Potential restoration sites for saltmarsh in a changing climate

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Executive summary/ Whakarāpopototanga Matua

Saltmarsh is an important component of the estuary, providing the fringing riparian margin between land and sea. Saltmarsh is a highly productive habitat that filters and deposits sediment and nutrients, acts as a buffer against introduced grasses and weeds, and provides important habitat for a variety of fish and bird species. Saltmarsh habitats provide a range of ecosystem services, including flood and erosion control, water quality improvements, carbon storage and are culturally significant to Māori. Climate change impacts such as sea level rise will change the suitable habitat elevation range for saltmarsh, requiring it to expand into inland areas. In some cases, 'coastal squeeze' may occur, where natural topography or human infrastructure will limit any inland migration potential.

Restoration and enhancement of saltmarsh habitat is a key goal for regional council, to meet regional and international obligations. To support this work, we have undertaken a regional assessment of elevation profiles of coastal land to identify potential locations for undertaking saltmarsh restoration projects, to support biodiversity and water quality outcomes. To maximise the adaptive capacity of coastal wetlands to sea level rise, there is a need to identify, manage and protect low lying lands that could allow for landward migration of saltmarsh ecosystems. This work aims to identify suitable land areas in preferred elevation ranges for saltmarsh habitats under current and future sea level rise levels, to support the restoration activities of the Coastal Catchments team.

LiDAR, field RTK GPS surveys and aerial imagery identified that the preferred elevation range for saltmarsh occurs between 0.8 m–1.2 m Moturiki RL. LiDAR was not very effective in identifying the correct elevation height within existing saltmarsh habitats due to false ground returns, however this will not affect the land-based assessments of elevation. There is 1416 ha of existing saltmarsh habitats mapped across the Bay of Plenty, with the majority being located in Tauranga and Ōhiwa Harbours. There was 4888 hectares of land identified within the saltmarsh current elevation range, with 3288 hectares of this currently in the pastural land use (67%). There are significant areas (6288 ha) that are below the preferred elevation range (i.e. less than 0.8 m Moturiki RL), which may provide opportunities to increase open tidal flat or mangrove habitat. Future sea level rise indicates potential migration pathways for saltmarsh habitat and can be used to future proof new restoration activities. There is likely to be an overall decrease in space available for saltmarsh due to land topography, however with gains and losses in different areas.

Ultimately there are still many unknowns regarding the rate of climate change/SLR and what impacts it will have on saltmarsh habitats, however, there is need for immediate action, utilising the best available information. Strategic planning can support natural inland migration and ensure that the existing mechanisms for biodiversity protection can be amended to extend inland as migration occurs. Further work is required to prioritise our restoration efforts based on SLR risk, and further develop management and policy options to support a broad range of future climate scenarios.

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Introduction/Kupu Whakataki

Saltmarsh Ecosystems

Saltmarsh is an important component of the estuary, providing the fringing riparian margin between land and sea. Saltmarsh is a highly productive habitat that filters and deposits sediment and nutrients, acts as a buffer against introduced grasses and weeds, and provides important habitat for a variety of fish and bird species. Saltmarsh habitats provide a range of ecosystem services, including flood and erosion control, water quality improvements, and are recognised as an important carbon sink (a form of blue carbon[1]). Saltmarsh and wetlands have high cultural and spiritual values for Māori, such as important traditional gathering sites for food, rongoā (medicines) and home to many taonga species (such as fish, birds, and plants for weaving) (Dymond *et al.*, 2021).

Coastal ecosystems dominated by plants play a critical role in the global sequestration of carbon that would otherwise remain in the atmosphere as CO_2 and exacerbate climate change (Duarte *et al.*, 2005, McLeod *et al.*, 2011). Global estimates calculate saltmarshes as having a carbon burial rate of 218 g C m^{-2} y^{-1} with a potential total global carbon burial of 4.8 – 87.2 Tg C yr^{-1} (McLeod *et al.*, 2011). An assessment of organic carbon stocks in a New Zealand estuary identified that saltmarsh held the greatest carbon (90 t ha^{-1}), compared to other estuarine habitats such as mangrove (46 t ha^{-1}), seagrass (27 t ha^{-1}) and unvegetated habitats (26 t ha^{-1})(Bulmer *et al.*, 2020). In general saltmarsh occurs from the mean high-water springs (MHWS) down to the midway point between mean low water springs (MLWS) and MHWS.

Climate change impacts for the Bay of Plenty region include potential sea level rise of 0.7 m by 2070, and up to 1.6 m by 2130 against the BOP Moturiki 1953 sea level datum. The rate of sea level rise in the Bay of Plenty is around 2.12 mm/year (calculated between 1961–2018 at Moturiki) (Bell & Hannah, 2019). Low lying coastal areas are particularly threatened by rising sea levels (Nguyen *et al.*, 2022), with impacts such as submergence and erosion, flood damage, and saltwater intrusion resulting in loss of coastal wetland ecosystems (Nicholls et al. 2007). As sea levels rise, saltmarsh will be pushed from its current elevation range. Where space is available inland, saltmarsh will migrate to remain in the preferential tidal height (Figure 1, panel a). However, in many areas “coastal squeeze” will occur, where seawalls, roads, land protection (stopbanks) and other human infrastructure limit such movement (Borchert *et al.*, 2018, Swales *et al.,* 2020)(Figure 1, panel b), or natural steep topography may limit migration, termed ‘coastal narrowing’ (Figure 1, panel c). Saltmarshes have some resilience to the impacts of sea level rise due to their ability to trap and store sediments: by stabilising emergent mudflats by slowing water velocity and causing sediment deposition out of the water, the plant roots bind sediments and improve resistance to erosion, and accumulation of organic material into the soil (Cahoon *et al.*, 2021). However if sea level rises too quickly, or the sediment supply or inundation through flooding is excessive, the saltmarsh may experience stress or deterioration (McLeod *et al.*, 2011).

