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Taihoro Nukurangi

Intertidal Habitat Mapping: Waikato Estuaries 2023

Prepared for Waikato Regional Council



Climate, Freshwater & Ocean Science

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Executive summary

- In February 2023, Waikato Regional Council (WRC) contracted the National Institute of Water and Atmospheric Research (NIWA), to perform rapid habitat assessment techniques for mapping intertidal habitats.
- These rapid habitat assessment techniques were developed, tested, and applied previously in 14 Coromandel estuaries (2013) and shown to be successful and useful.
- This report documents the application of these techniques in the same 14 estuaries: Otahu River, Tairua Harbour, 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. Shelly Beach estuary was also mapped, bringing the total number of estuaries assessed in 2023 to 15.
- This report provides a detailed description of the equipment and field techniques used for this habitat mapping. The repeatability and precision of the tracks and waypoints marked during the field work demonstrated that the differences between devices and personnel tracks/waypoints were no greater than 2 m.
- Based on the information collected in the field, characteristics of each estuary are described and supported with site photos.
- Habitat maps for each estuary are presented, showing the distribution and extent of a wide range of habitat types (18 in total).
- The most common habitats recorded across estuaries were High Density Burrows, High Density Cockles, Low Density Deposit Feeders, and Low Fauna, with all four of these habitat types observed in 14 of the 15 estuaries surveyed.
- Comparing the area covered by habitats mapped in 2013 versus in this study (2023), it was identified that Mangroves and HD Cockles habitat increased, however, most of the other habitat classes assessed decreased over time, which could have consequences for ecosystem functioning and the delivery of ecosystem services.

1 Introduction

Estuarine ecosystems are some of the most productive ecosystems worldwide. They contribute a range of ecosystem goods and services (direct and indirect benefits that humankind receives from the natural ecosystems), for example, the provision of food and raw materials, nutrient recycling, disturbance prevention, sediment remineralisation, water filtration and regulation, climate buffering, habitat structure, and cultural services such as spiritual heritage, leisure, and recreation (Townsend and Thrush, 2010, Snelgrove et al., 2014, Douglas et al., 2019, Hillman et al., 2020).

However, the destruction and degradation of coastal ecosystems, as consequence of the increased anthropogenic pressures (e.g., climate change, nutrient and sediment loads, pollution), is threatening the organisms living within these ecosystems, and thus the functioning and services they provide (Lohrer et al., 2004, Thrush et al., 2013, Simeoni et al., 2023). These threats are particularly severe and evident in estuaries due to the increasing changes in land use, long-term deposition of sediment, and nutrient inputs from terrestrial sources, exacerbated by climate change.

Many of these major threats in estuarine ecosystems result in habitat change, either as a consequence of direct physical disturbance or through shifts in the distribution of species (Thrush et al., 2008). Describing the change in coastal habitats is critical for predicting ecological consequences, such as alterations in ecosystem functioning and services, and for assisting management decisions. Yet, the assimilation of data for mapping coastal habitats is still challenging. Mapping coastal ecosystems using remote sensing with all the computational advancements has proven to be effective but is limited to detecting habitats with evident visual differentiation and/or surface characteristics. The use of traditional methods (e.g., *in-situ* habitat mapping) is relatively time consuming but provides robustness for assessing different habitats and addressing inherent issues encountered by remote sensing methodologies, for example giving comprehensive assessment of sediment characteristics and true on-ground verification. The development of new techniques incorporating both approaches could facilitate the accurate mapping of habitats in estuarine ecosystems, since these ecosystems are spatially complex and temporally dynamic under the compound effects of physical, hydrological, and biological processes.

In February 2023, Waikato Regional Council (WRC) contracted the National Institute of Water and Atmospheric Research (NIWA) to perform rapid habitat assessment techniques for intertidal areas in different estuaries in the Coromandel Region. The rapid assessment techniques were previously developed and tested in Tairua Harbour by NIWA in 2013 (Needham et al. 2013a) and then applied in 13 other Coromandel estuaries during the same year (Needham et al., 2013b). The rapid mapping technique proved to be effective in differentiating habitats associated with the provision of ecosystem goods and services (Townsend, 2017).

Approximately 10 years after the first mapping effort, this report documents the re-application of the rapid habitat assessment technique in 15 estuaries in the Coromandel Region (Figure 1). Fourteen of these 15 estuaries were assessed in 2013, enabling direct comparison between maps to detect change in estuarine habitats in the intervening 10 years. This report includes:

- A detailed description of the equipment and field techniques used for mapping the estuaries.
- An assessment of the repeatability and precision of maps produced.

- Descriptions of habitats following Needham et al. (2013b).
- Description of the estuaries, including qualitative observations of sediment types, maps/figures showing the different habitats, and relevant photos.
- Comparison between the habitats mapped in 2013 and the current (2023) habitats mapped, highlighting areas that have changed habitat type over time.
- Comments on potential stressors driving changes in estuarine habitats.

In addition to this report, the geo-tagged digital images collected during fieldwork, GIS shape files of habitats and the accompanying metadata have been provided to WRC.

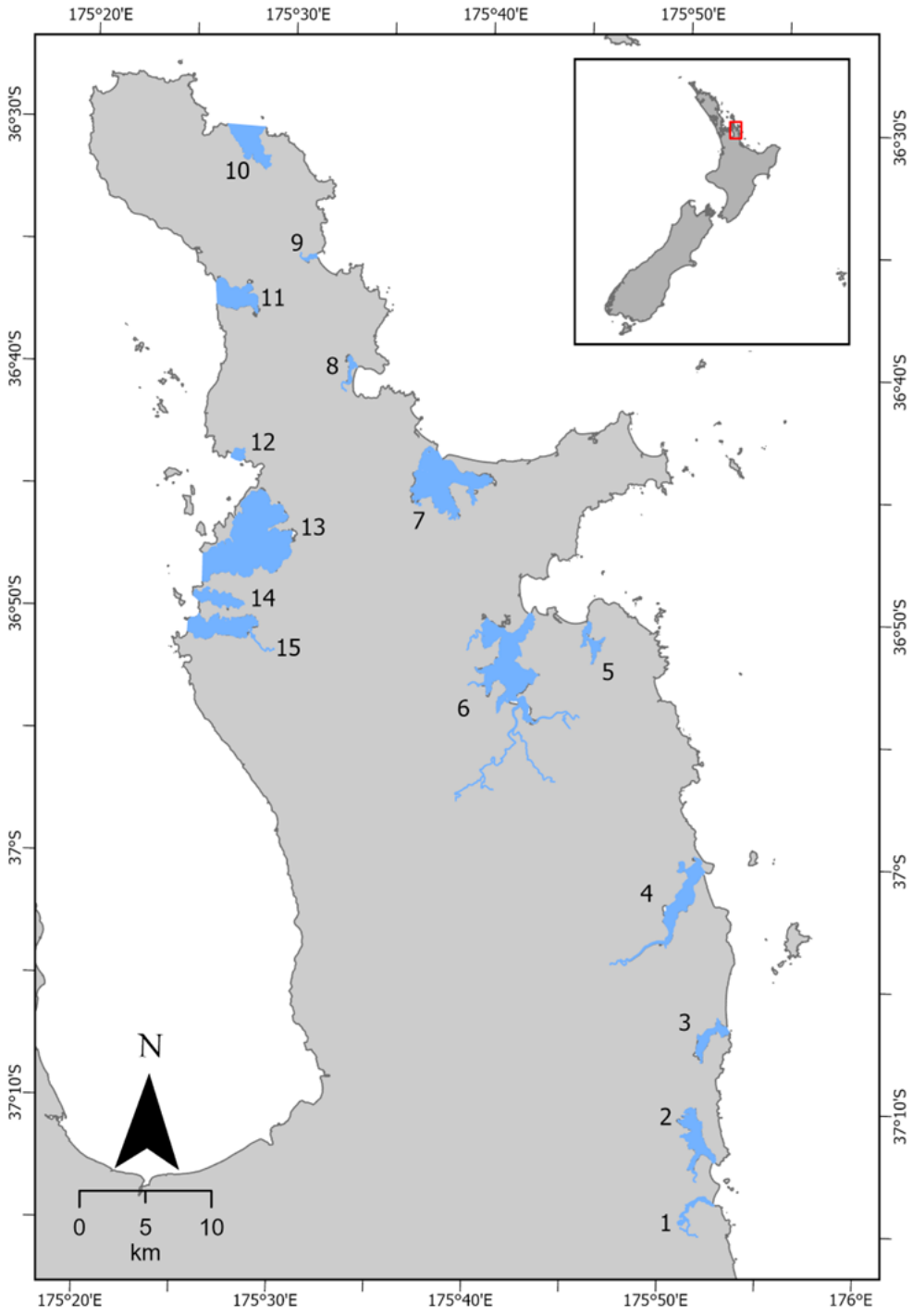

Figure 1: Estuaries and harbours (blue) where intertidal habitats were assessed in 2023. The study locations were: (1) Otahu River, (2) Whangamata Harbour, (3) Wharekawa Harbour, (4) Tairua Estuary, (5) Purangi River, (6) Whitianga Harbour, (7) Whangapoua Harbour, (8) Kennedy Bay, (9) Waikawau Bay, (10) Port Charles, (11) Colville Bay, (12) Shelly Beach/Kikowhakarere Bay (not studied previously), (13) Coromandel Harbour, (14) Te Kouma Harbour and (15) Manaia Harbour.

2 Methods

Habitat types and field techniques employed in 2023 were comparable to the rapid habitat assessment methodology described by Needham et al. (2013b). The methodology was designed to classify the intertidal area of estuaries, rapidly and accurately, into specific habitats derived for their links to ecosystem goods and services provision.

2.1 Field equipment

The field equipment required for rapid habitat assessments includes handheld Global Positioning System (GPS) units, cameras, quadrats, and trowels. The GPS units were Garmin GPSMAP 79sc and Garmin Montana 750i, which enabled recording of boundary tracks, waypoints, habitat names, and comments at specific locations during the field work. The cameras used were Olympus tough TG-6, which provided high resolution images (12 megapixels) and allowed the geo-tagging of image locations with GPS coordinates to facilitate the mapping analysis. In addition, the GPS Garmin Montana 750i has an in-built camera, providing an alternative means of geo-tagged image collection. Quadrats of 0.25 m^2 and trowels were used to assess certain habitat types, placing the quadrat on the sediment, and scraping and digging into the sediment to search for specific features relating to the different habitat types. Quadrats were also used for scale in images and to ensure consistency in assessments in different areas, across estuaries and between mapping personnel.

2.2 Field techniques

Field techniques followed the methodology proposed by Needham et al. (2013a) and Needham et al. (2013b). Briefly, a mix of techniques were used to cover extensive intertidal flats quickly and effectively – rapid assessment. Transects were walked in a zig-zag formation to maximise the areas covered (Figure 2). Changes (or similarities) in habitat type were confirmed by multiple personnel and noted using waypoints. Similarly, a fan formation, where each field worker would walk from a central point, was used to maximise coverage in long but narrow bays (Figure 3). Well defined boundaries between habitats were apparent for some habitat types (for example, raised sand banks, emergent vegetation). Where practicable, patch boundaries were walked in their entirety (Figure 4). When a habitat was too large or otherwise impracticable to be walked in its entirety (e.g., some mangrove, pneumatophore, and seagrass areas) a section of the perimeter was walked (noted by GPS waypoints, tracks, and comments) so that this could be referenced using the Waikato Regional Aerial Photography Syndicate (WRAPS 2019) aerial photos. Where possible, two individuals walked the perimeter of large habitats in opposite directions until they came together. Patches <10 m in their longest dimension were not noted on their own, as this is near the minimum accuracy of the GPS units, but these areas 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 document habitat characteristics and to cross reference habitat types to ensure consistency/repeatability for these and future surveys.

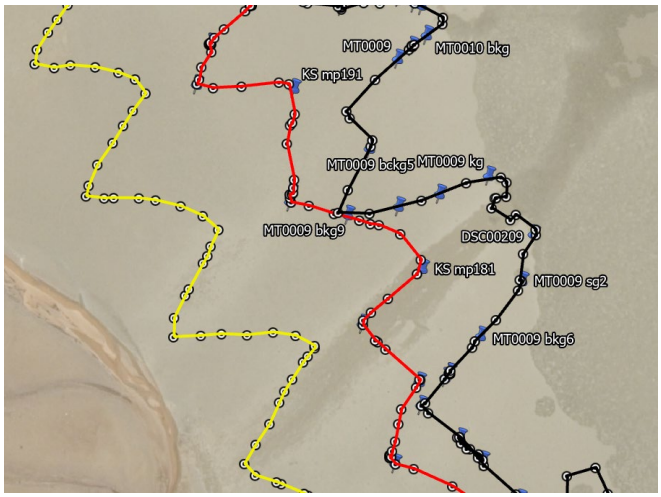

Figure 2: Transects walked and waypoints by three personnel in Whangamata displaying zig-zag technique for maximising the area covered.

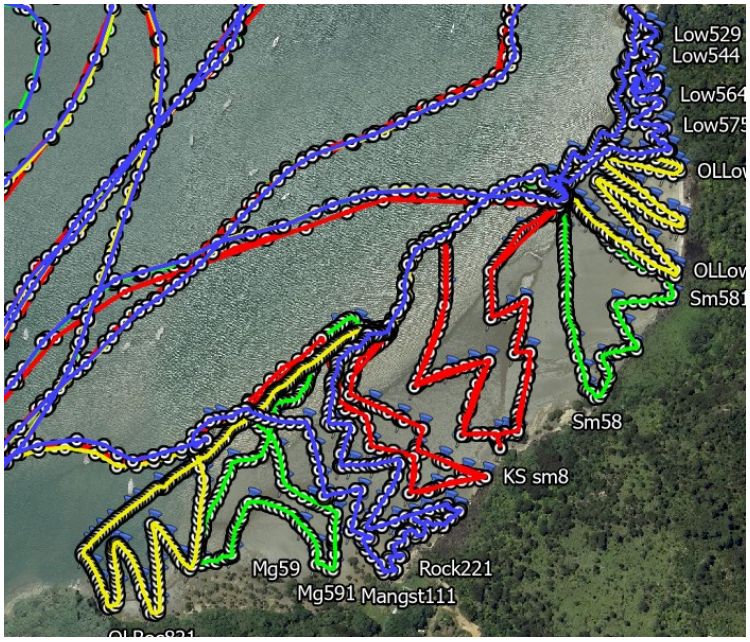

Figure 3: Transects walked and waypoints by four personnel in Whitianga using the fan formation, used for long narrow bays to maximise coverage.

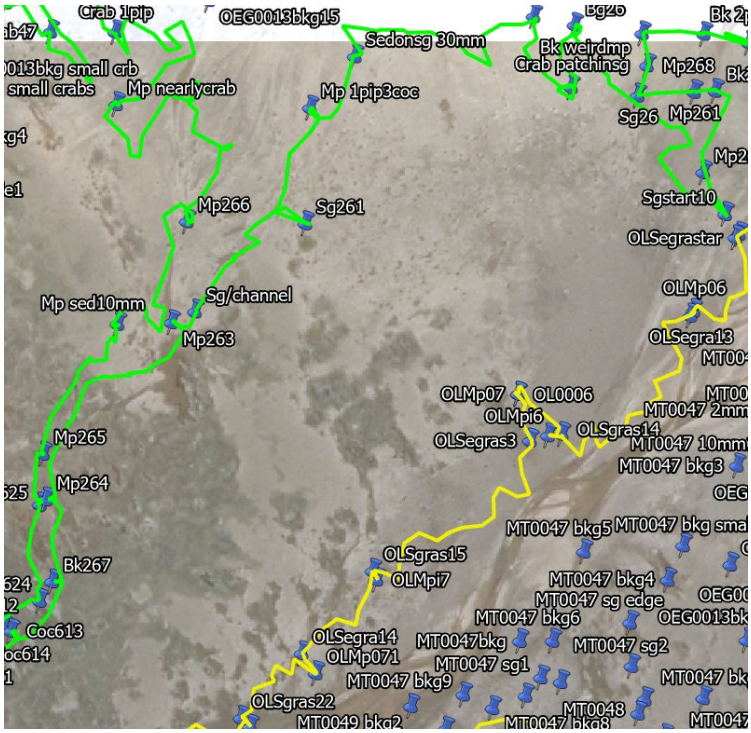

Figure 4: Transects walked and waypoints by two personnel in Whangapoua delimiting the boundary of seagrass.

3 Mapping accuracy

3.1 Instruments

Following Needham et al. (2013b) protocol, at the beginning of each day all GPS' and cameras were taken to a notable point that was identifiable in existing satellite or aerial images (e.g., boat ramp, parking lot, bridge). Waypoints and geo-tagged images were then recorded by all units at these noted locations at same time (Figure 5). As accuracy is dependent on the number of satellites available at any given time, this positioning enabled to offset any differences observed in daily measurements and boundaries. Generally, we observed low variability for within-day accuracy, and over a series of days for the same estuary sampled. Yet, during the 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.

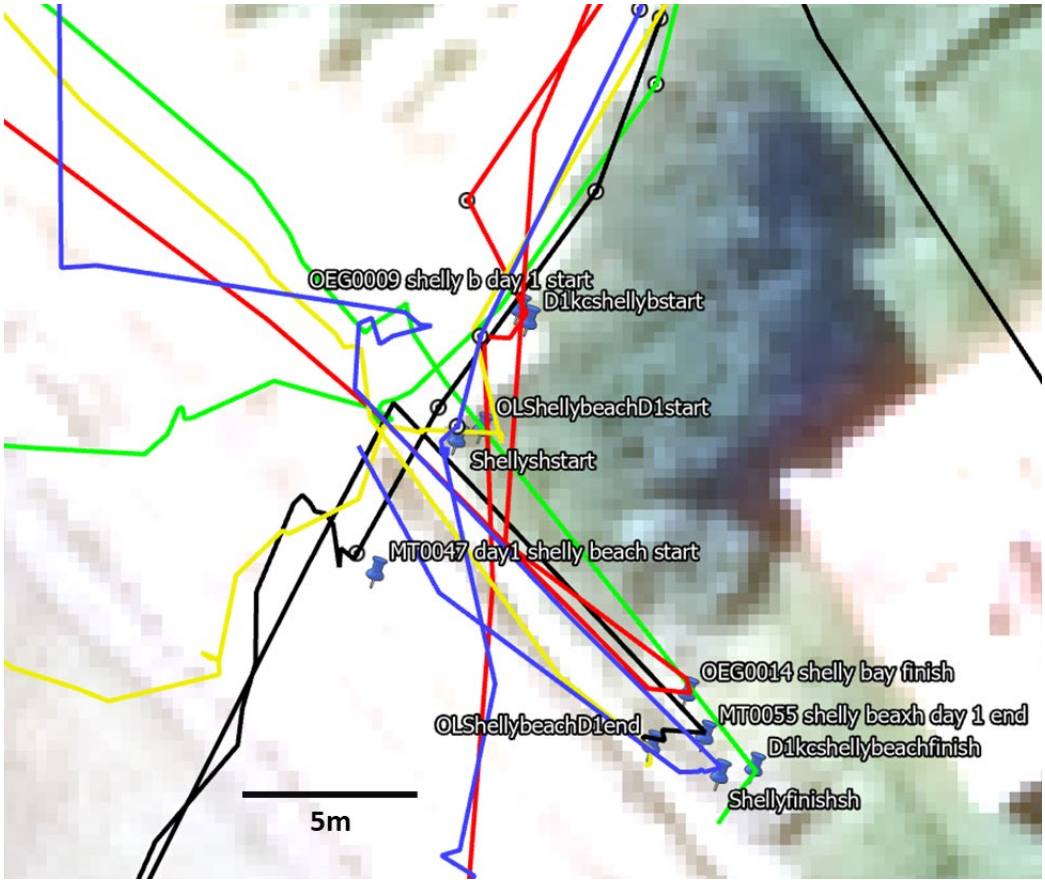

Figure 5: Example of waypoints taken in Shelly Beach at the start and end of the habitat mapping close to a visual reference. Waypoints labels showed the start and end point of each track.

3.2 Precision

Based on the information provided by the GPS manufacturer, the precision of the devices ranges from 1-5 m, which was the degree of error anticipated.

Differences in GPS precision were assessed by measuring the distance between tracks walked together at the same time. Approximately five measurements were collected over segments of track

varying between 50-100 m in length (Figure 6). This was repeated multiple times on different tracks. Precision across the 15 estuaries was generally very good with mean variations around 2 m or less for all estuaries (Table 1).

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

Estuary/Harbour	(n)	Average Variation (m)	Standard Deviation
Otahu River	5	1.56	0.46
Whangamata Harbour	5	1.01	0.23
Wharekawa Harbour	5	0.60	0.18
Tairua Estuary	5	1.28	0.24
Purangi River	5	0.96	0.26
Whitianga Harbour	5	1.36	0.20
Whangapoua Harbour	5	1.79	0.61
Kennedy Bay	5	0.87	0.28
Waikawau Bay	5	1.38	0.48
Port Charles	5	0.57	0.11
Colville Bay	5	0.98	0.18
Shelly Beach/Kikowhakarere Bay	5	0.91	0.26
Coromandel Harbour	5	0.64	0.15
Te Kouma Harbour	5	1.16	0.31
Manaia Harbour	5	1.24	0.46

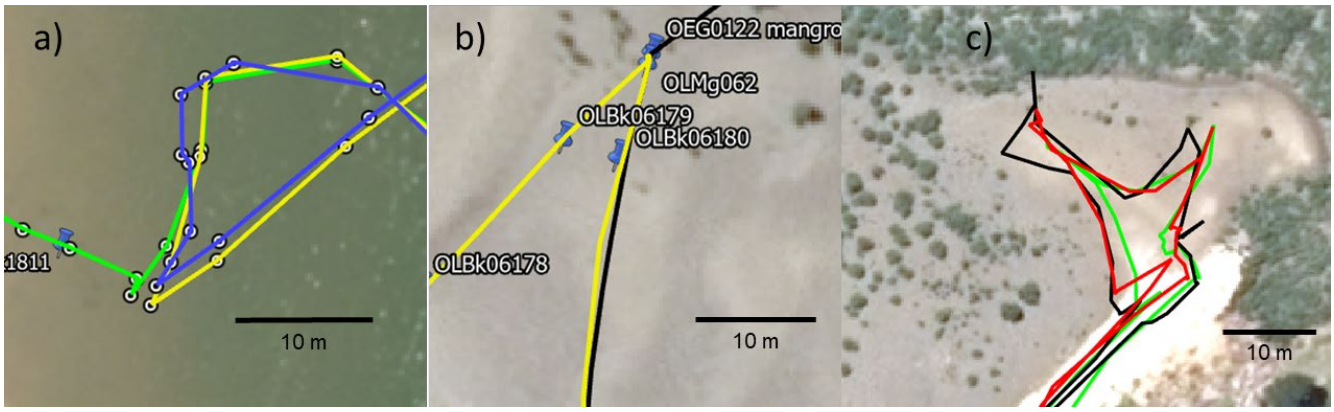

Figure 6: Examples of tracks assessed for precision measurements. a) Whangamata, b) Port Charles, and c) Te Kouma.

4 Habitat classification

The classification of the habitats largely followed Needham et al. (2013b) using the same habitat defining criteria and naming protocols to maintain consistency, allow comparability with previous work, and facilitate repeatability in the future (Table 2). Yet, descriptions and attributes of some habitats were modified slightly in some cases (see details in sections 4.1 and 4.2). In total, 18 habitats categories were identified, divided into three main groups: (1) Flora (3 classes), (2) Fauna (11 classes), and (3) Others (4 classes). Site-specific photographs of habitat categories are given in Section 8. One habitat class included in the original classification, Tube Worms and Crabs (Needham et al., 2013a, Needham et al., 2013b), was not observed in 2023.

4.1 Flora

4.1.1 Mangroves (*Avicennia marina*)

Mangrove habitat was defined as areas of adult mangrove plants greater than 10 m^2 in spatial extent. This definition excluded areas of seedlings and pneumatophores. Sediments within these mangrove patches varied between muddy-sand, sandy-mud, and mud, with predominantly crustacean burrows visible in the sediment between plants. The mangrove category was modified from Needham et al. (2013b), as previously saltmarsh was not considered. In this study, mangroves habitat also includes saltmarsh areas greater than 10 m^2 in spatial extent, as they often co-occurred.

4.1.2 Pneumatophores (*Avicennia marina*)

The pneumatophore habitat was differentiated from mangrove habitat (even though mangroves are the source of the pneumatophores). This is because pneumatophores can extend >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 the pneumatophore habitat were generally dominated by crustacean burrows and new mangrove seedlings.

4.1.3 Seagrass (*Zostera muelleri*)

A seagrass habitat was considered when seagrass showed sufficient density and extent (minimum of 10 m^2) to form a distinct bed rather than a collection of sparse single plants or small fragmented patches. Across the harbours and estuaries in the Coromandel Region, there was no ambiguity with assigning the seagrass habitat, as the seagrass was conspicuous and often dense where present. Within the seagrass habitat, there was a variety of infaunal species ranging from shrimp, crabs, *Austrovenus stutchburyi* and *Macomona liliana* and these were often in highest densities at the edges of seagrass patches. Islands of unvegetated sediment within larger seagrass patches were not demarcated unless greater than 10 m^2 and accessible.

4.2 Fauna

4.2.1 High Density (HD) *Amphibola crenata*

Amphibola distributions were often patchy and intermingled with mangrove fringes and/or HD Burrows. High Density *Amphibola* was defined as sites where ≥10 ind. 0.25m^2 were present in 3 or more random quadrats with a spatial extent of ≥ 10 m in any direction. This habitat was infrequently observed and may be ephemeral.

4.2.2 High Density (HD) Burrows (Crustacean burrows)

HD Burrows habitat was defined by the presence of a high number of conspicuous crabs and/or shrimp burrows on the sediment surface. Although burrows were present at high density (by definition), other common estuarine fauna were often 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 HD Burrow category was defined as containing ≥10 burrows of ≥20 mm aperture in a 0.25 m^2 quadrat however, those found in muddy sediments were often seen in densities > 40 burrows per quadrat. Repeated quadrats were thrown (~3 to 5 times) to verify burrow densities in each area.

4.2.3 High Density (HD) Cockles (*Austrovenus stutchburyi*)

Cockle habitat was defined based on two criteria: (1) sediment containing ≥10 individuals sized ≥20 mm shell length from a 15 x 15 cm area, and (2) sediment containing ≥3 individuals sized ≥40mm shell length per 15 x 15 cm area. Within cockle habitats it was typical to see other fauna (e.g., worm casts, *Macomona liliana* 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 and were generally observed in sand, muddy-sand sediments. 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.

4.2.4 High Density (HD) Crabs and Cockles

This mixed habitat category was defined by the presence of crabs and cockles in sufficient density to both qualify for their respective habitat categories. Crustacean burrows were found at densities of ≥10 burrows of ≥20 mm aperture per 0.25 m^2 within quadrats where cockles were found (amongst the crab burrows) at densities of ≥10 individuals sized ≥ 20 mm shell length per 15 x 15 cm area.

4.2.5 High Density (HD) Pipi (*Paphies australis*)

Pipi habitat was defined as sediment containing ≥10 individuals sized ≥40 mm 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. Pipi habitats recorded were often on the edge of main channels or in the low intertidal, boarding subtidal.

4.2.6 High Density (HD) Cockles and Pipi

This habitat was defined as areas where cockles and pipi were found together in sufficient density of both to 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). Cockles and pipi were also often found in the vicinity of channels, or were a transition between HD Cockles and HD Pipi.

4.2.7 High Density (HD) *Macomona liliana*

Macomona habitat was defined as sediment containing ≥4 *Macomona* sized ≥30 mm 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 found. Thus, quadrats had to be excavated to a depth >10 cm to verify the densities and sizes of *Macomona* present.

4.2.8 High Density (HD) Oysters (*Crassostrea gigas*)

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

4.2.9 Low Density (LD) Deposit Feeders

This habitat category acted as the baseline at each estuary and is deliberately broad to encompass the differing community structures in each location. LD Deposit Feeders habitat is characterised as having low to medium density of mainly deposit feeding fauna (containing gastropod species, polychaetes moving through the sediment, and bivalves (commonly *Austrovenus*, for example). The presence of large burrows is rare or infrequent (≤1 burrow of >2 mm diameter per 0.25 m^2 in n≥3 quadrats) although in some instances high densities of juvenile crabs and bivalves (i.e., less than 5 mm longest shell length) were also incorporated into this category.

4.2.10 Low Fauna

Low Fauna was used to categorise areas that were highly physically dominated, for instance, upper estuaries where coarse sediment dominated, or large expanses of wave rippled sand, or soft, highly aerated "beach" sand. The habitat was characterised by a general lack of any visible fauna in a 15 x 15 cm area.

4.2.11 Mounds and Pits

This mixed habitat category is similar to LD Deposit Feeders habitat, which was dominated by a mixed, predominantly deposit-feeding community (often *Macomona liliana*, polychaetes and cockles) at densities below their respective individual habitat thresholds. Mounds and Pits habitat differs from LD Deposit Feeders habitat by having noticeable topographic features in the sediment through the presence of Mounds and Pits. These pits and mounds were not dense on a quadrat-by-quadrat basis (ranging from <1 to ~4 per quadrat), yet, when looking across the flats, considerable disturbance and sediment undulations were notable (and differed from that of ray feeding pits). Anoxic sediment mounds were often good indicators of reworking.

4.3 Other mapped categories

4.3.1 Oyster farm

Oyster farms were identified as an area of the estuary or seabed being used for breeding and growing oysters commercially. In general, oyster farms were well delimited by the use of poles, mesh, and ropes and were able to be mapped accurately using aerial photography.

4.3.2 Rocky Reef

Rocky reefs habitats were defined as areas where exposed or submerged rock outcrops were present. This habitat was often found close to the land, associated with oysters, rocky shore invertebrate communities, or manmade channels.

4.3.3 Sediment deposition

The sediment deposition category was created for this study to highlight the effects of Cyclone Gabrielle which hit New Zealand between 12 - 16 February 2023. This habitat was identified when terrigenous fine sediment layers were found on top of the natural sediment surface of the estuaries and where it spanned >10 m^2 area. We detected significant terrigenous fine sediment deposition in Wharekawa and Whangamata harbours, and at Shelly Beach, when sampled approximately 7, 9 and 20 days after the cyclone, respectively. We are unsure how long the terrigenous fine sediment layers persisted or if they are still there.

4.3.4 Tapu

This classification represents areas with noted cultural and spiritual significance. Mapping these areas was either avoided (i.e., at Colville Bay) or undertaken only when escorted by kaitiaki (i.e., Manaia Harbour).

Table 2: Summary table of the habitat classification for Flora and Fauna groups used in this study.

Habitat Type	Qualifying information
Seagrass	Dense vegetation spanning more than 10 m^2.
Mangroves	Adult plants greater than 10 m^2 in spatial extent. Saltmarsh 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	Cockles were found ≥10 individuals sized ≥20 mm shell length and Pipi ≥10 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 Burrows	≥10 crustacean burrows of ≥20 mm aperture in a 0.25 m^2 quadrat. Repeated, randomly thrown quadrats (n=3 to 5) must yield the same density.
HD Crabs and Cockles	Both at densities to qualify for their respective habitat categories (above).
LD Deposit Feeders	Low to med density of mainly deposit feeding fauna.
Mounds and Pits	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 ind. 0.25 m^2 quadrat.

Habitat Type	Qualifying information
HD Amphibola	≥10 ind. 0.25m^{-2} were present in 3 or more random quadrats with a spatial extent of ≥10 m in any one direction.

5 Habitat maps

To create the habitat maps, all GPS units were downloaded using Garmin Basecamp software where all tracks and waypoints were compiled, overlayed, and colour coded. All data were imported into a .kmz file suitable for use in Google Earth and ArcGIS Pro. Photographs 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 the software ArcGIS Pro. Maps were created soon after the fieldwork was completed and completed habitat maps were scrutinised by the field team for QA.

Polygons were created using the 'create polygon' tool in ArcGIS Pro. This function allows the user to trace tracks and create polygons delimiting the different habitats. We performed the tracing of tracks and habitat delimitations using the (1) waypoints and tracks recorded on the field, (2) the 2019 WRAPS photographs (courtesy of WRC), (3) the 2013 habitat mapping GIS layers, (4) photographs taken *in situ* (see Section 8 for more details), and (5) written notes incorporated with marked GPS waypoints.

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 reefs have been included in the following maps. Similarly, oyster farms and areas of significant cultural and spiritual significance (tapu) are detailed in the appropriate estuaries as accessory information.

Comparison between habitats mapped in 2013 and the habitats mapped in this study was based on the area (m^2) surveyed. Detailed information of the total area surveyed for both mapping events (2013 and 2023) and the percentage coverage of each habitat type was included. However, as both surveys did not cover the same extents (e.g., Mangrove removals in Whangamata Harbour or the addition of a new marina in Tairua since 2013), a standardisation was done by clipping an area that was mapped in both surveys and comparing habitat types based on area coverage in m^2 and percentage. For all maps presented in the following sections, any areas uncoloured within the estuary represent channels and streams. In some cases, these do not match the underlying aerial image due to the dynamic nature of these features.

5.1 Otahu River

5.1.1 Sediment characteristics

This estuary was mainly firm sandy sediments with low densities of macrofauna. Few muddy sections close to the mangroves were also identified, and other small sections close to the edge of the channel had cockles and pipi. In the upper reaches, in the low fauna areas, the sediment was coarse-medium grained sand with small grained gravel and was soft to walk on.

5.1.2 Habitats

Otahu River is a relatively small estuary (877,977 m^2) characterised by 11 habitat classes. The largest area was dominated by mangroves (46.5% of the total area surveyed), followed by the low fauna (21.3%) and LD Deposit Feeders (13.7%) habitats (Figure 7).

