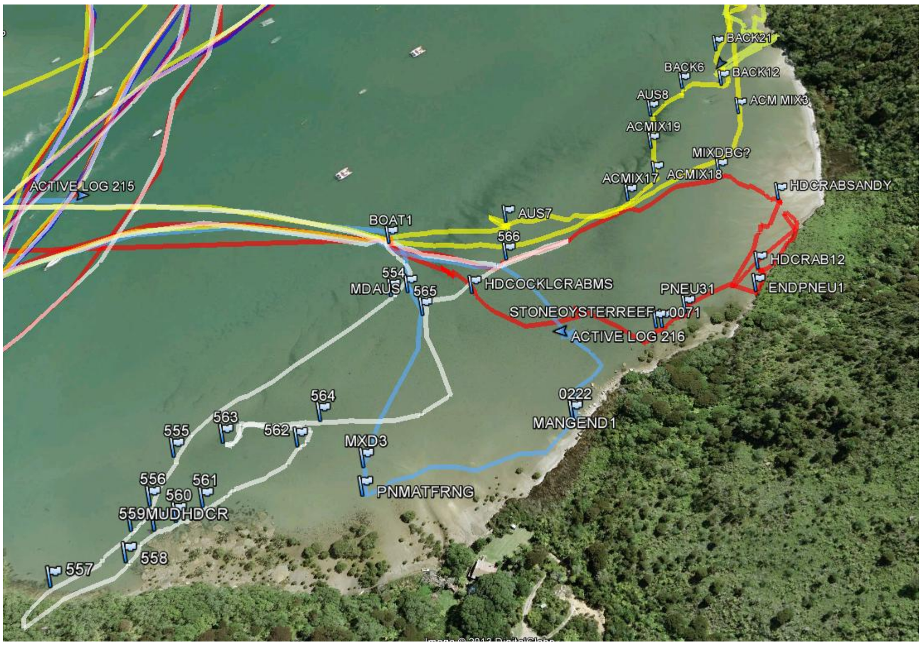


Figure 2-2: Transects walked by four personnel in fan formation, used for long narrow bays to maximise coverage.

2.4 Sediment assessment and particle sizes

Observations were made of sediment types to place intertidal areas into one of 5 non-overlapping categories (Figures 2-3 and 2-4):

- Mud – Sediment lacking a coarse or gritty texture when rubbed between the fingers, instead feeling smooth/silky. A person sinks at least ankle deep (~15 cm) into this sediment when walking in it. A person's feet should slide easily through the sediment with little resistance. Sinking depth alone does not define muddiness, as many factors (e.g., drainage, sorting, compaction, bioturbation, etc.) influence penetration depth.

- Sand – Sediment dominated by sand fractions with minor silts and clay fractions. Coarse and abrasive when rubbed between fingers. Generally firm underfoot (although not used in definition due to isolated areas of sinkable fine sand) and well-drained.

- Shell-hash – Sediment characterised by high densities of shell-hash on the surface. Visually observed to cover ~70-100% of sediment surface to the extent that very little (or none) of the underlying sediment is visible. Shells tend to be piled on top of each other. Underlying sediment is that of sandy-mud / muddy sand (as per the 'LD deposit feeder' category) unless otherwise stated. High density *Austrovenus* (cockles) and *Paphies* (pipi) categories are assumed to have some shell-hash on the surface, but not necessarily at the density to qualify as a 'shell-hash' sediment (Figure 2-4).

- Sandy mud/muddy sand mixture – Sediment that fell outside of the above classes and contained a mixture of sand and mud size fractions.

- Gravel – During the habitat mapping fieldwork it was necessary to add an extra sediment category as in isolated areas (e.g., patches in Kennedy Bay, Tairua Harbour, and Port Charles), the sediment surface was covered with a layer of coarse gravel, pebbles or cobble (Figure 5); differentiating it from the sediment types above. This often appeared to be the result of riverine input and this material often occurred in the middle or upper reaches of an estuary.

Figure 2-3: Example of the sediment types: mud (top), sand (middle) and sandy mud/muddy sand (bottom).

Figure 4: Example of the sediment types: Gravel mixtures (top) and shell-hash (bottom)

Figure 2-5: Example of the sediment types: Gravel mixtures (top) and shell-hash (bottom).

Sediment information across the estuaries and harbours has been included in the attributes table of each estuary so that sediment layers can be created if required.

Eighty-six sediment samples were collected across the 13 locations; covering a range of sediment types from the mouth to the head of each estuaries/harbours. Sediment was collected using a 2 cm internal diameter corer to a depth of 2 cm and placed in marked containers. Sediment-filled containers were photographed inside a representative quadrat (for visual reference) and waypoints were marked to record the location. Samples were frozen as soon as was practicable.

Sediment samples can be processed for granulometry and the data used to provide information on the specified categories above, for example, mean grain-size, range in grain-sizes covered by a sediment category (to identify the range in fine sediment percentage attributed to our ‘mud’ classification as other factors such as permeability and porosity may influence ‘sinkability’), and assessments of category distinction (to ensure that our muddy category is more muddy than the muddy sand or sand).

3 Precision obtained in field and repeatability

3.1 Instruments

At the beginning and end of each day, all GPS and cameras were taken to a notable point (i.e., visible and unchanging on satellite imagery), where a waypoint and photo were collected on each unit. When possible, points were also collected in the middle of the day. Accuracy of these geo-referencing devices is dependent on the satellite availability and position at any given time, and by collecting points over the course of the day we could assess the variation in our precision. Generally we found low variability for within-day precision, but higher variation between days i.e., for the same estuary sampled over a series of days. During our mapping process, efforts were made to (i) walk boundaries together to assess variability between devices and where possible (ii) for multiple people to walk the same boundaries independently to assess repeatability.

3.2 Precision

The preliminary work on Tairua Harbour indicated that the GPS units had a precision of 1 to 5 m which is within the degree of error anticipated (manufacturers quote ± 5 m). Geo-tagged photos were less precise, varying from their corresponding GPS unit by 19 + 6 m. The smallest deviation was 7 m and the largest was 26 m. Due to lower precision (and accuracy) associated with the cameras, an effort was made to take photos from within a habitat (ideally 20-30 m inside a habitat boundary). Photos and waypoints were paired in most instances.

Satellite coverage has the potential to alter over time. Differences in the precision of each individual's boundary lines were assessed by measuring the distance between two tracks walked together at the same time. Approximately four measurements were collected over segments of track varying between 50-100 m in length (Figure 3-1). This was repeated multiple times on different tracks, with greater repetition in the larger estuaries, which took longer to map (Table 3-1). Precision across the 13 estuaries was generally very good with mean variations around 5 m or less for all but 2 estuaries (Table 3-1). The exceptions to this were Port Charles and Te Kouma, where precision was closer to 7 m. Satellite coverage in Whangapoua Harbour was poor for short periods of time. During these periods there was a loss of definition where boundaries had been walked, however waypoints appeared largely unaffected and, as points were taken frequently, boundaries were interpolated between points using site photos and visual cues from WRAPS images.

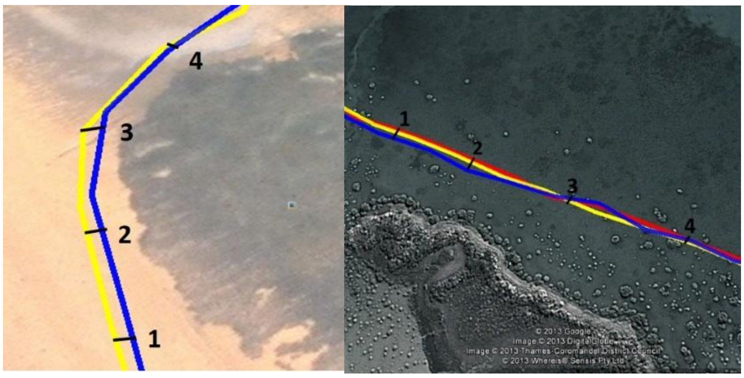


Figure 3-1: Examples of precision measurements for Manaia (left) and Whangapoua (right) harbours. In the examples shown measurements are approximately 30 m apart.

Table 3-1: Summary of GPS precisions, n = number of measurements made.

Estuary/Harbour	(n)	Average Variation (m)	Standard Deviation
Otahu River	8	2.03	0.93
Whangamata Harbour	14	2.74	1.93
Wharekawa Harbour	8	3.49	1.49
Purangi River	19	1.51	1.28
Whitianga Harbour	16	4.26	1.85
Whangapoua Harbour	16	5.91	4.26
Kennedy Bay	8	5.04	4.47
Waikawau Bay	8	3.54	0.94
Port Charles	6	7.45	4.44
Colville Bay	9	3.63	1.7
Coromandel Harbour	18	3.21	2.22
Te Kouma Harbour	8	7.33	4.82
Manaia Harbour	9	5.81	3.61

3.3 Repeatability

The ability for individuals to establish the same boundary lines (repeatability) was generally very good across the 13 estuaries/ harbours. For the conspicuous vegetation habitats there was virtually no error other than the precision of the GPS units (Figure 3-2a). An example is shown in Figure 3-2b of a less conspicuous cockle habitat from Whitianga. Some of the discrepancy between the two tracks, evident in the lower section, was due to changes in tidal inundation between circuits. In this example the average divergence (taken at 5 equidistant intervals along the length of the loop) was 3.58 m ±1.35 m (SD) and is well within the GPS margin for error (± 5 m).

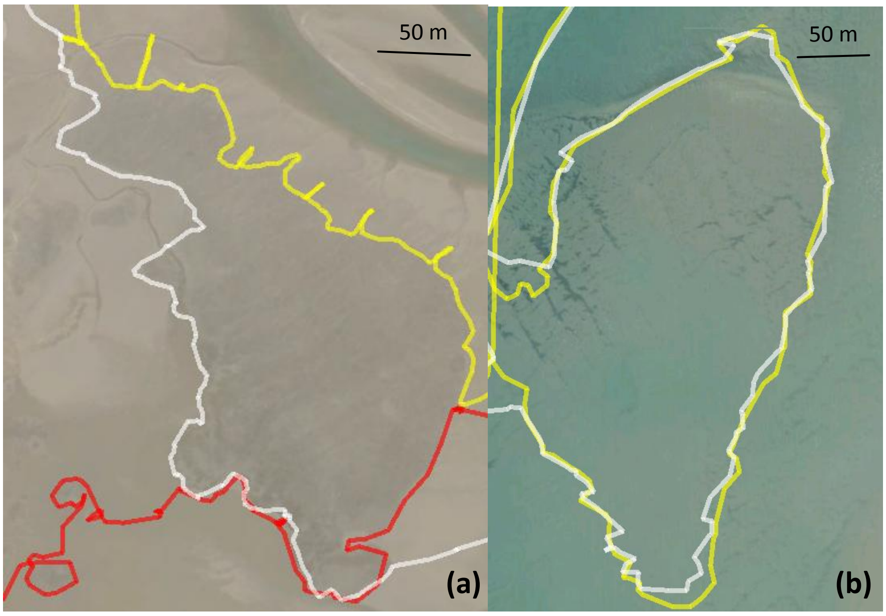


Figure 3-2: (a) A conspicuous seagrass boundary walked by three individuals (yellow, white and red lines) with a repeated section (Whangamata); (b) a repeated boundary walk (yellow and white lines) from a less conspicuous cockle habitat (Whitianga Estuary).

4 Habitat categories

Habitat categories were largely consistent with the Tairua Estuary methodology (Needham *et al.* 2013), although categories were redefined slightly in some cases (Table 4-1). More importantly, the total number of habitat categories had to be expanded slightly to accommodate new things that were encountered. Generally there were few problems with assigning habitat types in the field. Below we include information on the habitat types we defined, making detailed descriptions of the characteristics that distinguish them so that these methodologies can be repeated in the future. Site specific photographs of the following habitat categories are given in section 8.1.

4.1 Flora

4.1.1 Seagrass (*Zostera capricorni*)

To be considered a 'seagrass' habitat, the *Zostera* had to be of sufficient density and extent (minimum of 10 m^2) to form a distinct bed rather than a collection of sparse single leaves (e.g., photos section 8.1). Across the Coromandel there was no ambiguity with assigning the seagrass habitat, as the seagrass was conspicuous and often dense where present. Within seagrass habitat there was a variety of infaunal species ranging from shrimp, crabs, cockles and *Macomona* and these were often in highest densities at the edges of seagrass patches. Islands of 'bare' sediment within larger seagrass patches were not demarcated unless greater than 10 m^2 and accessible. The presence of sparse seagrass is noted in the GIS shape file attributes tables, however, regular vegetation surveys conducted by WRC (Graeme, 1997, 1998a, b, 1999, 2010) provide far greater detail on the extent and composition of such habitats.

4.1.2 Mangroves (*Avicennia marina*)

Mangrove habitat was defined as areas of adult *Avicennia marina* plants greater than 10 m^2 in spatial extent. This definition excluded areas of seedlings and pneumatophores. Sediments within these mangrove patches varied between sandy-mud and mud, with predominantly crustacean burrows visible in the sediment between plants.