An additional complicating factor is the widespread increase of mangroves in the Bay of Plenty (Park 2015). Mangrove habitats occur in the upper intertidal zone, below the saltmarsh habitat. Work in Sydney Harbour has identified that mangrove surface elevation gain has matched the rate of sea level rise, thus the mangrove habitat may be stable under the current sea level rise rates, however the same was not observed in saltmarsh habitat (Rogers *et al.*, 2019). There may be landward movement of mangroves into saltmarsh habitat, which has been observed occurring across the Bay of Plenty, although this was localised to edges of the saltmarsh vegetation and channel infilling (Park, 2015). Across the Bay of Plenty there has been a total loss of 1432.9 ha of saltmarsh to reclamation (Park 2000), which represents a 60% loss of saltmarsh habitat throughout the region as a whole. The majority of saltmarsh loss occurred in Tauranga Harbour (693.4 ha) and Waihī Estuary (403.6

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[1] Carbon sequestration by marine ecosystems, such as algae, seagrass, mangroves and saltmarsh.

ha). With accelerating sea level rise coastal managers are needing to develop strategies to increase the adaptive capacity of coastal ecosystems, to ensure their survivorship for future generations (Borchert *et al.*, 2018). Options to preserve saltmarsh ecosystems include protecting and preserving inland regions, allowing for natural migration landwards; managed realignment/tidal reconnection (in cases where human infrastructure is limiting migration); or monitoring/protection to build saltmarsh resilience where topography limits migration potential.

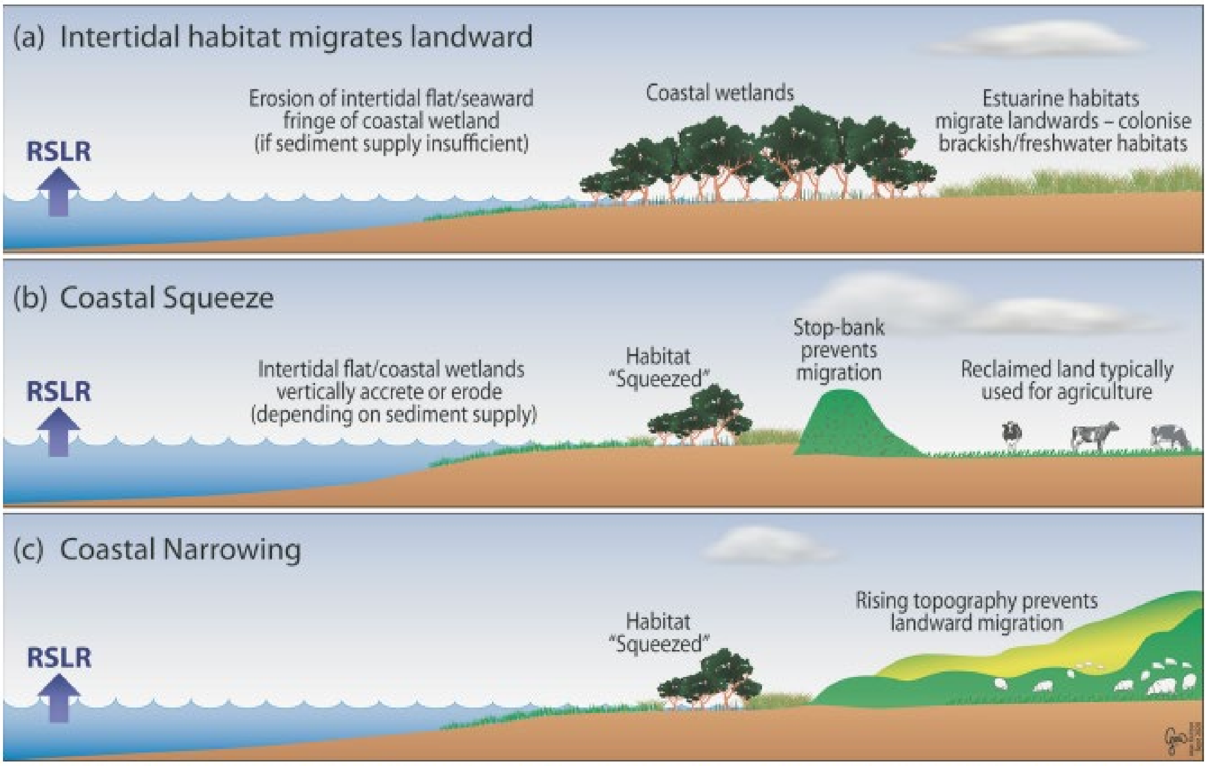

Figure 4: Potential estuarine habitat responses to relative sea level rise (RSLR): (a) habitats naturally migrate landward to displace brackish/freshwater habitats where there are no physical barriers; (b) coastal squeeze occurs where natural landward migration of estuarine habitats is prevented by hard protection structures and/or reclamation; and (c) migration is prevented by rising land topography (i.e. coastal narrowing). Adapted from Pontee (2013).

Figure 1 Potential response of saltmarsh ecosystems to rising sea levels (taken from Swales et al. 2020).

Legislative framework

There are several relevant international[2], national, and regional policy drivers which frame our response to managing saltmarsh restoration (Figure 2). Our response to international agreements is cascaded through in regulation and policy documents. Nationally, we have the Resource Management Act and four key policy statements[3] that direct the management, use, and protection of saltmarsh.