5.1.3 Change in habitats over time

The habitat HD Crab and Cockles and HD Macomona habitats (after extensive digging and checking) were absent in 2023 compared to 2013 (Table 3, Figure 8). In terms of total standardised area (i.e., total area that was mapped in both years), it was identified that Mangroves and HD Pipi habitats covered similar percentage of area in 2013 and 2023, and only increased 0.3% over time (Table 4, Figure 8). The area covered by HD Cockles increased 30,833 m^2 over time, which corresponded with the decrease of the area covered by HD Burrows, LD Deposit Feeders, and Mounds and Pits (3.4%, 1.8%, and 3.6% respectively) over time. Seagrass habitat was similarly low in both years compared to other habitats (Table 4, Figure 8). No evident changes in habitats were observed in the upper and lower section of the estuary and most of the change occurred in the middle section of the estuary (Figure 8).

Table 3: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Otahu River.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Burrows	48 504	5.65	24 662	2.81
HD Cockles	12 058	1.41	46 950	5.35
HD Cockles and Pipi	4 380	0.51	1965	0.22
HD Crab and Cockles	595	0.07	-	-
HD Macomona	3 831	0.45	-	-
HD Pipi	8 257	0.96	8237	0.94
LD Deposit Feeders	116 988	13.64	120 573	13.73
Low Fauna	200 723	23.40	187 733	21.38
Mangroves	362 908	42.30	408 507	46.53
Mounds and Pits	64 161	7.48	34 536	3.93
Pneumatophores	3090	0.36	12 008	1.37
Rocky Reef	28 797	3.36	29 478	3.36
Seagrass	3 604	0.42	3 328	0.38

Table 4: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Otahu River estuary. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Burrows	45 822	6.10	20 224	2.69	-25599	-3.41
HD Cockles	11 449	1.53	42 283	5.63	30 833	4.10
HD Cockles and Pipi	4 145	0.55	529	0.07	-3 616	-0.48
HD Crab and Cockles	594	0.08	-	-	-594	-0.08
HD Macomona	3 828	0.51	-	-	-3 828	-0.51
HD Pipi	4 292	0.57	5 591	0.74	1 299	0.17
LD Deposit Feeders	107710	14.35	93540	12.45	-14170	-1.89

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
Low Fauna	115 249	15.35	147 812	19.68	32 562	4.34
Mangroves	362 260	48.26	364 639	48.54	2 379	0.32
Mounds and Pits	61 701	8.22	34 052	4.53	-27 649	-3.68
Pneumatophores	2 740	0.36	11 331	1.51	8 592	1.14
Rocky Reef	28 239	3.76	28 239	3.76	0	0.00
Seagrass	3 200	0.43	2 922	0.39	-278	-0.04

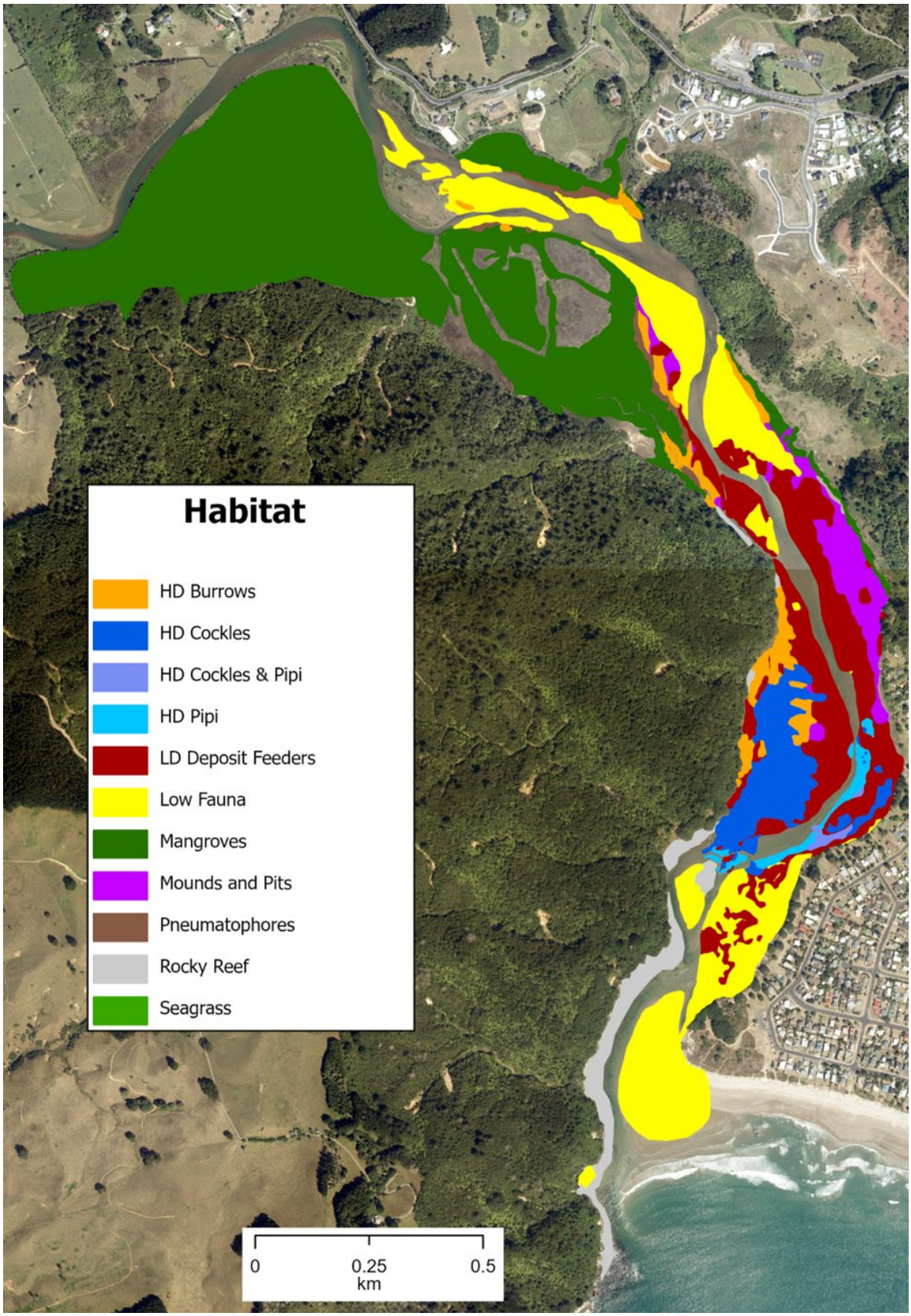

Figure 7: 2023 habitats mapped in Otahu River (right flipped).

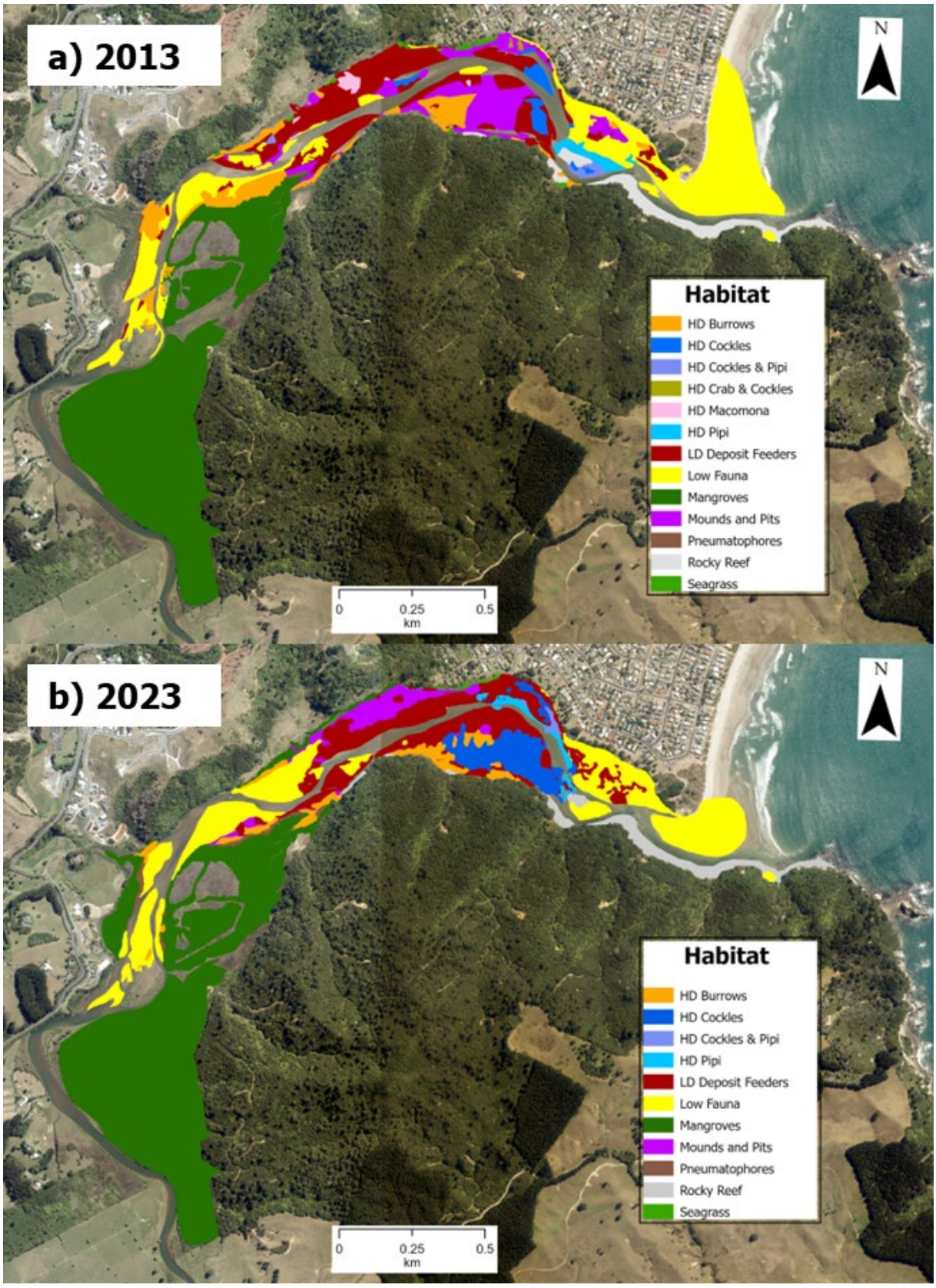

Figure 8: Comparison of the habitats mapped in a) 2013 and b) 2023 in Otahu River.

5.2 Whangamata Harbour

5.2.1 Sediment characteristics

Close to the mouth of the harbour, water moves very quickly out through the channel, leading to large areas of dynamic and Low Fauna sediment with swept sand waves. Away from the mouth, the sediment in Whangamata Harbour was dominated by seagrass with firm muddy sand and some large muddy sections. These large muddy areas hosted a high abundance of crabs, and sometimes cockles. The seagrass areas were mainly dominated by cockles living within the seagrass matrix. Sediment deposition, a result of Cyclone Gabrielle (approximately 9 days earlier), was identified mainly in an embayment in the upper section of the harbour, covering an area of 156,245m^2. It was perhaps the most evident terrigenous sediment deposition observed across all estuaries mapped, several cm thick in places with layers of crusty dry material over the top of thick soup-like silty-clay (Figure 9).



Figure 9: Sediment deposition in the weeks following Cyclone Gabrielle. At this site, there were three layers of the "soupy" silty terrigenous sediment separated by a hard crusty dry layer indicating several sedimentation events. (Photo credit: Dr Michael Townsend, WRC).

5.2.2 Habitats

Whangamata Harbour was one of the largest estuaries mapped with an intertidal area of 3,909,360 m^2 and contained 13 identifiable habitat classes. The largest area was dominated by Mangroves (24.5% of the total area surveyed), followed by HD Burrows (20.9%), and LD Deposit Feeders (12.6%) habitat (Figure 10).

5.2.3 Change in habitats over time

The habitat HD Amphibola was absent in 2023 compared to 2013, while HD Oysters habitat was identified in 2023 but absent in 2013 (Table 5, Figure 11). Based on the total standardised area (i.e., total area that was covered in both years), a decrease in the area covered by Mangroves was identified (147,787 m^2), aligning with the manual removal of mangroves (Lundquist et al., 2017) (Table 6, Figure 11). The area covered by HD Burrows and HD Cockles habitats increased (3.4% and 6.2% respectively) from 2013 to 2023. The increase of area covered by HD Burrows was associate with the decrease in Mangroves, while the increase of area covered by HD Cockles was related to decreases in Seagrass (Table 6, Figure 11). The area covered by Mounds and Pits decreased (300,719 m^2) and largely transitioned to LD Deposit Feeders over time (Table 6, Figure 11). Most of the changes in habitats identified over time were in the upper and middle section of the estuary, while the lower section remained similar over time (Figure 11).

Table 5: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Whangamata Harbour.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Amphibola	600	0.02		
HD Burrows	670008	18.31	793152	20.29
HD Cockles	129330	3.53	381624	9.76
HD Crab and Cockles	64517	1.76	32033	0.82
HD Macomona	413	0.01	4061	0.10
HD Oysters			28	<0.01
LD Deposit Feeders	318941	8.71	495156	12.67
Low Fauna	206377	5.64	193811	4.96
Mangroves	972818	26.58	958318	24.51
Mounds and Pits	696004	19.02	381998	9.77
Pneumatophores	17951	0.49	17869	0.46
Rocky Reef			2002	0.05
Seagrass	582901	15.9	490102	12.54
Sediment Deposition			156245	4.00

Table 6: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Whangamata Harbour. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Amphibola	599	0.02			-599	-0.02
HD Burrows	643163	18.45	762853	21.85	119690	3.40
HD Cockles	119493	3.43	337143	9.66	217650	6.23
HD Crab and Cockles	56555	1.62	27759	0.80	-28796	-0.83

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Macomona	413	0.01	4 056	0.12	3 643	0.10
LD Deposit Feeders	302 771	8.68	462 884	13.26	160 113	4.57
Low Fauna	172 651	4.95	150 892	4.32	-21 759	-0.63
Mangroves	94 1851	27.02	794 064	22.75	-147 787	-4.27
Mounds and Pits	656 083	18.82	355 365	10.18	-300 719	-8.64
Pneumatophores	17 265	0.50	17 489	0.50	224	0.01
Rocky Reef			766	0.02	766	0.02
Seagrass	575 480	16.51	478 710	13.71	-96 770	-2.79
Sediment Deposition			99 067	2.84	99 067	2.84

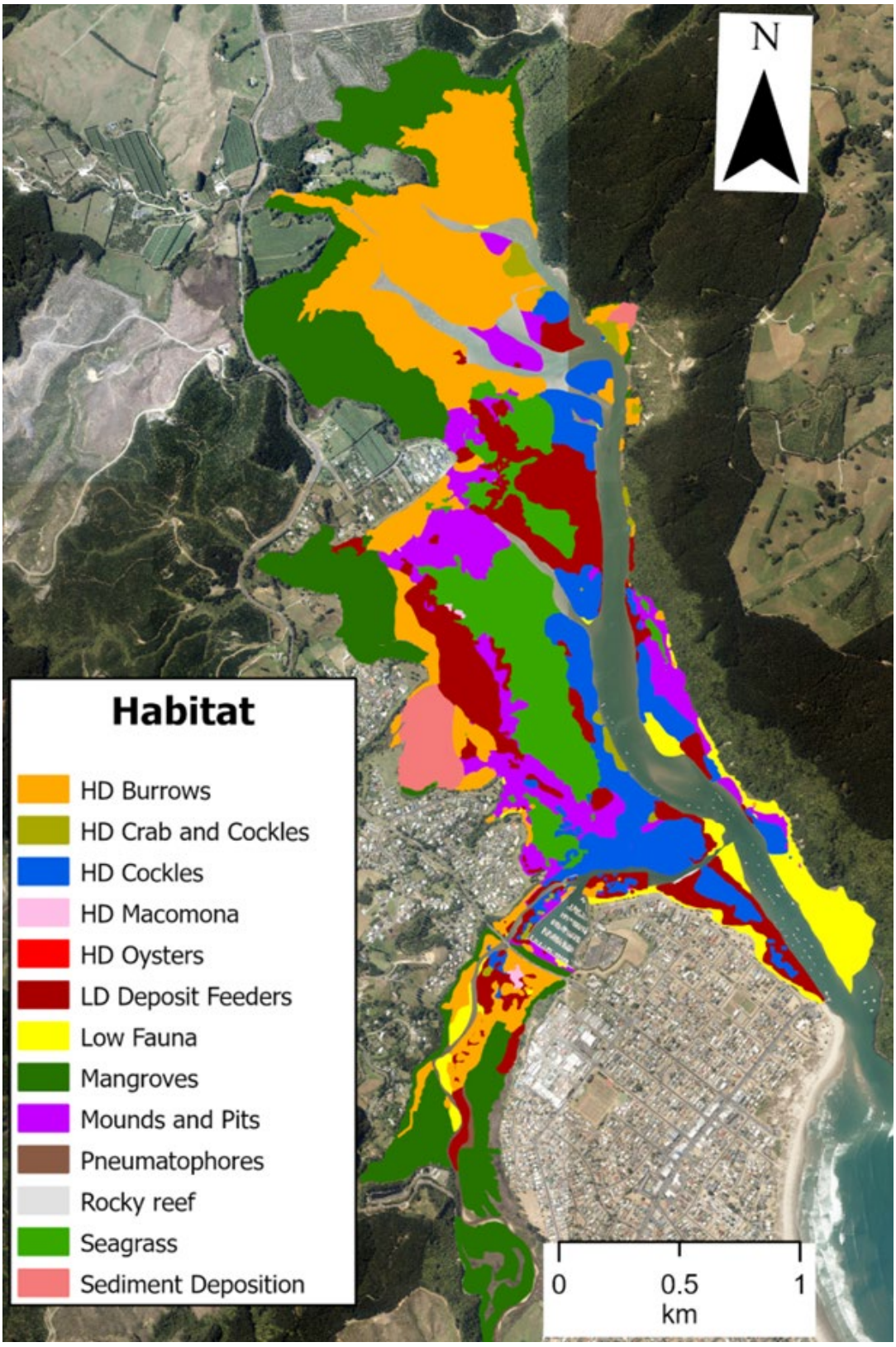

Figure 10: 2023 habitats mapped in Whangamata Harbour.

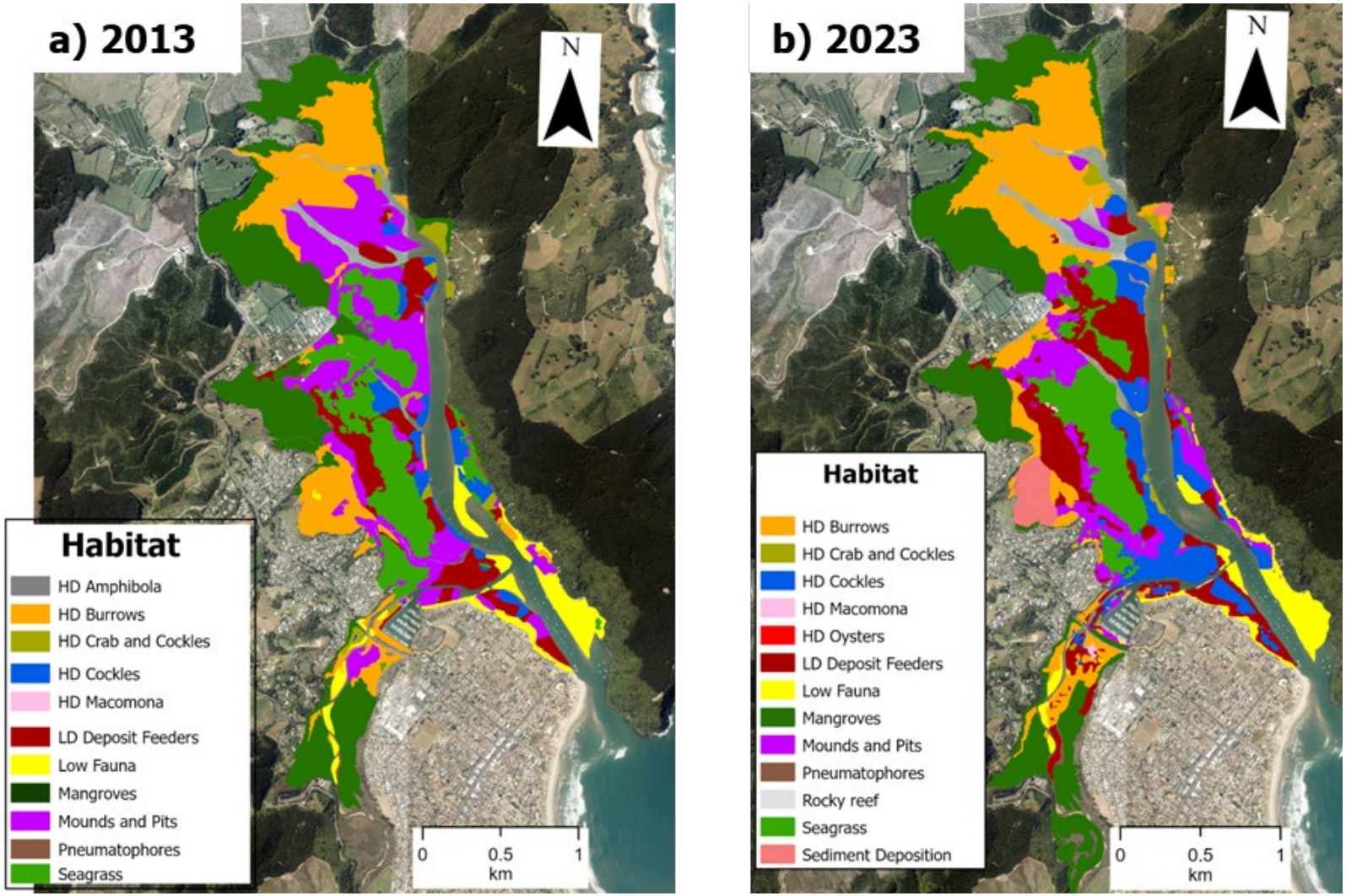

Figure 11: Comparison of the habitats mapped in a) 2013 and b) 2023 in Whangamata Harbour.

5.3 Wharekawa Harbour

5.3.1 Sediment characteristics

This estuary was dominated by large sections of sandy firm sediment, especially through the middle of the harbour. The dynamic sediment sand banks and sand spit closer to the mouth were softer to walk across, with low fauna. Muddy sediment deposits were also identified, but mainly in the upper reaches of the estuary – associated with the catchment around the Tawatawa Stream. This sediment deposition occurred during and after Cyclone Gabrielle (approximately 7 days earlier) and was up to 10 cm deep and spanned 60,970 m^2 area (Figure 12). In 2013, it was noted that sediment inputs from catchment sources were occurring by the Opoutere Bridge. This was noted again in 2023, but the amount deposited was not as great as that identified in the upper reaches.



Figure 12: Large sedimentation deposited in the upper reaches of Wharekawa Harbour (Photo credit: WRC).

5.3.2 Habitats

Wharekawa Harbour has an intertidal area of 1,666,024 m^2 and contained 13 identifiable habitat classes. The largest area was dominated by Mangroves (31.4% of the total area surveyed), closely followed by LD Deposit Feeders (30.5%) (Figure 12). Seagrass was almost absent (0.13%). Large areas with HD cockles near the channel were observed (Figure 13).

5.3.3 Change in habitats over time

Wharekawa Harbour showed a substantial decrease in HD Macomona habitat, as this habitat was not observed in the 2023 survey (Table 7, Figure 14). Copious sediment deposition, as consequence of cyclone Gabrielle, was identified in the middle section of the estuary and in a few arms in 2023 (Table 7, Figure 14). Based on the total standardised area (i.e., total area that was covered in both years), it was identified that the area covered by Seagrass habitat largely decreased (26.2%) from 368,032 m^2

in 2013 to 1,925 m^2 in 2023 (Table 8, Figure 14). Most of the areas where Seagrass was recorded in 2013, were identified as LD Deposit Feeders areas in 2023, which resulted in an increase of 15.4% of the area covered by this habitat. The area covered by HD Cockles and Low Fauna habitats also increased over time (Table 8, Figure 14), while the area covered by HD Amphibola and HD Pipi decreased from 2013 to 2023, with very low area remaining in 2023 (Table 8, Figure 14). Few and minor changes were detected in the lower section of the estuary, while the most evident changes were identified in the middle and upper section of the estuary (Figure 14).

Table 7: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Wharekawa Harbour.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Amphibola	565	0.04	15	<0.01
HD Burrows	107 809	7.04	106 513	6.39
HD Cockles	43 849	2.86	112 542	6.76
HD Macomona	5175	0.34		
HD Oysters	1000	0.07	1189	0.07
HD Pipi	22 654	1.48	1098	0.07
LD Deposit Feeders	295 449	19.30	509 160	30.56
Low Fauna	134 883	8.81	215 335	12.93
Mangroves	374 752	24.48	524 484	31.48
Mounds and Pits	120 293	7.86	99 268	5.96
Pneumatophores	18 061	1.18	23 527	1.41
Rocky Reef	14 033	0.92	9 834	0.59
Seagrass	392 331	25.63	2 089	0.13
Sediment Deposition			60 970	3.66

Table 8: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Wharekawa Harbour. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Amphibola	555	0.04	15	<0.01	-540	-0.04
HD Burrows	98 363	7.05	96 615	6.92	-1748	-0.13
HD Cockles	42 456	3.04	102 620	7.35	60 163	4.31
HD Macomona	4 322	0.31			-4 322	-0.31
HD Oysters	751	0.05	1 106	0.08	355	0.03
HD Pipi	14 448	1.04	1 098	0.08	-13350	-0.96
LD Deposit Feeders	279 056	20.00	494 795	35.44	215 739	15.44
Low Fauna	114 143	8.18	174 254	12.48	60 111	4.30
Mangroves	335 069	24.01	343 286	24.59	8 217	0.58
Mounds and Pits	112 658	8.07	92 644	6.64	-20 013	-1.44
Pneumatophores	17 549	1.26	22 373	1.60	4 824	0.34

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
Rocky Reef	7 888	0.57	6 439	0.46	-1 449	-0.10
Seagrass	368 032	26.38	1 925	0.14	-366 108	-26.24
Sediment Deposition			58 799	4.21	58 799	4.21

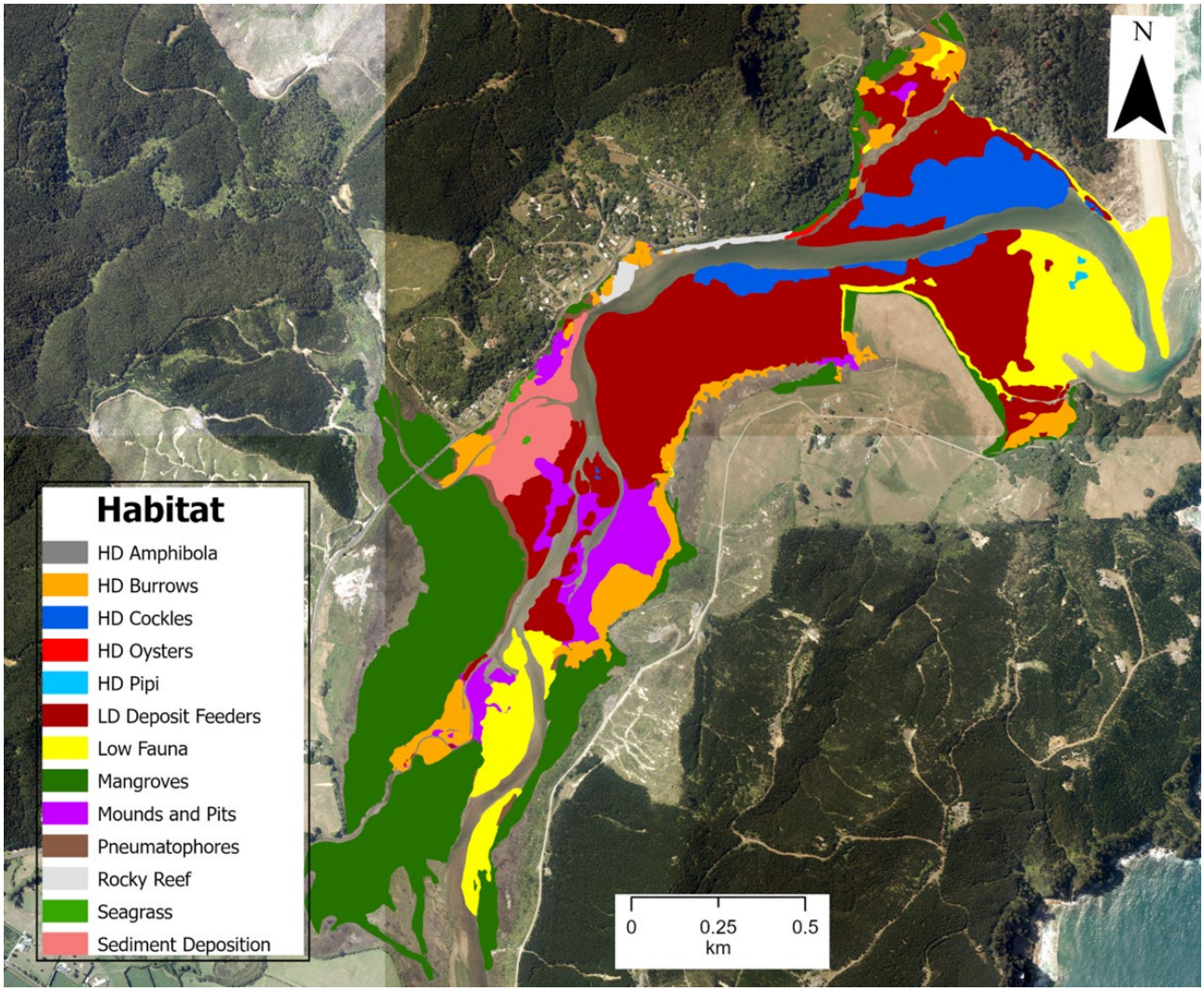

Figure 13: 2023 habitats mapped in Wharekawa Harbour.

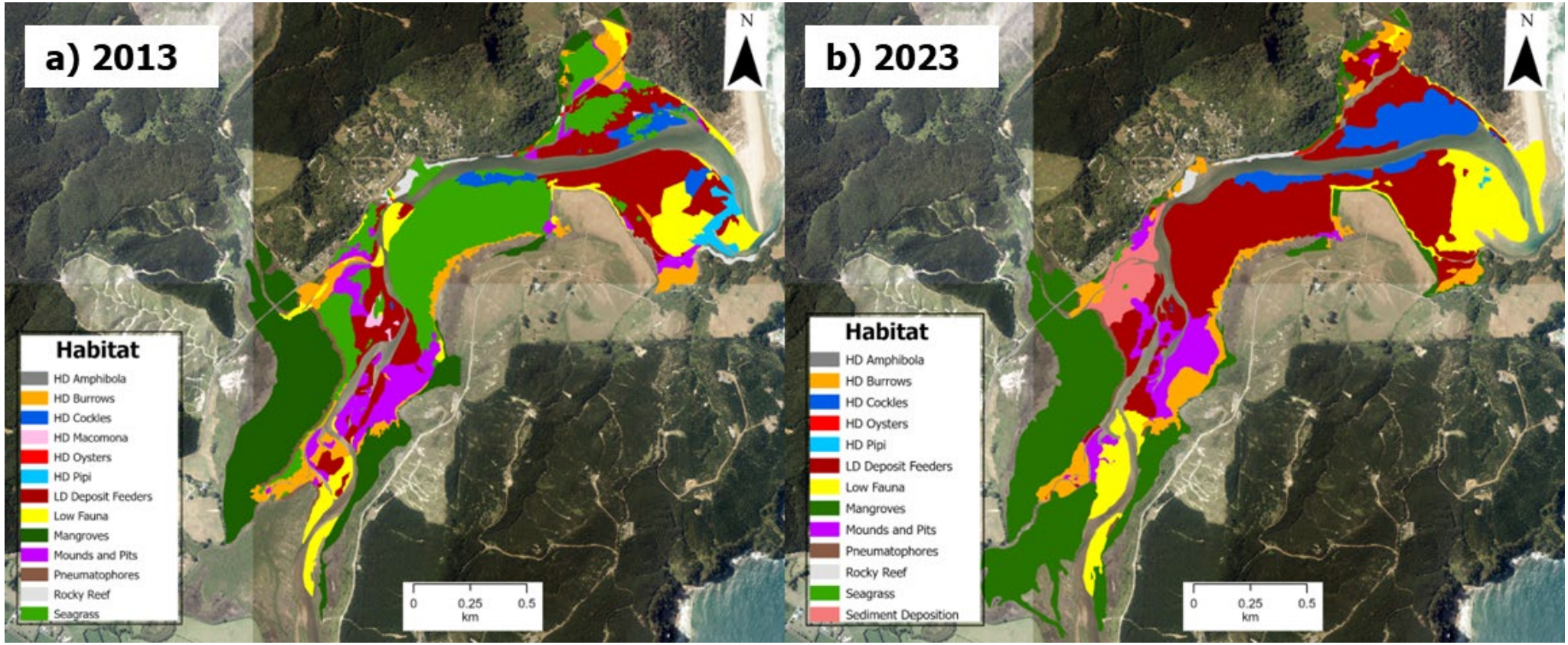

Figure 14: Comparison of the habitats mapped in a) 2013 and b) 2023 in Wharekawa Harbour.

5.4 Tairua Harbour

5.4.1 Sediment characteristics

Tairua Harbour was dominated by large areas of firm sandy sediment with low fauna areas especially close to the mouth of the harbour (light-coloured, fine-grained sand) and in the upper reaches of the harbour. The large sandy areas in the middle of the harbour hosted a high abundance of cockles. Since the habitat mapping in 2013, Tairua Marina was constructed and is now operational, which has modified the water flow in the estuary altering some of the habitats previously mapped (Figure 15).