4.1.3 Pneumatophores (*Avicennia marina*)

The pneumatophore habitat was distinguished from mangrove habitat (even though mangroves are the source of the pneumatophores). This is because pneumatophores can extend more than 5 m past the edge of the mangrove foliage (and are therefore distinguishable even given the ±5 m accuracy of the GPS units). The sediments between the emergent root structures in this habitat were generally dominated by crustacean burrows and new mangrove seedlings. However due to the conspicuous above ground features created by dense pneumatophores, and their known influences on gaseous exchange (Kitaya *et al.* 2002) and bed flow dynamics, this was kept separate from our 'crustacean burrows' category.

4.2 Fauna

4.2.1 HD Cockles (*Austrovenus stutchburyi*)

High density (HD) cockle habitat was defined as sediment containing 10 or more individuals (≥ 10) sized 20 mm or greater in shell length (≥ 20 mm) from a 15 x 15 cm area. This criteria was modified following exploration of Manaia Harbour where large cockles (≥40mm shell length) were found but in lower densities. If there were more than 3 of these large cockles per 15 x 15 cm area, this too was considered to be 'cockle habitat' as large individuals can make a significant and non-linear contribution to functions (e.g., filtration rates, movement) and therefore ecosystem services. Cockles ≥40 mm were not found in any estuaries or harbours other than Manaia. Accessory information on where these were identified is given in the attributes table of the GIS layer. Within cockle habitats it was typical to see other fauna (e.g., worm casts, *Macomona* surface features, gastropod activity, etc.). However these were present in comparatively low densities. Cockle habitats typically had a fine layer of shell-hash visible at the sediment surface (but see section 2.4). Across the cockle habitat, cockles were not uniformly distributed with aggregations of individuals and sparser patches evident. Establishing the boundaries of habitats required the sampling of multiple quadrats to ascertain where cockles had dropped in density.

4.2.2 HD Pipi (*Paphies australis*)

High density (HD) pipi habitat was defined as sediment containing 10 or more individuals sized 40 mm or greater in shell length from a 15 x 15 cm area. Excavated sediment needed to be sorted carefully to separate live specimens from dead shells. Scattered shell material was typically present on the sediment surface. The edges of beds could often be ascertained by repeatedly probing the top few cm of sediment until resistance became less.

4.2.3 HD Cockles & Pipi

This habitat category was created following the survey of Otahu Estuary, where cockles and pipi were found together in sufficiently high density to both qualify for their respective habitat categories (i.e., ≥10 cockles sized ≥20 mm shell length were present per 15 x 15 cm area, as were ≥10 pipi individuals sized ≥40 mm shell length). This habitat was exclusive to Otahu Estuary.

4.2.4 HD Macomona *(Macomona liliana)*

High density (HD) *Macomona* (wedge shell) habitat was defined as sediment containing more than 4 *Macomona* sized 30 mm or greater in shell length per 15 x 15 cm area. The presence of *Macomona* was indicated by the conspicuous tracks that they leave in the sediment surface. However tracks alone could not be used to establish habitat as there was considerable variation in the size and density of track marks relative to the number of *Macomona* 30 mm or greater in shell length found. Thus, quadrats had to be excavated in order to verify the densities and sizes of *Macomona* present. Differentiation between high and medium density *Macomona* habitats was conducted in Tairua, but was abandoned in subsequent surveys due to the difficulty of separating medium density *Macomona* habitat from that of 'LD deposit feeder' habitat.

4.2.5 HD Oysters *(Crassostrea gigas)*

High density (HD) oyster habitats were typically found around the fringes of harbours and estuaries on rocks and firm substrates. Oyster habitat was defined as covering greater than 80% of the 0.25 m^2 quadrat when repeated several times over areas greater than 10m in one dimension (often oyster habitat could be long and narrow).

4.2.6 HD Crustacean Burrows

The high density (HD) 'crustacean burrow' habitat was defined by the presence of a high number of conspicuous crabs and/or shrimp burrows on the sediment surface. These were typically in high density, whilst other common estuarine fauna were lacking. Burrow structures are acknowledged to differ according to the species creating them and the sediment environment in which they are found. Typically, greater burrow densities are found in consolidated muddy sediments, as burrows tend to persist for longer once constructed in these cohesive sediments (Needham *et al.* 2010). To encompass the range and form of burrows among habitats, the high density crustacean burrow category was defined as containing 10 burrows or more of 20 mm or greater aperture in a 0.25 m^2 quadrat, although in reality, those found in muddy sediments were often seen in densities in excess of 40 burrows per 0.25 m^2. Repeat quadrats were thrown (~3 to 5 times) to verify burrow densities in each area. The 'moderate density' crustacean burrow habitat, developed during the Tairua survey, proved time consuming and difficult to distinguish from that of our mixed 'mounds and pits' category (4.2.9 below) and was amalgamated into it.

4.2.7 HD Crabs and Cockles

This mixed habitat category was created following the survey of Purangi River, where crabs and cockles were found together in sufficiently high density to both qualify for their respective high density habitat categories. Crustacean burrows were found at densities of 10 burrows or more of 20 mm or greater aperture per 0.25 m^2 within quadrats and cockles were found (amongst the crab burrows) at densities of 10 or more individuals sized 20 mm or greater in shell length per 15 x 15 cm area. This habitat was seen in multiple locations in estuaries and harbours around the Coromandel.

4.2.8 Low Density (LD) Deposit Feeders

This habitat category acted as our baseline community (called 'background' in Tairua), at each estuary and is deliberately broad to encompass the differing community structures in each location. The presence of large burrows is rare or infrequent (>1 burrow of >2 mm diameter per 0.25m^2 in $n \geq 3$ quadrats) although in some instances high densities of juvenile crabs were also incorporated into this category. Details of where this occurred are given in the attributes table of the individual GIS shape files. Beds of juvenile bivalves incorporated into this category were also noted in the accessory data (see section 4.2.10).

4.2.9 Mounds and Pits

This mixed community habitat category was similar to 'low density deposit feeder' habitat in that it was dominated by a predominantly deposit-feeding community (often *Macomona*, polychaetes and cockles) at densities below their respective individual high density habitat thresholds. 'Mounds and pits' habitat differed from 'low density deposit feeder' habitat by having noticeable topographic features in the sediment through increased bioturbation. These pits and mounds were not dense on a quadrat by quadrat basis (ranging from <1 to ~4 per quadrat), however when looking across the flats, considerable disturbance and sediment undulations were notable (and differed from that of ray feeding pits). Anoxic sediment mounds are often good indicators of reworking.

4.2.10 Low Fauna

This habitat was not previously defined, but was used to categorise areas that were highly physically dominated, for instance, upper estuaries where coarse sediments dominated or areas with large expanses of wave rippled sand. These environments were typically sparsely populated by benthic organisms; the habitat was characterised by a general lack of any visible fauna in a 15 x 15 cm area.

Infrequently, these coarse, mobile sediments contained juvenile pipi (observable due to the presence of tiny pits in the sediment surface). Although not a deposit feeder, and therefore not naturally part of the 'low density deposit feeder' category composition, juvenile pipi, when present, were in great enough abundance to warrant acknowledgement. Juvenile pipi dominated habitats were therefore placed in the 'low density deposit feeder' category and notes on their location are given in the accessory information in the GIS layer to differentiate them from our more typical 'low density deposit feeder' classification.

4.2.11 HD *Amphibola*

This category proved the least successful of those developed, as *Amphibola* (mud-flat snail) distributions were often patchy and intermingled with mangrove fringes and/or high density burrows. High density (HD) *Amphibola* was defined as sites where 10 individuals or more per 0.25 m^2 were present in 3 or more random quadrats with a spatial extent of 10 m or greater in any direction. These were infrequently observed. The presence of *Amphibola* at lower densities or associated with other habitats is detailed in shapefile attributes tables.

4.2.12 Tube worms and crabs

Tube worm mats were only recorded in Te Kouma. In the outer bays of Te Kouma, dense tube worm habitat was defined when tube worms occupied >60% of the area within sampled quadrats. However, in this instance, the matrix also included high densities of crabs (≥10 burrows per 0.25 m^2) and so was renamed accordingly.

Table 4-1: Summary of the habitats and their qualifying descriptions.

Habitat Type	Qualifying information
Seagrass	Dense vegetation spanning more than 10 m^2.
Mangroves	Adult plants greater than 10 m^2 in spatial extent.
Pneumatophores	Border of the adult plants protruding laterally >5 m.
HD Cockles	≥10 individuals sized ≥20 mm shell length per 15 x 15 cm area, or >3 individuals sized ≥40 mm shell length per 15 x 15 cm area. Typically with a fine layer of associated shell-hash.
HD Pipi	≥10 individuals sized ≥40 mm (shell length) from a 15 x 15 cm area. Typically associated with some shell-hash.
HD Cockles and Pipi	≥10 cockle individuals sized ≥20 mm shell length *and* ≥10 pipi individuals sized ≥40 mm shell length from a 15 x 15 cm area.
HD *Macomona*	≥4 individuals sized ≥30 mm (shell length) from a 15 x 15 cm area. Tracks are a poor indicator of density.
HD Oyster	Covering greater than 80% of the 0.25 m^2 quadrat. Must be repeatable over an area >10m in one dimension.
HD Crustacean Burrows	≥10 burrows of ≥20 mm aperture in a 0.25 m^2 quadrat. Repeated, randomly thrown quadrats (n=3 to 5) must exceed the density threshold.
HD Crabs and Cockles	Both at densities to qualify for their respective habitat categories (above).
LD Deposit Feeders (Background)	Low to med density of mainly deposit feeding fauna.
Mounds and Pits (Mixed)	Similar to LD deposit feeder category but with noticeable surface topography. Burrows and mounds range from <1 to 4 per 0.25 m^2 quadrat.
Low Fauna	Sparse fauna often in densities lower than 1 individual per 0.25 m^2 quadrat.
HD *Amphibola*	≥10 individuals per 0.25 m^2 were present in 3 or more random quadrats with a spatial extent of ≥10 m in any one direction.
Tube worms and crabs	Covering greater than 80% of the 0.25 m^2 quadrat. Must be repeatable over an area >10 m in one dimension. Crabs in densities great enough to qualify for their own category.

5 Habitat Maps

To create the habitat map, all GPS units were downloaded using Garmin Basecamp software where all tracks and waypoints were compiled in to one file, overlaid and colour coded. All data was transposed in to a .kmz file suitable for us

e in *Google Earth*. All photographs (see appendix for example habitat images) were batch processed to thumbnail size and imported to *Google Earth* using *GeoSetter* freeware. This information, alongside written notes, was used to create maps in GIS format.

Polygons were created using the trace function where complete track loops around a habitat patch existed. Where a seaward boundary had been walked, the Hauraki Gulf intertidal extent 2013 layer (courtesy of WRC, AC) was overlaid and the boundary traced. It should also be noted that this polygon did not always match our observations at the channel edge perfectly, with some of our mapped areas appearing sub-tidal when using this layer. Where this occurred, the underlying WRAPS (2012) photograph was used to define the water's edge.

Where 'zig-zag' or 'fan' techniques had been used to cover large or wide intertidal flats, changes in community structure were assessed between all transects before using this information to interpolate boundaries between them. Waypoint information, site photographs and physical features visible from the WRAPS images were also used to aid the specific positioning of each boundary.

Areas of 'rocky reef' have been included in the following maps; however no assessment of their associated community structure or relevance to ecosystem goods and services has been made (these areas were largely just rock). Similarly 'dead oyster reef', 'oyster farm' and areas of significant cultural and spiritual significance (tapu) polygons have been created for the appropriate estuaries as accessory information.

5.1 Otahu River

Information is provided to assist repeating the mapping process at a future date if desired.

<u>Access and timing:</u>

- Accessed easily on foot from the main beach or any of the signposted access points along the length of the estuary.
- Tidal period slightly asymmetric, longer exposure period after low tide.
- Fast flowing deep channel should not be crossed until low tide and then only at mid to head end of the estuary.
- 1 day, 3 people (Figure 5-1).

<u>Other notes:</u>

- Primarily firm sandy sediment with very little mud, however there is evidence of sedimentation in the upper reaches by State Highway 25 near to the site currently under development.

- Obvious high flow areas. Some modification by way of coastal defence in terms of groynes and gabiens near to Patuwai Drive.
- Very little seagrass.
- Good public interest and naturalist groups in the area.