Regional planning documents include hapū/iwi management plans which generally set out ancestral connection, aspirations to restore degraded areas, and direction to protect areas of cultural significance. Department of Conservation's Conservation Management Strategies outline their priorities for regional biodiversity. Regional councils have the function of controlling the use of land for the purpose of maintaining and enhancing ecosystems in water bodies and coastal water (S30 Resource Management Act). These functions are reflected in Regional Coastal Environment Plans which local City and District Council plans must be consistent with. The Regional Coastal Environment Plan includes both the coastal marine area and adjacent land which interfaces with this environment. The objectives and policies aim to protect and/or enhance saltmarsh habitats, some of which are mapped as Indigenous Biological Diversity Areas[4]. These sites give effect to New Zealand Coastal Policy Statement Policy 11 by avoiding, remedying, or mitigating adverse effects of activities.

Current policy, including Te Mana o Te Taiao/Aotearoa New Zealand Biodiversity Strategy provides a call to action on the desperate need to start protecting and enhancing biodiversity. As part of the implementation of these international, national, and regional drivers, the BOPRC is incentivising and supporting landowners and care groups to achieve biodiversity driven restoration projects. This work is funded in accordance with the Environmental Programme Grants Policy (BOPRC, 2021), which provides a mechanism to enact the statutory obligations under the RMA to protect and restore ecological integrity at biodiversity sites.

Public participation in environmental and habitat protection projects is often limited due to time and financial restraints; however, incentives can remove these barriers whilst fostering community goodwill and joint public good outcomes. Some of the financial support provided through the Environmental Programme Grants Policy can include plant purchases, pest plant and animal control, ecological assessments, restoration of indigenous fish passages, and re-establishment of estuarine coastal wetlands. The grants policy provides for restoration and enhancement at Priority Biodiversity Sites (representing a full range of the regions indigenous ecosystem types) and re-establishment of estuarine coastal wetlands. Many of these projects include significant financial contribution into marginal estuarine habitats, such as saltmarsh, thus it is important to consider the potential longevity of restoration projects in the face of climate change and sea level rise.

There is the potential for blue carbon credits to be marketed at a local and national level for voluntary carbon off-setting (Weaver et al. 2022), and research in this space is ongoing. This may enable coastal blue carbon (such as saltmarsh restoration projects) to function as a funding mechanism for new restoration projects.

[2] Aotearoa is a signatory to the United Nations Convention on Biological Diversity and Convention on Wetlands of International Importance.

[3] New Zealand Coastal Policy Statement, National Policy Statement for Freshwater Management, the proposed National Policy Statement for Indigenous Biodiversity and Te Mana o te Taiao – The Aotearoa New Zealand Biodiversity Strategy 2020.

[4] Living organisms or plants that occur naturally in New Zealand and their associated ecosystems.

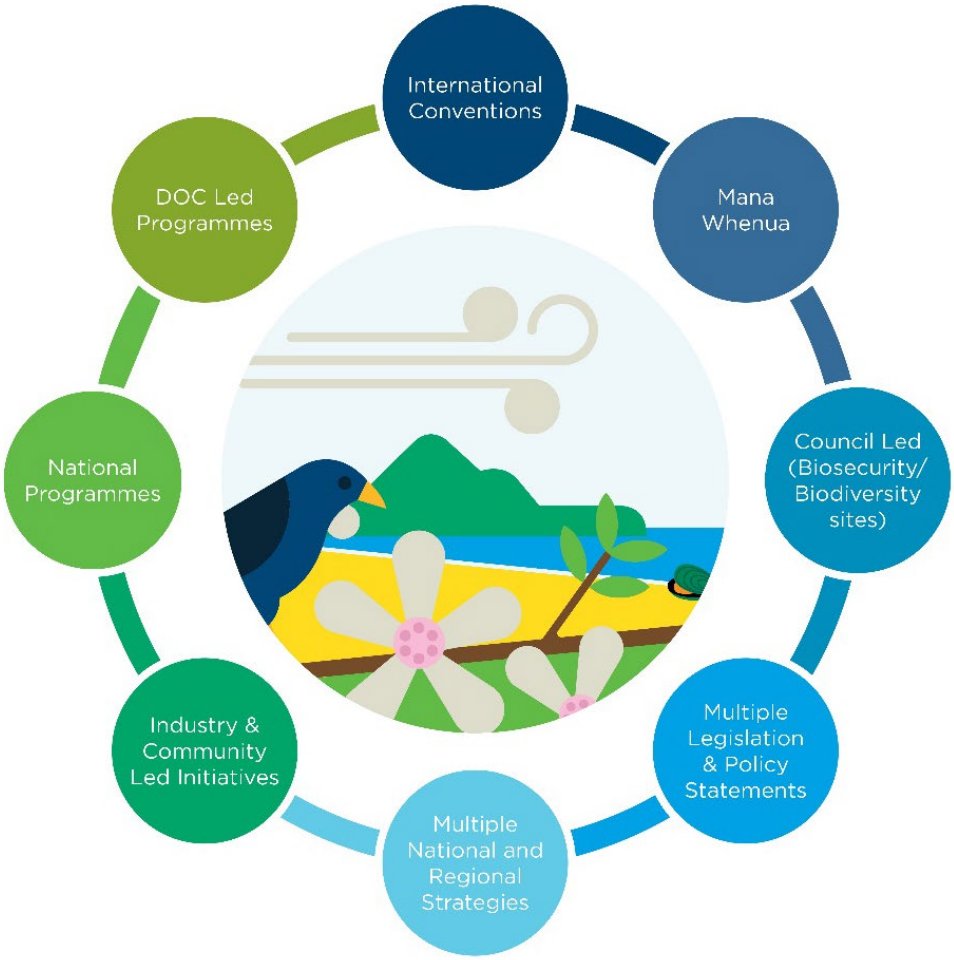

Figure 2 Policy drivers that link to restoration of saltmarsh habitats in New Zealand.