Figure 15: Habitat change in the area of Paku Bay, Tairua Harbour. a) March 2013, b) October 2013, c) November 2015, and d) May 2022 (Aerial images obtained from Google Earth).

5.4.2 Habitats

Tairua Harbour has an intertidal area of 4,371,248 m^2, and it was characterised by 13 habitat classes. The largest area was dominated by LD Deposit Feeders (37.1% of the total area surveyed), followed by Low Fauna (19.9%), and Mangrove (12.0%) habitats (Figure 16).

5.4.3 Change in habitats over time

The most evident changes identified for Tairua were the absence of HD Amphibola in 2013, and the presence of HD Cockles and Pipi, and HD Cockles and Crabs in 2023 (Table 9, Figure 17). Based on the total standardised area (i.e., total area that was covered in both years), it was clear that the area covered by Seagrass habitat decreased the most (30.3%) from 2013 to 2023 (Table 10, Figure 17). The areas where Seagrass was lost was mainly replaced by LD Deposit Feeders and HD Cockles habitats, which coverage area increased 34.4% and 9.3% respectively (Table 10, Figure 17). The increased of area covered by LD Deposit Feeders also corresponded to a decrease in area covered by HD Macomona (5.4%), reducing from 177,977 m^2 in 2013 to only 7,982 m^2 in 2023. In the upper and middle section of the estuary, Mangroves habitat coverage decreased (3.6%) over time, which aligned with the increase of area covered by Mounds and Pits (Table 10, Figure 17). HD Macomona was still detected on the intertidal by Pauanui, but the extent has declined by 5.4%. Tairua was one of the estuaries that showed the most evident changes in habitats mapped across the whole harbour over time (Figure 17).

Table 9: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Tairua Harbour.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Amphibola	1123	0.02		
HD Burrows	347 921	7.70	61 787	1.41
HD Cockles	12 240	0.27	366 252	8.38
HD Cockles and Pipi			3 440	0.08
HD Cockles and Crabs			595	0.01
HD Macomona	179 806	3.97	8 976	0.21
HD Oysters	4 362	0.09	456	0.01
LD Deposit Feeders	788 426	17.44	1 623 926	37.15
Low Fauna	920 115	20.36	871 489	19.94
Mangroves	701 102	15.51	528 099	12.08
Mounds and Pits	189 013	4.18	492 416	11.26
Pneumatophores	8 386	0.18	42 149	0.96
Rocky Reef			29 023	0.66
Seagrass	1 365 934	30.23	342 640	7.84

Table 10: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Tairua Harbour. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Amphibola	1 122.5082	0.04			-1123	-0.04
HD Burrows	325 397.9268	10.34	41 413.79524	1.32	-28 3984	-9.02
HD Cockles	11 134.03627	0.35	304 214.5463	9.68	29 3081	9.32
HD Cockles and Pipi			729.4410048	0.02	729	0.02
HD Cockles and Crabs			458.6009327	0.01	459	0.01
HD Macomona	177 977.6246	5.65	7 982.387558	0.25	-16 9995	-5.40
HD Oysters	3 943.293312	0.13	351.1231598	0.01	-3 592	-0.11
LD Deposit Feeders			1 090 496.117	34.69	109 0496	34.69
Low Fauna	688 213.224	21.86	602 439.4819	19.16	-8 5774	-2.70
Mangroves	464 916.1787	14.77	349 034.2605	11.10	-115 882	-3.67
Mounds and Pits	182 900.6669	5.81	373 203.1348	11.87	190 302	6.06
Pneumatophores	7 264.687795	0.23	29 999.42891	0.95	22 735	0.72
Rocky Reef			13 318.4713	0.42	13 318	0.42
Seagrass	128 5031.911	40.82	329 813.8762	10.49	-955 218	-30.33

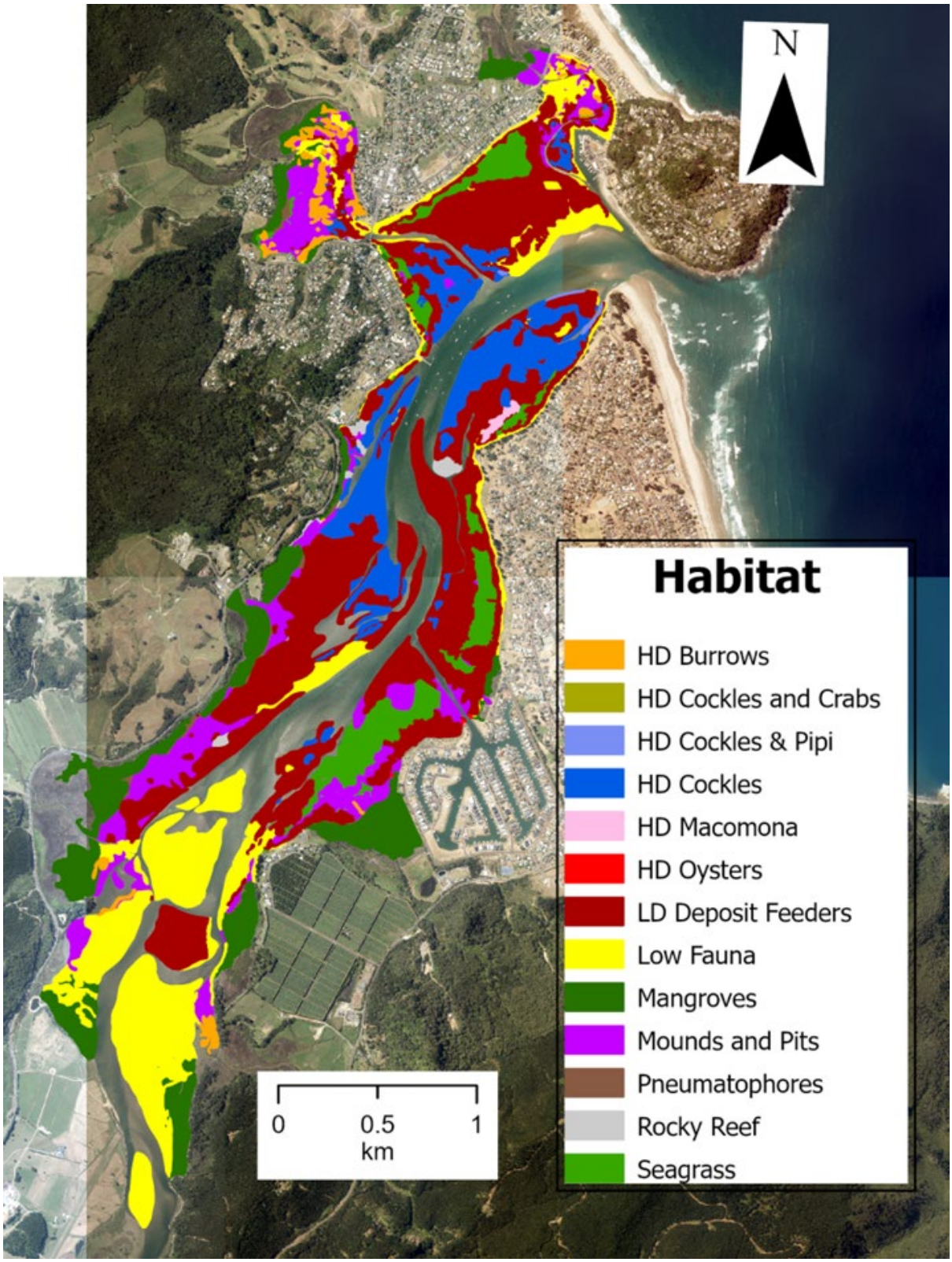

Figure 16: 2023 habitats mapped in Tairua Harbour.

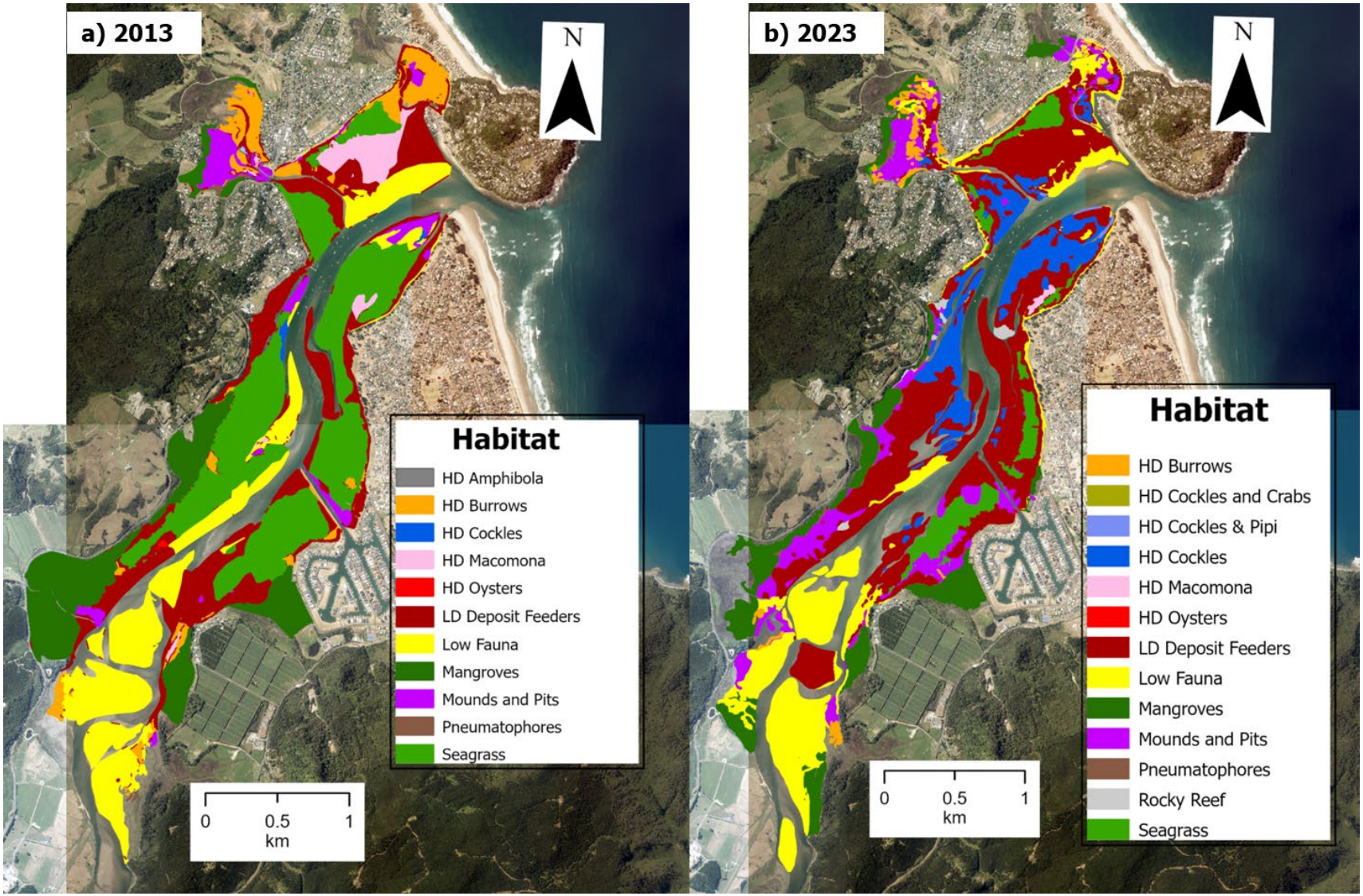

Figure 17: Comparison of the habitats mapped in a) 2013 and b) 2023 in Tairua Harbour.

5.5 Purangi River

5.5.1 Sediment characteristics

The sediment was mainly firm sand with small sections of muddy sediment alongside mangroves. High abundance of cockles was found in these sandy sediments, throughout the entire estuary even in the upper reaches.

5.5.2 Habitats

This estuary is of medium size (intertidal area 1,184,062 m^2), and patchy with respect to habitat distribution, including 11 habitat classes. Mangrove habitat was the largest area (54.3% of the total area surveyed), followed by HD Cockles (12.7%) (Figure 18). The other habitats contributed less than 10% each to the total area (Figure 18).

5.5.3 Change in habitats over time

Purangi River estuary showed a total decrease of the area covered by HD Macomona habitat, as it was absent in 2023 (Table 11, Figure 19). Based on the total standardised area (i.e., total area that was covered in both years), the most evident change was the decrease of the area covered by HD Burrows habitat (Table 12, Figure 19). The decrease of HD Burrows habitat in the upper section of the estuary resulted in an increase of area covered by mainly Mounds and Pits (4.3%) and Mangroves (0.9%), while in the mid-section of the estuary HD Burrows habitat was replaced by HD Cockles habitat, which increasing from 71,1583 m^2 in 2013 to 121,615 m^2 in 2023 (Table 12, Figure 19). The area previously covered by HD Macomona habitat in the middle section of the estuary was replaced by HD Crab and Cockles, which increased 1.1% over time (Table 12, Figure 19).

Table 11: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Purangi River.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Burrows	190 120	16.18	68 925	5.82
HD Cockles	72 040	6.13	151 487	12.79
HD Crab and Cockles	17 560	1.49	32 794	2.77
HD Macomona	2 502	0.21		
HD Oysters	450	0.04	582	0.05
HD Pipi	8 780	0.75	4 341	0.37
LD Deposit Feeders	58 689	5.00	48 050	4.06
Low Fauna	30 834	2.62	36 233	3.06
Mangroves	695 020	59.15	645 696	54.53
Mounds and Pits	49 386	4.20	103 856	8.77
Pneumatophores	48 641	4.14	86 958	7.34
Rocky Reef	930	0.08	5 140	0.43

Table 12: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Purangi River estuary. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Burrows	185 429	17.49	59 460	5.61	-125 970	-11.89
HD Cockles	71 583	6.75	121 615	11.47	50 032	4.71
HD Crab and Cockles	17 547	1.66	30 190	2.85	12 643	1.19
HD Macomona	2 500	0.24			-2 500	-0.24
HD Oysters	445	0.04	553	0.05	109	0.01
HD Pipi	8 713	0.82	655	0.06	-8 057	-0.76
LD Deposit Feeders	56 182	5.30	30 767	2.90	-25 415	-2.40
Low Fauna	27 521	2.60	30 675	2.89	3 154	0.30
Mangroves	597 966	56.42	608 128	57.34	10 163	0.93
Mounds and Pits	46 136	4.35	92 294	8.70	46 157	4.35
Pneumatophores	45 333	4.28	82 238	7.75	36 904	3.48
Rocky Reef	564	0.05	3 908	0.37	3 344	0.32

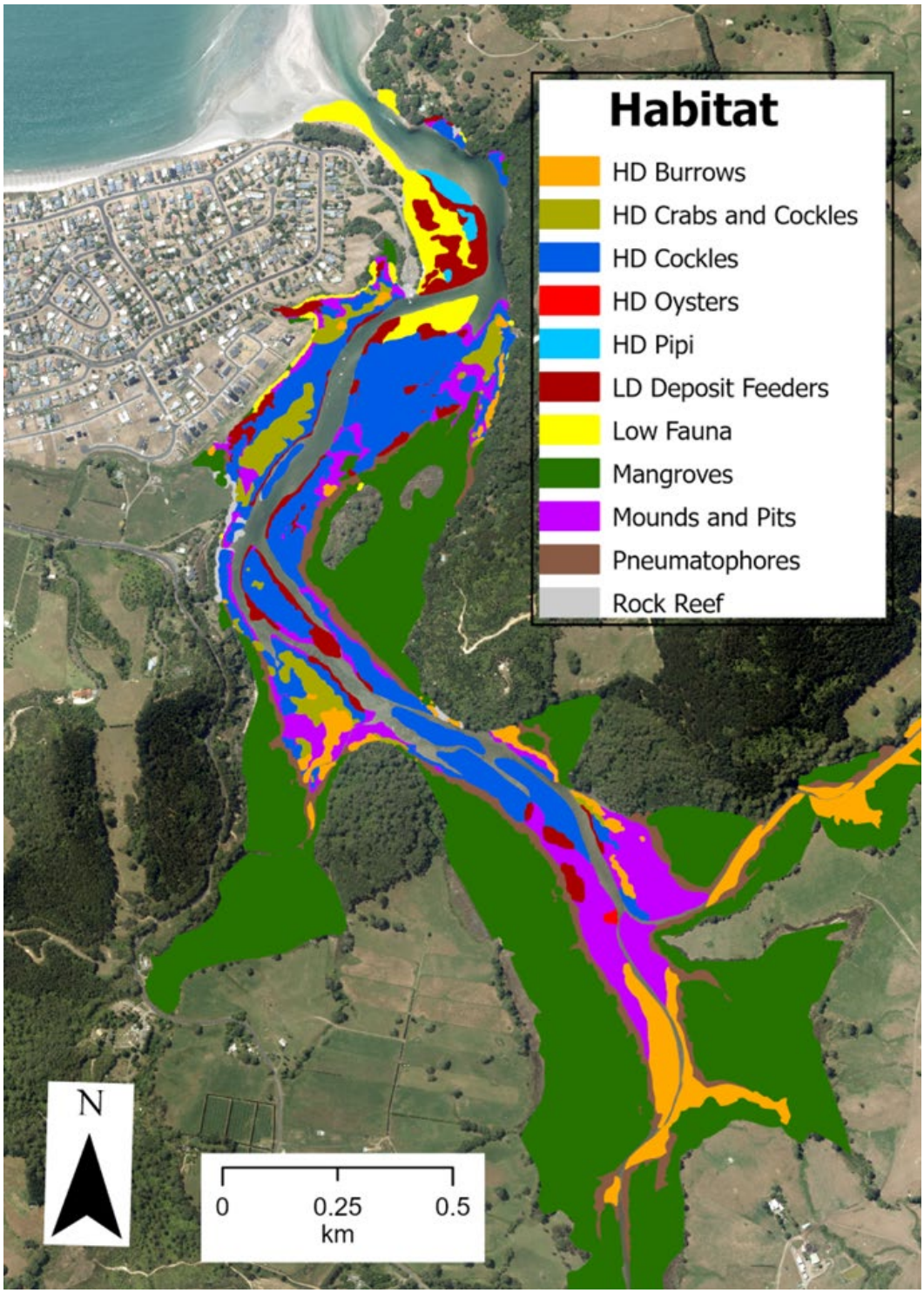

Figure 18: 2023 habitats mapped in Purangi River.

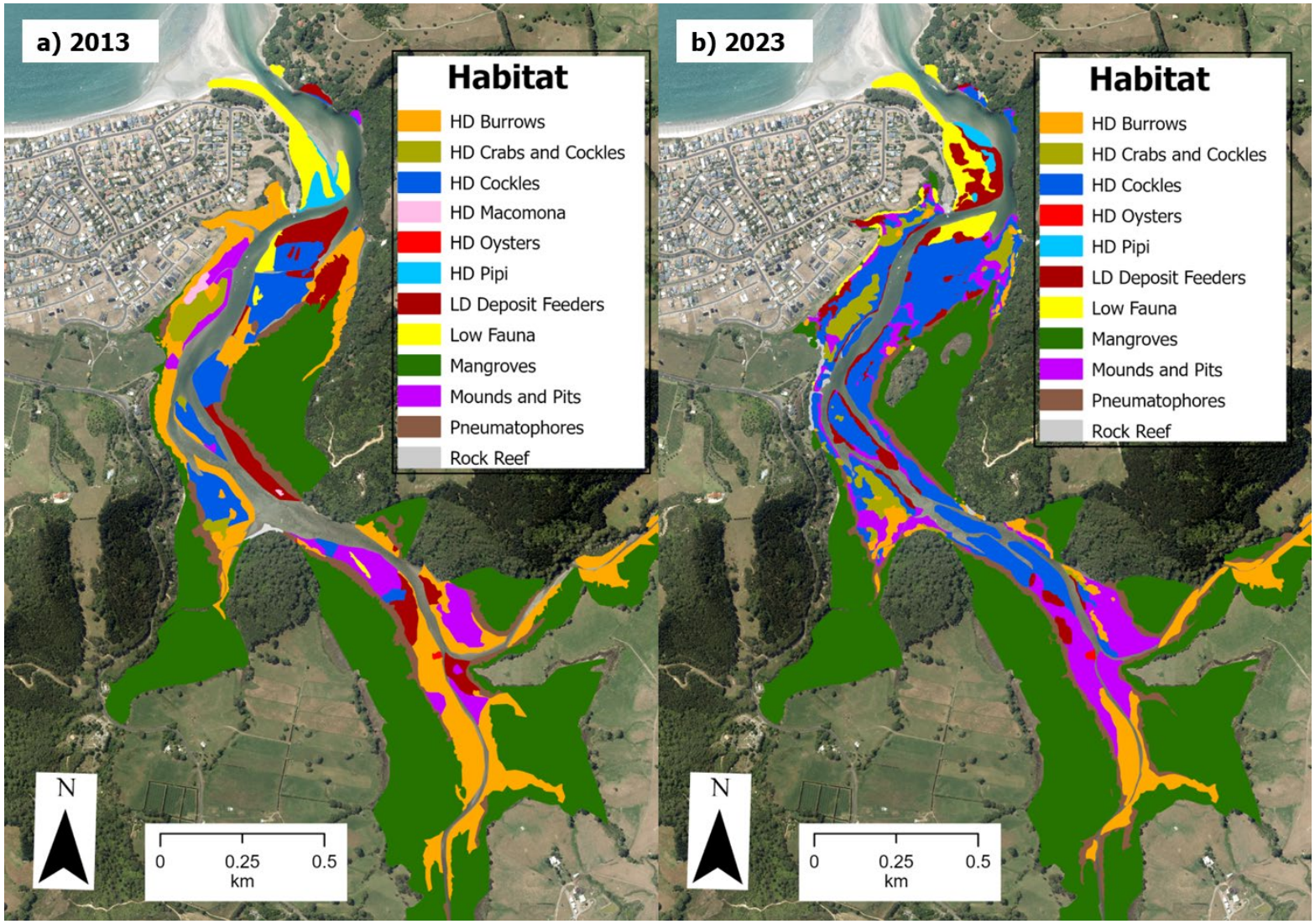

Figure 19: Comparison of the habitats mapped in a) 2013 and b) 2023 in Purangi River.

5.6 Whitianga Harbour

5.6.1 Sediment characteristics

There was a large range of sediment types in the harbour, with large areas of firm sandy sediment and several other sections that were extremely muddy (sinking to knee and waist deep). These muddy areas were located where expected, in the upper reaches of the Harbour, along upper margins of the main channel, around peripheral streams, and close to Mangrove habitat.

5.6.2 Habitats

Whitianga Harbour was the second largest estuary, with 10,286,455 m^2 intertidal area to map. Whitianga Harbour was characterised by 12 habitat classes. Mangroves habitat was the most extensive habitat type observed (50.7% of the total area surveyed), followed by HD Burrows (19.6%), and Mounds and Pits (10.5%) habitats (Figure 20).

5.6.3 Change in habitats over time

Whitianga Harbour showed very small areas covered by HD Amphibola, HD Oysters, and Seagrass habitats in 2013, yet these three habitat classes were absent from the harbour in 2023 (Table 13, Figure 21). In contrast, HD Pipi habitat was identified in 2023 after not being recorded in 2013 (Table 13, Figure 21). Based on the total standardised area (i.e., total area that was covered in both years), decreases in area covered by HD Burrows (4.4%), HD Crab and Cockles (6.2%), and HD Macomona (0.03%) habitats were the most evident changes, highlighting that the extension of HD Crab and Cockles and HD Macomona were strongly reduced from 629,888 m^2 in 2013 to 34,730 m^2 in 2023, and 3,760 m^2 in 2013 to 792 m^2 in 2023 respectively (Table 14, Figure 21). The decrease in HD Burrows habitat was related to increase in area covered by Mounds and Pits (3%), while HD Crab and Cockles, and HD Macomona decreases aligned with increased area cover by of HD Burrows and Mounds and Pits (Table 14, Figure 21). The majority of the habitat changes were identified in the middle section of the estuary, while the area covered by Mangroves habitat remained similar over time (Table 14, Figure 21).

Table 13: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Whitianga Harbour.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Amphibola	61	<0.01		
HD Burrows	2 300 663	23.57	2 018 147	19.62
HD Cockles	345 794	3.54	502 084	4.88
HD Crab and Cockles	658 702	6.75	34 730	0.34
HD Macomona	3 760	0.04	792	0.01
HD Pipi			18 842	0.18
HD Oysters	1 039	0.01		
LD Deposit Feeders	215 527	2.21	764 848	7.44
Low Fauna	133 535	1.37	282 564	2.75
Mangroves	5 140 940	52.68	5 222 897	50.77

Habitat	2013 area (m²)	2013 (%)	2023 area (m²)	2023 (%)
Mounds and Pits	750 177	7.69	1 080 921	10.51
Oyster Farm	119 890	1.23	140 103	1.36
Pneumatophores	80 417	0.82	202 838	1.97
Rocky Reef	8 928	0.09	17 689	0.17
Seagrass	18	<0.01		

Table 14: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Whitianga Harbour. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m²)	2013 (%)	2023 area (m²)	2023 (%)	Change (m²)	Change (%)
HD Amphibola	43	<0.01			-43	<-0.01
HD Burrows	2202 412	23.18	1 777 810	18.70	-424 602	-4.49
HD Cockles	311 638	3.28	430 873	4.53	119 235	1.25
HD Crab and Cockles	629 888	6.63	32 168	0.34	-597 719	-6.29
HD Macomona	3 758	0.04	779	0.01	-2 979	-0.03
HD Oysters	1 037	0.01			-1 037	-0.01
HD Pipi			2 234	0.02	2 234	0.02
LD Deposit Feeders	173 161	1.82	574 881	6.05	401 720	4.22
Low Fauna	127 315	1.34	181 619	1.91	54 305	0.57
Mangroves	5 122 061	53.91	5 150 800	54.17	28 738	0.25
Mounds and Pits	726 455	7.65	1 016 124	10.69	289 669	3.04
Oyster Farm	119 582	1.26	134 007	1.41	14 425	0.15
Pneumatophores	76 625	0.81	193 755	2.04	117 130	1.23
Rocky Reef	7 028	0.07	14 361	0.15	7 333	0.08
Seagrass	18	<0.01			-18	<-0.01

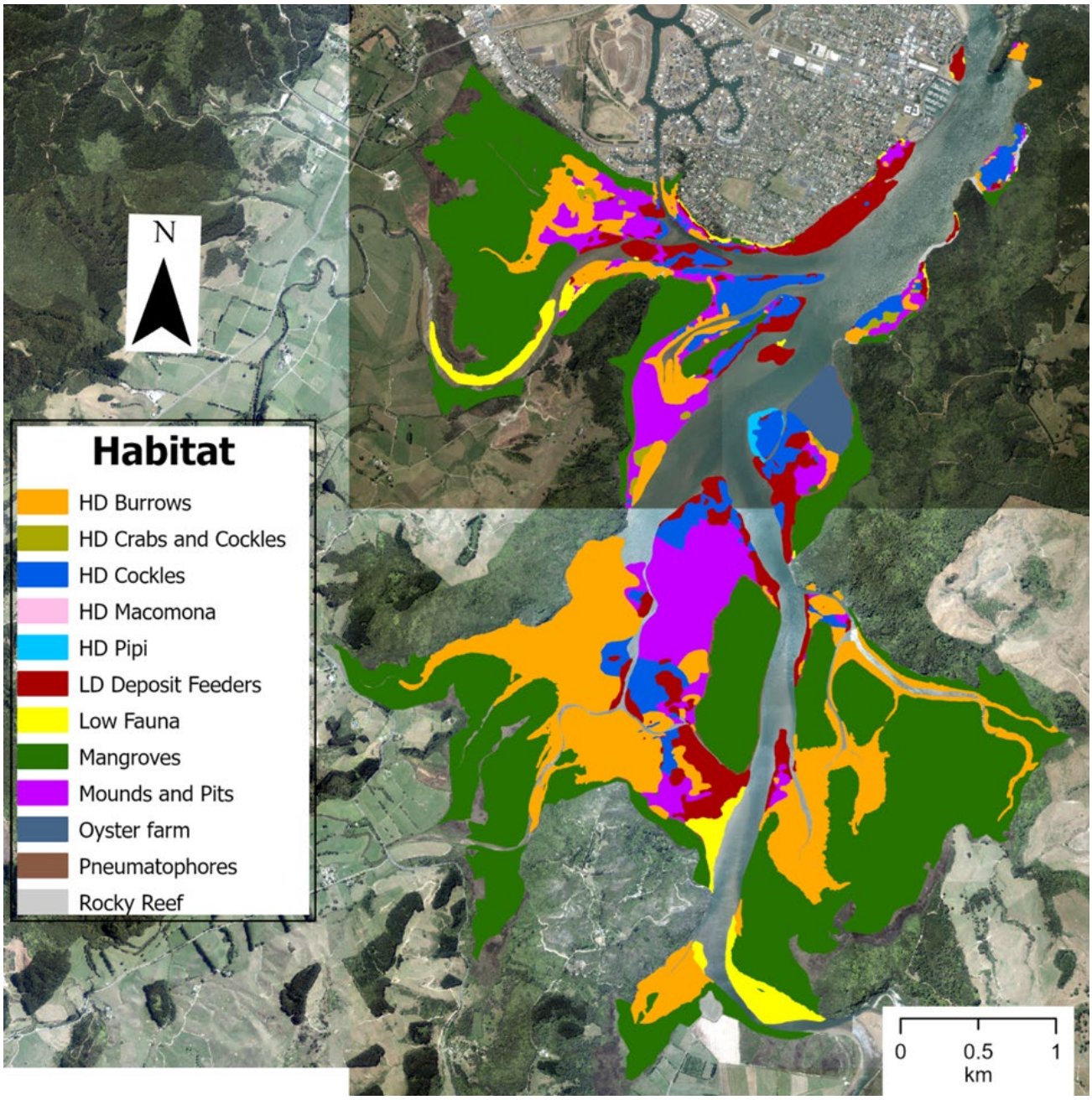

Figure 20: 2023 habitats mapped in Whitianga Harbour.

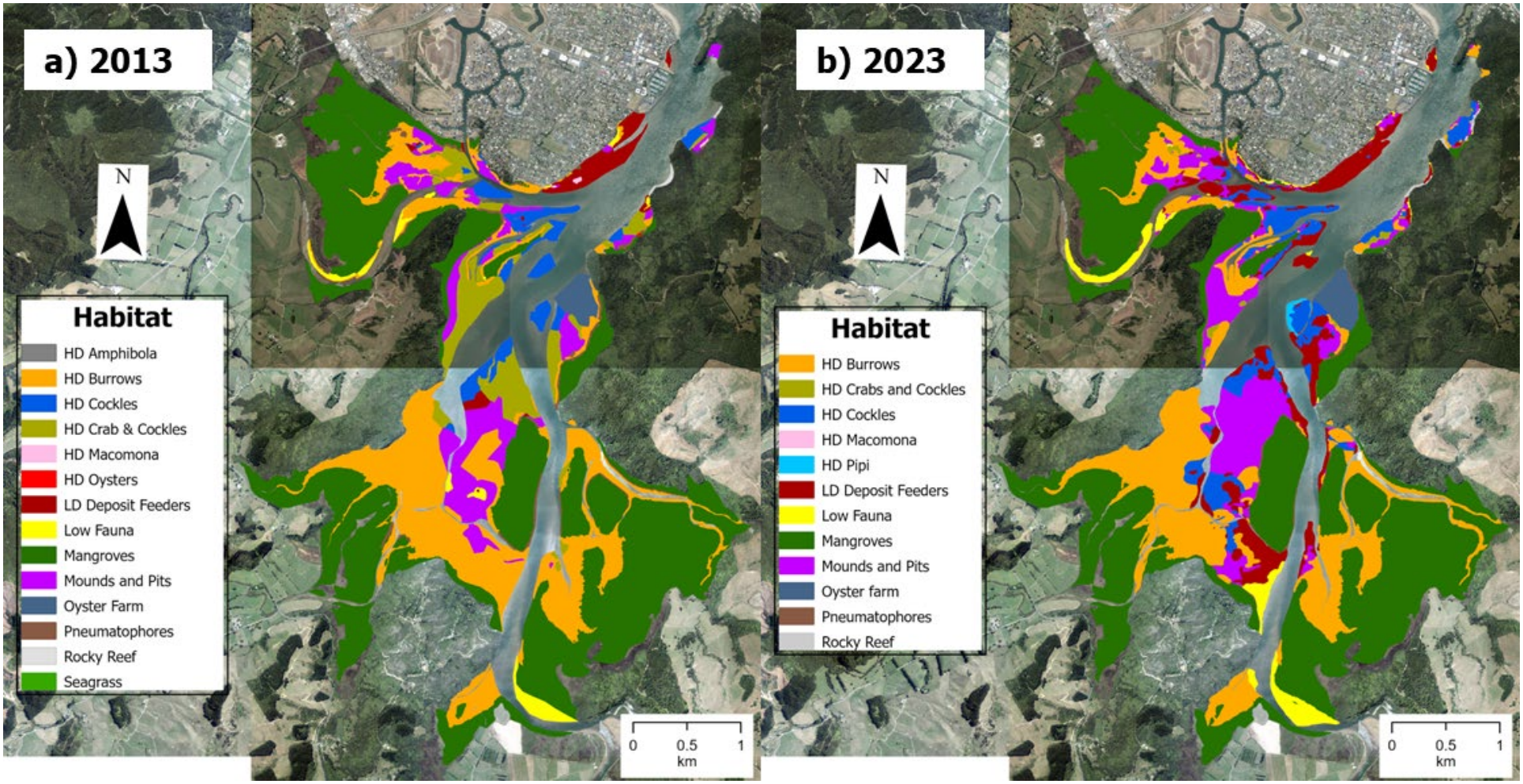

Figure 21: Comparison of the habitats mapped in a) 2013 and b) 2023 in Whitianga Harbour.