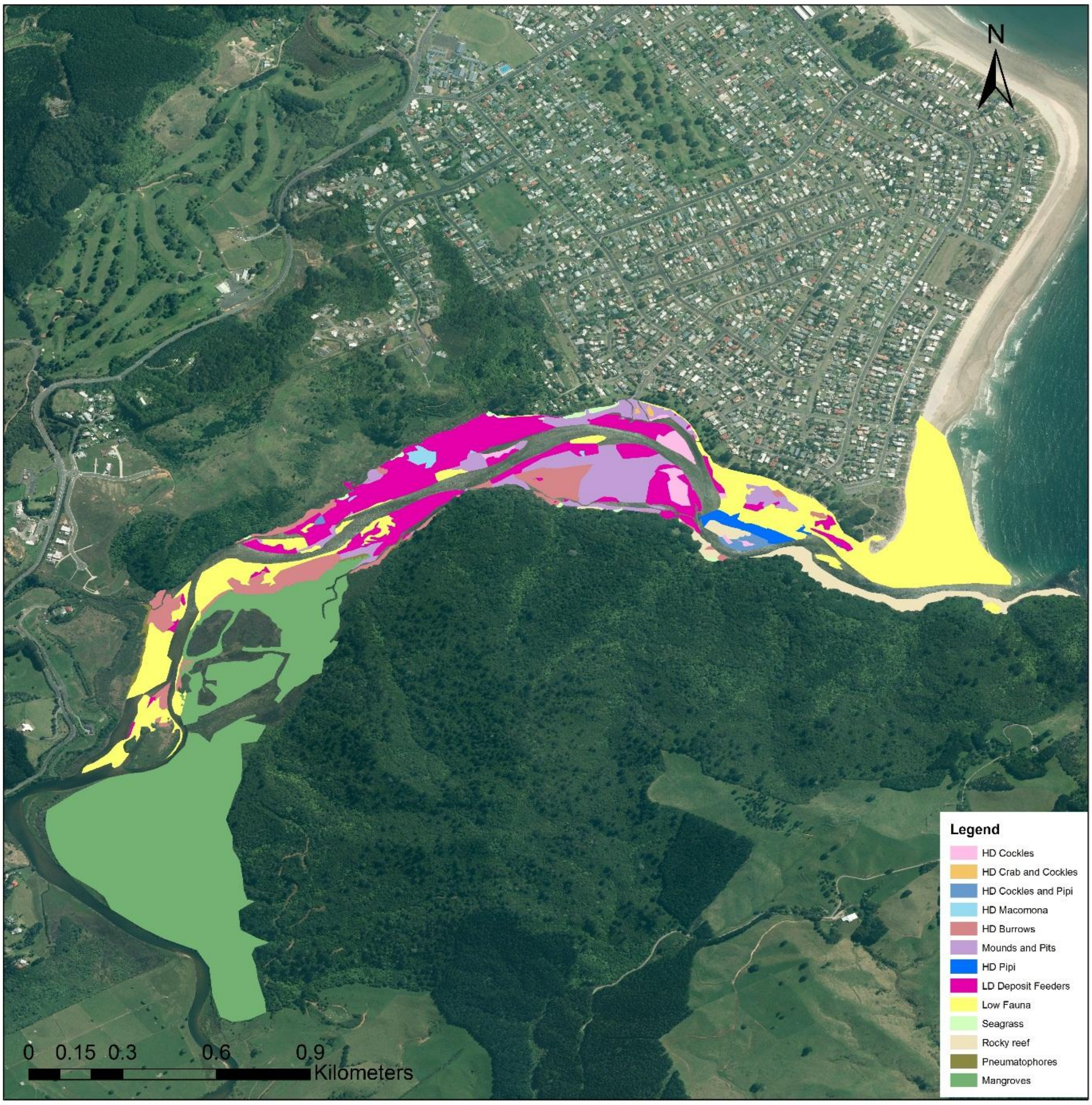


Figure 5-1: Otahu River habitat map.

5.2 Whangamata Harbour

Access and timing:

- Accessed by boat via main harbour channel, although much of the estuary can be reached on foot from the western suburbs if required.
- 2 days, 4 people (Figure 5-3).

Other notes:

- Mangrove removal was actively taking place in the western embayments during our survey. Localised disturbance of the benthos in these locations is therefore occurring although the duration of this effect is as yet unknown. Due to the modifications that are being conducted here, the Whangamata habitats may undergo larger changes and the map may require earlier revision, relative to others in the Coromandel.
- Fish feeding pits (primarily rays, observed from sediment imprints) were particularly apparent in the western bays of this estuary. Due to their smaller size and high frequency, these could be misinterpreted as sediment formations caused by burrowing unless examined carefully (Figure 5-2).
- Large, lush seagrass patches extended across a significant proportion of the intertidal.
- Mud was mainly limited to the upper, northern section of the estuary.

Figure 5-2: High frequencies of small ray pits in the western bays of Whangamata could be mistaken for burrows.

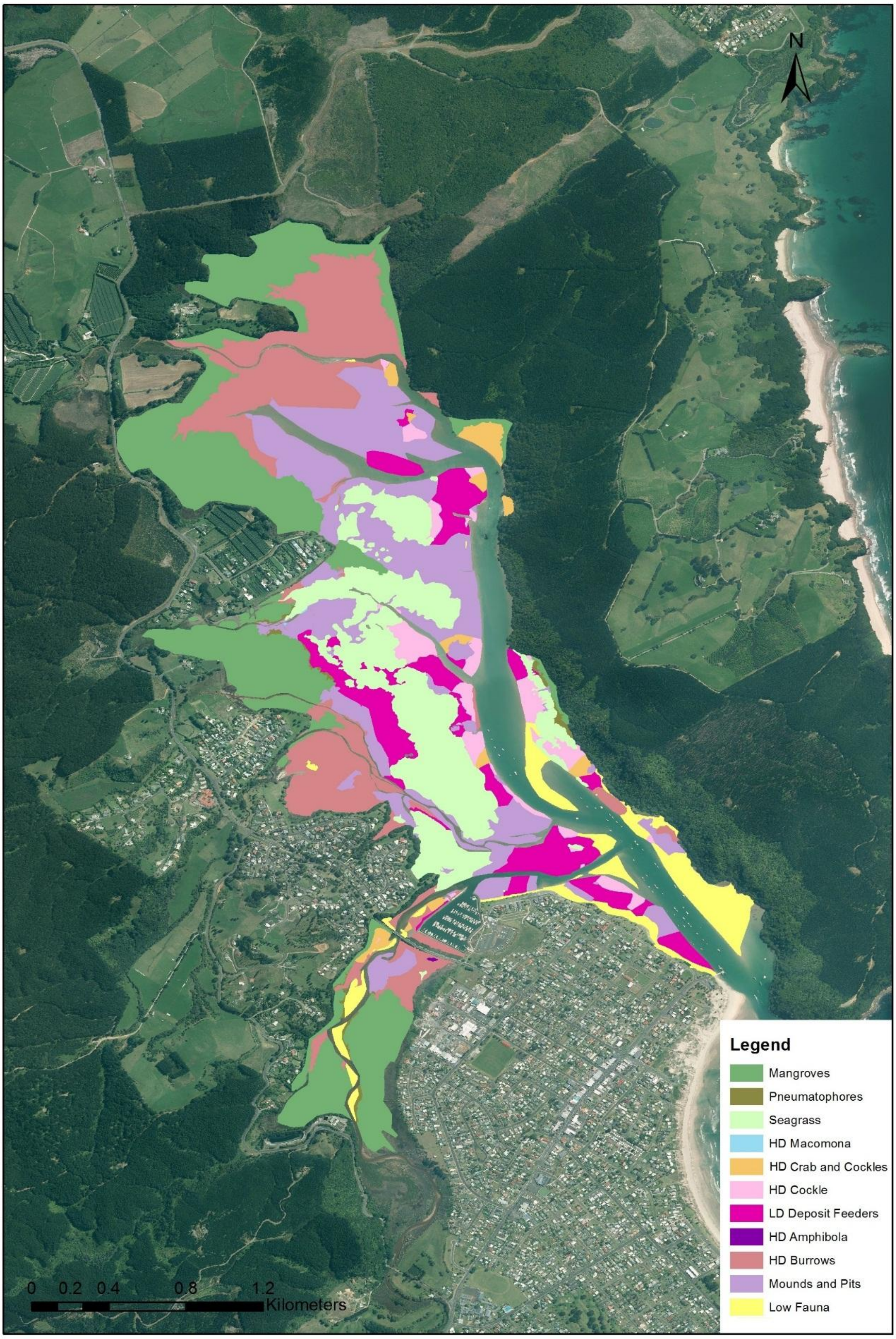


Figure 5-3: Whangamata habitat map.

5.3 Wharekawa Harbour

Access and timing:

- Accessed primarily on foot from Opoutere Road. A deep channel (~40 m width) with strong currents required boat access for the southern-eastern sand flat. Kayaks were used for practicality (although a boat ramp is available from Opoutere Road, approx. mid harbour).
- The tidal period is asymmetric, taking longer to ebb.
- 2 days, 3 people (Figure 5-4).

Other notes:

- The course of the channel has changed over the last few years in the upper reaches of the harbour.
- The large sand flat by the mouth is physically dominated. Sediment transitions between sand and sandy mud between this flat and the large patch of seagrass on the southern side of the harbour.
- Mangroves have been cleared in front of the dwellings by the water's edge at 120 Opoutere Road.
- Sedimentation is occurring from the stream by Opoutere Bridge.

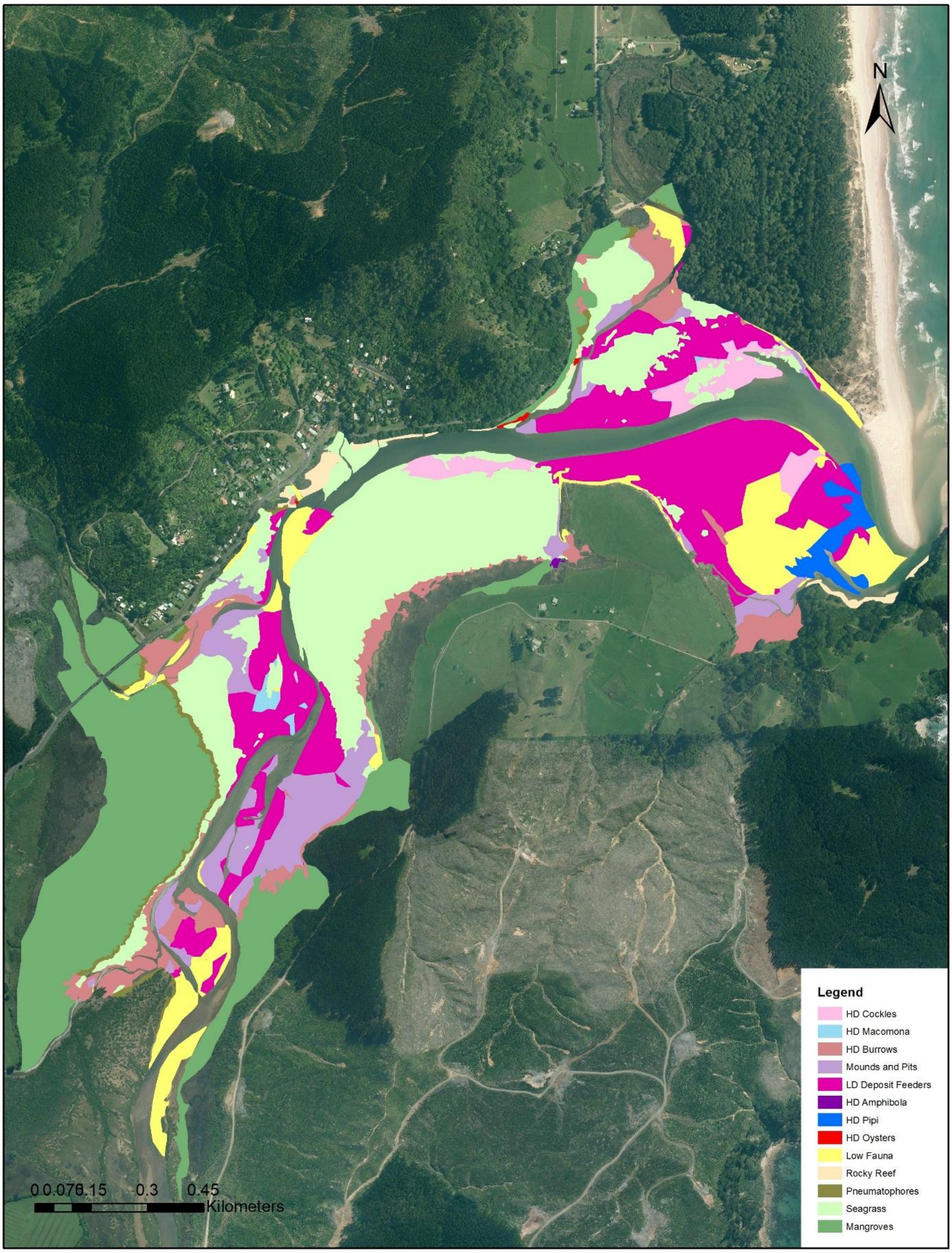


Figure 5-4: Wharekawa Habour habitat map.

5.4 Purangi River

Access and timing:

- Deep Channel with boat access required, launching from the ramp at the end of Captain Cook Road.
- Tidal ebb and flood are asymmetric here and flats are exposed up to 4 hours before low water but only ~2 hours past.
- 2 days, 4 people (Figure 5-5).

Other notes:

- Sandy sediment is stained a metallic orange over a sizeable area near to the creek by Purangi Landing road (section 8.1.4) visible on Google Earth/ WRAPS.
- Narrow harbour entrance.
- Large area of viniculture on the eastern side of the Harbour by Purangi Road.