Purpose/Take

Restoration and enhancement of saltmarsh habitat is a key goal for regional council, to meet regional and international obligations outlined above. To maximise the adaptive capacity of coastal wetlands to sea level rise, there is a need to identify, manage and protect low lying lands that could allow for landward migration of saltmarsh ecosystems and support coastal adaptation. To support this work, we have undertaken a regional assessment of elevation profiles of coastal land to identify potential locations for undertaking saltmarsh restoration projects. This work will support informed decision making on where to prioritise restoration and/or managed realignment[5] of saltmarsh habitats, where we expect higher potential impacts of sea level rise.

The project goals include:

- Map current lowland habitat in suitable elevation range for saltmarsh,
- Investigate longevity of saltmarsh restoration projects in future sea level rise scenarios,
- Identify future migration pathways and restoration opportunities.

We present two case study sites that have undergone restoration activities to discuss the implications and management options for sea level rise identified in these locations.

[5] The creation of saltmarsh via removal of coastal protection, allowing flooding to an area previously protected from flooding.

Methodology/Huarahi

The initial approach taken to investigate future saltmarsh in the Bay of Plenty Region is simple and readily repeatable using existing datasets, with a similar approach used in another New Zealand study (Stevens & Southwick, 2021), and other international studies (Di Nitto *et al.*, 2014, Enwright *et al.*, 2015, Borchert *et al.*, 2018). While there are several refinements that can be undertaken before commencing any restoration works, the methodology has proved useful to support initial discussions and planning focusing on biodiversity goals and saltmarsh restoration. The spatial analysis made use of two key existing datasets: a region wide elevation model (LiDAR, 2011) and Manaaki Whenua's Land Cover Database (LCDB, version 5).

The Bay of Plenty region was split into nine catchments for assessing the saltmarsh elevation range, which align with catchment surface drainage areas (Figure 3).

Figure 3 *The nine surface drainage catchments that saltmarsh elevation range was mapped.*

Field GPS surveys, LiDAR and aerial photography observations of existing saltmarsh were used to define the 'current elevation range' for saltmarsh habitats throughout the Bay of Plenty region. Surveys of three representative saltmarsh sites were conducted across the Bay of Plenty using a Trimble R12 GPS between September to October 2022. Through the use of RTK surveying, we were able to achieve sub-centimetre accuracy in elevation and position. These levels are referenced to the LINZ network and local BOPRC benchmarks which can be converted to Moturiki datum or NZVD2016. This data was compared to the LiDAR dataset to see how effective our LiDAR performed across the existing saltmarsh habitats. Using this methodology, the current lower and upper extent of saltmarsh was identified to fall between +0.8 m and +1.2 m Moturiki Reduced Level (RL) (or +0.51 m to +0.91 m NZVD2016). This captures a number of key saltmarsh ecosystems including herbfield, rushland, shrubland and sedgeland communities. The region wide elevation model was then utilised to identify all land within this current saltmarsh elevation range. Using elevation to map potential saltmarsh habitat enables us to identify areas where saltmarsh would be expected, however, due to hydrological barriers (e.g., stopbanks, bunds, drainage schemes) saltmarsh is not currently present.

After saltmarsh elevation ranges were identified, Manaaki Whenua's Land Cover Database (LCDB, version 5) was used to distinguish between land cover types within each selected elevation range. A set of simplified landcover categories were used based on grouping of the classification in the LCDB:

- *Indigenous cover*: alpine grass/herbfield, broadleaved indigenous hardwoods, fernland, flaxland, indigenous forest, landslide, mānuka and/or kanuka, matagouri or grey scrub, sub alpine shrubland, tall tussock grassland
- *Water*: estuarine open water, lake or pond, not land, river
- *Exotic cover*: gorse and/or broom, mixed exotic shrubland
- *Exotic forest*: exotic forest, forest – harvested
- *Other*: gravel or rock, sand or gravel
- *Wetland*: herbaceous freshwater vegetation, herbaceous saline vegetation, mangrove,
- *Pasture*: high producing exotic grassland, low producing grassland
- *Horticulture*: deciduous hardwoods, orchard, vineyard, or other perennial crop, short-rotation cropland
- *Urban*: built-up area, surface mine or dump, transport infrastructure, urban parkland/open space.

To model potential changes to saltmarsh elevation ranges due to climate change, six near future absolute sea level rise scenarios were selected (from +0.1 m to +0.6 m) and corresponding 'future elevation ranges' for saltmarsh were determined. The scenarios provide an estimate of potential future sea levels within the next 30 to 80 years depending on our carbon emissions trajectory. It was assumed that the current saltmarsh elevation thresholds would remain constant into the future, therefore the potential impact of sea level rise on saltmarsh was assessed by adding the estimated sea level rise value (e.g., +0.2 m or +0.6 m) to the upper and lower current elevation ranges for saltmarsh. For example, an elevation range of +1.0 m to +1.4 m Moturiki RL was selected under a +0.2 m scenario and +1.4 m to +1.8 m Moturiki RL for the +0.6 m scenario. We assumed no vertical accretion of saltmarsh due to a lack of regional data.

The current extent of saltmarsh was assessed using an internal BOPRC layer "Wetland Extent – Mapping Project", which delineated freshwater and estuarine wetlands across the Bay of Plenty using 2015/2017 aerial photography (see Fitzgerald & Price 2018 for methodology). We used the classification layer "wetland system" and "estuarine" to extract the current estuarine wetland areal extent, excluding the wetland structure "mangrove" to remove purely mangrove ecosystems (which cover a wide area in the Bay of Plenty), but retain mangrove-saltmarsh mixed ecosystems. These various processing steps allowed us to identify the current saltmarsh habitat extent, current potential area available for saltmarsh restoration across land use types and identify potential future migration pathways and saltmarsh response to sea level rise scenarios.