5.7 Whangapoua Harbour

5.7.1 Sediment characteristics

The sediment types across the estuary spanned between sandy and muddy. Close to the mouth there was fine-medium grained sand, which was light coloured and soft to walk on. On the large western flat, close to the harbour mouth and in some eastern sections, there were patches of hard packed firm sand. In areas close to mangroves, the sediment was often soft and muddy.

5.7.2 Habitats

Whangapoua Harbour was the largest estuary mapped (11,481,748 m^2), and it was characterised by 13 habitat classes. The largest area was dominated by Mangroves (40.0% of the total area surveyed), followed by Seagrass (20.1%), and LD Deposit Feeders (17.2%) habitat (Figure 22).

5.7.3 Change in habitats over time

Compared to the habitats mapped in 2013, HD Amphibola habitat was absent in 2023 (Table 15, Figure 23). The most evident changes were detected in the habitats HD Burrows and LD Deposit Feeders, which decreased 2.7% and 7.2% respectively over time (Table 16, Figure 23). Decrease of area covered by HD Burrows habitat aligned with increase in area covered by Mangroves (391,132 m^2) in the middle section of the estuary (Table 16, Figure 23). Similarly, the decrease in area covered by LD Deposit feeders corresponded to increased Seagrass habitat (1.3%) in the middle section of the estuary, and increased HD Cockles habitat (2.7%) in combination with Low Fauna (0.17%) in the upper section of the estuary (Table 16, Figure 23). There were evident changes in the distribution and area covered by the different habitats, yet the habitats mapped remained stable over time, with most of the changes located in the middle section of the estuary (Table 16, Figure 23).

Table 15: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Whangapoua.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Amphibola	16 839	0.15		
HD Burrows	536 958	4.67	252 030	2.20
HD Cockles	271 005	2.36	624 380	5.44
HD Crab and Cockles	21 276	0.19	42	<0.01
HD Macomona	15 409	0.13	4 238	0.04
HD Oysters	2 474	0.02	494	<0.01
HD Pipi	83 472	0.73	188 328	1.64
LD Deposit Feeders	2 685 583	23.36	1 982 159	17.26
Low Fauna	510 253	4.44	572 772	4.99
Mangroves	4 387 625	38.17	4 600 894	40.07
Mounds and Pits	715 103	6.22	781 132	6.80
Oyster Farm	18 180	0.16		
Pneumatophores	33 188	0.29	158 208	1.38
Rocky Reef	2 082	0.02	3 653	0.03
Seagrass	2 195 066	19.10	231 3418	20.15

Table 16: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Whangapoua Harbour. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Amphibola	16 830	0.16			-16 830	-0.16
HD Burrows	499 845	4.67	206 939	1.94	-292 906	-2.74
HD Cockles	262 876	2.46	551 077	5.15	288 201	2.70
HD Crab and Cockles	18 727	0.18	42	<0.01	-18 685	-0.17
HD Macomona	15 400	0.14	3 424	0.03	-11 977	-0.11
HD Oysters	2 473	0.02	426	0.00	-2 046	-0.02
HD Pipi	19 095	0.18	134 614	1.26	115 520	1.08
LD Deposit Feeders	2 535 914	23.71	1 758 981	16.45	-776 933	-7.27
Low Fauna	445 648	4.17	463 373	4.33	17 725	0.17
Mangroves	4 113 831	38.47	4 504 963	42.13	391 132	3.66
Mounds and Pits	667 199	6.24	711 274	6.65	44 075	0.41
Oyster Farm	2 596	0.02			-2 596	-0.02
Pneumatophores	28 524	0.27	149 359	1.40	120 836	1.13
Rocky Reef	1 926	0.02	238	<0.01	-1 687	-0.02
Seagrass	2063 002	19.29	2 210 929	20.67	147 927	1.38

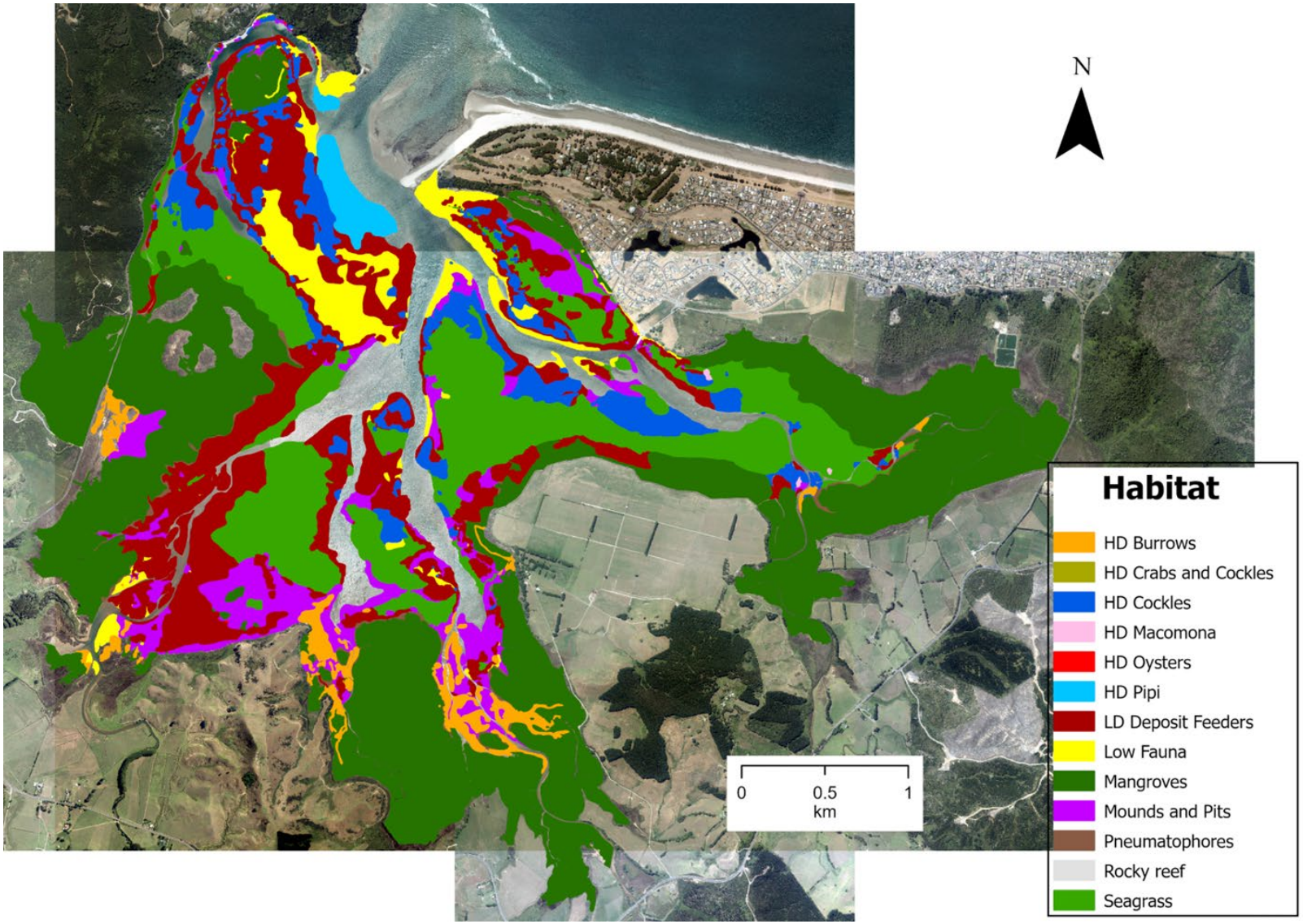

Figure 22: 2023 habitats mapped in Whangapoua harbour.

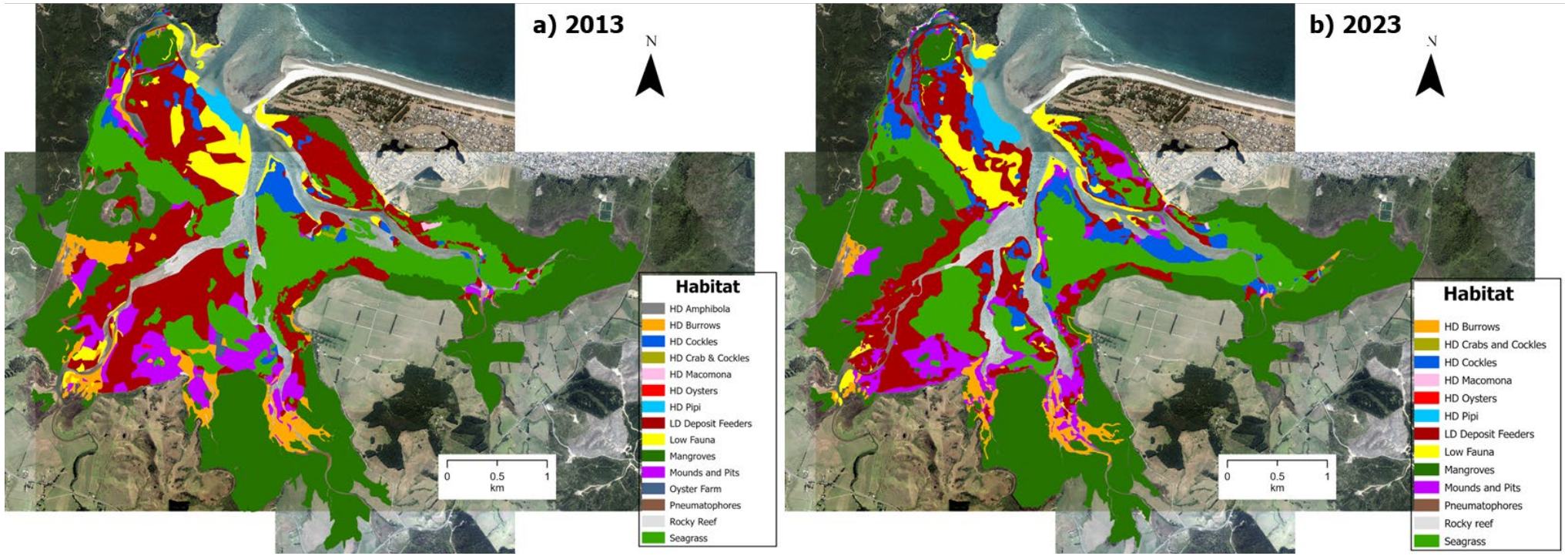

Figure 23: Comparison of the habitats mapped in a) 2013 and b) 2023 in Whangapoua harbour.

5.8 Kennedy Bay

5.8.1 Sediment characteristics

The sediment in Kennedy Bay was dominated by firm sandy sediment. A few muddy sediment areas were identified close to Mangrove habitats.

5.8.2 Habitats

Kennedy Bay was one of the smallest estuaries mapped (572,434 m^2) and it was characterised by 12 habitat classes. The largest area was dominated by LD Deposit Feeders (27.6% of the total area surveyed), followed by Mangroves (25.7%), and Low Fauna (19.5%) habitats (Figure 24).

5.8.3 Change in habitats over time

HD Crabs and Cockles habitat was absent in 2023 after a small amount of this habitat class was detected in 2013 (Table 17, Figure 25). In contrast, HD Pipi and Seagrass habitats were identified in the 2023 mapping after going undetected in 2013 (Table 17, Figure 25). The most evident habitat change was identified in the lower section of the estuary, close to the mouth, where the large areas of HD Cockles detected in 2013 decreased considerably from 28,674 m^2 to 2,191 m^2 in 2023 (Table 18, Figure 25). Yet, it was noted that there are still cockles in the outer bay area, but cockles were below the density classified as HD Cockles habitat. The area covered by Mangroves habitat expanded 8.3% in 2023, increasing mainly in the middle eastern section of the estuary, which replaced areas previously covered by HD Burrows habitat (Table 18, Figure 25). The decrease identified in the area covered by HD Burrows also corresponded to the increase of area covered by Mounds and Pits habitat in the upper section of the estuary (Table 18, Figure 25).

Table 17: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 Kennedy Bay.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Amphibola	483	0.06	90	0.02
HD Burrows	151 486	18.70	79 074	13.62
HD Cockles	68 263	8.43	2 305	0.40
HD Crab and Cockles	3 964	0.49		
HD Oysters	995	0.12	3 532	0.61
HD Pipi			12 079	2.08
LD Deposit Feeders	105 458	13.02	158 107	27.23
Low Fauna	354 198	43.73	111 867	19.27
Mangroves	83 891	10.36	147 161	25.35
Mounds and Pits	24 654	3.04	48 320	8.32
Pneumatophores	8 503	1.05	9 770	1.68
Rocky Reef	8 122	1.00	8 122	1.40
Seagrass			129	0.02

Table 18: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Kennedy Bay. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Amphibola	483	0.10	90	0.02	-393	-0.08
HD Burrows	136 770	28.31	76 089	15.61	-60 682	-12.70
HD Cockles	28 674	5.94	2 191	0.45	-26 483	-5.49
HD Crab and Cockles	3 935	0.81			-3 935	-0.81
HD Oysters	972	0.20	2 638	0.54	1 666	0.34
HD Pipi			2 638	0.54	2 638	0.54
LD Deposit Feeders	92 768	19.20	132 741	27.24	39 972	8.03
Low Fauna	111 393	23.06	96 356	19.77	-15 037	-3.29
Mangroves	74 107	15.34	115 240	23.65	41 133	8.31
Mounds and Pits	22 009	4.56	46 268	9.49	24 259	4.94
Pneumatophores	8 219	1.70	9 256	1.90	1 037	0.20
Rocky Reef	3 741	0.77	3 741	0.77	0	0
Seagrass			99	0.02	99	0.02

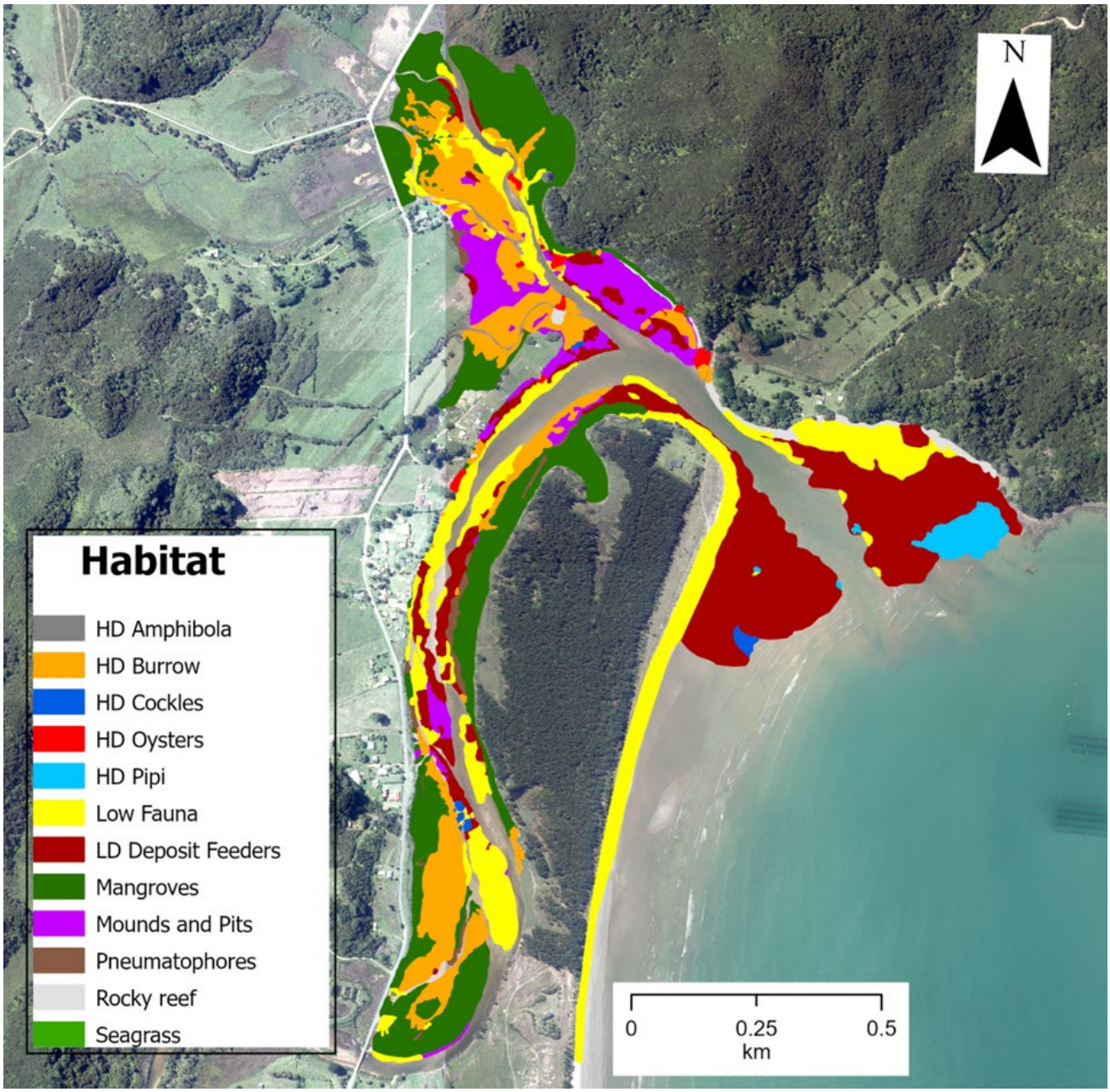

Figure 24: 2023 habitats mapped in Kennedy Bay.

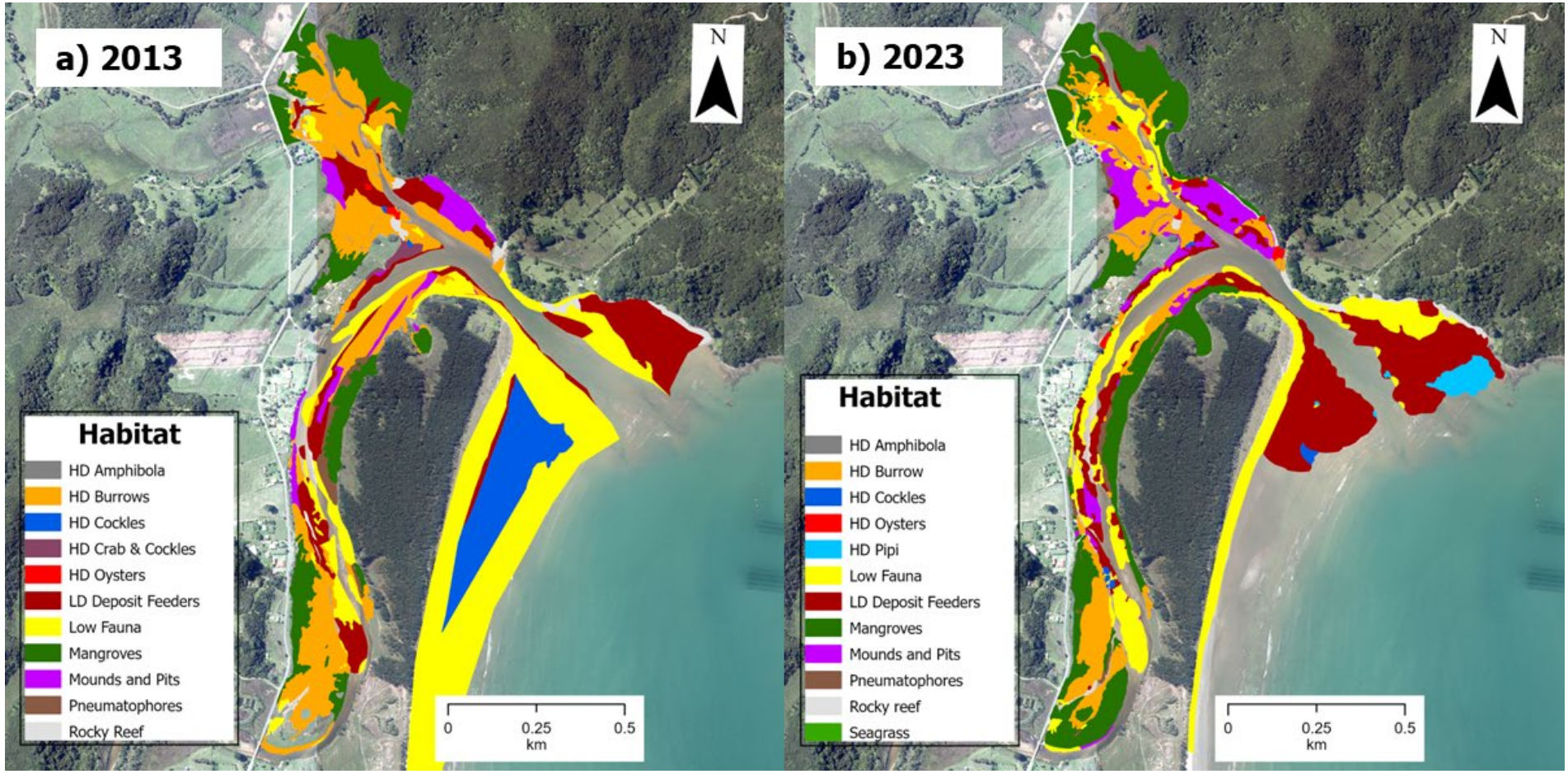

Figure 25: Comparison of the habitats mapped in a) 2013 and b) 2023 in Kennedy Bay.

5.9 Waikawau Bay

5.9.1 Sediment characteristics

The sediment in Waikawau Bay was dominated by large areas of firm to soft sandy sediments. At the mouth of the estuary the sediment transitions into fine-medium grain sediment merging into dynamic beach sands. Small areas with muddy sediment were identified in the vicinity of the mangroves, with a large basin like area of Mounds and Pits.

5.9.2 Habitats

Waikawau Bay was one of the smallest estuaries mapped (201,216 m^2) and eight habitat classes were observed. The largest area was dominated by Low Fauna (32.0% of the total area surveyed), followed by Mangroves (24.7%), and LD Deposit Feeders (15.8%) habitats (Figure 26).

5.9.3 Change in habitats over time

HD Amphibola and HD Crabs and Cockles habitats were absent in 2023 despite small areas of these habitat types documented in 2013 (Table 19, Figure 27). The most evident changes in habitat mapped across the estuary were identified in Mangroves and LD Deposit Feeders categories. The area covered by Mangroves habitat almost doubled with an increase from 17,526 m^2 in 2013 to 36,592 m^2 in 2023, replacing the area covered previously by HD Burrows, which was reflected in the large decrease (11.8%) of this last habitat in 2023 (Table 20, Figure 27). The area covered by LD Deposit Feeders habitat exponentially increased from 2,910 m^2 in 2013 to 27,190 m^2 in 2023. This change in habitat was most evident in the middle section of the estuary, which also corresponded to a decrease in the area covered by Low Fauna and Mounds and Pits (Table 20, Figure 27).

Table 19: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Waikawau Bay.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Amphibola	26	0.02		
HD Burrows	43 136	25.17	26 190	13.02
HD Cockles	7 211	4.21	7 489	3.72
HD Crab and Cockles	2 905	1.70		
LD Deposit Feeders	4 301	2.51	31 860	15.83
Low Fauna	58 180	33.95	64 501	32.06
Mangroves	18 473	10.78	49 721	24.71
Mounds and Pits	35 356	20.63	21 299	10.59
Pneumatophores	1 767	1.03	25	0.01
Rocky Reef			131	0.07

Table 20: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Waikawau Bay. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Amphibola	26	0.02			-26	-0.02
HD Burrows	41 121	25.62	22 160	13.81	-18 960	-11.81
HD Cockles	7 207	4.49	7 489	4.67	282	0.18
HD Crab and Cockles	2 904	1.81			-2 904	-1.81
LD Deposit Feeders	2 910	1.81	27 190	16.94	24 280	15.13
Low Fauna	52 425	32.67	45 993	28.66	-6432	-4.01
Mangroves	17 526	10.92	36 592	22.80	19 066	11.88
Mounds and Pits	34 951	21.78	21 006	13.09	-13 946	-8.69
Pneumatophores	1 413	0.88	25	0.02	-1 389	-0.87
Rocky Reef			24	0.01	24	0.01

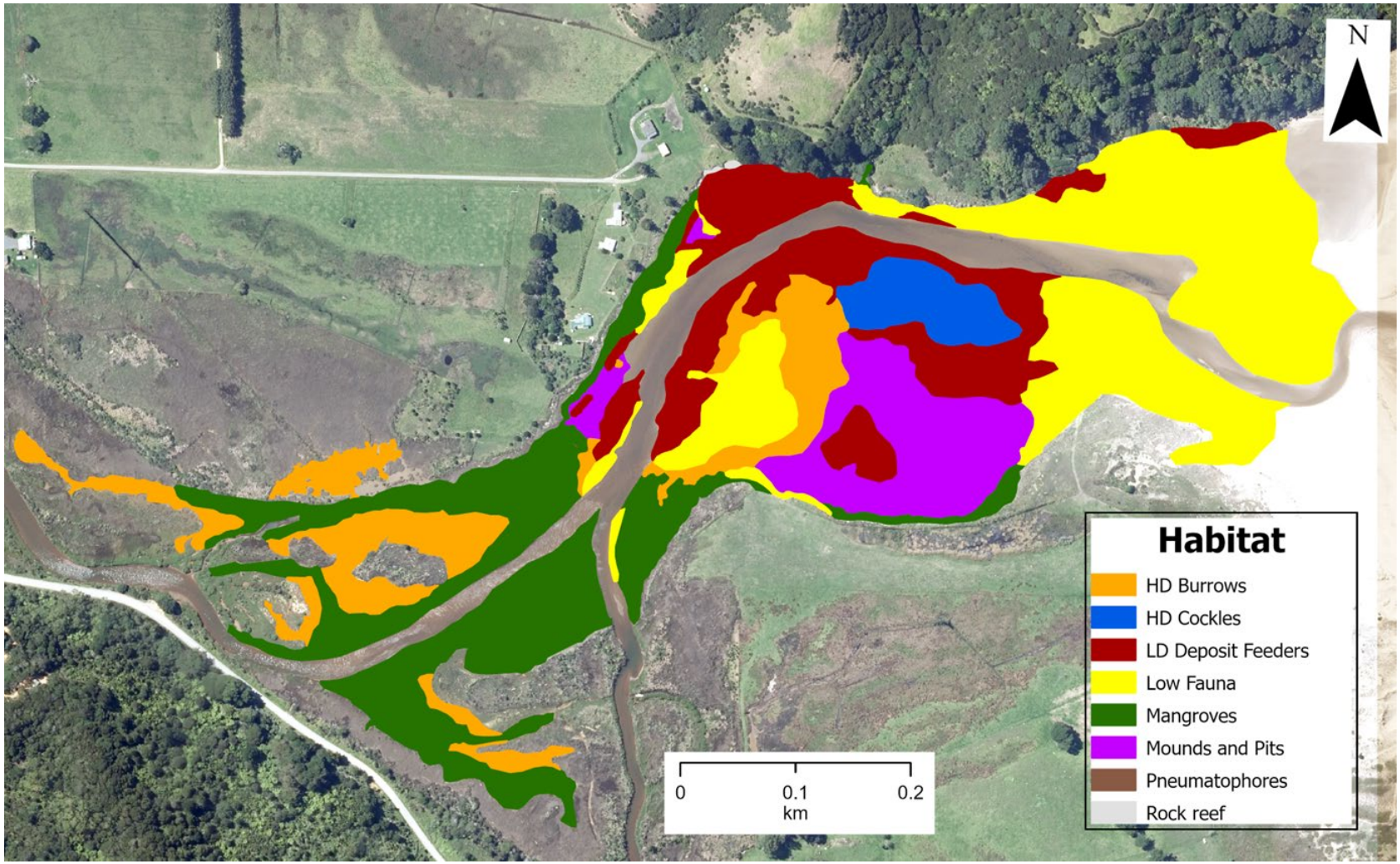

Figure 26: 2023 habitats mapped in Waikawau Bay.

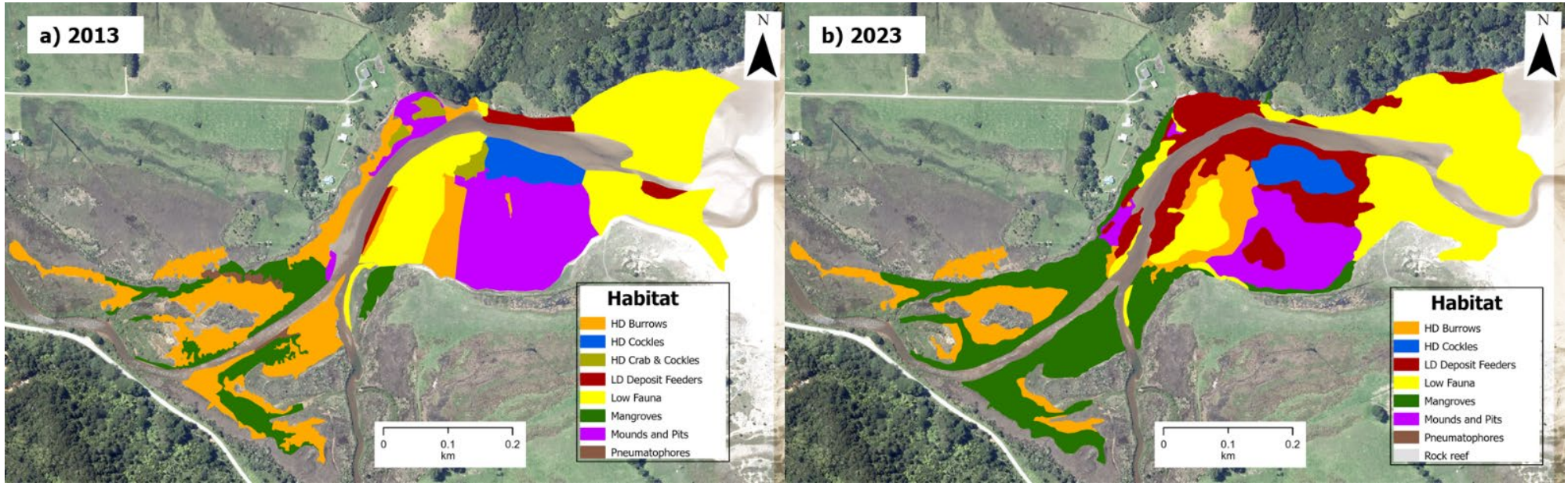

Figure 27: Comparison of the habitats mapped in a) 2013 and b) 2023 in Waikawau Bay.

5.10 Port Charles

5.10.1 Sediment characteristics

Most of the sediment in Port Charles was firm sandy sediment. Large areas near to the Tangiaro Stream were covered in dense gravel and appeared to lack infauna. Needham et al. (2013b) noted that there was evidence of sediment inputs via terrestrial source occurring around the outflow of the Parakete Stream. This was also evident in 2023, with muddy sediments and high abundance of crabs found along the channel inflow and close to the mangroves.

5.10.2 Habitats

Port Charles was one of the smallest estuaries mapped (489,341 m^2), with eight habitat classes. The largest areas were dominated by Low Fauna (47.6% of the total area surveyed) and LD Deposit Feeders (39.5%) habitats (Figure 28). The other habitats accounted for less than 5% each of the total area surveyed.

5.10.3 Change in habitats over time

The Mounds and Pits habitat was absent in 2023 despite a small area of this habitat being detected in 2013 (Table 21, Figure 29). The most noticeable changes were identified in northern and centre areas of the estuary. The area covered by Mangroves habitat expanded (~3,000 m^2), replacing areas previously covered by HD Burrows, LD Deposit Feeders, and Pneumatophores habitats (Table 22, Figure 29). The Low Fauna habitat also increased towards the middle section of the estuary, which contributed to decrease of LD Deposit Feeder habitat (Table 22, Figure 29). HD Burrows habitat was limited to a small fringe close to Mangroves habitats, while the area covered by HD Cockles increased from 1,591 m^2 in 2013 to 11,156 m^2 in 2023, mainly in the middle section of the estuary (Table 22, Figure 29).