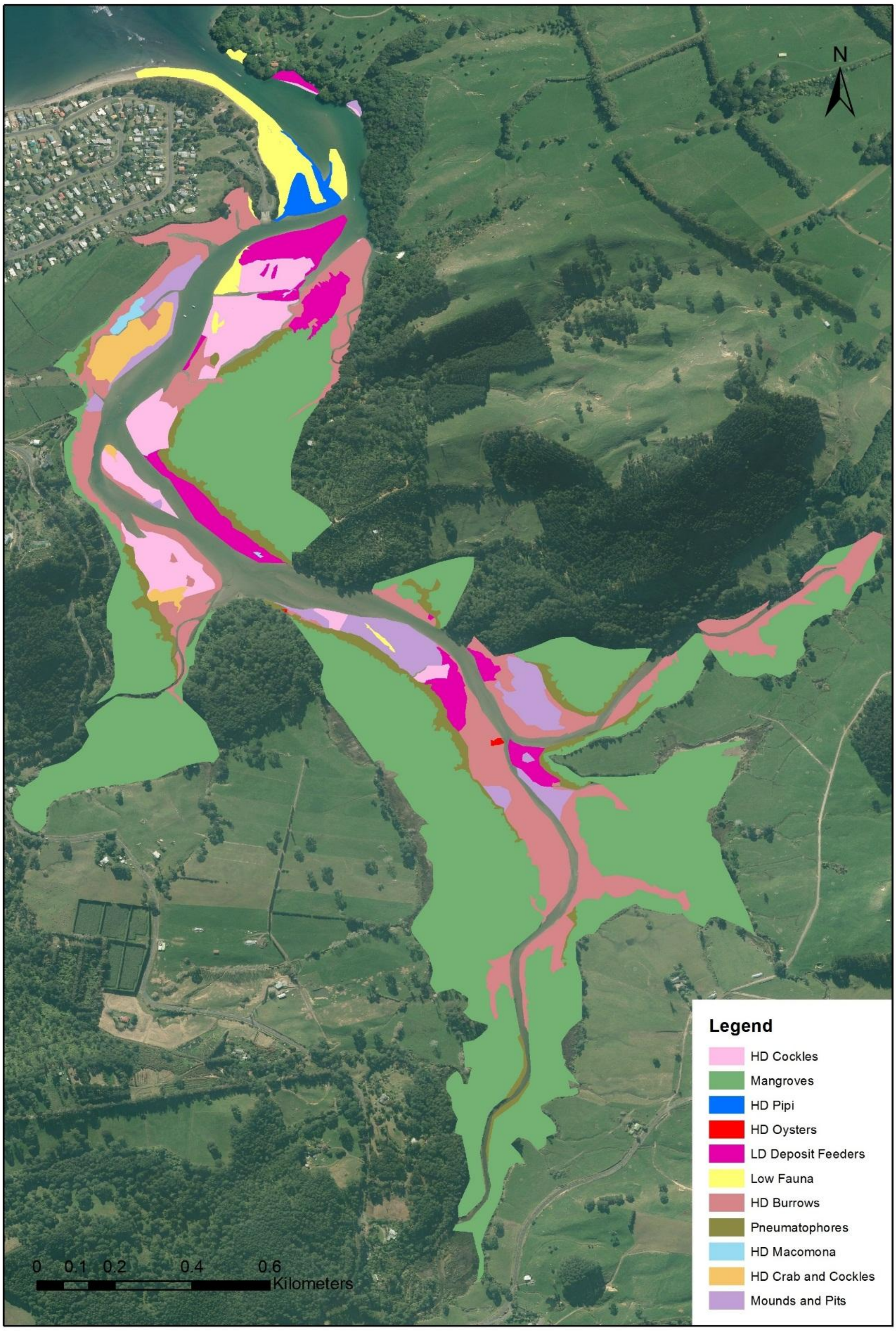


Figure 5-5: Purangi River habitat map.

5.5 Whitianga Harbour

Access and timing:

- Boat access required, sizeable harbour.
- Upper estuary is accessible at high tide due to shallow and narrow channels. These flats are exposed approximately 1 h before low tide.
- The lower estuary has approximately a 3h window pre and post low tide.
- 4 days, 4 people.

Other notes:

- Areas of thick mud in places towards the head of the estuary i.e., waist deep.
- Areas of firm sand still persist into the reaches of the upper estuary despite large areas of mud. This is likely due to strong physical forces associated with the tidal drainage and/or riverine output (Figure 5-6).
- The channel between waterway and main harbour channel is dynamic and is migrating.
- Busy Harbour for boating and recreational uses (Figure 5-7).

Figure 5-6: Sandy sediment in the upper reaches of Whitianga Harbour.

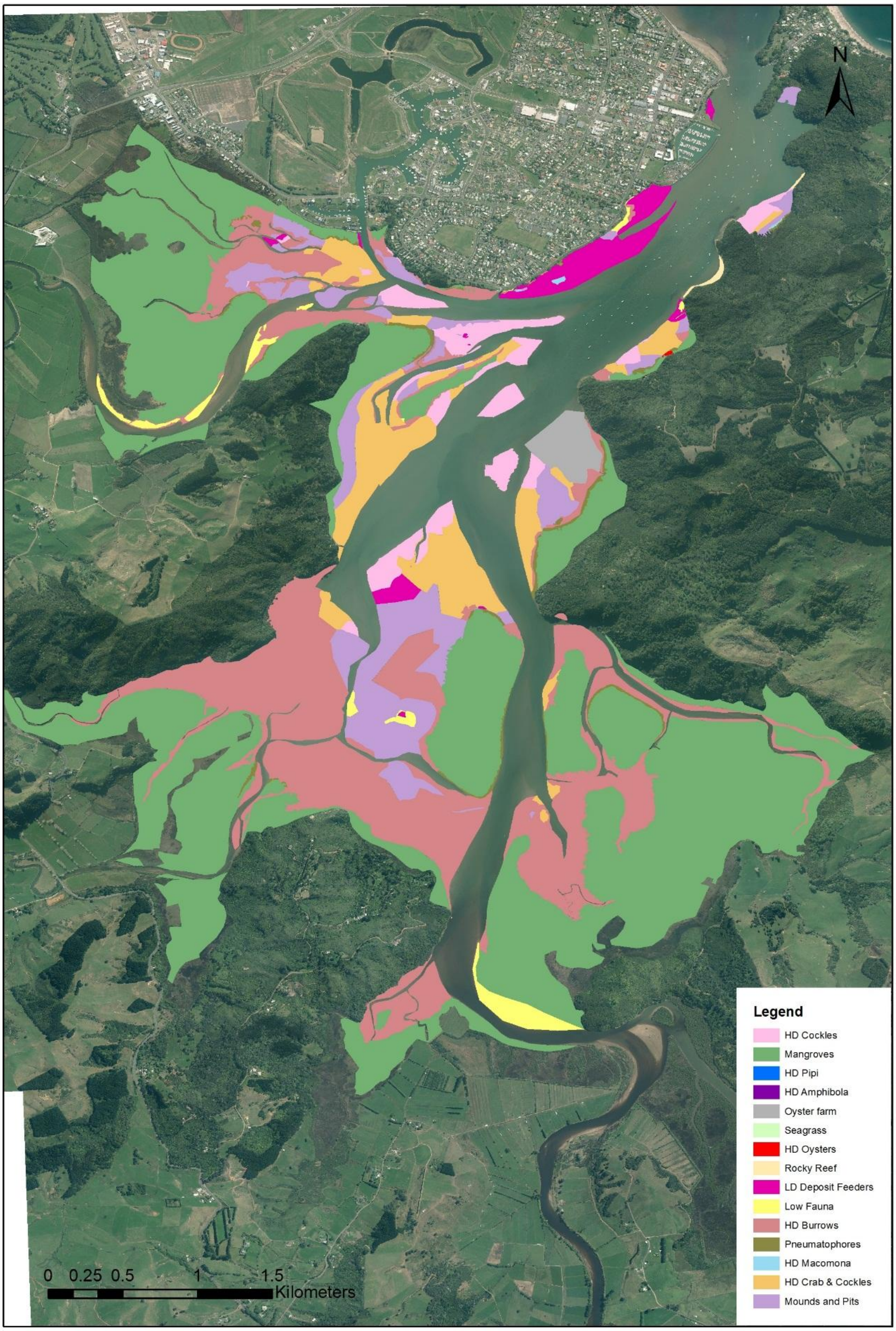


Figure 5-7: Whitianga Harbour habitat map.

5.6 Whangapoua Harbour

Access and timing:

- Accessed on foot from the road on the western side of the Harbour. Boat access used for the eastern side, launching at Whangapoua boat ramp. Access by foot is possible from Matarangi although restricted due to agriculture and a lack of public roads.
- All areas accessible at high water, however harbour drains well and many channels unnavigable at mid tide.
- Heavy boat traffic at times in the outer harbour.
- 4 days, 4 people (Figure 5-8).

Other notes:

- Some areas on the eastern side of the estuary had extremely hard compacted sand (sandstone like, with a fine silt layer on top). This has been added to the accessory information on the GIS attributes table.
- Poor satellite coverage at times affecting tracks, waypoints seem unaffected.
- Oyster farm in the upper central section of the Harbour looks in a state of disrepair; unsure if this is still active.
- Thick seagrass patches throughout the harbour.
- Dense patches of cockles in the outer harbour (densities >>1000 per m^{-2}, visual estimate).

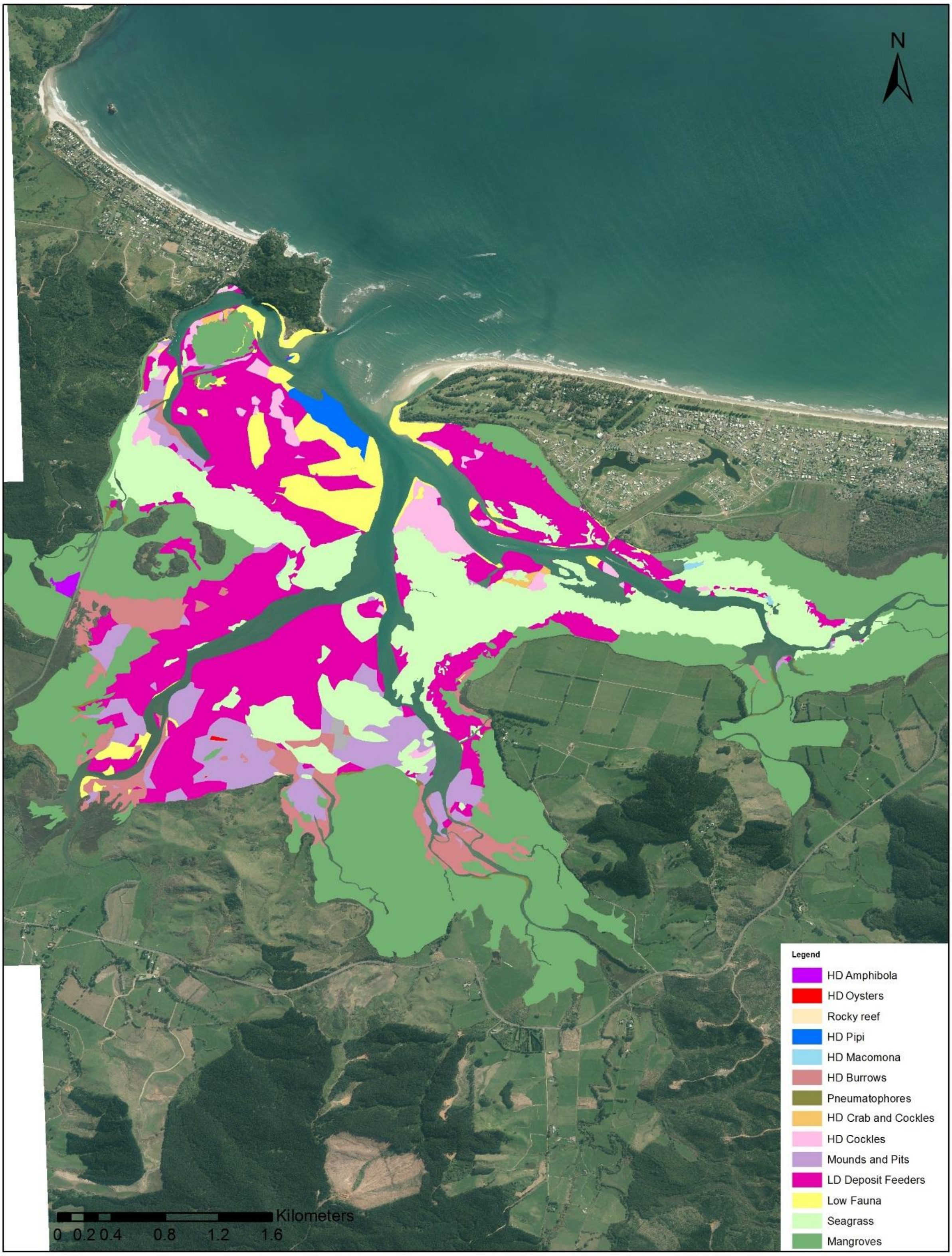


Figure 5-8: Whangapoua Harbour habitat map.