A number of example site locations are provided as spatial maps in the text and in the appendix, whilst it is assumed that the GIS files will be used for more detailed site-specific examination.

Spatial mapping assumptions

These maps were produced for internal use to support strategic planning and discussions on priority locations for saltmarsh restoration, before undertaking further site-specific investigations. As such, there are several assumptions that need to be clearly acknowledged before utilising these data sets. No editing or further validation has occurred on these datasets or spatial layers, so these must be considered only as “potential” sites for saltmarsh restoration based purely on elevation profiles identified through LiDAR.

We selected the 2011 LiDAR dataset as it was the only region wide elevation model that was converted to the Moturiki Datum, and therefore may not align with some locations in the region that have undergone significant alterations e.g. in Maketū with the Kaituna River re-diversion. Site based assessments will be required before considering restoration programmes.

No modelling of saltmarsh dynamics was included in this work, such as the vertical accretion of saltmarsh. Increasing sediment loads are predicted for the Bay of Plenty region by SEDNET modelling (Vale et al. 2021), which may support increased elevation capital of existing saltmarsh habitats and support climate resilience. A programme of work is underway with Future Coasts Aotearoa, which is aiming to address these modelling complexities, with case study sites located at Athenree and Ōhiwa in the Bay of Plenty. Additionally, we have recently installed Rod Surface Elevation Tables (RSETs) into saltmarsh and mangroves at these same sites, to gather data on relative elevation gain or loss in these habitats.

No hydrodynamic, salinity or sediment transport modelling was conducted in this work. As sea levels rise, and the intertidal zones decrease, it is expected that the hydrodynamics and sediment transport mechanisms of the harbour will also shift. Hydrology at site locations will need to be assessed prior to restoration activities, as there may be a mix between fully saline sites and freshwater influenced habitats identified in the potential saltmarsh elevation layers. Some of the locations identified will not have direct water flow influence (in particular for the Rangitāiki and Whakatāne surface drainage catchments) and are located far inland, suggesting restoration will be focused on freshwater wetland species rather than saltmarsh. For these locations results can be compared to the GIS outputs of the BOPRC Coastal Inundation Project, to identify areas currently connected vs disconnected from the ocean and identify critical tipping points where the water will overtop existing elevation barriers.

Results/Ngā Otinga

Assumptions of saltmarsh elevation range

LiDAR, ground GPS surveys and aerial photography was used to confirm the current elevation range of +0.8 m to +1.2 m Moturiki RL for existing saltmarsh habitat. Across the region there are numerous examples of saltwater influence on marginal farmlands, exhibited in Figure 4 below. The upper level of saltwater influence aligns well with the upper potential limit for saltmarsh habitat, and in some instances identifies land that sits well below that range, such as in the Rangitāiki Catchment.

This mapping has only identified the suitable elevation range, and not whether the sites are suitable from a hydrology aspect. If the site has significant freshwater inflow (or is located far from an ocean connection), most of the wetland in that range would likely be freshwater wetland, rather than saltmarsh. Site specific investigations will be required in all regions prior to beginning restoration projects.

Elevation surveys were conducted across three estuaries in the Bay of Plenty, including Tauranga Harbour (Waikareao), Ōhiwa Harbour (Nukuhou) and Waiōtahe Estuary (Waiōtahe) (Figure 5). The saltmarsh elevation results are displayed in Figure 6, along with the dominant saltmarsh species observed. The surveys confirm the small elevational range of saltmarsh across the Bay of Plenty, between +0.8 m to +1.2 m Moturiki RL. The dominant species across these surveys included oioi (*Apodasmia similis*), sea rush (*Juncus kraussii*), and saltmarsh ribbonwood (*Plaginathus divaricatus*) present at the edges. Mangrove shrubland/forest was present below 0.8 m Moturiki RL at sites that contained mangroves (Tauranga and Ōhiwa).

The field GPS surveys confirmed that there is some variation in the elevation detected by LiDAR, and the actual elevation height. Due to the high density of saltmarsh vegetation, LiDAR can return false ground returns (Chassereau *et al.*, 2011, Hladik & Alber, 2012) making the site generally appear higher in elevation. A linear regression between LiDAR and ground GPS surveys at three saltmarsh sites show that the average variation was 0.24 m (Appendix 1, Figure 16). There was higher variability in Waiōtahe, likely due to the large number of logs and debris present within the saltmarsh from the nearby river inflow. This shows that for existing saltmarsh habitats, the LiDAR potential saltmarsh elevation ranges may not accurately delineate existing saltmarsh habitats, thus the BOPRC wetlands GIS layer will be used to account for these areas. This will not have an impact on identifying marginal habitats for restoration activities.