Table 21: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Port Charles.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Burrows	8 719	2.55	1 716	0.35
HD Cockles	1 592	0.47	11 157	2.28
HD Oysters	8 597	2.51	8 817	1.80
LD Deposit Feeders	159 365	46.56	193 654	39.57
Low Fauna	133 002	38.86	233 201	47.66
Mangroves	27 642	8.08	31 906	6.52
Mounds and Pits	1 394	0.41	1 424	
Pneumatophores	1 992	0.58	7 466	0.29
Rocky Reef				1.53

Table 22: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Port Charles. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Burrows	8 227	2.50	1 600	0.49	-6 627	-2.02
HD Cockles	1 591	0.48	11 156	3.39	9 565	2.91
HD Oysters	7 859	2.39	4 781	1.45	-3 078	-0.94
LD Deposit Feeders	157 130	47.80	109 414	33.29	-47 715	-14.52
Low Fauna	127 823	38.89	171 129	52.06	43 307	13.17
Mangroves	22 680	6.90	25 022	7.61	2 342	0.71
Mounds and Pits	1 393	0.42			-1 393	-0.42
Pneumatophores	1 991	0.61	1 108	0.34	-883	-0.27
Rocky Reef			4 485	1.36	4 485	1.36

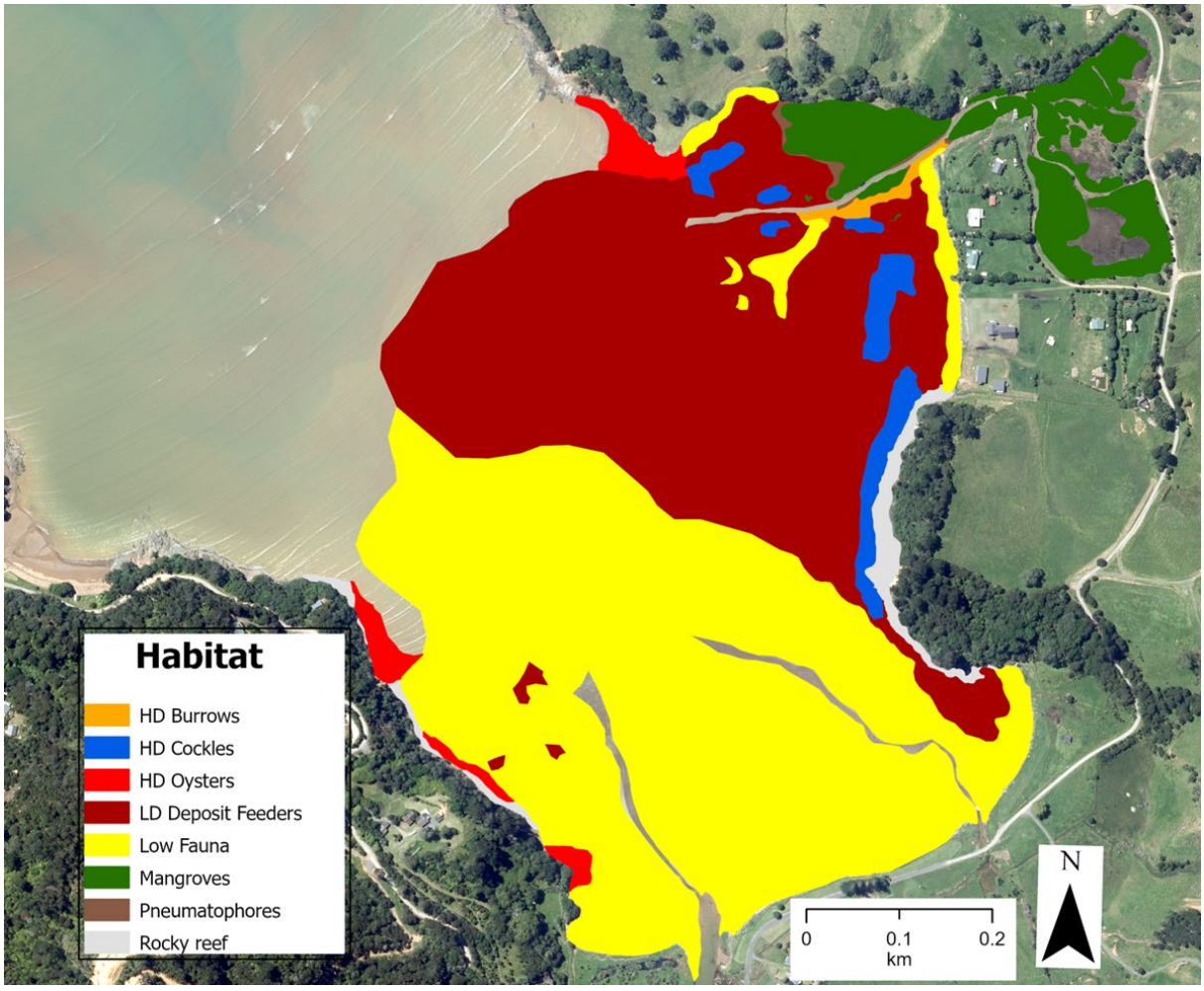

Figure 28: 2023 habitats mapped in Port Charles.

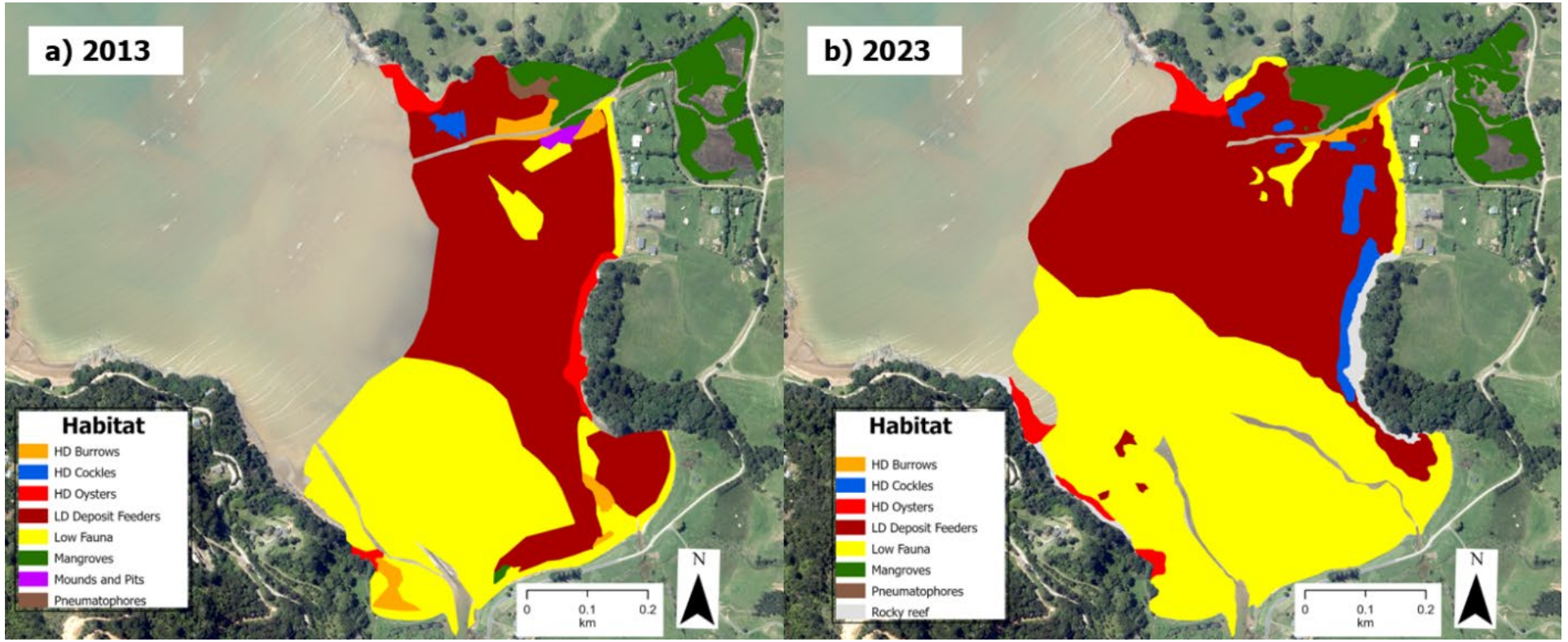

Figure 29: Comparison of the habitats mapped in a) 2013 and b) 2023 in Port Charles.

5.11 Colville Bay

5.11.1 Sediment characteristics

Sediment characteristics in Colville Bay were dominated by large uniform areas of firm sandy sediments. In eastern intertidal areas close to the Umangawha Stream and an area of Mounds and Pits habitat, the presence of a fine silty sediment layer on top of the firm sand was noted.

5.11.2 Habitats

Colville Bay is a relatively large estuary (1,909,309 m^2), and it was characterised by 11 habitat classes. The largest areas were dominated by Low Fauna (50.3% of the total area surveyed) and LD Deposit Feeders (21.5%) habitats (Figure 30). The other habitats accounted for less than 5% each of the total area surveyed. Areas indicted as tapu in 2013 due to locations of urupā in the surrounding marshland and hillsides were avoided, respected and left out of the mapping again in 2023.

5.11.3 Change in habitats over time

The HD Amphibola habitat was absent in 2023 despite a small amount noted as present in 2013 (Table 23, Figure 31). In contrast, a small area of Seagrass (difficult to see on the map in Figure 30) was observed on the northern flat and close to the Mounds and Pits habitat along the channel edge in 2023 (Table 23, Figure 31). Noticeable habitat changes were identified in the middle section of the estuary and outer bay. The area covered by LD Deposit Feeders habitat largely increased (12.5%), replacing large areas covered by Low Fauna habitat, which decreased by 12.9% (Table 24, Figure 31). HD Pipi habitat was detected in both surveys. Although the area of HB Pipi habitat was greater in 2023 than in 2013, more area in the lowest part of the intertidal zone (where pipi were observed to be abundant) was able to be sampled in 2023 due to our presence in that part of the estuary during peak spring low tides. When the analysis was restricted to the area surveyed in 2013 (our means of undertaking a standardised comparison of change), the area of HD Pipi habitat in Colville Bay was shown to decrease by about 10,000 m^2 (Table 24, Figure 31). Slight increases of Mangroves and Mound and Pits habitats were detected in the norther section of the estuary, which corresponded to a decrease in area covered by HD Burrows (Table 24, Figure 31), a common transition recorded from HD burrows to Mangroves habitat across the studied estuaries.

Table 23: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Colville Bay.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Amphibola	3 859	0.29		
HD Burrows	14 271	1.06	11 777	0.75
HD Cockles	2 342	0.17	4 031	0.26
HD Macomona	1 448	0.11	3 702	0.24
HD Oysters	4 440	0.33	10 116	0.64
HD Pipi	19 695	1.46	42 304	2.70
LD Deposit Feeders	220 639	16.32	410 604	26.16
Low Fauna	988 173	73.08	960 711	61.21
Mangroves	68 985	5.10	74 618	4.75
Mounds and Pits	28 352	2.10	31 128	1.98

Habitat	2013 area (m²)	2013 (%)	2023 area (m²)	2023 (%)
Rocky Reef			20 417	1.30
Seagrass			24	<0.01

Table 24: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Colville Bay. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m²)	2013 (%)	2023 area (m²)	2023 (%)	Change (m²)	Change (%)
HD Amphibola	3 757	0.29			-3 757	-0.29
HD Burrows	13 497	1.03	11 727	0.91	-1 770	-0.12
HD Cockles	2 340	0.18	3 916	0.30	1 576	0.13
HD Macomona	1 369	0.10	3 678	0.29	2 309	0.18
HD Oysters	4 385	0.33	2 776	0.22	-1 609	-0.12
HD Pipi	19 690	1.50	9 533	0.74	-10 157	-0.76
LD Deposit Feeders	211 651	16.12	368 119	28.64	156 467	12.53
Low Fauna	963 618	73.37	776 412	60.41	-187 206	-12.96
Mangroves	64 714	4.93	72 435	5.64	7 721	0.71
Mounds and Pits	28 326	2.16	29 174	2.27	848	0.11
Rocky Reef			7 351	0.57	7 351	0.57
Seagrass			24	<0.01	24	<0.01

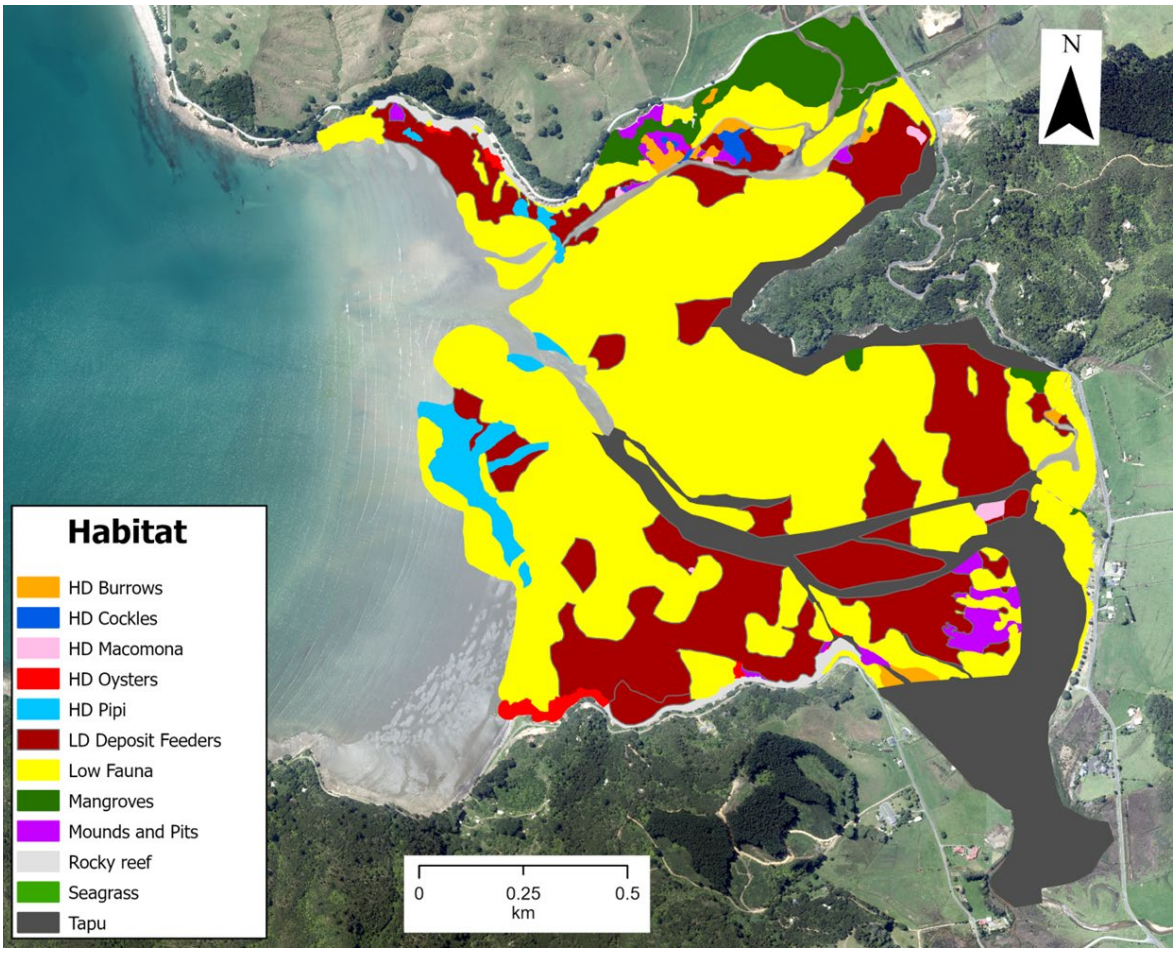

Figure 30: 2023 habitats mapped in Colville Bay.

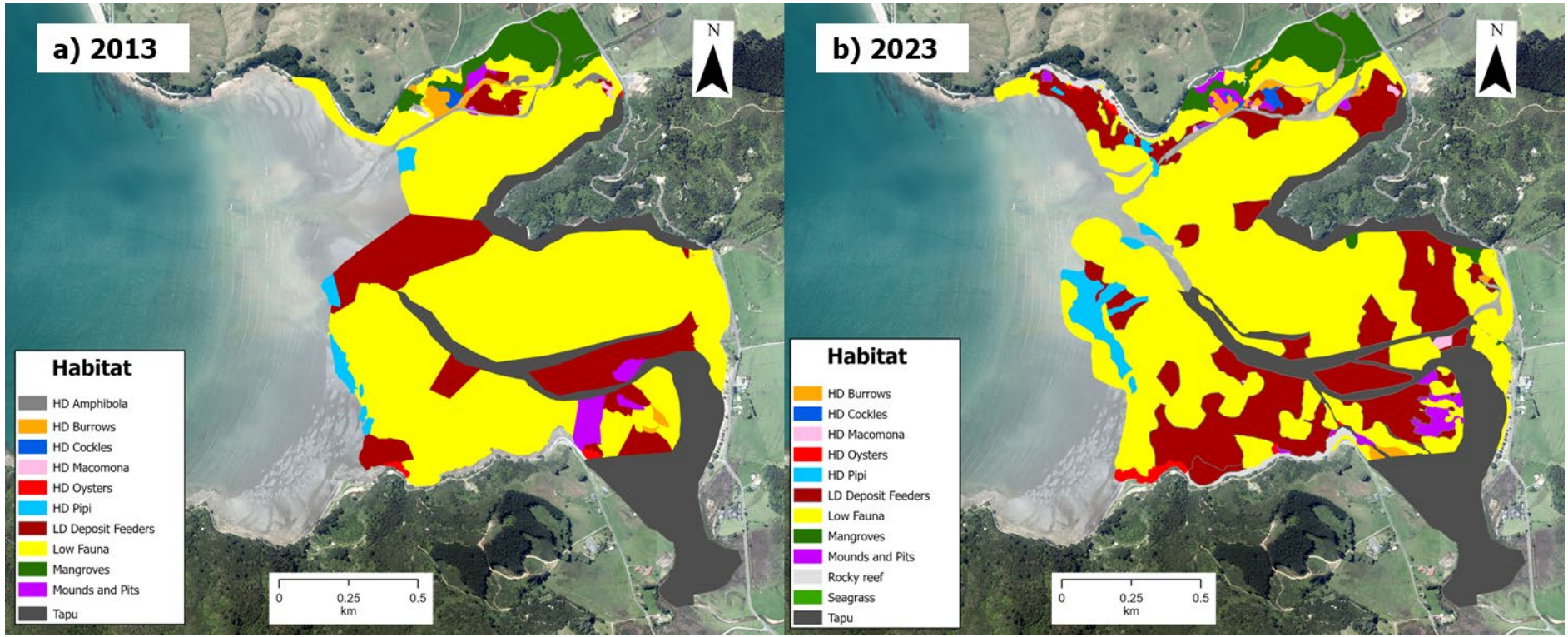

Figure 31: Comparison of the habitats mapped in a) 2013 and b) 2023 in Colville Bay.

5.12 Shelly Beach (Kikowhakarere Bay)

5.12.1 General description

Shelly Beach was a new addition to the mapping fieldwork in 2023 (i.e., this estuary was not mapped in 2013). It was accessed by foot from the end of Calloway Lane. The intertidal area of Shelly Beach was approximately 196,967 m^2, making it the smallest estuary mapped. A large rock platform extends out into the bay along both sides of the estuary. Shelly Beach was sampled on a day with a 0.92 m predicted low tide, and five people were able to cover the estuary in less than one day. On the day, several residents expressed concern about the amount of sediment deposited in the estuary after Cyclone Gabrielle. The amount of terrigenous material present on the day of mapping was considerably reduced compared to that described by the residents but it was still evident approximately 20 days after the passage of the cyclone.

5.12.2 Sediment characteristics

Sediments in Shelly Beach were dominated by large sections of firm sandy sediments and seagrass. The seagrass areas had large sized cockles living within the seagrass matrix. As mentioned above, sediment deposition areas were identified at the time of mapping and appeared to have come from streams on both sides of the Top 10 Holiday Park. The sediment deposits we observed were likely a consequence and remnant of Cyclone Gabrielle.

5.12.3 Habitats

Shelly Beach was characterised by 11 habitat classes (Table 25). The largest areas were dominated by LD Deposit Feeders (36.3% of the total area surveyed) and Seagrass (35.1%) habitats (Figure 32). The other habitats accounted for less than 10% each of the total area surveyed, highlighting the presence of large sized cockles in unvegetated sediment within the Seagrass and on the seaward side of the meadow and two patches of HD Pipi on the low intertidal in the middle and to the east of the Bay.

5.12.4 Change in habitats over time

Shelly Beach was not mapped in 2013 and we understand this to be the first intertidal habitat assessment for this estuary.

Table 25: Summary table showing the area and percentage of area covered by each habitat in 2023 for Shelly Beach.

Habitat	Area (m^2)	%
HD Burrows	732	0.37
HD Cockles	5 273	2.68
HD Cockles and Pipi	41	0.02
HD Oysters	1 787	0.91
HD Pipi	107	0.05
LD Deposit Feeders	71 652	36.38
Low Fauna	18 265	9.27
Mounds and Pits	9 754	4.95
Rocky Reef	15 762	8.00
Seagrass	69 300	35.18
Sediment Deposition	4 294	2.18

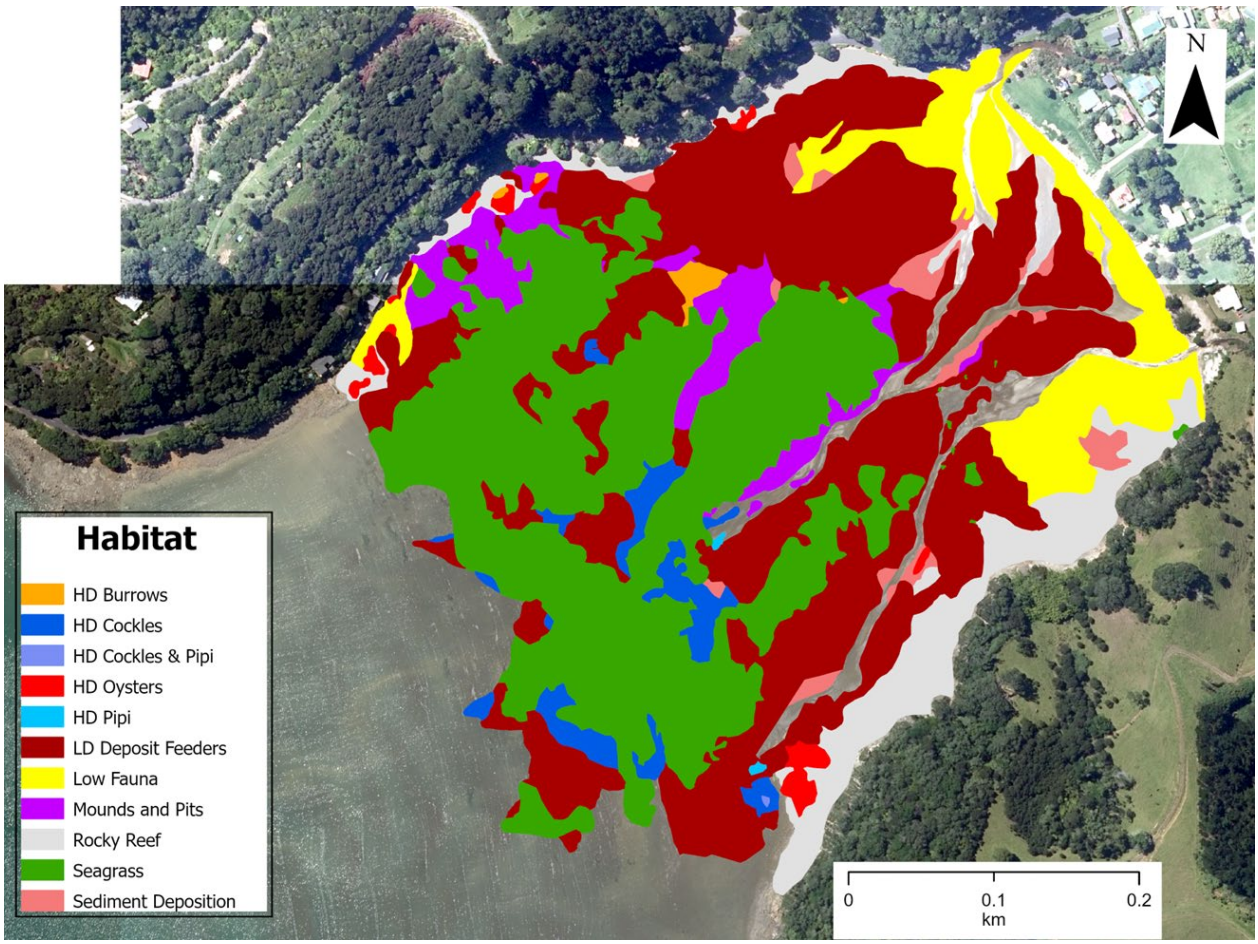

Figure 32: 2023 habitats mapped in Shelly Beach.

5.13 Coromandel Harbour

5.13.1 Sediment characteristics

The northern half of Coromandel Harbour was dominated by large areas of very muddy sediment, especially around the commercial shellfish racks. In the southern half of the Harbour, while there was muddy sediment in discrete patches (mainly around mangroves), most areas were either firm sandy sediment with low density deposit feeding communities, or firm medium to coarse grained sand (often with gravel) with very low invertebrate abundance.

5.13.2 Habitats

Coromandel Harbour has extensive intertidal flats with an area of approximately 5,874,833 m^2 and was the third largest estuary mapped. It was characterised by 14 habitat classes. The largest area was dominated by Seagrass (30.0% of the total area surveyed), followed by Mangroves (19.7%), and LD Deposit Feeders (16.1%) habitat (Figure 33).

5.13.3 Change in habitats over time

All the habitats assessed in 2013 were present in 2023 (Table 26, Figure 34). A common feature of the intertidal area in Coromandel Harbour over both years was the dense and expansive seagrass meadows in both the northern and southern halves of the harbour (Figure 34). The most evident change was the decrease in areas covered by HD Burrows (6.9%) and Low Fauna (4.2%) habitats. The area covered by HD Burrows decreased mainly in the northern half of the harbour, which coincided with increased area covered by HD Cockles and LD Deposit Feeders habitat (Table 27, Figure 34). Decrease in area covered by Low Fauna was identified in the southern half of the harbour, these areas transitioned to areas cover by LD Deposit Feeders and Seagrass habitats (Table 27, Figure 34). Another habitat change detected was a slight increase in Mangroves habitat from 978,886 m^2 in 2013 and 1,085,501 m^2 in 2023, accompanied by a decrease in the area covered by HD Burrows (Table 27, Figure 34). The expansion of Seagrass habitat was also evident in both halves of the harbour, extending from 1,422,401 m^2 in 2013 to 1,708,147 m^2 in 2023 (Table 27, Figure 34).

Table 26: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Coromandel.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Amphibola	879	0.02	1 053	0.02
HD Burrows	767 033	13.27	345 422	5.88
HD Cockles	123 265	2.13	265 161	4.51
HD Crab and Cockles	192 067	3.32	43 684	0.74
HD Oysters	32 038	0.55	3 257	0.06
HD Pipi	14 224	0.25	8 156	0.14
LD Deposit Feeders	543 620	9.40	946 923	16.12
Low Fauna	404 199	6.99	177 008	3.01
Mangroves	1 167 568	20.20	1 162 171	19.78
Mounds and Pits	61 7602	10.68	626699	10.67
Oyster farm	450 050	7.79	439267	7.48
Pneumatophores	14 326	0.25	37883	0.64

Habitat	2013 area (m²)	2013 (%)	2023 area (m²)	2023 (%)
Rocky Reef	27 622	0.48	51781	0.88
Seagrass	1 425 904	24.67	1 766 368	30.07

Table 27: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Coromandel Harbour. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m²)	2013 (%)	2023 area (m²)	2023 (%)	Change (m²)	Change (%)
HD Amphibola	879	0.02	951	0.02	72	<0.01
HD Burrows	700 994	12.94	325 324	6.01	-375 670	-6.94
HD Cockles	117 996	2.18	252 926	4.67	134 931	2.49
HD Crab and Cockles	169 391	3.13	41 690	0.77	-127 701	-2.36
HD Oysters	20 849	0.38	3 086	0.06	-17 763	-0.33
HD Pipi	13 577	0.25	2 396	0.04	-11 180	-0.21
LD Deposit Feeders	535 603	9.89	724 506	13.38	188 903	3.49
Low Fauna	391 839	7.23	160 103	2.96	-231 736	-4.28
Mangroves	978 886	18.07	1 085 501	20.05	106 614	1.97
Mounds and Pits	611 682	11.29	615 359	11.36	3 677	0.07
Oyster farm	427 688	7.90	425 450	7.86	-2 238	-0.04
Pneumatophores	13 722	0.25	35 561	0.66	21 839	0.40
Rocky Reef	10 564	0.20	33 993	0.63	23 429	0.43
Seagrass	1 422 401	26.26	1 708 147	31.54	285 745	5.28

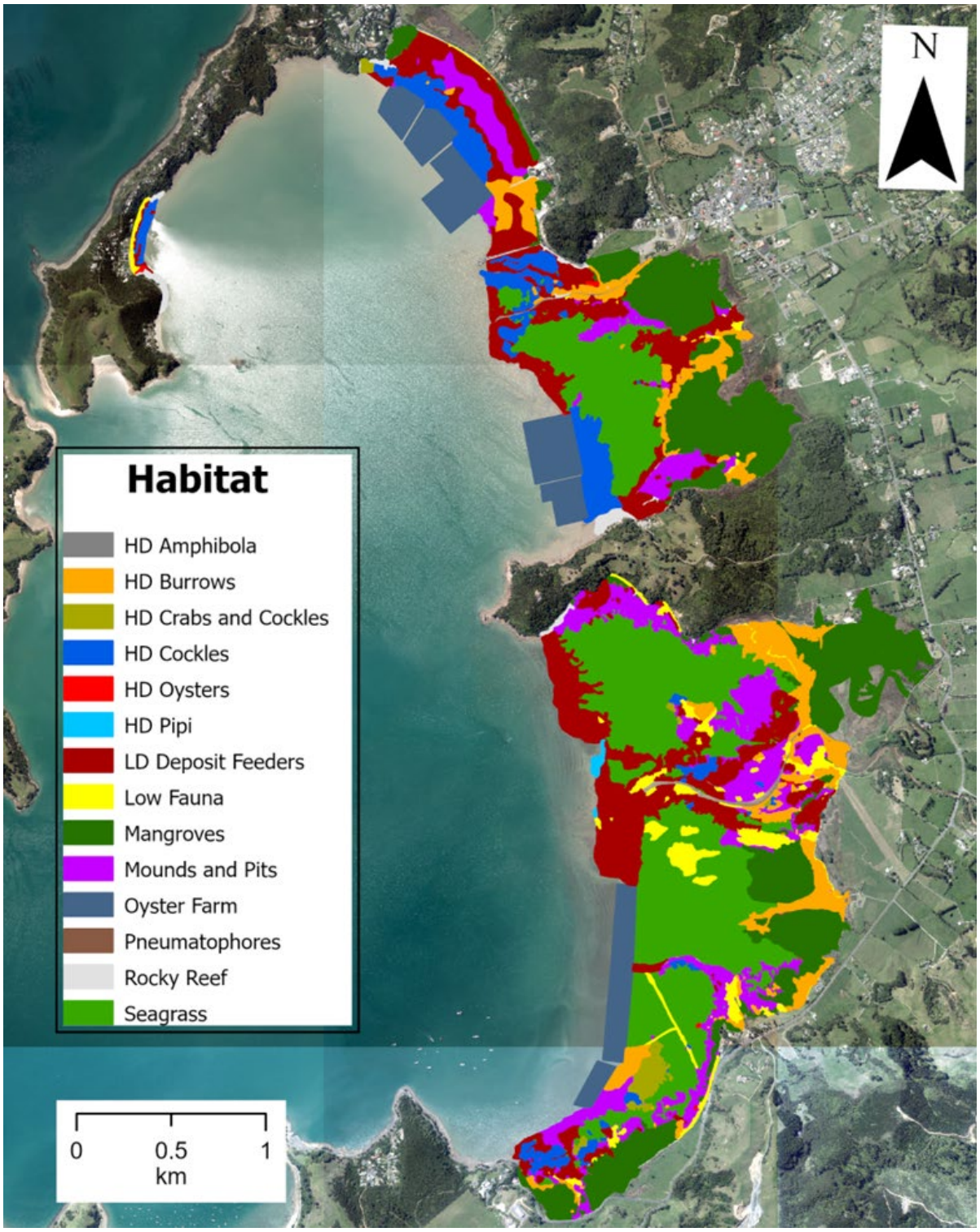

Figure 33: 2023 habitats mapped in Coromandel harbour.

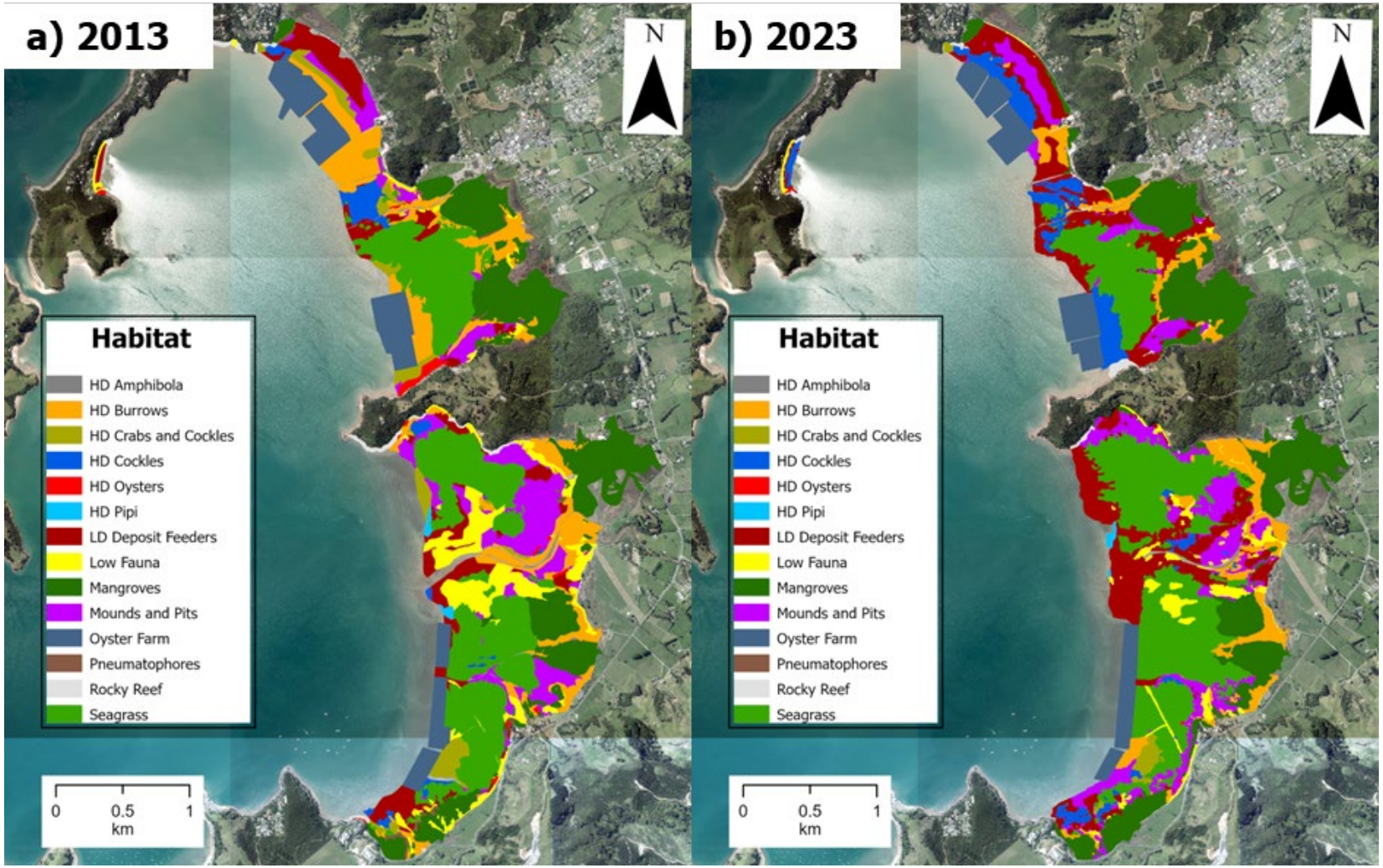

Figure 34: Comparison of the habitats mapped in a) 2013 and b) 2023 in Coromandel harbour.