5.7 Kennedy Bay

Access and timing:

- Accessible by foot; Kennedy Bay Road runs along the vast majority of this long, thin Estuary and there are multiple entry and exit points.
- All channels are shallow at mid-low tide.
- ~6 h tidal window.
- 1 day, 4 people (Figure 5-9).

Other notes:

- In the upper estuary, large expanses of fairly coarse sand were home to juvenile pipi, notable from the surface as tiny pits. These were the dominant fauna in this area.
- Although not a deposit feeder, and therefore not naturally part of the ‘LD deposit feeder’ category composition, juvenile pipi were present in high enough densities to warrant acknowledgement. Habitats with these organisms were still placed in the ‘LD deposit feeder’ category but their location was noted in the accessory information in the GIS layers. This habitat was not seen expansively in any other estuary.

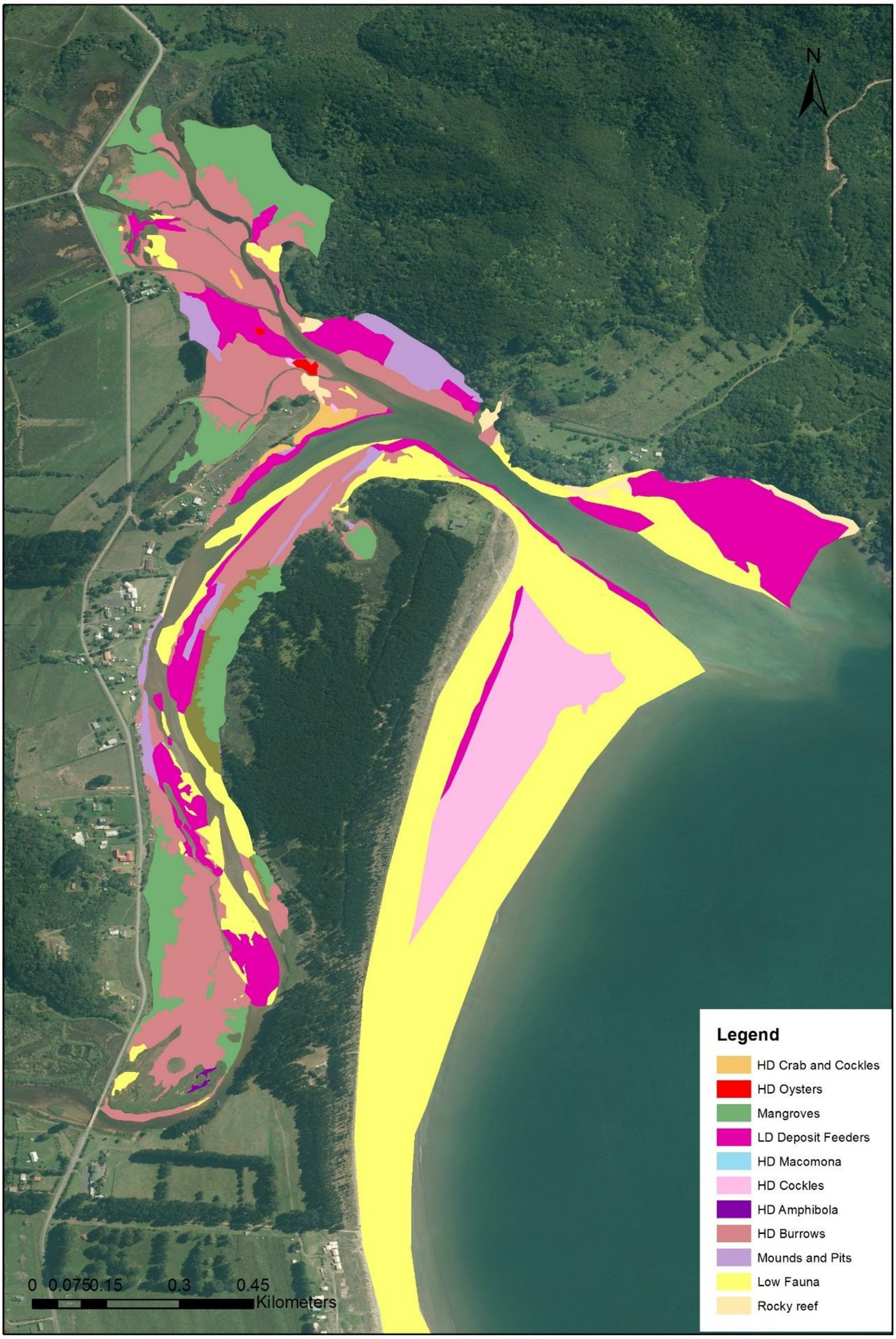


Figure 5-9: Kennedy Bay habitat map.

5.8 Waikawau Bay

Access and timing:

- Accessible by foot. Entry from Waikawau Beach Road at the head of the estuary or via the footpath through the dunes to the beach and around.
- All channels are shallow at mid-low tide.
- ~6 h tidal window.
- 3 hrs, 4 people (Figure 5-10).

Other notes:

- Small, narrow estuary.
- Physically dynamic toward the mouth, with the estuary merging into beach habitats.
- Large areas of the intertidal are dominated by saltmarsh.

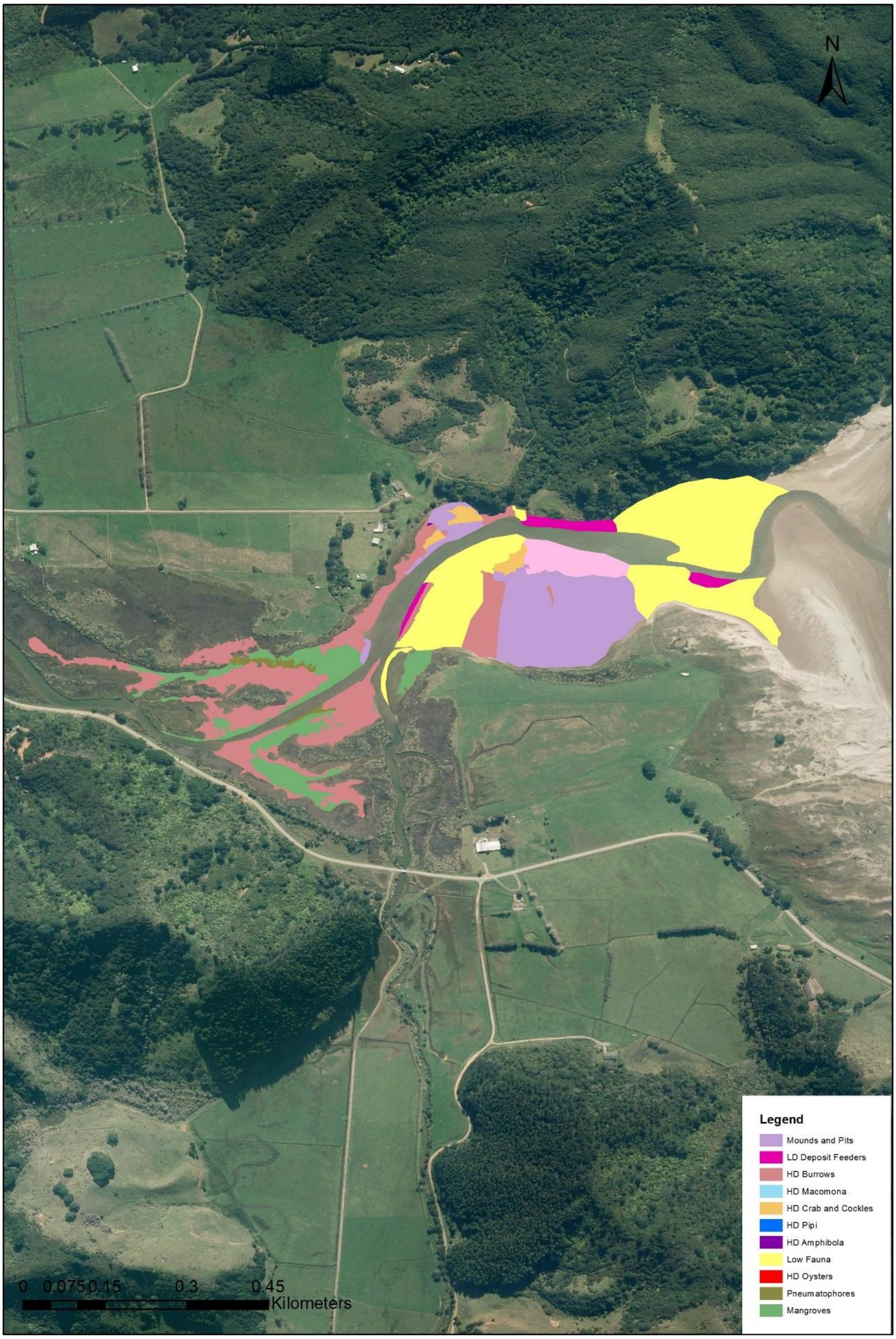


Figure 5-10:Waikawau Bay habitat map.

5.9 Port Charles

Access and timing:

- Accessible by foot. Easy access from Carey Road.
- 2 people 3 hrs (Figure 5-11).
- Both channels on either side of the bay are shallow.

Other notes:

- Large intertidal areas near to the main river are covered in dense gravel and consequently have an absence of infauna.
- There is evidence of sedimentation occurring around the outflow of the river in the northern section of the bay.

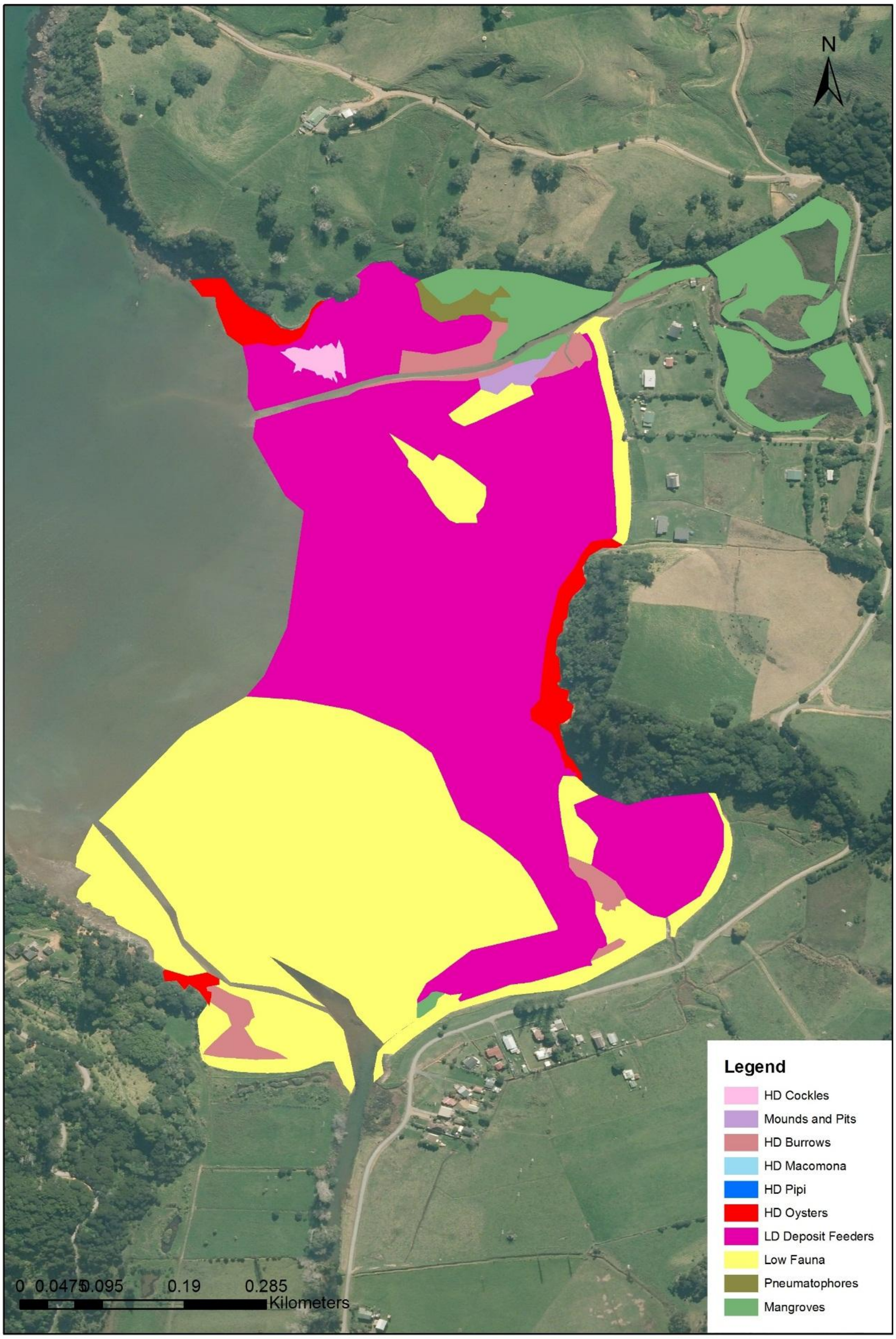


Figure 5-11: Port Chalmers habitat map.