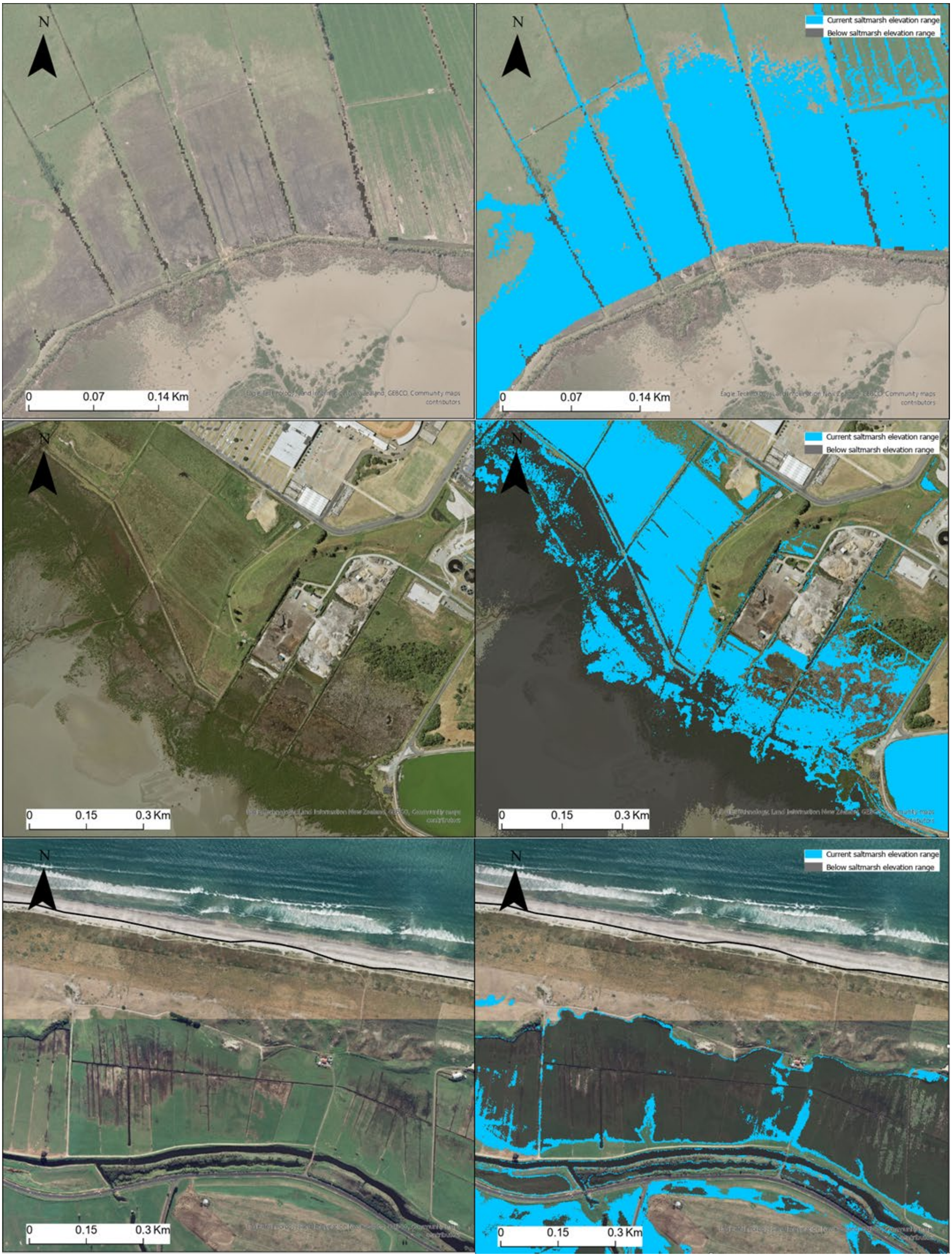

Figure 4 *Visual evidence of saltwater intrusion/tidal inundation at sites across the Bay of Plenty. The 0.8 m–1.2 m Moturiki RL regions are shown in blue, and areas below 0.8 m Moturiki RL in grey.*

Figure 5 *Site locations for the RTK GPS elevation survey in the Bay of Plenty. Waikareao sites A and B in Tauranga Harbour. Nukuhou sites C and D in Ōhiwa Harbour. Waiōtahe site E in Waiōtahe Estuary.*