5.14 Te Kouma Harbour

5.14.1 Sediment characteristics

The sediment in Te Kouma Harbour was dominated by large areas of muddy sediment, especially in the upper part of the estuary and associated with mangroves and oyster racks. Yet, the small embayments closer to the entrance of the harbour were characterised by sandy sediments and rocky reef.

5.14.2 Habitats

Te Kouma Harbour was relatively large with an intertidal area of 875,750 m^2 and characterised by 12 habitat classes. The largest area was dominated by Mounds and Pits (26.6% of the total area surveyed), followed by Mangroves (23.7%), and HD Burrows (20.6%) habitats (Figure 35).

5.14.3 Change in habitats over time

The 'HD Crabs and Tube Worm' habitat was absent in 2023, relative to 2013 when 8202 m^2 of this habitat type was recorded on the low intertidal in northern and southern arms of the Harbour (Table 28, Figure 36). The most evident habitat changed identified was the decrease of Seagrass habitat. Seagrass habitat decreased from covering 47,028 m^2 in 2013 to only 6 m^2 mapped in 2023 located close to Pneumatophore and Mangroves habitats in the lower section of the harbour (Table 29, Figure 36). In the eastern section of the harbour, the area covered by Mangroves habitat extended, corresponding with decreased area cover by Mounds and Pits (Table 29, Figure 36). Another noticeable change was evident in the middle section of the harbour, where the area covered by HD Burrows habitat almost doubled from 88,452 m^2 in 2013 to 166,296 m^2 in 2023 (Table 29, Figure 36). The increase of the habitat HD Burrows resulted in decreased area cover by the habitats Mounds and Pits, HD Crab and Cockles, and LD Deposit Feeders comparing 2013 to 2023 mapping (Table 29, Figure 36). It was also noticed that there was an addition of a new rack between the two blocks of Oyster farm mapped in 2013, however the new continuous block of racks was slightly smaller in area than in 2013.

Table 28: Summary table showing the total area and percentage of area covered by each habitat in 2013 and 2023 for Te Kouma Harbour.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Burrows	93 146	12.70	179 189	20.46
HD Cockles	6 668	0.91	15 837	1.81
HD Crab and Cockles	59 576	8.12	53 115	6.07
HD Crab and Tubeworms	11 350	1.55		
HD Oysters	19 593	2.67	19 448	2.22
LD Deposit Feeders	43 619	5.95	19 074	2.18
Low Fauna	24 165	3.29	20 721	2.37
Mangroves	176 931	24.12	207 784	23.73
Mounds and Pits	137 558	18.75	233 034	26.61
Oyster farm	68 265	9.31	67 287	7.68
Pneumatophores	8 840	1.21	13 935	1.59

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
Rocky Reef	36 771	5.01	46 320	5.29
Seagrass	47 047	6.41	6	<0.01

Table 29: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Te Kouma Harbour. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)	Change (m^2)	Change (%)
HD Burrows	88 452	12.95	166 296	24.00	77 844	11.05
HD Cockles	6 622	0.97	15 802	2.28	9 180	1.31
HD Crab and Cockles	59 448	8.70	52 980	7.65	-6 469	-1.06
HD Crab and Tubeworms	8 202	1.20			-8 202	-1.20
HD Oysters	17 241	2.52	16 958	2.45	-282	-0.08
LD Deposit Feeders	40 923	5.99	18 487	2.67	-22 436	-3.32
Low Fauna	18 394	2.69	18 742	2.70	349	0.01
Mangroves	163 688	23.96	182 718	26.37	19 030	2.41
Mounds and Pits	131 090	19.19	114 772	16.56	-16 318	-2.63
Oyster farm	61 326	8.98	64 397	9.29	3 072	0.32
Pneumatophores	8 833	1.29	13 804	1.99	4 971	0.70
Rocky Reef	31 916	4.67	27 964	4.04	-39 52	-0.64
Seagrass	47 028	6.88	6	<0.01	-47 022	-6.88

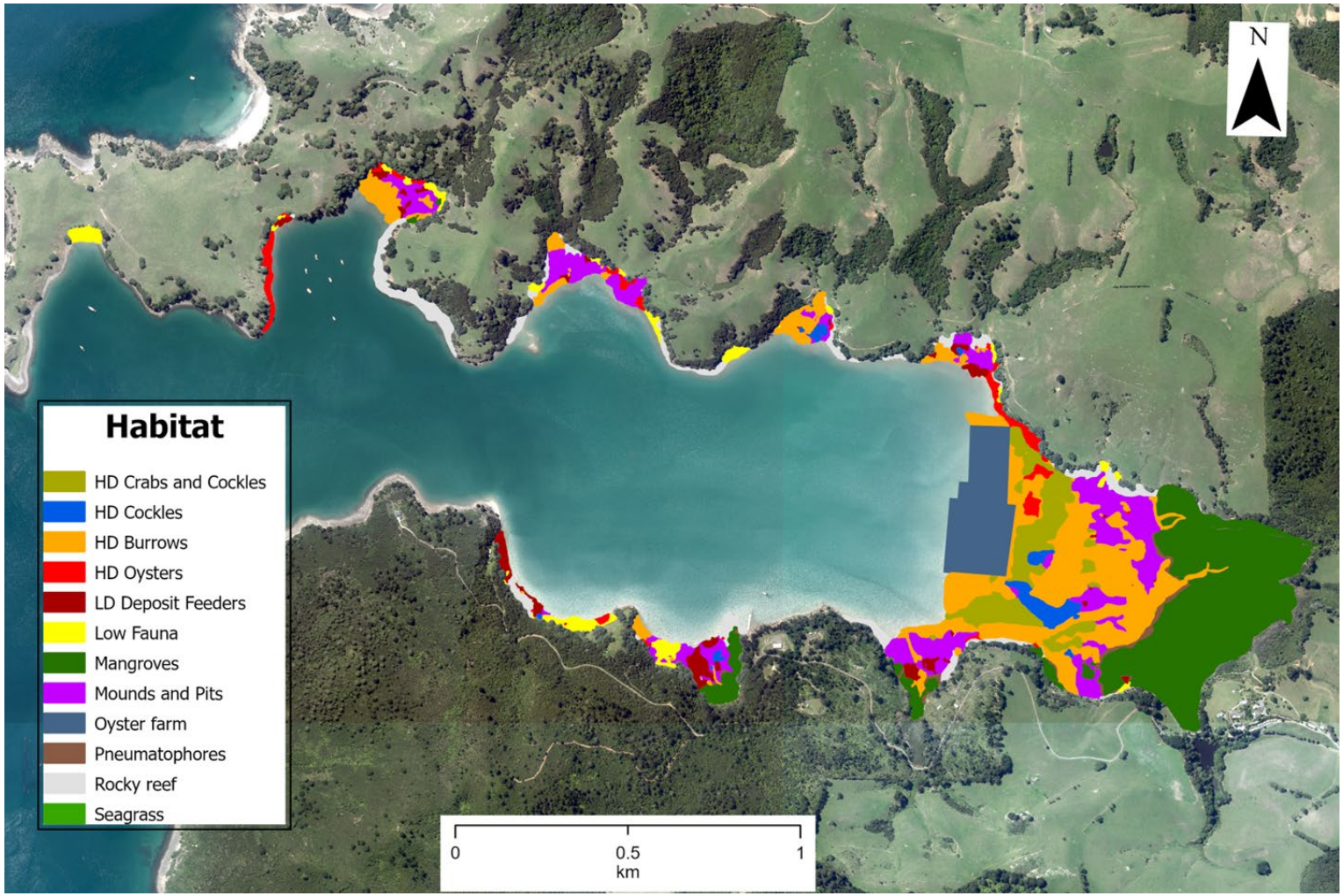

Figure 35: 2023 habitats mapped in Te Kouma harbour.

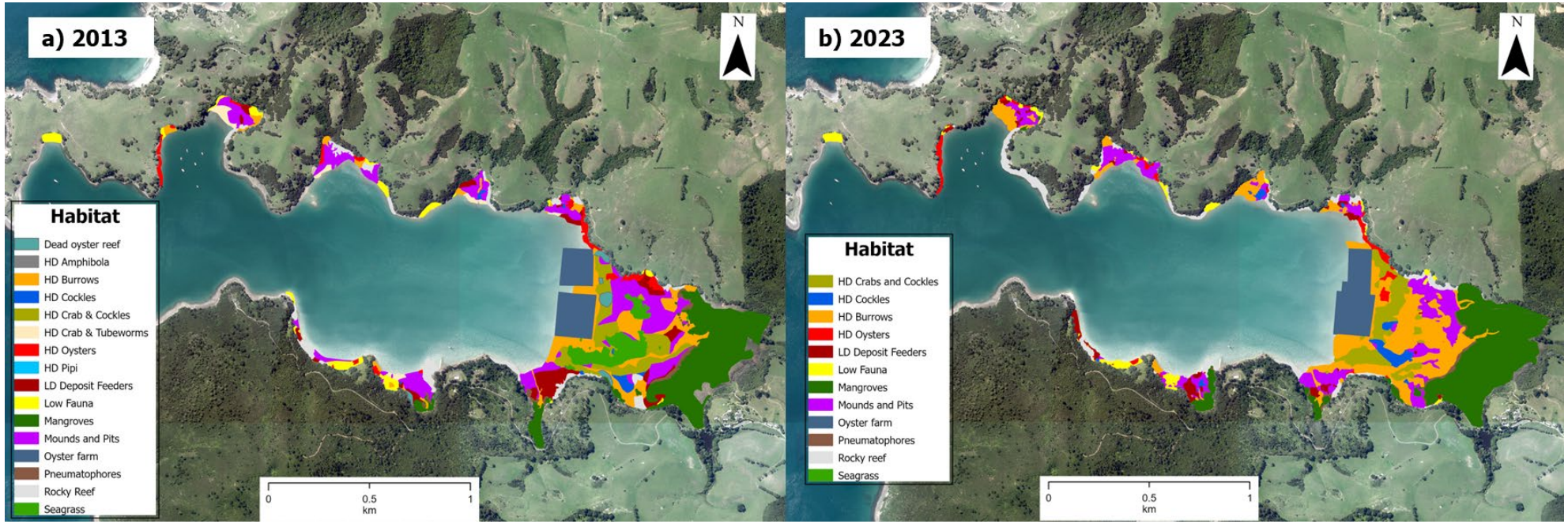

Figure 36: Comparison of the habitats mapped in a) 2013 and b) 2023 in Te Kouma harbour.

5.15 Manaia Harbour

5.15.1 Sediment characteristics

The sediment characteristics of Manaia Harbour were highly variable across the extent of the estuary. Many large areas contained firm sandy sediment, while the sediment within and around the seagrass meadows was very soft and muddy. Unvegetated sediment patches within the seagrass meadows were generally firmer underfoot and dominated by HD Cockles. Sandy areas in the upper reaches of the harbour were very coarse grained.

5.15.2 Habitats

Manaia Harbour was one of the largest estuaries mapped with an intertidal area of 3,848,346 m^2. This estuary was characterised by 13 habitat classes. The largest areas were dominated by Mangroves (48.8% of the total area surveyed) and Seagrass (14.4%) habitats (Figure 37). The other habitats each accounted for less than 10% of the total area surveyed.

5.15.3 Change in habitats over time

The habitat HD Amphibola was absent in 2023, after a very small area (350 m^2) was identified in 2013. In contrast, a small area of HD Macomona habitat was observed in 2023 (117 m^2) after not being recorded in 2013 (Table 30, Figure 38). In the upper section of the estuary, Mangroves habitat remained very similar with only a slight increase in cover area from 2013 to 2023 (Table 31, Figure 38). In contrast, noticeable habitat changes were identified in the middle and lower section of the estuary. The most evident change was the increase of area covered by Seagrass habitat, from 327,041 m^2 in 2013 to 469,757 m^2 in 2023 (Table 31, Figure 38). The increase of Seagrass habitat corresponded to a decrease in area covered by Mounds and Pits in the south upper section of the estuary, yet the total decrease in area covered by Mounds and Pits was minimal due to an increase in this habitat in the north upper section of the estuary, which aligned with a decrease in the area covered by HD Burrows habitat in this location (Table 31, Figure 38). Along the main channel of the estuary, a decrease in the area covered by Low Fauna was recorded, which coincided with increased area covered by LD Deposit Feeders (Table 31, Figure 38), a common transition for these habitats over time observed also in other estuaries. Comparing only the same areas mapped in both years, the habitat HD Pipi showed a slight decrease in 2023. However, the total area occupied by HD Pipi was larger in 2023, likely due to our ability to cover more area in the vicinity of main tidal channel in 2023, relative to 2013.

Table 30: Summary table showing the total area and the percentage of area covered by each habitat in 2013 and 2023 for Manaia Harbour.

Habitat	2013 area (m^2)	2013 (%)	2023 area (m^2)	2023 (%)
HD Amphibola	772	0.02		
HD Burrows	29 8750	8.14	174 539	4.54
HD Cockles	19 669	0.54	82 298	2.14
HD Crab and Cockles	26 574	0.72	7 102	0.18
HD Macomona			117	<0.01
HD Oysters	3 737	0.10	4 080	0.11

Habitat	2013 area (m²)	2013 (%)	2023 area (m²)	2023 (%)
HD Pipi	48 850	1.33	130 013	3.38
LD Deposit Feeders	297 089	8.09	379 689	9.87
Low Fauna	302 030	8.23	179 937	4.68
Mangroves	1 892 747	51.56	1 881 292	48.89
Mounds and Pits	4089 80	11.14	366 532	9.52
Pneumatophores	25 070	0.68	56 676	1.47
Rocky Reef	18 749	0.51	32 076	0.83
Seagrass	328 285	8.94	553 995	14.40

Table 31: Summary table showing the standardised area and percentage of area covered by each habitat in 2013 and 2023 for Manaia Harbour. Change refers to the increase (+) or decrease (-) of area covered by each habitat over time.

Habitat	2013 area (m²)	2013 (%)	2023 area (m²)	2023 (%)	Change (m²)	Change (%)
HD Amphibola	350	0.01			-350	-0.01
HD Burrows	288 011	8.25	154 322	4.42	-133 689	-3.83
HD Cockles	18 493	0.53	79 330	2.27	60 837	1.74
HD Crab and Cockles	23 634	0.68	7 102	0.20	-16 533	-0.47
HD Macomona			117	0.00	117	0.00
HD Oysters	3 679	0.11	3 058	0.09	-621	-0.02
HD Pipi	41 394	1.19	36 956	1.06	-4438	-0.13
LD Deposit Feeders	287 107	8.23	317 173	9.08	30 066	0.86
Low Fauna	252 615	7.24	154 187	4.42	-98 428	-2.82
Mangroves	1 804 528	51.70	1 832 940	52.49	28 413	0.79
Mounds and Pits	402 402	11.53	357 242	10.23	-45 159	-1.30
Pneumatophores	24 474	0.70	54 661	1.57	30 186	0.86
Rocky Reef	16 674	0.48	24 876	0.71	8 202	0.23
Seagrass	327 041	9.37	469 757	13.45	142 716	4.08

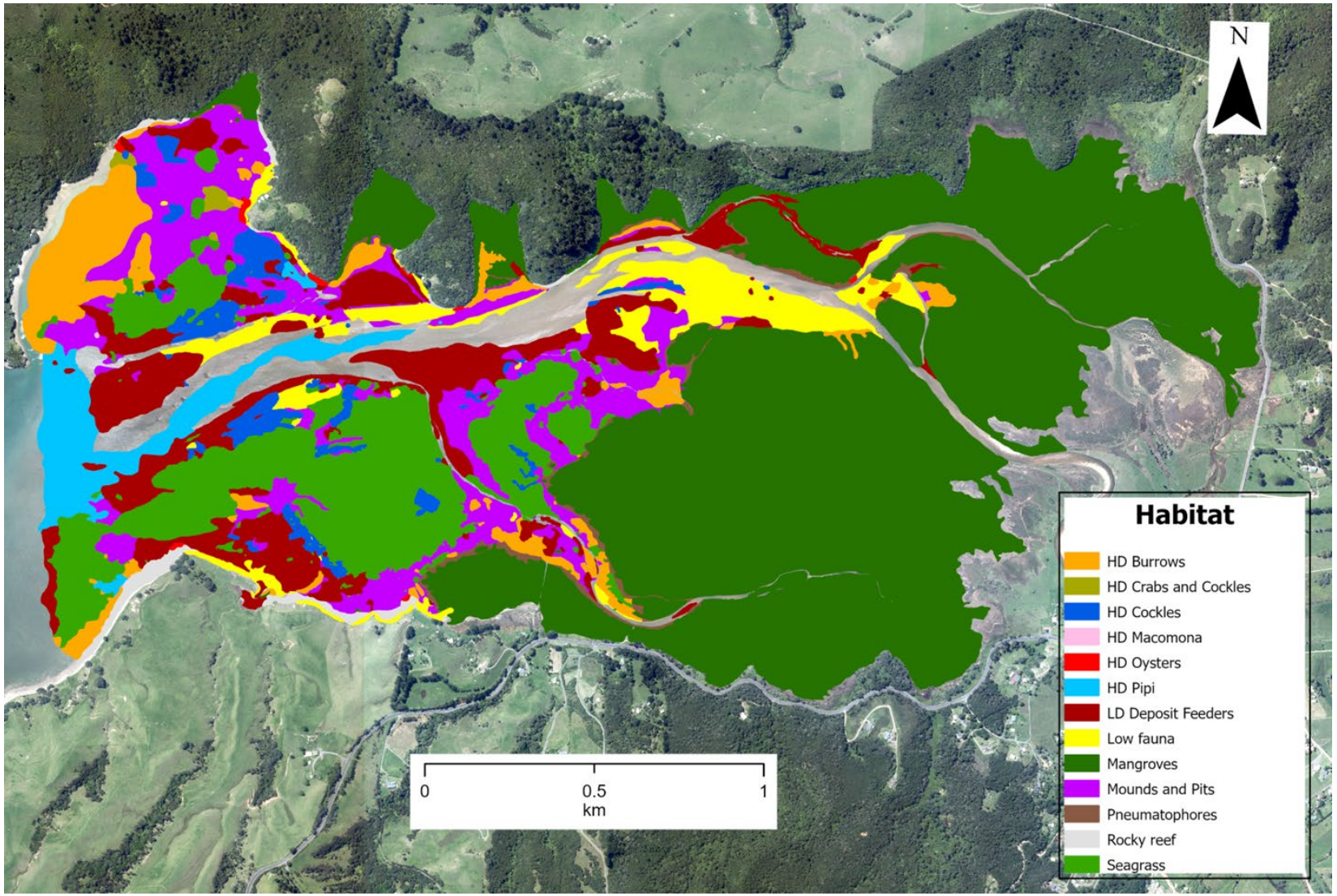

Figure 37: 2023 habitats mapped in Manaia Harbour.

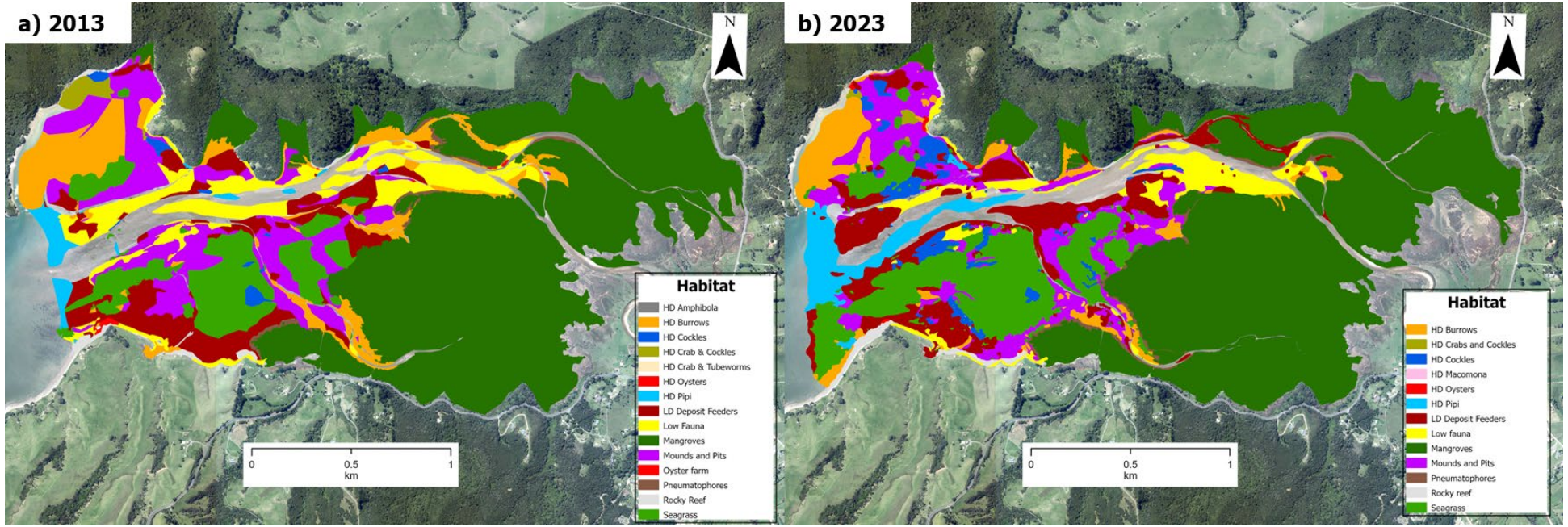

Figure 38: Comparison of the habitats mapped in a) 2013 and b) 2023 in Manaia Harbour.

6 Patterns of habitat change over time

In this report, the distributions of biologically defined habitat classes found in the intertidal zones of fifteen Coromandel Peninsula estuaries are presented. In fourteen of the estuaries, maps and data from 2013 and 2023 are provided, and therefore changes in the intervening decade were assessed. Overall, the area covered by the different habitats assessed changed over time across the studied estuaries (Table 32). Across all estuaries, the habitat mapping revealed a transitioning pattern, for example, when the area covered by one habitat increased, the area covered by another habitat decreased. However, we also identified the loss of specific habitats (e.g., HD Amphibola, HD Crabs and Tube Worm, HD Cockles and Pipi) in selected estuaries (Table 32).

In general, the most evident change identified across estuaries was the increase in area covered by Mangroves habitat. The area covered by Mangroves habitat increased in 12 of the 14 estuaries, with the highest increased area recorded in Whangapoua Harbour (391,132 m^2). Increases in area covered by mangroves often correlated with decreases in HD Burrows habitat, which aligned with 12 of the 14 estuaries showing decreased HD Burrows habitat. Yet, HD Burrows habitat is often within Mangroves habitat. Thus an increase in area covered by mangroves is the result of a common transition from HD Burrows to Mangroves, which does not necessarily suggest a complete loss of HD Burrows habitat. Interestingly, we identified decrease of area covered by Mangroves habitat in two estuaries, Whangamata Harbour and Tairua Harbour. The decrease in Mangroves in these estuaries was large (147,787 m^2 and 115,882 m^2 respectively) and not due to natural processes, rather a result of manual and mechanical removal activities occurring over time (Lundquist et al., 2017). In consequence, areas cleared from mangroves often resulted in extended HD Burrows habitats. Removal of mangroves occurred in an attempt to control the expansion of these habitats (Lundquist et al., 2017). These removals range in size and scale from large mechanical consented removals to smaller local scale hand removals in embayment's and property fronts. In Whangamata Harbour large-scale changes have occurred and continue to occur with the removal of mangroves across significant expanses of intertidal flat. Excessive mangrove habitat loss could negatively impact the overall functioning and services that estuaries provide. With climate change and sea level rise increasingly threatening the coastal zone, the loss of the carbon sequestration and coastal shoreline protection services could be particularly problematic.

Another noticeable habitat change was identified in Seagrass habitat. Seagrass habitat decreased in 6 of 11 estuaries, which in most cases were located on the East coast of the Peninsula (i.e., not on the Firth of Thames side); Table 32). The largest decrease in Seagrass habitat was found in Tairua Harbour (955,218 m^2). The decreases in area covered by Seagrass habitat were often located in the mid to lower sections of the estuary. Intertidal seagrass is known to decline with elevated sedimentation and heat waves. In Coromandel estuaries, rates of sediment loading have been estimated to be 10-100 times higher now than they were in pre-human times (Hunt, 2019), associated with deforestation, mining, and road building in the catchments. The increased sedimentation (Thrush et al., 2003a, Thrush et al., 2003b, Lohrer et al., 2004) in combination with climate change could be factors affecting seagrass and contributing to the decrease in area covered by this habitat, as demonstrated previously with negative effects on macroinvertebrate abundance, richness and diversity and key ecosystem functions (Lohrer et al., 2010, Lohrer et al., 2004, Lohrer et al., 2023). Nevertheless, reduction in areas covered by Seagrass habitat corresponded to increases in areas covered by HD Cockles habitat. We found that the HD Cockles habitat increased in 13 of the 14 estuaries, and in most cases this habitat type was recorded in areas where Seagrass was previously found. This finding aligned with previous observations describing the relationship between seagrass

and cockles. It was often reported that Seagrass habitat frequently foster high densities of cockles living within this habitat. This was another example of transitioning change from habitats dominated by Seagrass to habitats dominated by HD Cockles. In estuaries where Seagrass habitat increased (5 of 11 estuaries), the increase was very low except in Whangapoua (147,927 m^2) and Coromandel (285,745 m^2), which replaced areas previously covered by Mounds and Pits and HD Cockles.

The area covered by the habitats HD Crab and Cockles (7/10), HD Macomona (6/9), and HD Pipi (6/8) decreased in most of the estuaries studied (Table 32). In most cases, these habitats were replaced by LD Deposit Feeders habitat or HD Cockles habitat. The decrease of these habitats could be attributed to effects of stressors such as sediment loading. *Macomona liliana* and *Paphies australis* are documented to favour sediments with low percentage mud, where *Austrovenus stutchburyi* can occur across a greater range of sediment mud content values. The Coromandel Peninsula has steep terrain and high rates of rainfall, creating a naturally high potential for landslips and hillslope soil erosion, which in combination with poor land use practices (logging, gold mining) has elevated sediment loading rates by one to two orders of magnitude relative to natural baselines (Hunt et al. 2019). This has likely led to substantial increases in intertidal sedimentation and infilling in many Coromandel estuaries, with major implications for the distribution of intertidal habitat types. Sediment loading has been repeatedly shown to disrupt benthic communities and alter habitats and functions (Lohrer et al., 2004, Thrush et al., 2003b, Thrush et al., 2003a), for example smothering of flora and fauna, and elevating sediment muddiness which is inversely correlated with macrofauna and the abundance of key species like cockles, pipi and seagrass.

The habitat that decreased in almost all estuaries was HD Amphibola (in 9 of the 10 estuaries where it was detected in 2013). Yet, this finding is not representative of the complete absence of *Amphibola crenata* in the studied estuaries. *Amphibola crenata* organisms were recorded in most of the estuaries, however, the density of these transient organisms was not high enough to be considered as HD Amphibola habitat.

LD Deposit Feeders (9/14) and Low Fauna (7/13) habitats increased in most estuaries (Table 32). These two habitats were strongly associated. In many cases, increase in the area covered by LD Deposit Feeders resulted in decrease in area covered by Low Fauna, but this pattern was also found in the inverse direction. It could be explained as a transition from habitats with higher numbers of organisms (i.e., deposit feeders) to habitats with a reduced number of organisms (i.e., low fauna). Stressors such as increasing sediment loading, development of coastal areas, and climate change could be contributing to this habitat change. In contrast, the transition from Low Fauna to LD Deposit Feeders habitats could be facilitated by improvements in the sediment condition and changes in water flows.

Table 32: Summary table showing the changes in habitats over time. Increase in area over time is showed as "+" (green shading) and decrease in area is showed as "-" (yellow shading). Blanks are showing the absence of habitats in the studied estuaries. The assessment performed in Shelly Beach was the baseline and is shown as * (grey shading).

Habitat	Otahu River	Whangamata Harbour	Wharekawa Harbour	Tairua Harbour	Purangi River	Whitianga Harbour	Whangapoua Harbour	Kennedy Bay	Waikawau Bay	Port Charles	Colville Bay	Shelly Beach	Coromandel Harbour	Te Kouma Harbour	Manaia Harbour
HD Amphibola		-	-	-		-	-	-	-		-	*	+		-
HD Burrows	-	+	-	-	-	-	-	-	-	-	-	*	-	+	-
HD Cockles	+	+	+	+	+	+	+	-	+	+	+	*	+	+	+
HD Cockles & Pipi	-			+								*			
HD Crab & Cockles	-	-		+	+		-	-	-			*	-	+	-
HD Macomona	-	+	-	-	-	-	-				+	*			+
HD Oysters				-	+	-	-	+		-	-	*	-	-	-
HD Pipi	+		-		-	-	+				-	*	-		-
LD Deposit Feeders	-	+	+	+	-	+	-	+	+	-	+	*	+	-	+
Low Fauna	+	-	+	-	+	+	+	-	-	+	-	*		+	-
Mangroves	+	-	+	-	+	+	+	+	+	+	+	*	+	+	+
Mounds and Pits	-	-	-	+	+	+	+	+	-	-	+	*	+	-	-
Oyster farm						+	-					*	-		
Pneumatophores	+	+	+	+	+	+	+	+	-			*	+	+	+
Seagrass	-	-	-	-		-	+	+			+	*	+	-	+
Sediment Deposition		+	+									*			

7 Final Remarks

Estuaries are semi-enclosed coastal waterbodies where freshwater and seawater mix. Estuarine ecosystems have the potential to be influenced by many anthropogenic pressures, for example pollutants, contaminants, and increasing sediment inputs running off the land and entering estuaries via freshwater. We mapped estuarine habitats in across the Coromandel region with the aim to detect changes in habitats over time. In this report, we provided evidence of several changes in habitats comparing the mapping carried out in 2013 and the current mapping (2023).

The most evident habitat changes identified were the increase in area covered by Mangroves and HD Cockles, which could assist enhancement of ecosystem functioning and services. However, decreases in area covered by Seagrass, HD Amphibola, HD Burrows, HD Crab and Cockles, HD Cockles and Pipi, HD Macomona, and HD Pipi between 2013 and 2023 across all estuaries studied were also evident. The decline in these habitats could be a response to multiple stressors. For example, (1) freshwater contaminants including nutrients (e.g., inorganic nitrogen and phosphorus), faecal contaminants (e.g., E. coli), heavy metals (e.g., copper, lead, zinc, mercury), pesticides, polycyclic aromatic hydrocarbons (e.g., petroleum products), industrial pollutants (e.g., polychlorinated biphenyls), microplastics, pharmaceuticals, and more. (2) Land use practices in coastal catchments, and storm drain and sewage treatment discharges, which can affect estuarine water quality and benthic habitat characteristics. (3) Terrigenous sediment inputs, which is one of the best studied and most significant threats to estuaries in New Zealand with demonstrated deleterious effects on macroinvertebrate abundance, richness and diversity and key ecosystem functions, especially under current climactic conditions where severe and frequent storms are becoming the norm. (4) Coastal development including shoreline hardening, causeways, and other engineered structures, for example, the artificial waterways at Tairua Estuary (Pauanui) and Whitianga, and the Whangamata Marina. These major engineering projects have all disturbed/removed intertidal habitats and continue to have effects (e.g., in Whitianga the Whangamaroro River continues to change its course near the Waterway). (5) The establishment of aquaculture with broader ecological issues that include the effects of pests (fouling pests, toxic/noxious microalgae, disease), creation of novel habitat (e.g., by fouling of farm structures and accumulation of shell), alteration to nutrient cycling, depletion of suspended particulate matter, and related effects on higher trophic level animals including fish, seabirds, and marine mammals. In addition to muddy sediment, aquaculture has resulted in increased shell-hash across the sediment surface, generally on the shoreward side of farms (e.g., seen in Te Kouma). (6) Climate and ocean related drivers (e.g., sea surface temperature, pH, El Niño / La Niña phases, sea level rise). It is difficult to disentangle the effects of multiple stressors and environmental drivers that occur across varying spatial and temporal scales. However, regular monitoring of sentinel sites and the tracking of changes in the distributions of habitats over time facilitates our understanding of the interplay of drivers and can lead to improved management.