5.10 Colville Bay

Access and timing:

- Accessed on foot. Easy entry from Colville Road.
- Some areas and streams are Tapu due to locations of Urupa in the surrounding marshland and hillsides. Guidance is needed.
- Although this bay is large, it is subject to high energy flows and has large expanses of rocks, coarse sand and low fauna. Large, uniform habitats make this bay quick to survey relative to its size.
- 4 hrs, 2 people (Figure 5-12).

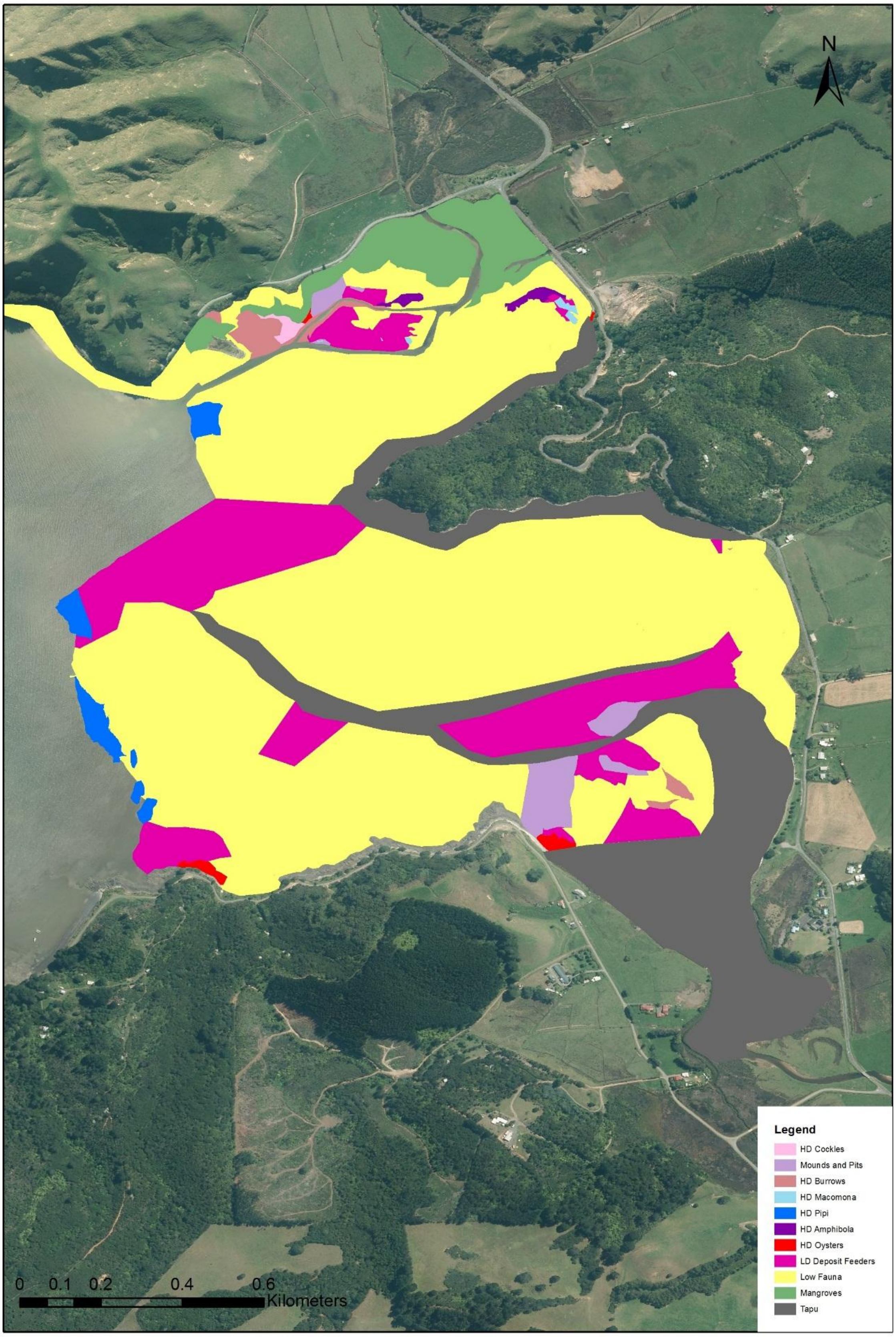


Figure 5-12: Colville Bay habitat map.

5.11 Coromandel Harbour

Access and timing:

- Accessed on foot. Easy entry for McGregor Bay from Long Bay Road, Wharf Road and from Koromiko Drive. Whangarahi Stream is deep in places but can be crossed at mid-low tide near the corner of Wharf Road. Brickfield Bay accessed from Coromandel Glass Workshop off Tiki Road (permission needed).
- 4 people, 6 days.

Other notes:

- Coromandel Harbour has extensive intertidal flats and is host to many mussel and oyster farms.
- The large shell bank in Brickfield Bay is migrating shoreward (Figure 5-13). *Google Earth* images show that it has moved approximately 60 m since 2001; equating to a rate of ~5 m y^{-1}.
- Intertidal oyster farms have altered flow dynamics and facilitated silt and mud accrual in the surrounding areas (Figure 5-14).
- More litter present than any of the other estuary.

Figure 5-13: The shell bank found in Brickfield Bay. Seen as the white outline in the centre of the picture (right). The bank is comprised of pipi and some cockle shells (left).

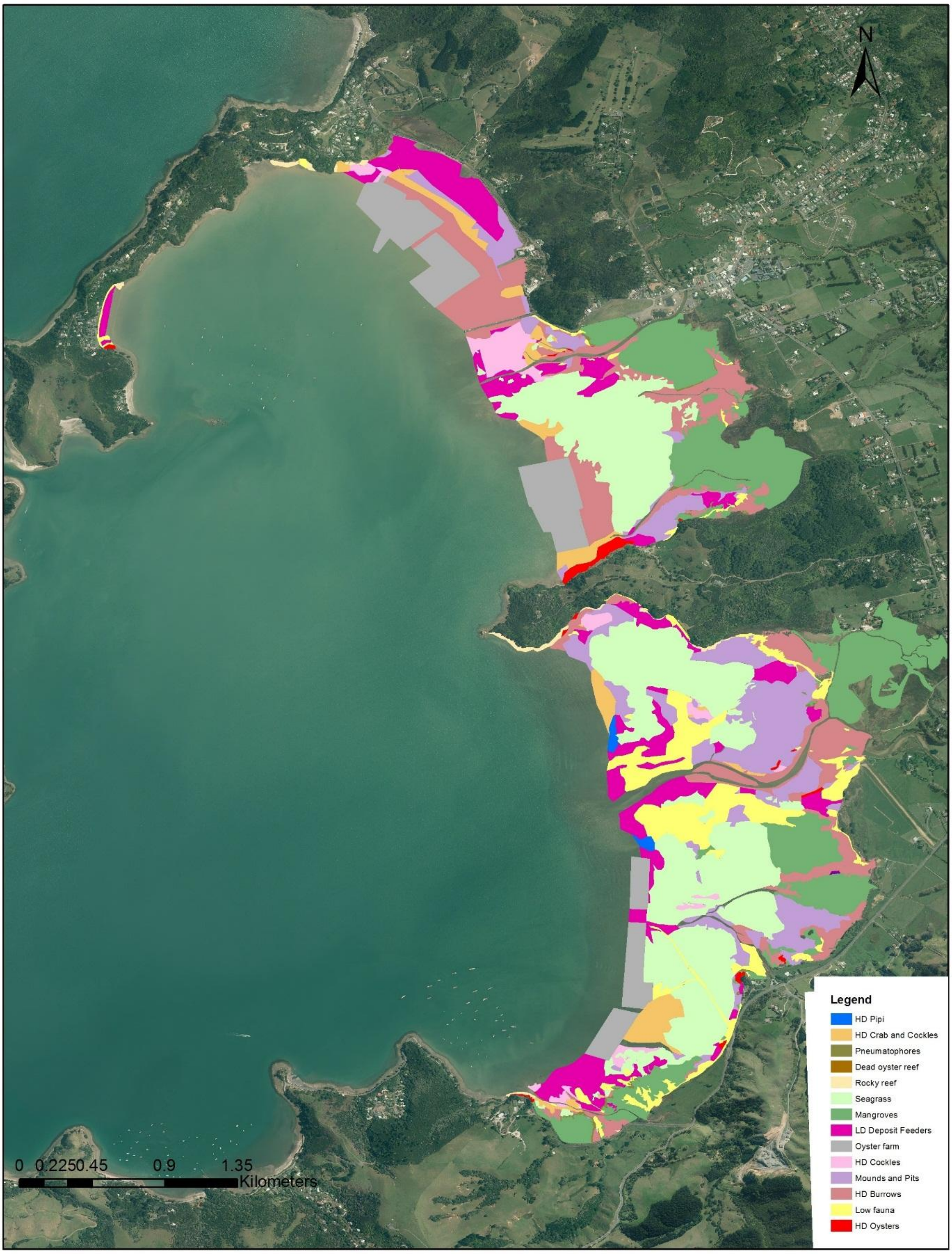


Figure 5-14: Coromandel Harbour habitat map.

5.12 Te Kouma Harbour

Access and timing:

- Smaller bays accessed by boat (launching from Coromandel Harbour). The large flat behind the oyster farm reached by foot via access from Te Kouma cottages (off Castle Rock Road).
- Very muddy conditions with sharp oyster reef make this harbour difficult underfoot.
- 1 day 4 people.

Other notes:

- Extensive oyster farms across the width of the bay.
- Some oyster reef outside of the farm were covered in a fine layer of silt giving them, at first observation, the appearance of our ‘crustacean burrows’ category. These were easily differentiated when inspected more closely.
- Oyster spat have seeded inside the main embayment on the sheltered side of the farms. However much of this is covered in a fine layer of silt/mud.
- Outer bays had coarse sand and tubeworm communities.

Due to their close proximity, Te Kouma and Manaia maps are displayed together in Figure 5-15

5.13 Manaia Harbour

Access and timing:

- Accessed via private land with permission of Ngati Whanaunga from Manaia Road.
- Access point passed close to Urupa positioned within the mangroves.
- Main Harbour channel can be crossed in most places from mid-low tide.
- Tide floods very quickly and rapidly covers the intertidal habitats.
- 2.5 days, 4 people.

Other notes:

- Mangroves covered an extensive proportion of the intertidal area.
- Isolated pockets of bare sediment deep within the mangrove habitat could not be accessed for observation of habitat type.
- Local information on sediment changes suggests that the intertidal flat has extended out of the harbour mouth into the Firth of Thames.
- Patches containing large cockles were observed (>45mm shell length), however these were mainly at low densities.

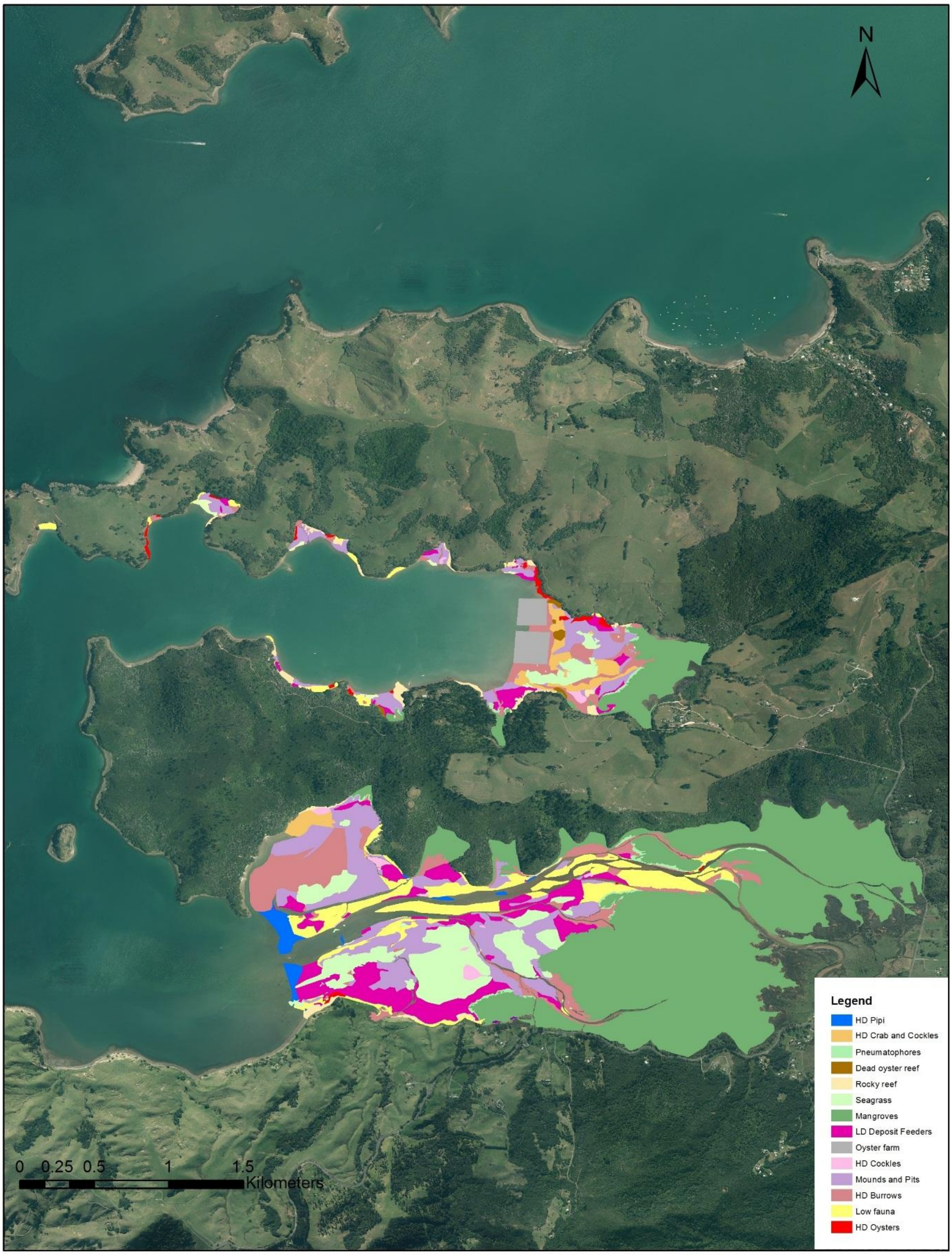


Figure 5-15:Te Kouma (upper) and Manaia Harbour (lower) habitat map.