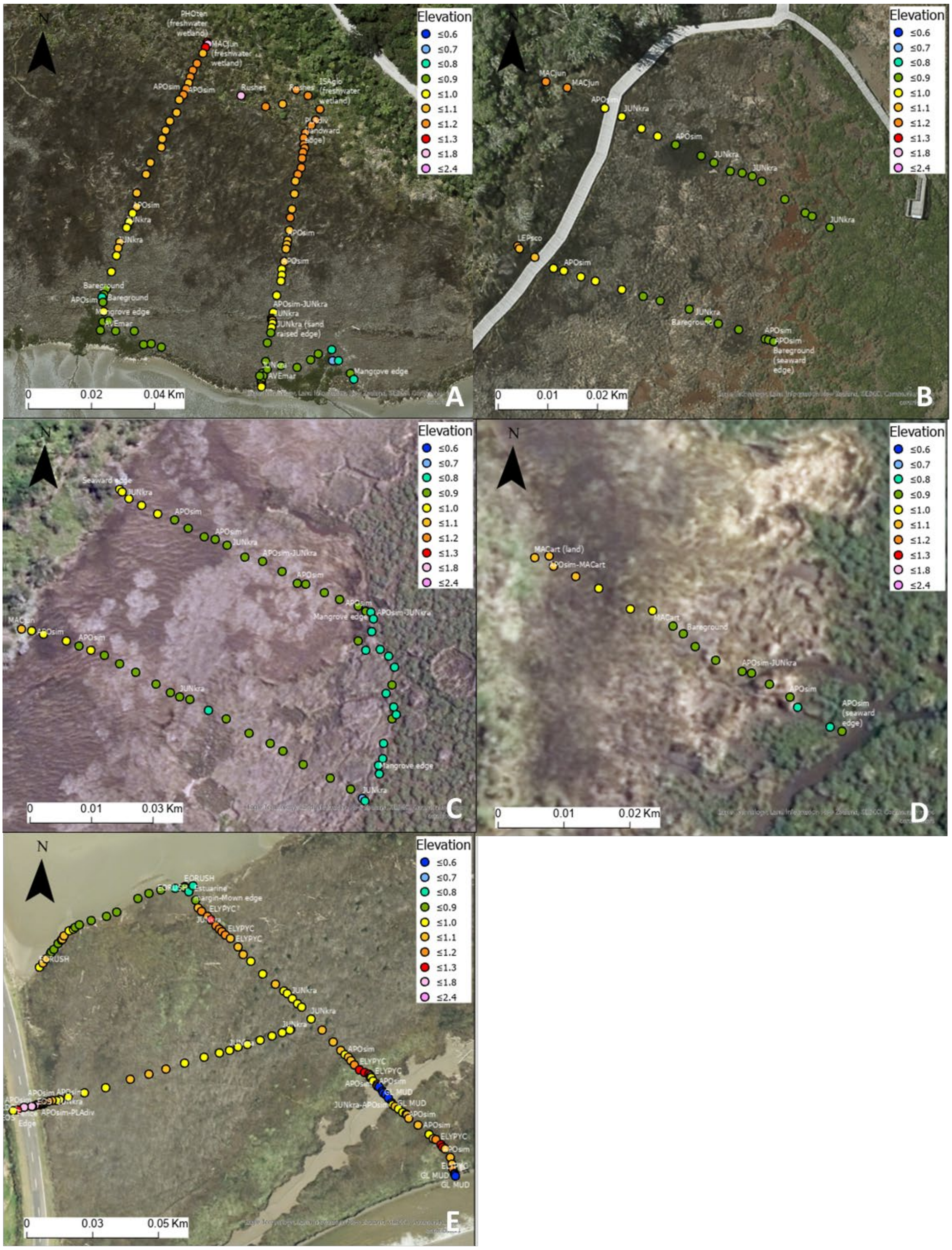

Figure 6 *Elevation transect survey in Waikareao (A-B), Nukuhou (C-D), and Waiōtahe (E) from saltmarsh lower edge/mangrove interface to upper freshwater wetland interface/upper elevation limit (see Figure 5 for site locations). Dominant estuarine wetland species are noted where transitional boundaries occur. JUNkra = Juncus kraussii (sea rush). APOsim = Apodasmia similis (oioi/jointed wire rush). MACjun = Machaerina juncea (bare twig rush). ISAglo = Isachne globosa (swamp millet). LEPsco = Leptospermum scoparium (mānuka). PHOten = Phormium tenax (harakeke/flax). MACart = Machaerina articulata (jointed twig rush). Exotic species; ELYpyc = Elytrigia pycnantha (Sea couch).*

Current estuarine wetlands extent

Estuarine wetland extents across the Bay of Plenty has been mapped in 2018 as part of a broader programme mapping wetlands regionwide. This mapping identified 891.7 ha of saltmarsh[6] wetland class[7] (excluding mangrove structural class) (Table 1). Most of the saltmarsh is held within the Tauranga catchment (600 ha), although a proportion of this includes a herbfield+mangrove mix (135 ha), thus overinflates the actual coverage of saltmarsh in the Tauranga region. Ōhiwa holds the second largest area at 141 ha. Rangitāiki and Waitahanui catchments currently hold no mapped estuarine wetlands.

Table 1 Total area (hectares) of existing saltmarsh and structural class[8] mapped in the BOPRC 'Wetland Extent Mapping Project' layer across surface drainage catchments.

	Grassland	Herbfield	Reedland	Rushland	Shrubland	Sedgeland	Other	Total saltmarsh area
Tauranga	-	550.6	-	6.6	7.3	-	35.2	599.7
Kaituna	-	20	-	-	-	-	0.7	20.7
Pongakawa	-	82.1	-	-	-	-	-	82.1
Waitahanui	-	-	-	-	-	-	-	-
Rangitāiki	-	-	-	-	-	-	-	-
Whakatāne	0.7	-	3.9	2.5	-	2	6.6	15.7
Ōhiwa	1.4	8.7	-	56.8	40	0.6	33.8	141.3
Waioeka	13.5	-	-	16.7	-	-	-	30.2
Motu	-	-	-	2	-	-	-	2
Regionwide	**15.6**	**661.4**	**3.9**	**84.6**	**47.3**	**2.6**	**76.3**	**891.7**

[6] Saltmarsh - estuarine habitats of mainly mineral substrate in the intertidal and subtidal zones, but also including habitats in the supratidal and in the inland saline hydrosystem, includes the full range of vegetation structures typical of the intertidal zone, from herbfield to rushland, scrub, and mangrove scrub or low forest (Johnson & Gerbeaux 2004).

[7] Wetland class - is governed by distinctive combinations of substrate factors, water regime, and the consequent factors of nutrient status and pH (Johnson & Gerbeaux 2004).

[8] Structural Class - is concerned with the general growth form or structure (physiognomy) of the vegetation, or the leading type of ground surface. (Johnson & Gerbeaux 2004).

Current potential restoration area in suitable saltmarsh elevation

Across the Bay of Plenty there is a total of 4888 hectares of land that falls within the 0.8 m–1.2 m Moturiki RL preferred elevation range for saltmarsh habitat (Table 2). There are a variety of land use types that fall within this range, such as forestry, horticulture, pasture and urban land uses. For most catchments, the majority of the land use within these areas is in pasture (67%) (Figure 7), with 3288 hectares within a suitable elevation height for saltmarsh.

There is a significant portion of land that falls below the suitable elevation height for saltmarsh which is currently in alternative land uses (Table 2), such as shown below in the Kaituna Catchment (Figure 8). There are significant areas similar to this across the Bay of Plenty, which are currently maintained as viable lowland pasture due to pumping and drainage schemes. These areas cover over 6000 hectares across the Bay of Plenty, with expansive regions present in the Rangitāiki, Whakatāne, Pongakawa and Kaituna catchments. Spatial maps for the remainder of the Bay of Plenty are displayed in Appendix 2.