8 Estuary Habitat photos

8.1 Otahu River

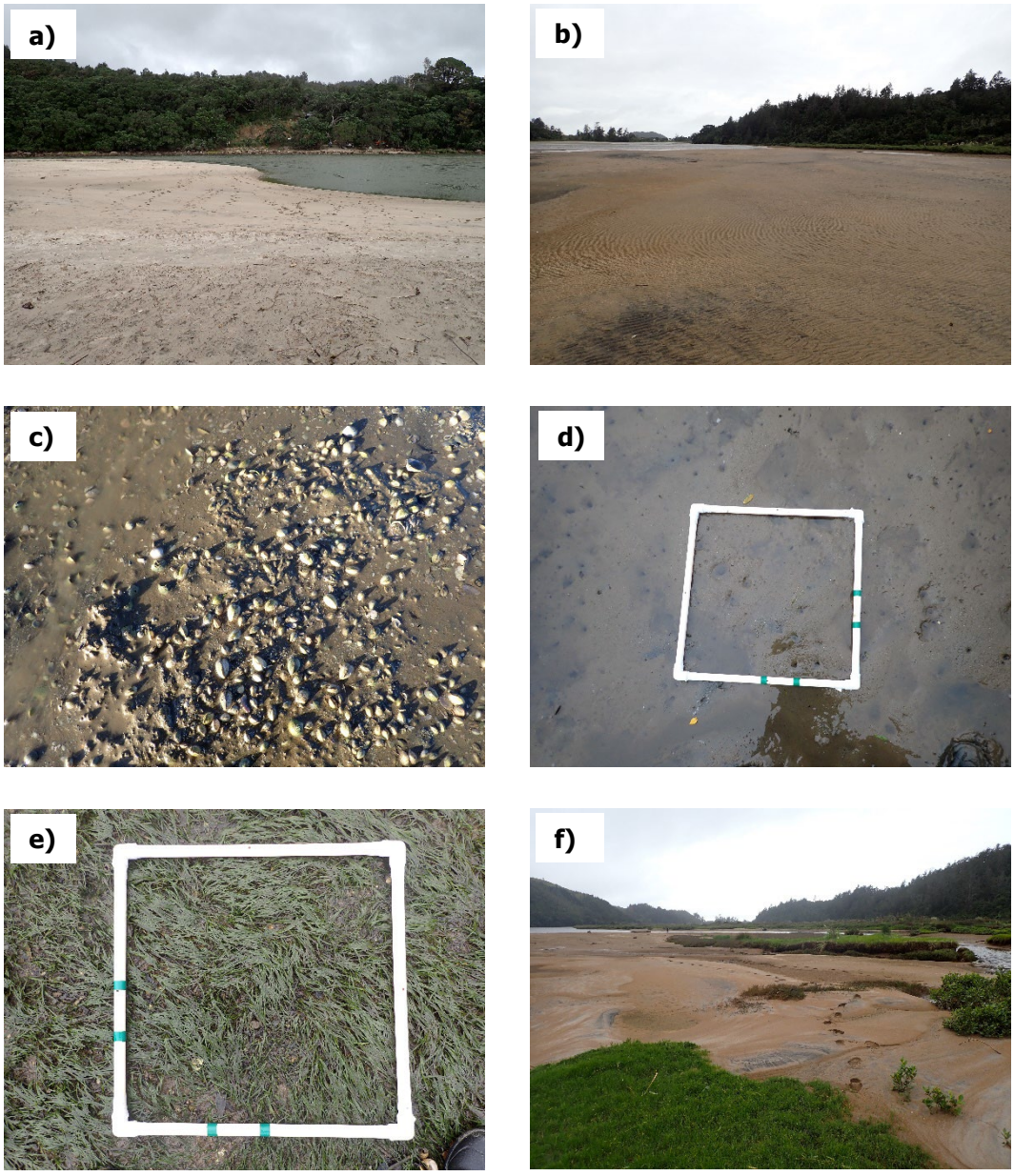

Figure 39: Examples of the habitats found in Otahu River during the 2023 mapping. a-b) Low Fauna close to the mouth of the estuary, c) HD Cockles, d) HD Burrows, and e) Seagrass, f) Low Fauna in the upper reaches of the estuary.

8.2 Whangamata Harbour

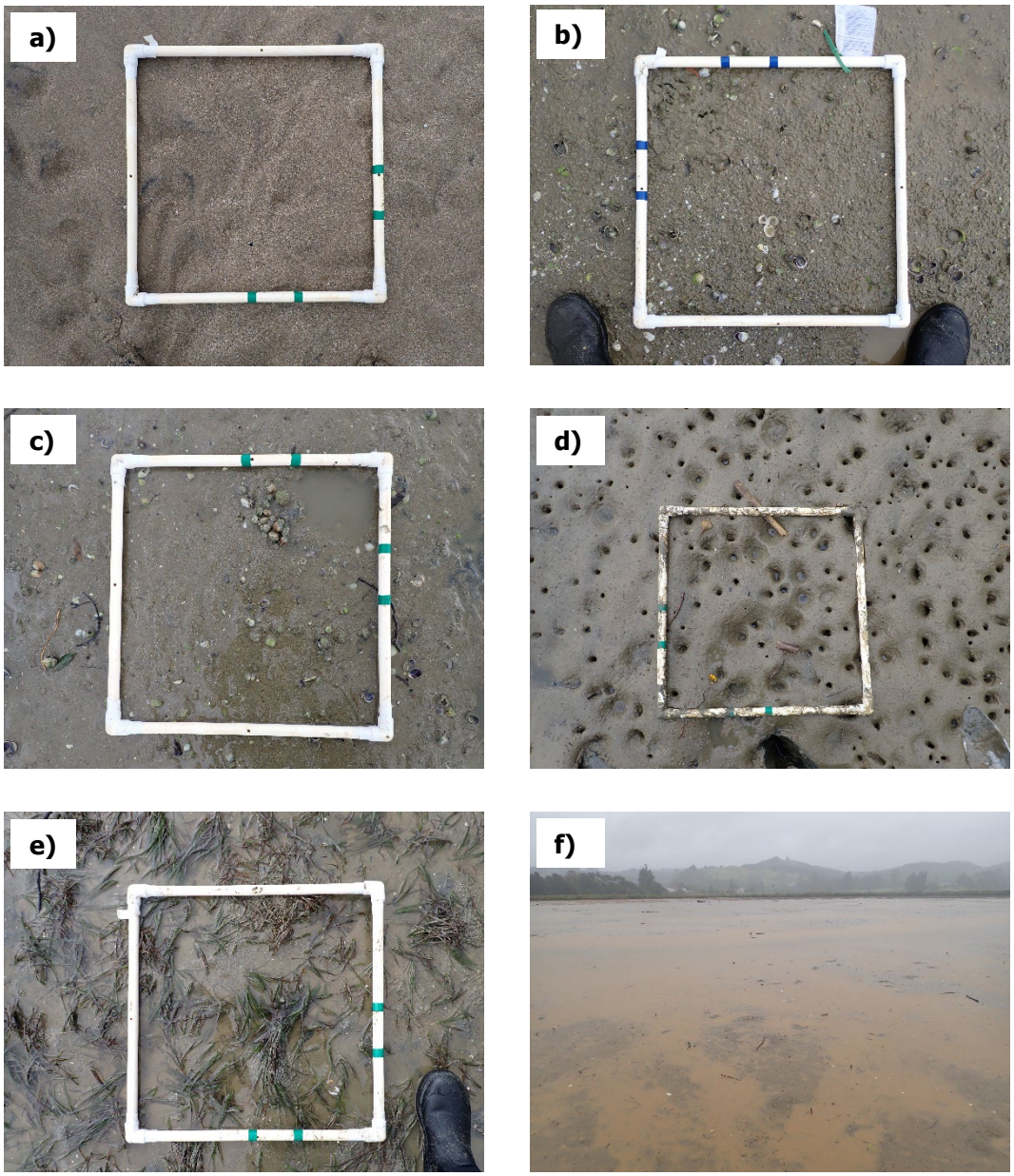

Figure 40: Examples of the habitats found in Whangamata Harbour during the 2023 mapping. a) Sandy habitats with Low Fauna, b) LD Deposit Feeders, c) HD Cockles, d) HD Burrows, e) Seagrass, and f) terrigenous Sediment Deposition.

8.3 Wharekawa Harbour

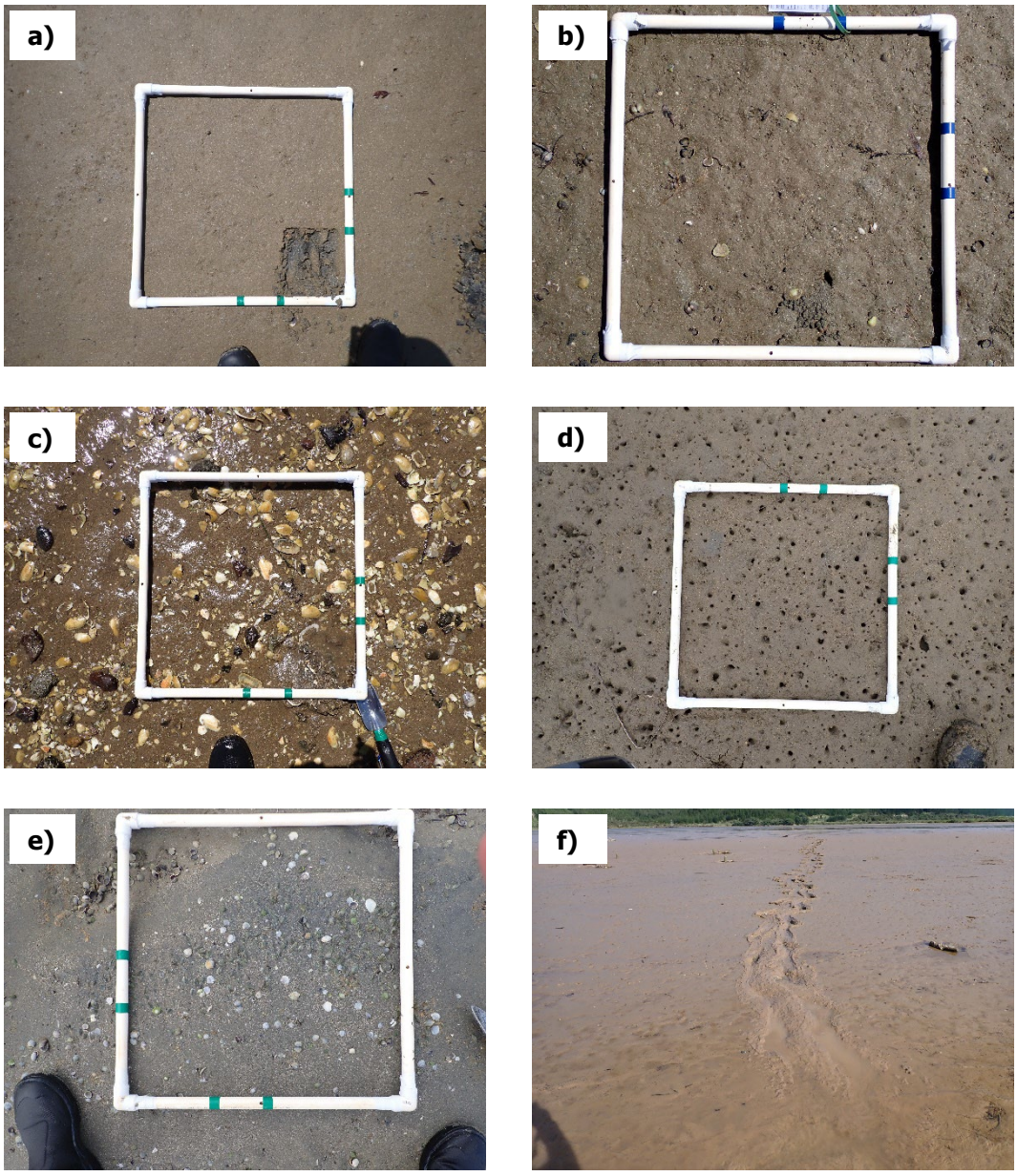

Figure 41: Examples of the habitats found in Wharekawa Harbour during the 2023 mapping. a) Sandy habitats with Low Fauna, b) LD Deposit Feeders, c) coarse sand and shell sediment with Low Fauna, d) HD Burrows, e) HD Cockles, and f) terrigenous Sediment Deposition.

8.4 Tairua Harbour

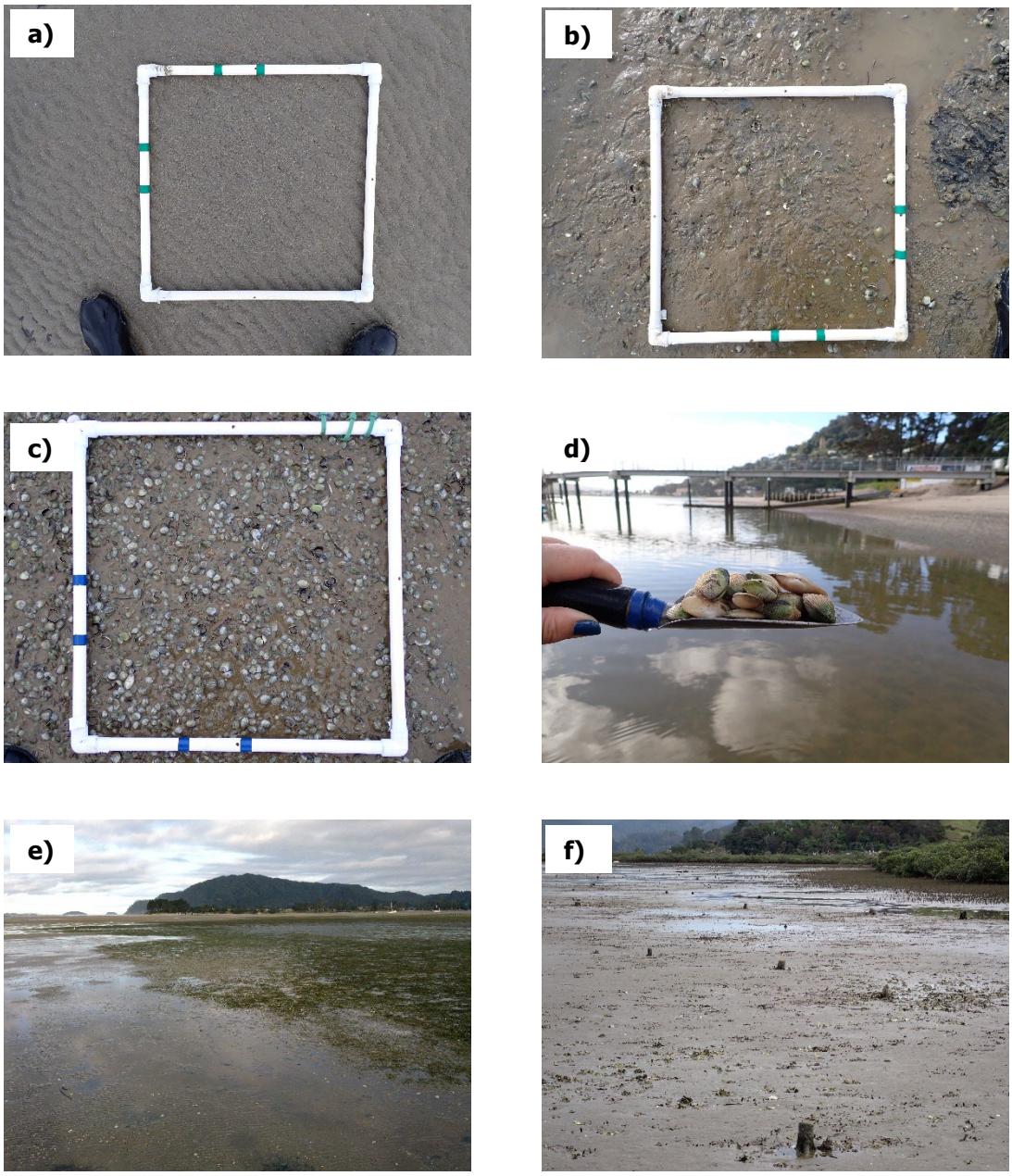

Figure 42: Examples of the habitats found in Tairua Harbour during the 2023 mapping. a) sandy sediment with Low Fauna, b) LD Deposit Feeders, c) HD Cockles, d) HD Cockles and Pipi, e) Seagrass, and f) areas where mangrove removal was evident.

8.5 Purangi River

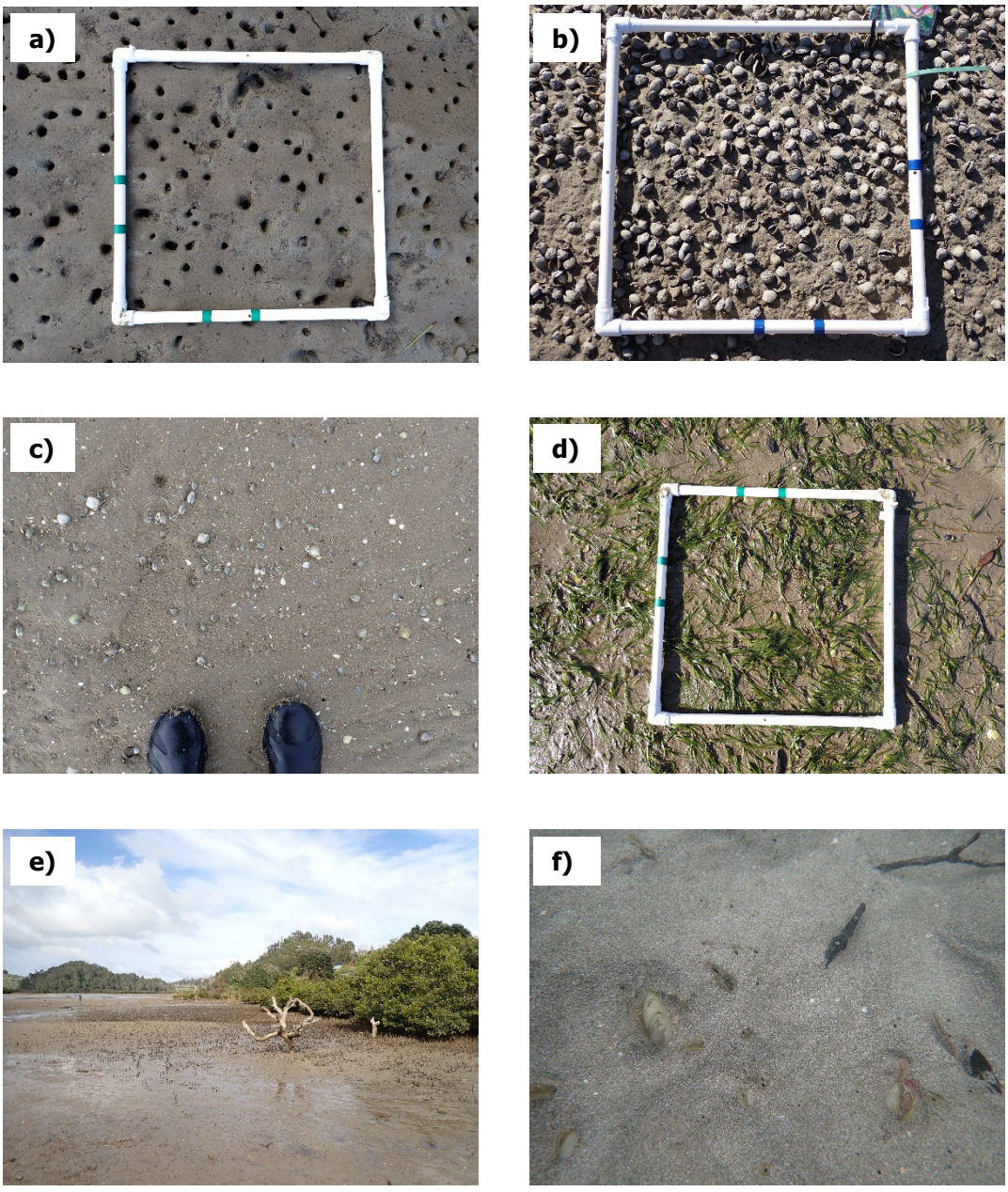

Figure 43: Examples of the habitats found in Purangi River during the 2023 mapping. a) HD Burrows, b) firm sediment high density cockle shall hash and HD Cockles, c) HD Cockles in sandy firm sediment, d) Seagrass, e) Mangroves, Pneumatophores and evidence of manual mangrove removal, and f) Underwater photograph of HD Pipi and siphons on the sediment surface by the mouth of the estuary.

8.6 Whitianga Harbour

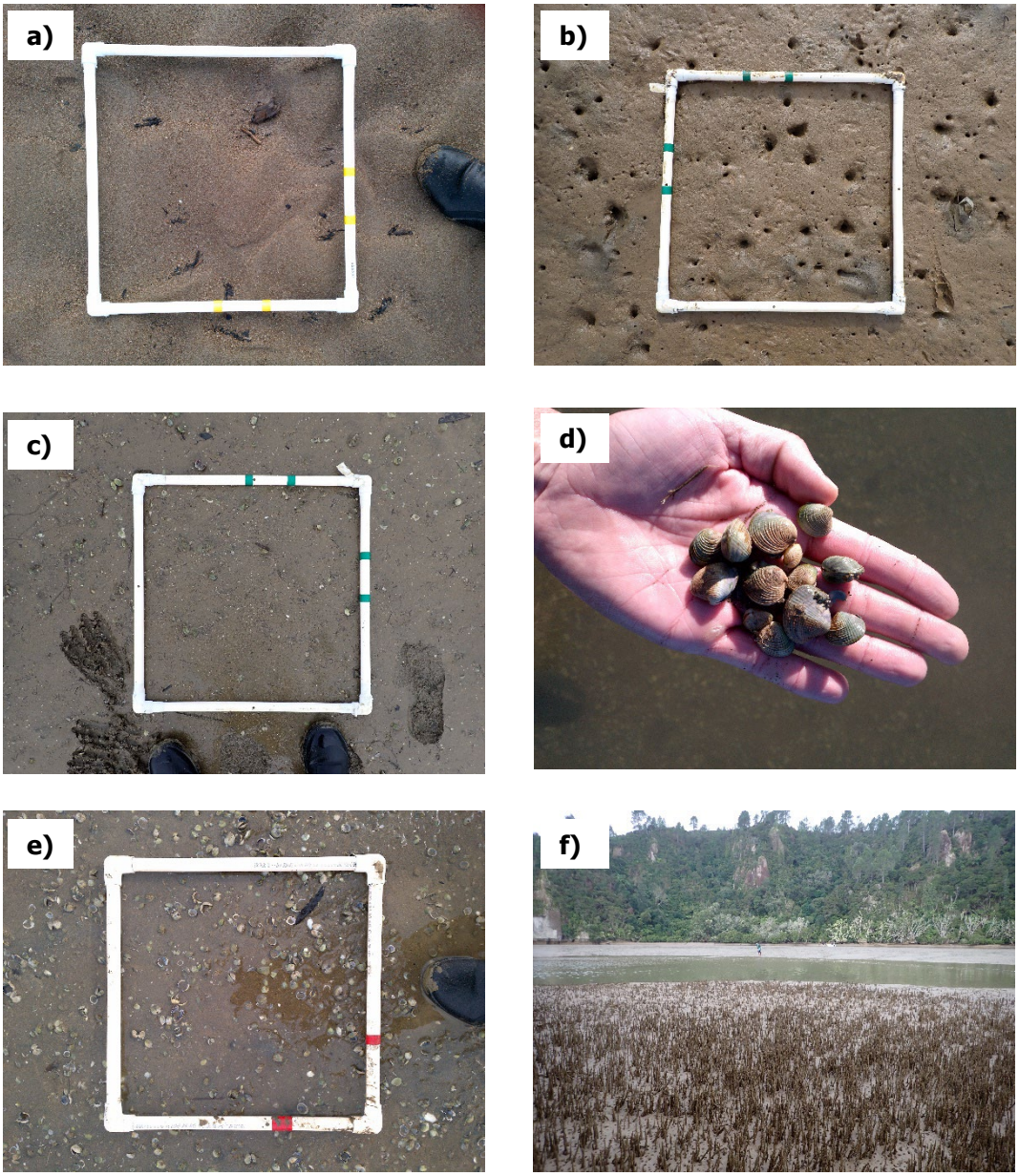

Figure 44: Examples of the habitats found in Whitianga Harbour during the 2023 mapping. a) Sandy Low Fauna habitat, b) HD Burrows, c) HD Cockles in sandy sediment, and d) HD Cockles excavated from 15*15 cm area, e) LD Deposit Feeders, and f) Pneumatophores extending to the channel edge.

8.7 Whangapoua Harbour

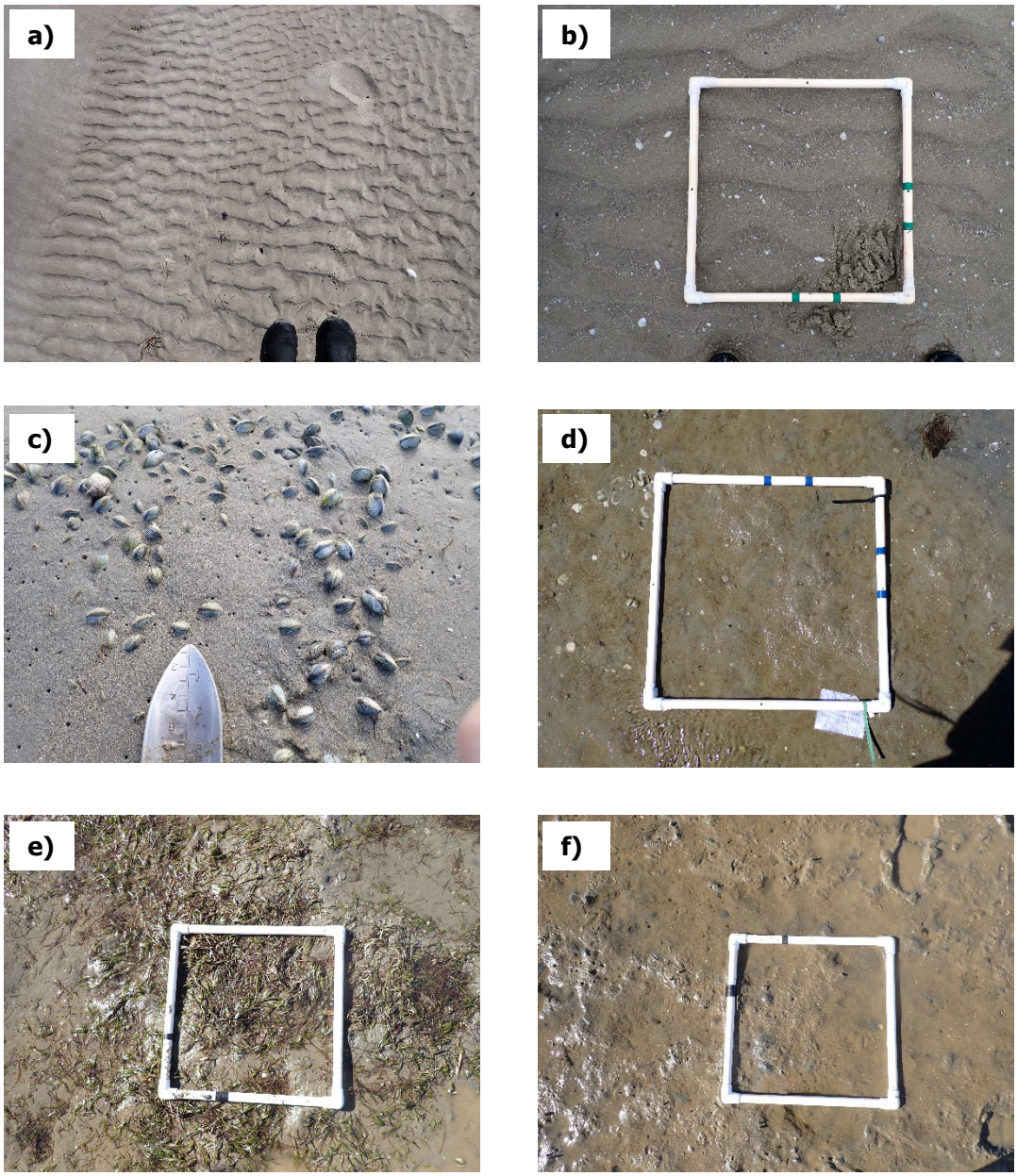

Figure 45: Examples of the habitats found in Whangapoua Harbour during the 2023 mapping. a-b) Sandy habitats with Low Fauna, c) HD Cockles, d) LD Deposit Feeders, e) Seagrass, and f) firm sandy LD Deposit Feeder habitat with terrigenous sediment deposition.

8.8 Kennedy Bay

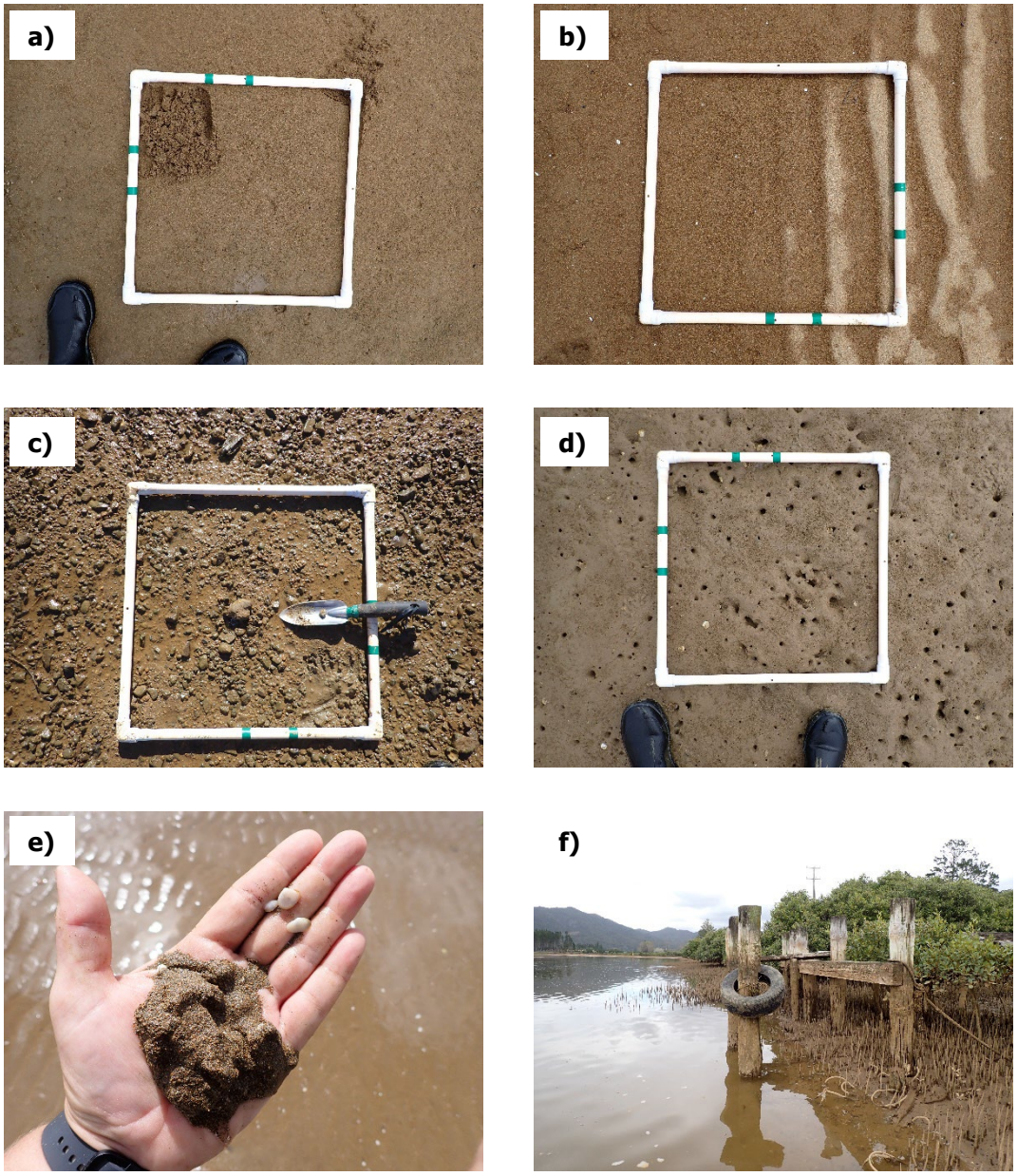

Figure 46: Examples of the habitats found in Kennedy Bay during the 2023 mapping. a-b) Sandy habitats with Low Fauna, c) coarse sandy sediment with gravel and Low Fauna, d) HD Burrows, e) coarse sandy sediment with LD Deposit Feeders featuring juvenile Pipi), and f) Mangroves and Pneumatophore fringe.