6 Threats

There are a number of potential threats to New Zealand's intertidal habitats, due mainly to human activities, land usages and climate change. In Table 4, we indicate susceptibility of the different habitats to the following threats.

- Elevated turbidity
- Elevated suspended sediments
- Elevated sedimentation rates
- Elevated nutrients
- Low oxygen conditions in water column
- Contaminants
- Invasive species
- Anthropogenic physical disturbance
- Overharvesting
- Disease
- Climate change
  - sea level rise
  - temperature rise
  - Increases in storm severity
  - ocean acidification

Not all of the threats are equally likely to occur and intensity and frequency of occurrence, together with whether the threat occurs individually or in combination with other threats, will be major factors in determining the degree of impact. None of these aspects are taken into account in Table 6-1, e.g., Table 6-1 "overharvesting" column does not relate to current levels of harvesting in relation to sustainability levels around the Coromandel Peninsula, rather it lists the habitats most likely to be overharvested. For 'mixed' species habitats, the degree of susceptibility stated is that of the most susceptible component. It is also important to note that some habitats are likely to increase in extent with some threats. For example, flora and fauna such as mangroves and their pneumatophores, mud crabs (in the HD crustacean burrows) and *Amphibola* are tolerant of muddy sediments. These habitats may actually respond by increasing in extent, at the expense of other more susceptible habitat types, in the face of sedimentation. In particular, the mud crab *Austrohelice crassa* was shown to be the only animal capable of emerging from deep clay depositions (9 cm) following simulated sedimentation events (Norkko et al. 2002). Finally, Table 6-1 uses a three level scoring system only, higher susceptibility, lower susceptibility and none. This is mainly driven by the fact that knowledge of susceptibility of habitats to specific threats is variable. For example, while there has been New Zealand studies on the effects of heavy metals (copper, lead and zinc) on the abundance of many macrofaunal species, showing decreases at relatively low levels (Hewitt et al. 2009), no such information is available for seagrass.

Table 6-1: Summary of common threats with potential susceptibility of the habitat types. X indicates some susceptibility, XX indicates higher susceptibility, although there are varying levels of certainty related to the different habitats and threats. An XX in the overharvesting column does not indicate the current levels of harvesting in relation to sustainability levels around the Coromandel Peninsula, merely that removal for consumption can be a pressure on certain habitats.

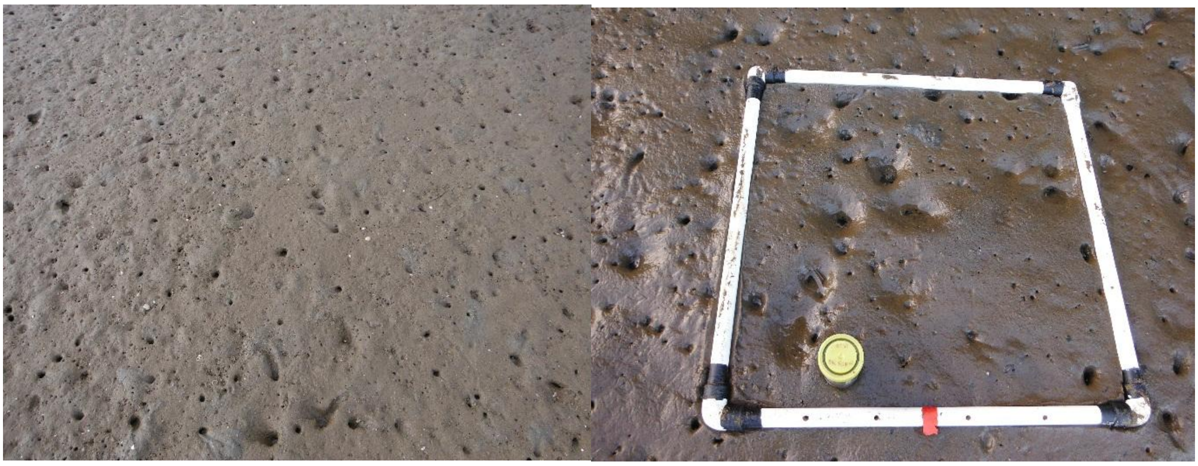
Habitat Type	Elevation in turbidity	Elevation in suspended sediments	Elevation in sedimentation rates	Elevation in nutrients	Low oxygen conditions in water column	Contaminants	Invasive species	Anthropogenic Physical disturbance	Overharvesting	Disease	Climate change: sea level rise	Climate change: temperature rise	Climate Change: Increases in storm severity	Climate Change: Ocean acidification
Seagrass	XX	XX	XX	XX			XX	XX		X		XX	X	
Mangroves								XX			XX	X	X	
Pneumatophores								XX			XX	X	X	
High Density Cockles	X	X	X	X	X	X	XX		XX	X		XX	X	X
High Density Pipi	X	XX	XX	X	X	X	XX		XX			XX	X	X
High Density Cockles and Pipi	X	XX	XX	X	X	X	XX		XX	X		XX	X	X
High Density Macomona		XX	XX		X	X	XX					X	X	X
High Density Oyster	X	XX	XX		X		XX		XX	X		XX	X	X
High Density Crustacean Burrows					X		XX					X	X	X
High Density Crab and Cockles	X	X	X	X	X	X	XX		X			XX	X	X
Low Density Deposit Feeders		X	XX		X	X	XX					X	X	X
Mounds and Pits (Mixed)		X	XX		X	X	XX					X	X	X
Low Fauna							XX							
High Density Amphibola					X		XX		XX			X	X	X
Tube worms and crabs		X	X		X	X	XX					X	X	X

7 Site habitat photos

7.1 Otahu River

Physically dominated sands with low levels of macrofauna (low-bio habitat).

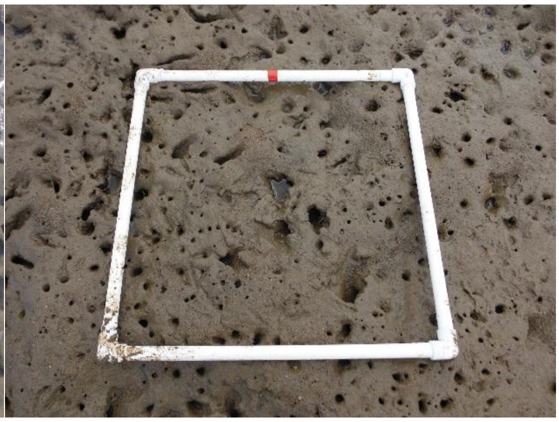
Muddy sand (left) and mud (right) examples of crab dominated habitat.



Pipi beds near to the mouth of the estuary where cockles co-exist.

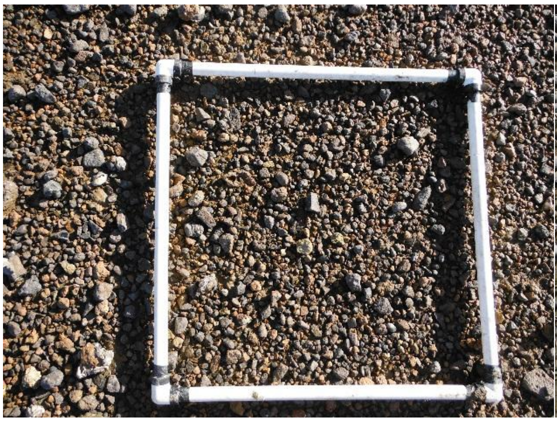
7.2 Whangamata Harbour

Crab dominated habitats of the Whangamata Harbour.

Typical ‘LD deposit feeder’ habitat of muddy sand with a mixture of deposit feeding worms and shellfish.

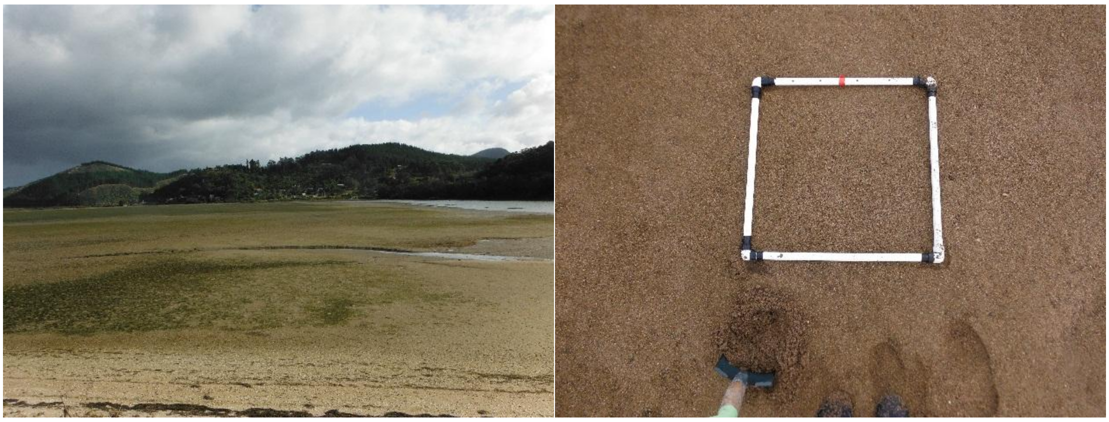
Different sediment types with a surface gravel covering sand (left) and cockle shell-hash covering muddy sand (right).



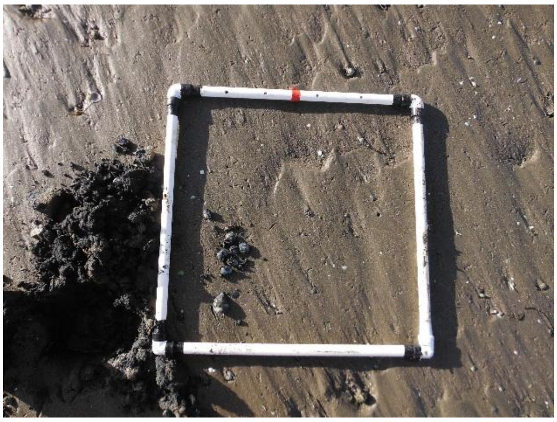

7.3 Wharekawa Harbour

Coarse sand with cockles exposed from physical reworking (left) and high densities of pipi in sands near to the harbour mouth.

Seagrass patches in the central section of the harbour (left) and sand with low levels of macrofauna (low-bio habitat) (right).

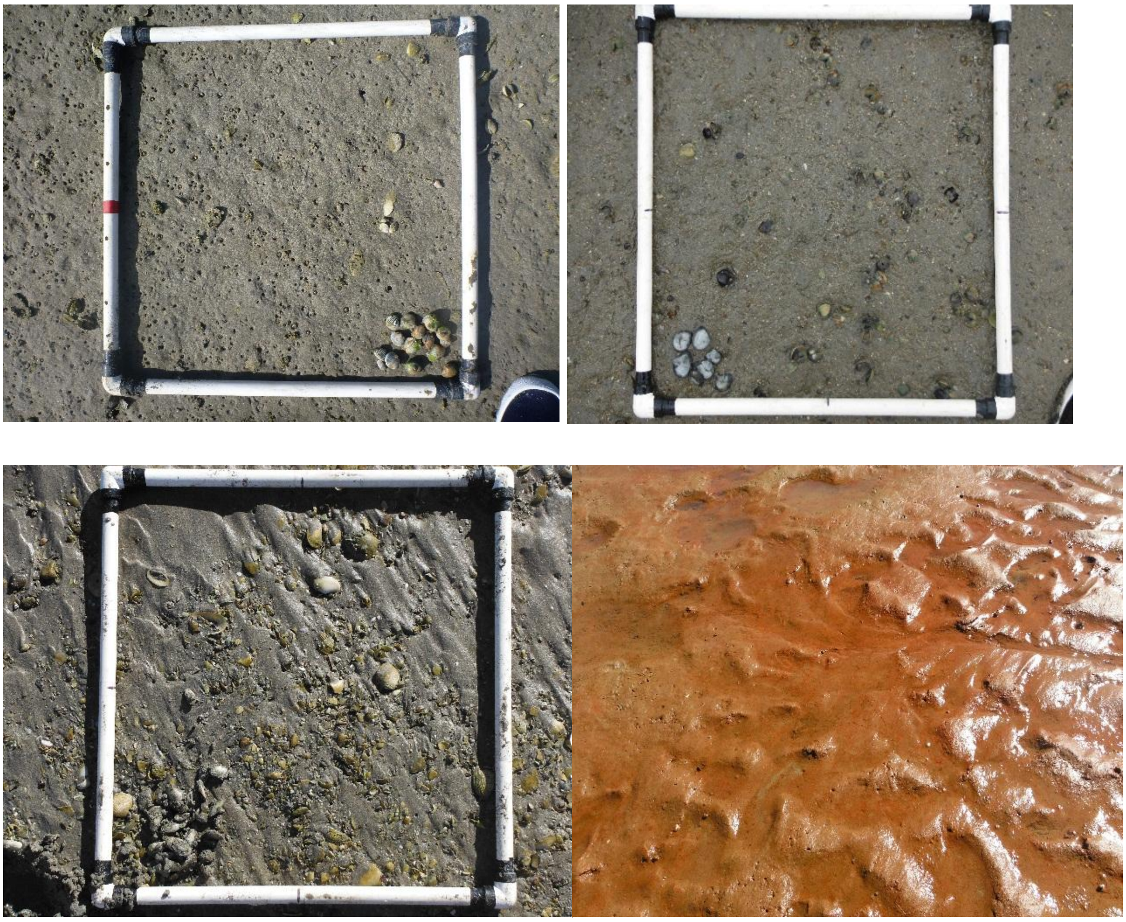


‘LD deposit feeder’ habitat with cockles. Cockle density is below ‘cockle habitat’ status.



7.4 Purangi River

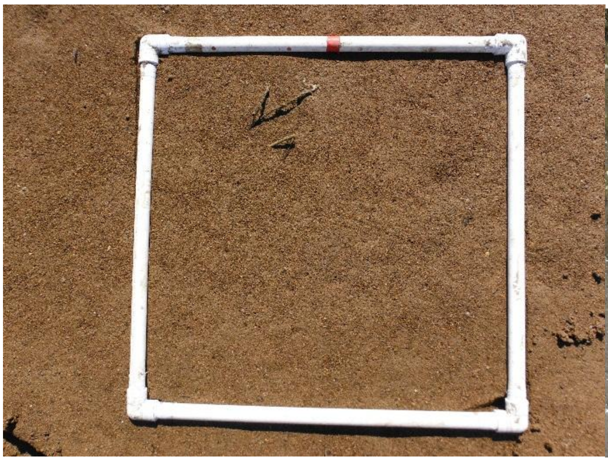
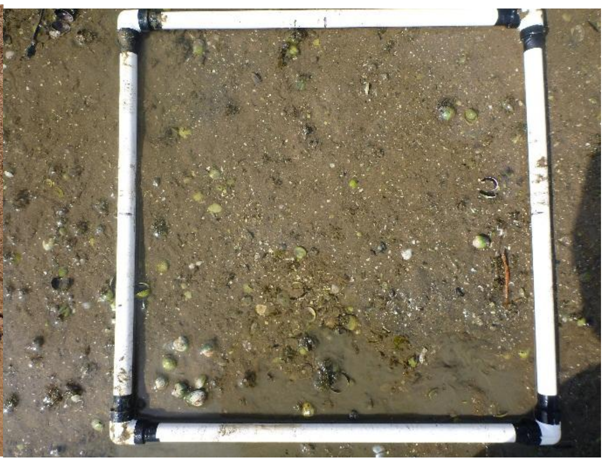
Different bivalve habitat types with cockles (left), *Macomona* (right) and pipi (below left). Sand discolouration close to the stream by the Purangi landing road (36° 50.533'S, 175° 45.337'E).



Muddy sediments with pneumatophores and sparse oyster reef attached (left) and crab habitat (right).

7.5 Whitianga Harbour

Low macrofauna sandy habitat (left) and typical 'LD deposit feeder' muddy sandy habitat (right) that has cockles present but in too low density to be considered cockle dominated.

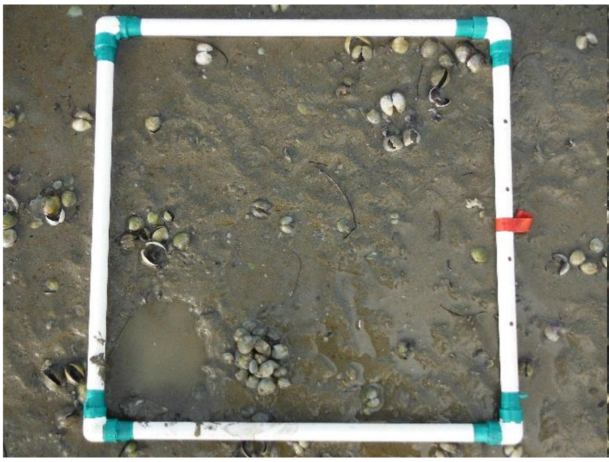
Muddy sand sediments with high abundances of cockles (left and right).

Large areas of the intertidal are dominated by crab habitat (with high burrow densities m^{-2}) in the lower sections of the Whitianga Harbour. Sediments here can be very deep mud (>knee deep).


7.6 Whangapoua Harbour

Cockle habitat near the mouth of the Harbour (left). In patches high flow causes erosion of sediment and results in exposure of live individuals in extremely high densities.



‘Low bio’ habitat with few organism present and high levels of physical sediment reworking evident from surface topography (left). Seagrass habitat from the lower section of the Harbour.

Pipi habitat from the left-hand-side of the Harbour mouth (left). Evidence of Asteroidean scavenging/predation on the pipi habitat evident in the shallow subtidal.

7.7 Kennedy Bay

Mangrove and pneumatophore habitats in Kennedy Bay (left) and 'low bio' habitat with few organism present (right).

Crab habitat with coarse riverine deposits/gravel on the sediment surface (left). Isolated pockets of sandy mud sediment with high densities of cockles (right) from the shorter arm of Kennedy Bay.

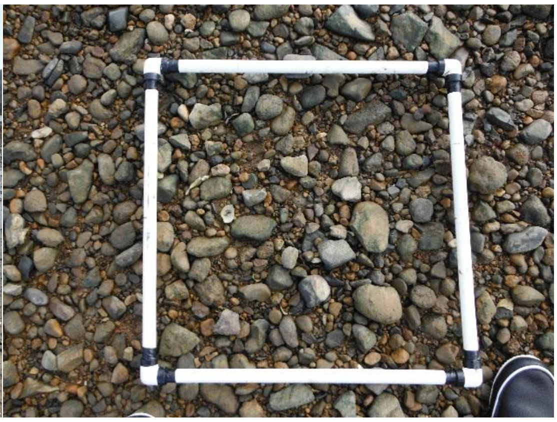
7.8 Waikawau Bay

Cockle habitat in muddy sand (left) and crab habitat with coarse riverine deposits/gravel on the sediment surface; a common feature of many of the harbours and estuaries.

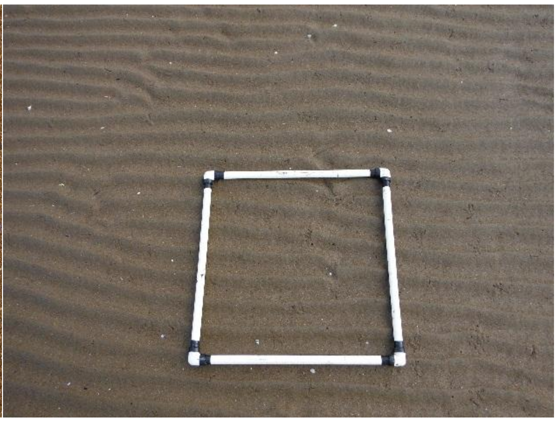

Mangroves from the upper reaches of Waikawau Bay (left) and sediment with pitted marks evident on the surface from the mid harbour section.


7.9 Port Charles

Contrasting sediments of Port Charles: Surface mud (left) associated with the outflow of the river by Carey road. Surface Gravel/pebbles cover the sandy sediment below and result in a lack of macrofauna close to the main settlement (right).

Strong physical forces result in areas of coarse sand with ‘low fauna’ habitat (left). Other areas also show evidence of reworking i.e., ripples but have retain a ‘low density deposit feeder’ habitat due to the presence of deposit feeding bivalves (*Macomona*).

7.10 Colville Bay

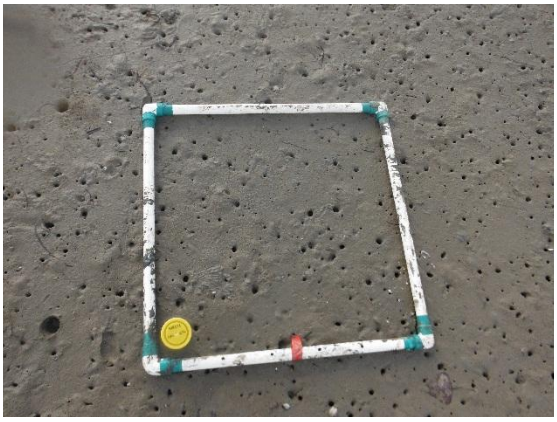
Physically dominated sands cover a large proportion of the Colville bay area (left and right).


Pipi habitat is presence (left). Areas close to the drainage channels show evidence of mud accumulation and associated fauna i.e., crab habitat (right).


7.11 Coromandel Harbour

Mud accumulation shoreward in of the oyster farms in McGregor Bay (left). Sandy sediment with ‘low fauna’ habitat (right).

Mangroves and pneumatophore habitat (left) with oyster reef attached. Crab habitats dominate near many of the channels (right).



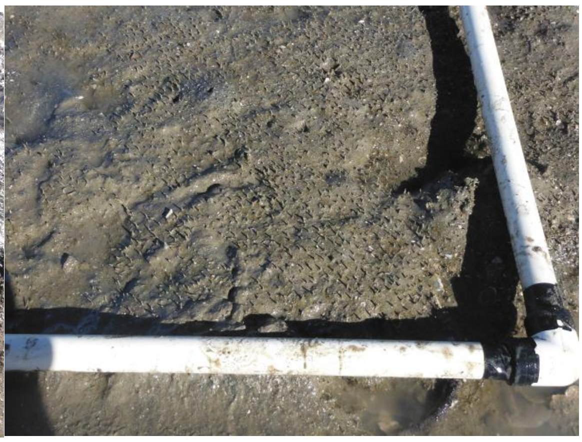
Large patches of seagrass habitat are found shoreward of the oyster farms in Brickfield Bay (left). Around seagrass patches and in other areas cockle habitats dominate (right).

7.12 Te Kouma Harbour

Oyster reef on the fringing rocks around the harbour (left). Mud accumulation associated with the oyster farm is evident and results in high mud fractions shoreward of it. Shellfish still persist and are found here i.e., cockle habitat (right).


‘Low fauna’ habitat from the most exposed outer Bay in Te Kouma Harbour (left). ‘low density deposit feeder’ habitat (right).

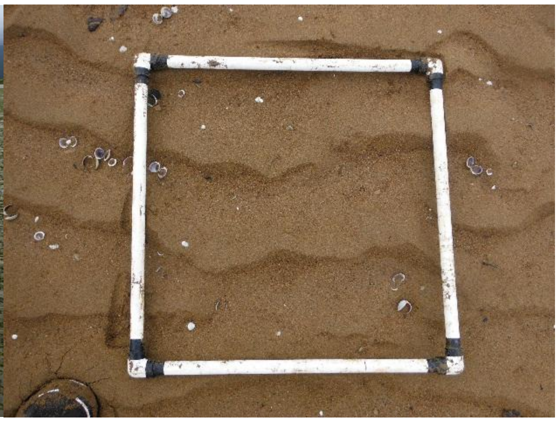

Tubeworm and crab habitats evident from the mid bays in Te Kouma Harbour (left and right)

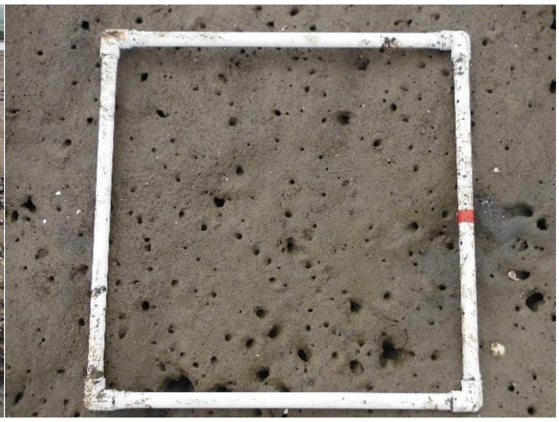
7.13 Manaia Harbour

A typical cockle habitat with a high density of individuals (left). Also patches with extremely large individuals (>40mm length) but generally at low density (right). These were incorporated in to the HD cockle habitat.


Seagrass habitat patches present throughout the harbour (left) and ‘low fauna’ habitat close to the main harbour channel (right).

Scattered oyster reef sits on top of the sandy sediment surface (left) and a muddy sand contains a high density of crab burrows (right).

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