8.9 Waikawau Bay

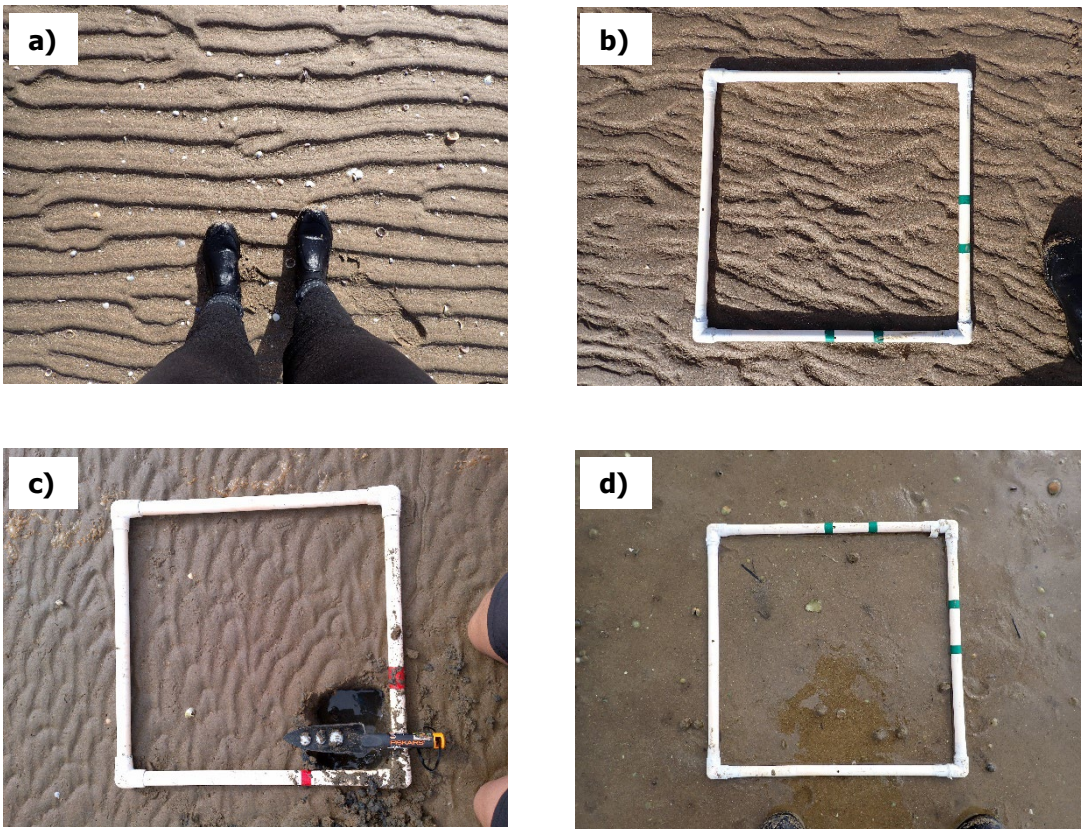

Figure 47: Examples of the habitats found in Waikawau Bay during the 2023 mapping. a)-b) Sandy sediment with Low Fauna, c-d) Sandy sediment with LD Deposit Feeders.

8.10 Port Charles

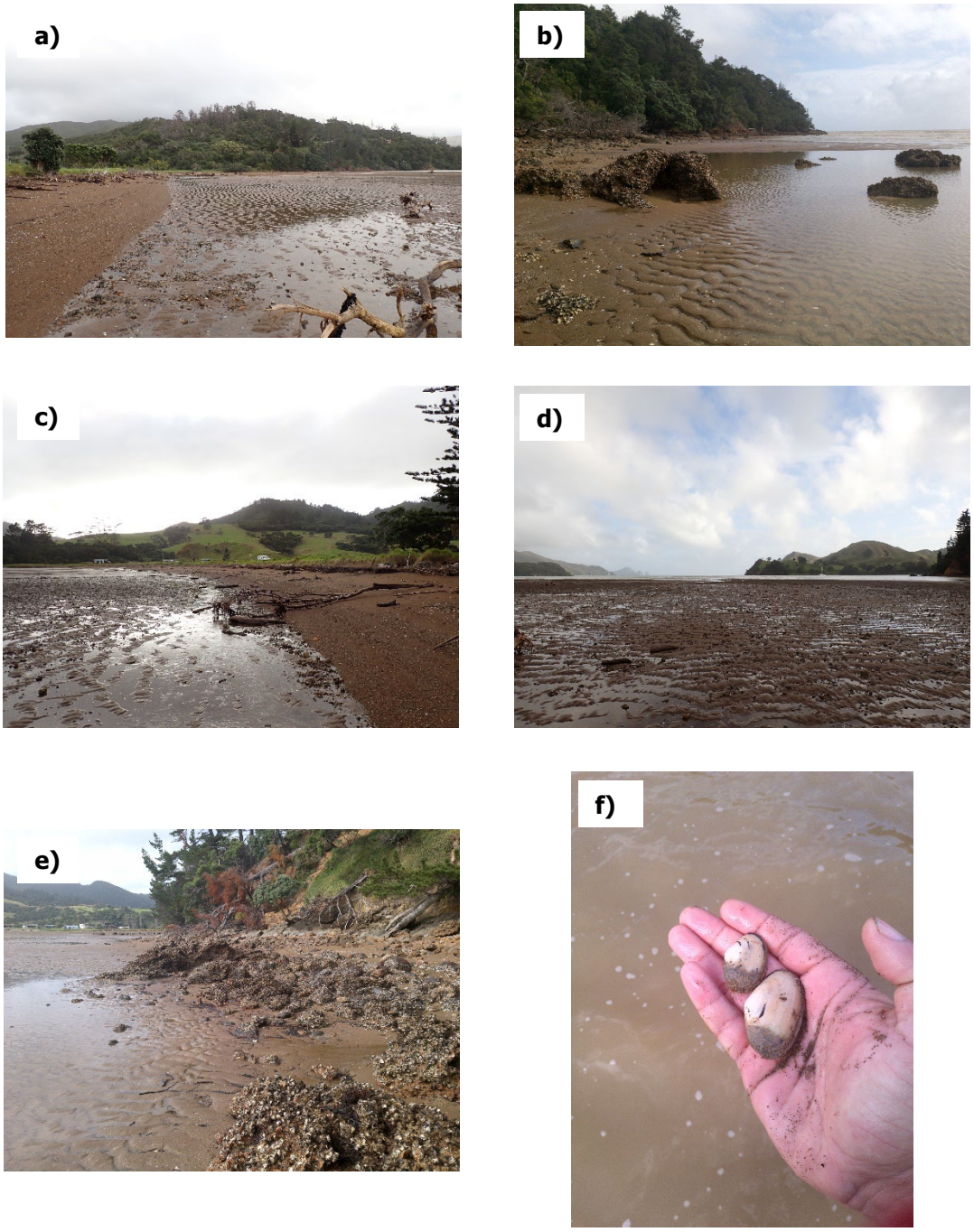

Figure 48: Examples of the habitats found in Port Charles during the 2023 mapping. a-d) Coarse sandy sediment, often with gravel and Low Fauna, and e), HD Oysters, and f) some individuals of Pipi.

8.11 Colville Bay

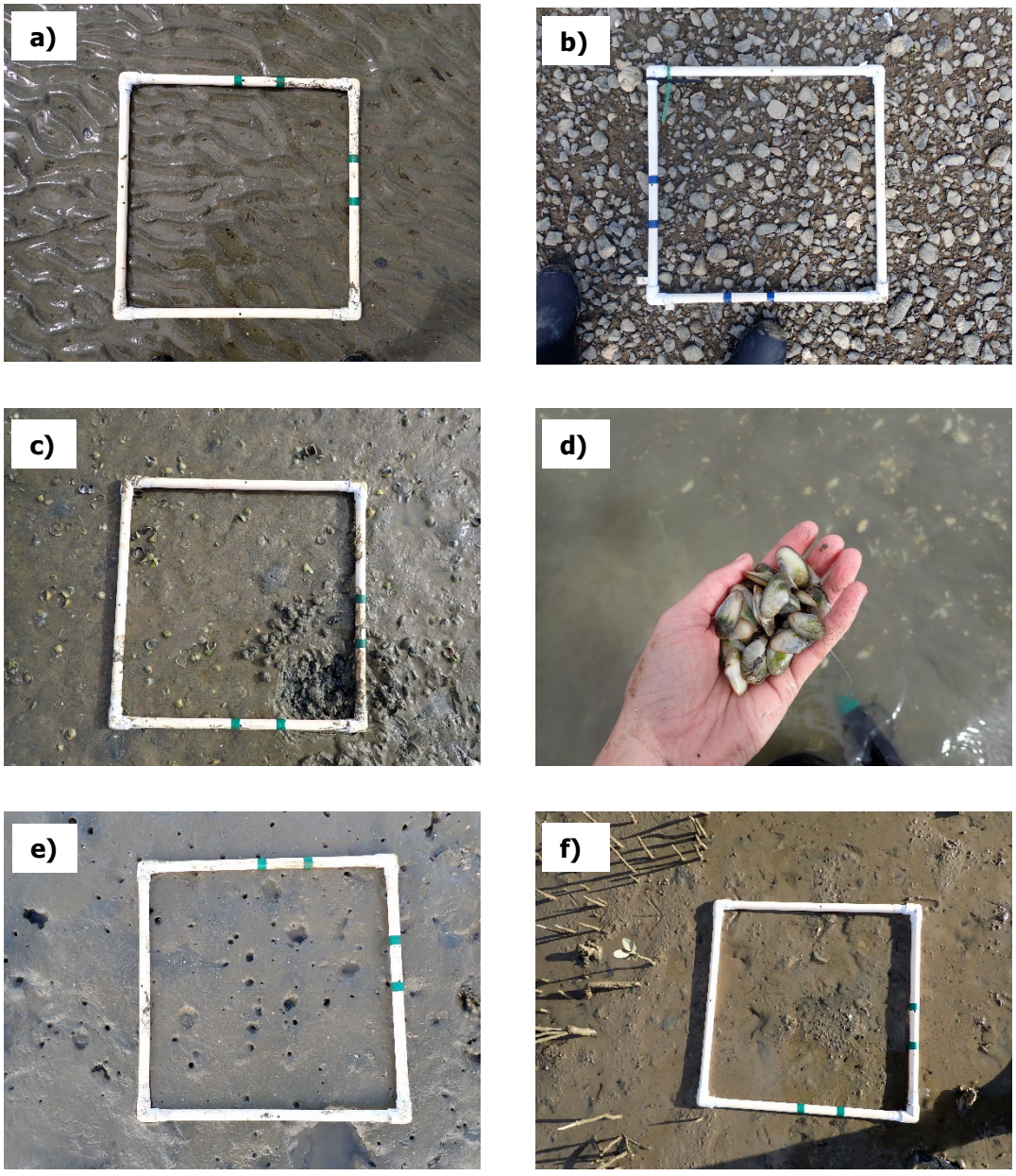

Figure 49: Examples of the habitats found in Colville Bay during the 2023 mapping. a-b) Low Fauna habitats, c) HD Cockles, d) HD Pipi on the low intertidal, e) HD Burrows, and f) LD Deposit Feeders.

8.12 Shelly Beach

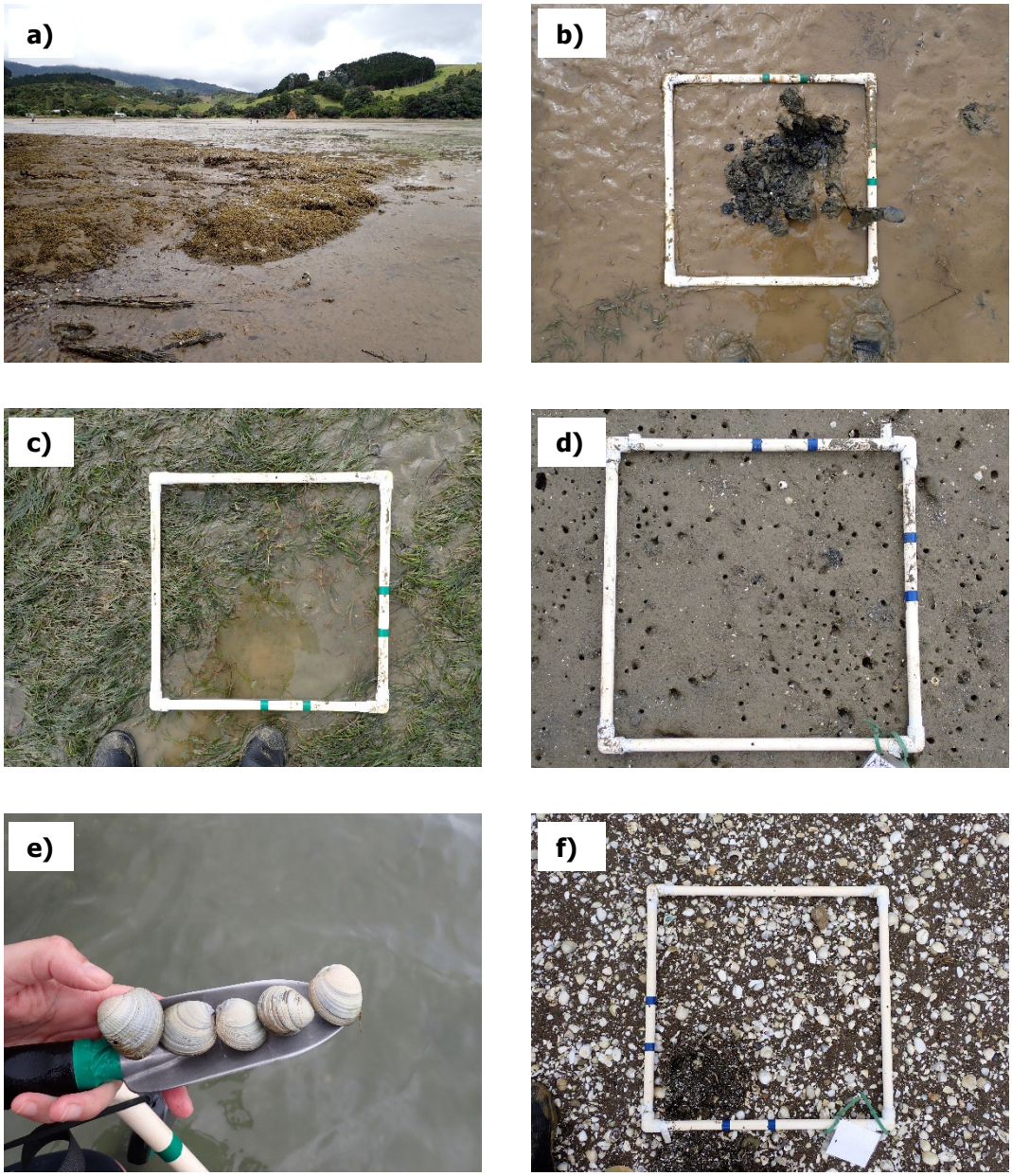

Figure 50: Examples of the habitats found in Shelly Beach during the 2023 mapping. a) Rocky platform, b) LD Deposit Feeders with terrigenous sediment deposition, c) Seagrass, d) HD Burrows, e) HD Cockles, and f) Coarse sand and shell hash with Low Fauna.

8.13 Coromandel Harbour

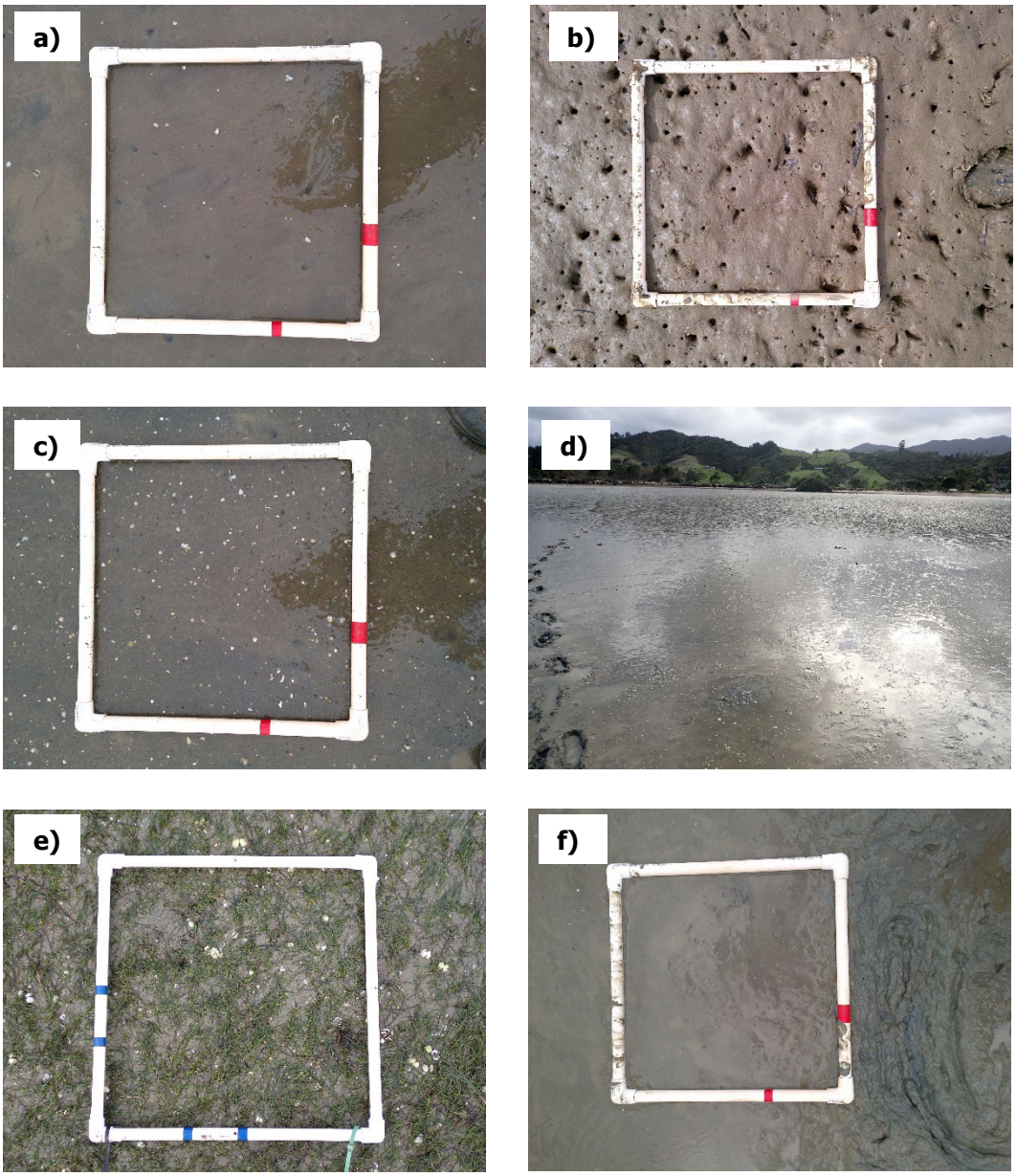

Figure 51: Examples of the habitats found in Coromandel Harbour during the 2023 mapping. a) muddy sediment with Low Fauna, b) HD Burrows, c-d) LD Deposit Feeders, e) Seagrass, and f) terrigenous Sediment Deposition.

8.14 Te Kouma Harbour

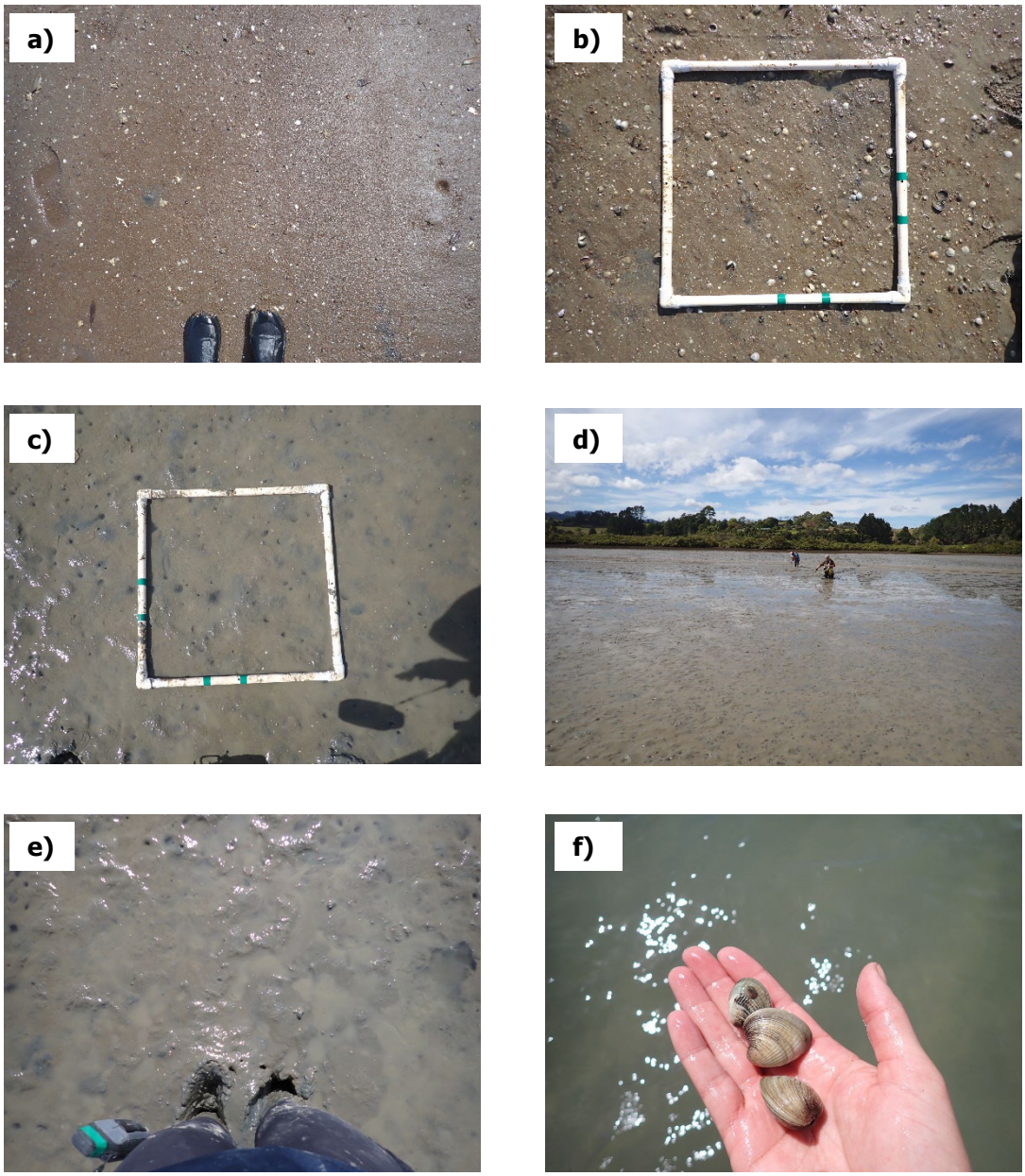

Figure 52: Examples of the habitats found in Te Kouma Harbour during the 2023 mapping. a) sandy sediment with Low Fauna, b) LD Deposit Feeders, c) HD Burrows, d-e) muddy areas with HD Burrows, and f) an example of cockles found at an HD Cockles habitat.

8.15 Manaia Harbour

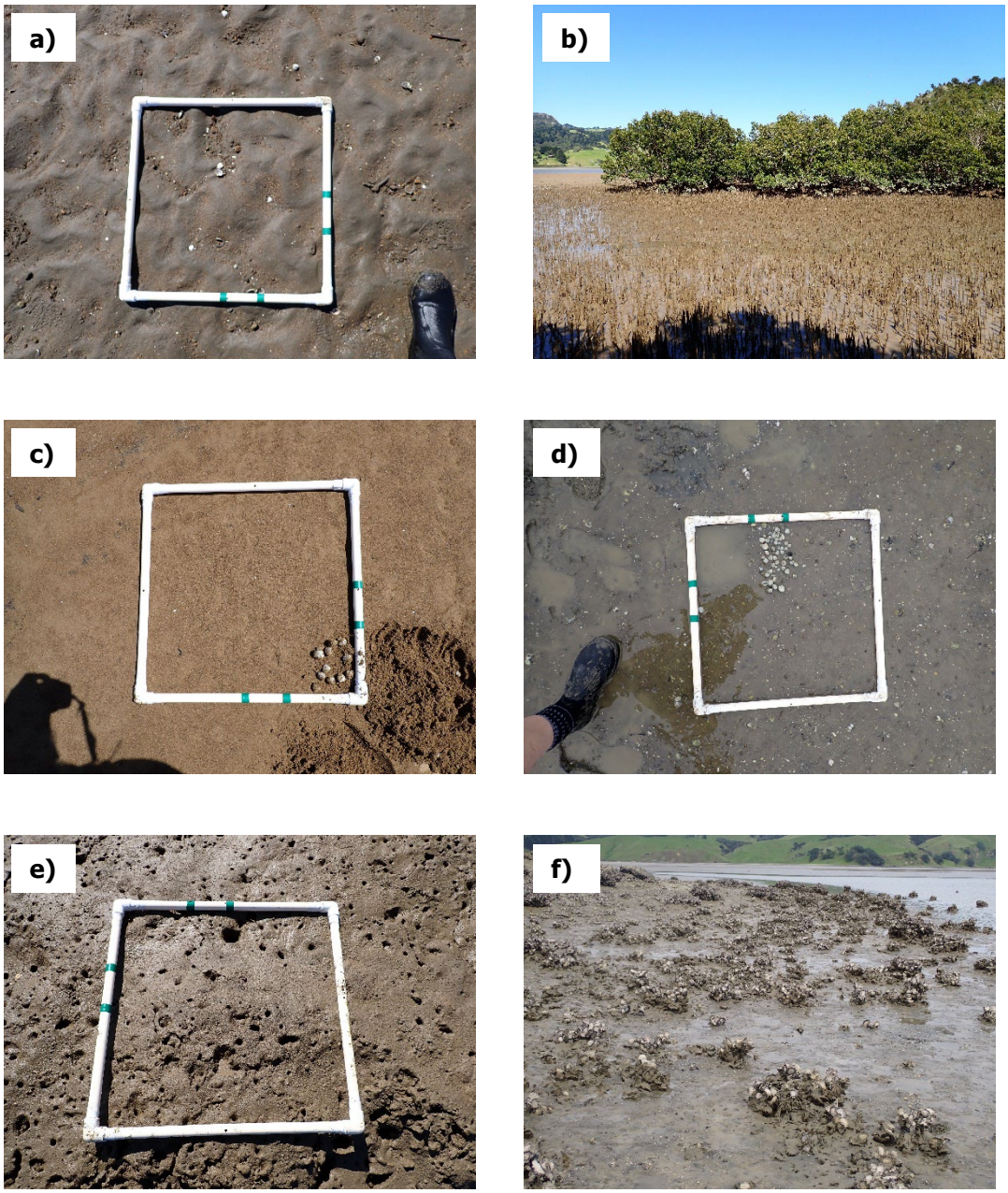

Figure 53: Examples of the habitats found in Manaia Harbour during the 2023 mapping. a) sandy sediment with Low Fauna, b) Mangroves and Pneumatophores, c) HD Cockles in sandy sediments, d) HD Cockles in muddy sediments, e) HD Burrows, and f) HD Oysters and HD Burrows fringing.

9 Appendix

9.1 General description and logistics for each estuary/harbour mapped

9.1.1 Otahu River

The intertidal area (877,977 m^2) of Otahu River was easily accessed on foot from the main beach. A low tide of 0.5 m or below was required and, although the estuary is small, it is complex and required the entire low tide window. The tidal period is slightly asymmetric, and there is a longer exposure period after low tide. Mapping was completed by four people over one day. There was a fast-flowing deep channel with high density pipi at the channel edge.

9.1.2 Whangamata Harbour

Whangamata Harbour was mapped over two days by five people where teams utilised a boat and easy public access from land. The estuary was one of the largest mapped with an intertidal area of 3,909,360 m^2. On the first day, one team launched a boat at the Whangamata Beach and accessed the eastern bank and northern reaches, while another team mapped the north-western flat on foot via road access from Patiki Place. On the second day, a boat was launched to access around the marina and south-western side of the harbour, while two people mapped the arm of the estuary west of the marina (access via the park on Hetherington Road) and then the southwestern intertidal zone moving towards the estuary mouth.

9.1.3 Wharekawa Harbour

The intertidal area (1,666,024 m^2) of Wharekawa Harbour was mapped across two days by five people, and access was obtained from Opoutere Carpark and the boat ramp along Opoutere Road. The eastern intertidal area was accessed using kayaks to transverse the 4 m wide channel. The tide at this harbour is asymmetric, with periods of intertidal habitat exposure tending to be longer after the predicted time of low tide than before it.

9.1.4 Tairua Harbour

Due to weather disruption and field crew illness, Tairua Harbour was mapped across seven days. Tairua Harbour was one of the largest estuaries mapped, with an intertidal area of 4,371,248 m^2. Due to the large intertidal flats and the patchiness of some habitats, it is most efficient to map this harbour with teams of 2-3 people. Access of Pepe Inlet and the intertidal area along the western side of the main channel was achieved on foot from multiple points along from the road. A boat was launched at the ramp on Wharf Road to access the eastern and upper harbour intertidal areas. However, there are multiple access points along the eastern section of the Harbour, that would be appropriate for mapping. Five people could map the entire estuary in four days.

9.1.5 Purangi River

Purangi River estuary is located to the east of Whitianga Harbour. It was accessed by boat via the boat ramp at the end of Captain Cook Road. Two people mapped this estuary over two days, so very low tides were selected to allow for maximum intertidal exposure time to access all areas required. Care must be taken when working around the intertidal areas near the mouth of the river, as the mouth is narrow, and the current is very strong when the tide is ebbing. Tidal ebb and flood are asymmetric here and flats are exposed up to 4 hours before low water but only ~2 hours past.

9.1.6 Whitianga Harbour

The mapping required four people over four days. Whitianga Harbour was accessed by boat using the ramp at the end of Robinson Road. An in-depth knowledge of the Harbour, specifically the way it ebbs and floods, was required to plan the fieldwork. Some intertidal areas expose late and then cover quickly only allowing 1 or 2 hours to map the area (i.e., sand banks along the main channel), while other areas expose late but then remain exposed for 3-4 hours after low tide (i.e., intertidal area west of the entrance to Whitianga Waterways).

9.1.7 Whangapoua Harbour

Whangapoua Harbour was the largest estuary mapped (11,481,748 m^2). As such, mapping required three teams of 2-3 people over four days. On most days, a boat was launched from the boat ramp on Whangapoua Road. It was most efficient to launch at this point as it provided quick access to most of the harbour, including the eastern side by Matarangi. The upper reaches of the estuary were accessed along Whangapoua Road, from the road and private property known to WRC staff. All areas of the harbour are accessible by boat at high tide however, some of the channels in the upper reaches of the harbour are too shallow for a boat with a low-profile hull from mid-low-mid tide tidal state.

9.1.8 Kennedy Bay

Kennedy Bay was mapped by accessing the estuary at the bridge close to the intersection of Mangatu and Kennedy Bay roads and then working our way across the estuary exiting at the bridge at the southern end of the estuary (also on Kennedy Bay Road). Kennedy Bay was one of the smallest estuaries mapped (572,434 m^2). It was narrow and long and, although the main channel had some deep sections, it was generally easy to cross at mid and low tides. This estuary was mapped during a 0.49 m low tide, which allowed five people to map the estuary in one day with a working window of 6 hours.

9.1.9 Waikawau Bay

Waikawau Bay was accessed by foot from Beach Road via a public path, through the dunes to the beach. The estuary is small and narrow and was one of the smallest mapped (201,216 m^2), thus two people were able to survey this estuary in one day. The intertidal area was easy to access, however, the channels along the mangroves were deep and fast flowing. Crossing the main channel near the mouth of the estuary is only recommended near low tide.

9.1.10 Port Charles

Port Charles was accessed by foot from the carpark located on Carey Road. This estuary was one of the smallest mapped (489,341 m^2), but it nevertheless required copious walking. Because the total number of habitat types was lower and they were not fragmented (few large extents rather than many small extents), two people were able to rapidly map the estuary in one day. Tangiaro and Parakete stream channels that enter either side of the estuary were shallow and diminished in the interior of the estuary.

9.1.11 Colville Bay

Colville Bay was accessed by foot with the team entering from the side of Port Jackson Road or from the picnic area on Colville Road. Colville Bay is a relatively large estuary (1,909,309 m^2), however, three people were able to cover the area in one large day. The bay was mapped on a day where the low tide was 0.54 m, which may have been lower than the day it was mapped in 2013. The northern

intertidal area was completely exposed in 2023, suggesting that the area may have been mapped more thoroughly in 2023 relative to 2013. Sandflat areas and streams in the southern portion of the bay were indicted as tapu in 2013 due to locations of urupā in the surrounding marshland and hillsides; these areas were avoided, respected and left out of the mapping (Figure 30, Figure 31).

9.1.12 Shelly Beach (information also presented in section 5.12)

Shelly Beach was a new addition to the mapping fieldwork in 2023 (i.e., this estuary was not mapped in 2013). It was accessed by foot from the end of Calloway Lane. The intertidal area of Shelly Beach was approximately 196,967 m^2, making it the smallest estuary mapped. A large rock platform extends out into the bay along both sides of the estuary. Shelly Beach was sampled on a day with a 0.92 m predicted low tide, and five people were able to cover the estuary in one day. On the day, several residents expressed concern about the amount of sediment deposited in the estuary after Cyclone Gabrielle. The amount of terrigenous material present on the day of mapping was considerably reduced compared to that described by the residents but it was still evident after approximately 20 days post-cyclone.

9.1.13 Coromandel Harbour

Coromandel Harbour has extensive intertidal flats with an area of approximately 5,874,833 m^2 and was the largest estuary mapped. The estuary was accessed using a variety of public (park and road access) and pre-arranged private access points. The strategy of mapping this Harbour involved leaving cars at two points and working from one to the other each day, moving down the harbour in that fashion over six days. This Harbour was the most physically taxing to map with a large portion of muddy areas, and sinky seagrass.

9.1.14 Te Kouma Harbour

Te Kouma Harbour was accessed by boat from Sugar Loaf boat ramp and from land adjacent to Te Kouma Cottages accommodation. The boat was utilised to access the small bays along the northern and southern coastlines of the Harbour and provided support to the team mapping the upper intertidal adjacent to the oyster racks. The intertidal area (875,750 m^2) was mapped by five people over two days. However, it would be possible to map with five people in one day during spring low tide conditions.

9.1.15 Manaia Harbour

We were joined in 2023 by a kaitiaki from Ngati Whanaunga, who also accompanied the mapping team in 2013. Manaia Harbour was accessed by foot via private land from Manaia Road. Five people covered the entire intertidal area (3,848,346 m^2) of the estuary in three days. When working in this Harbour, it is best to choose very low tides and work quickly and systematically to ensure broad coverage, as many areas only uncover for short periods of time. The main channel was able to be crossed two hours on either side of predicted low tide.

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