The surface drainage catchments with the largest area of potential saltmarsh area within the pasture land-use type include Rangitāiki (786 ha), Whakatāne (760 ha), Kaituna (690 ha), Tauranga (376 ha) and Pongakawa (331 ha). Much of the area mapped in the Waitahanui Catchment is along the open coastline/sand banks and is unlikely to be suitable locations for saltmarsh. Also, large areas of land within the Rangitāiki to Whakatāne surface drainage catchments are well inland of potential saltwater influence and may be more suitable for freshwater wetland restoration (highlighting the requirement for site specific hydrology assessments).

Table 2 Current potential saltmarsh area (hectares) between 0.8 m–1.2 m Moturiki RL across simplified land use types (LCDB v5, see Methods). Area below 0.8 m Moturiki RL and outside of the estuary margins (to exclude current estuarine mudflats) are shown in the last column.

	Exotic cover	Exotic Forest	Horticulture	Indigenous cover	Other	Pasture	Urban	Water	Wetland	Total potential area	Area below 0.8 Moturiki RL
Tauranga	5.3	26.9	24.6	14.3	3.6	376	33.4	59.1	491	**1034**	342
Kaituna	11	0.6	24	1.9	0.6	690	0.3	20.6	168	**918**	970
Pongakawa	1.5	0.4	0.2	0.3	3.7	331	2.1	5.2	77.9	**422**	1539
Waitahanui	0	0	0	0	3.4	0.6	0	0	0	**4.0**	4
Rangitāiki	1.8	1.5	42.7	1.6	0.5	786	0.5	35.7	31.6	**902**	1707
Whakatāne	0.6	1.0	232	2.0	0.1	760	15	17.8	10.2	**1039**	1049
Ōhiwa	0.2	0.5	25	5.8	5.8	213	1.4	33.5	79.6	**365**	361
Waioeka	0	0.2	20.5	1.6	0.8	80.2	4.7	4.2	10.9	**123**	250
Motu	0.1	0.2	2.0	3.1	5.7	50.6	0	16.1	2.1	**79.9**	67
Regionwide	**20.4**	**31.3**	**371**	**30.6**	**24.1**	**3288**	**57.4**	**192**	**872**	**4888**	**6288**

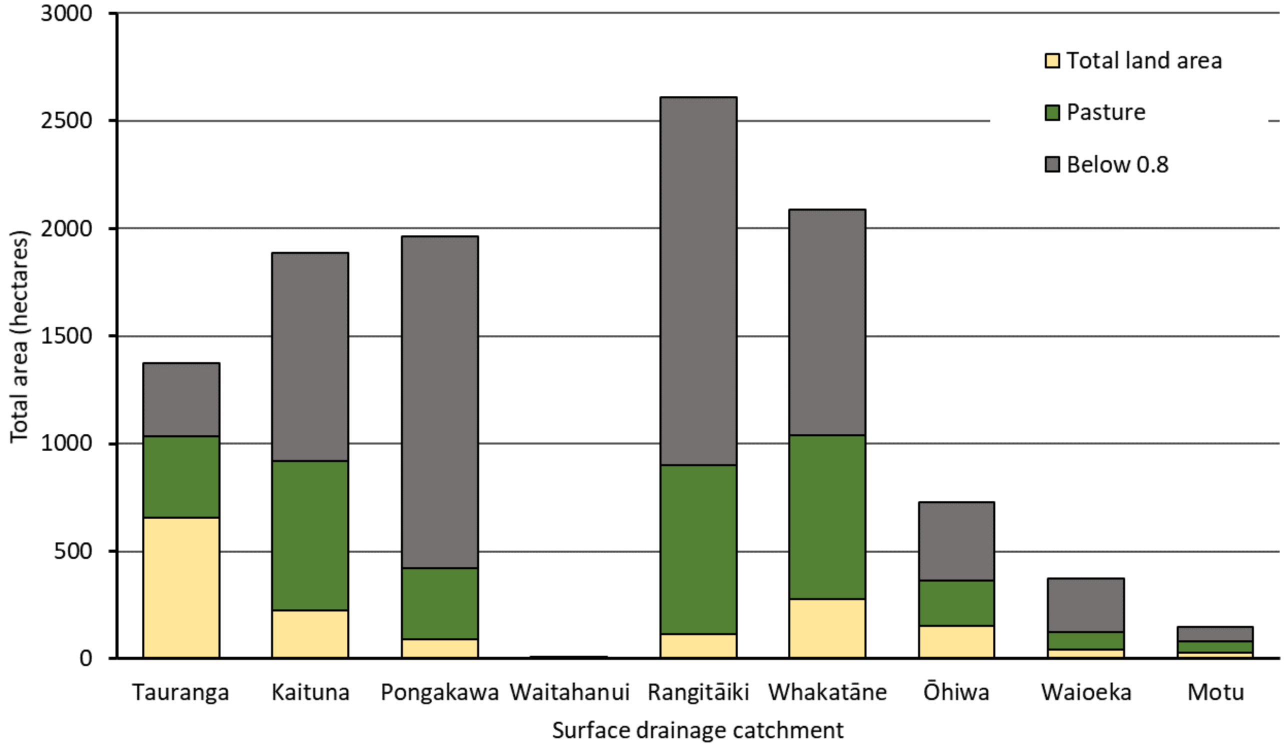

Figure 7 *Current potential saltmarsh area (hectares) in 0.8 m–1.2 m Moturiki RL (yellow), the potential saltmarsh area within 'pasture' land use (green), and the area below 0.8 m Moturiki RL (grey).*

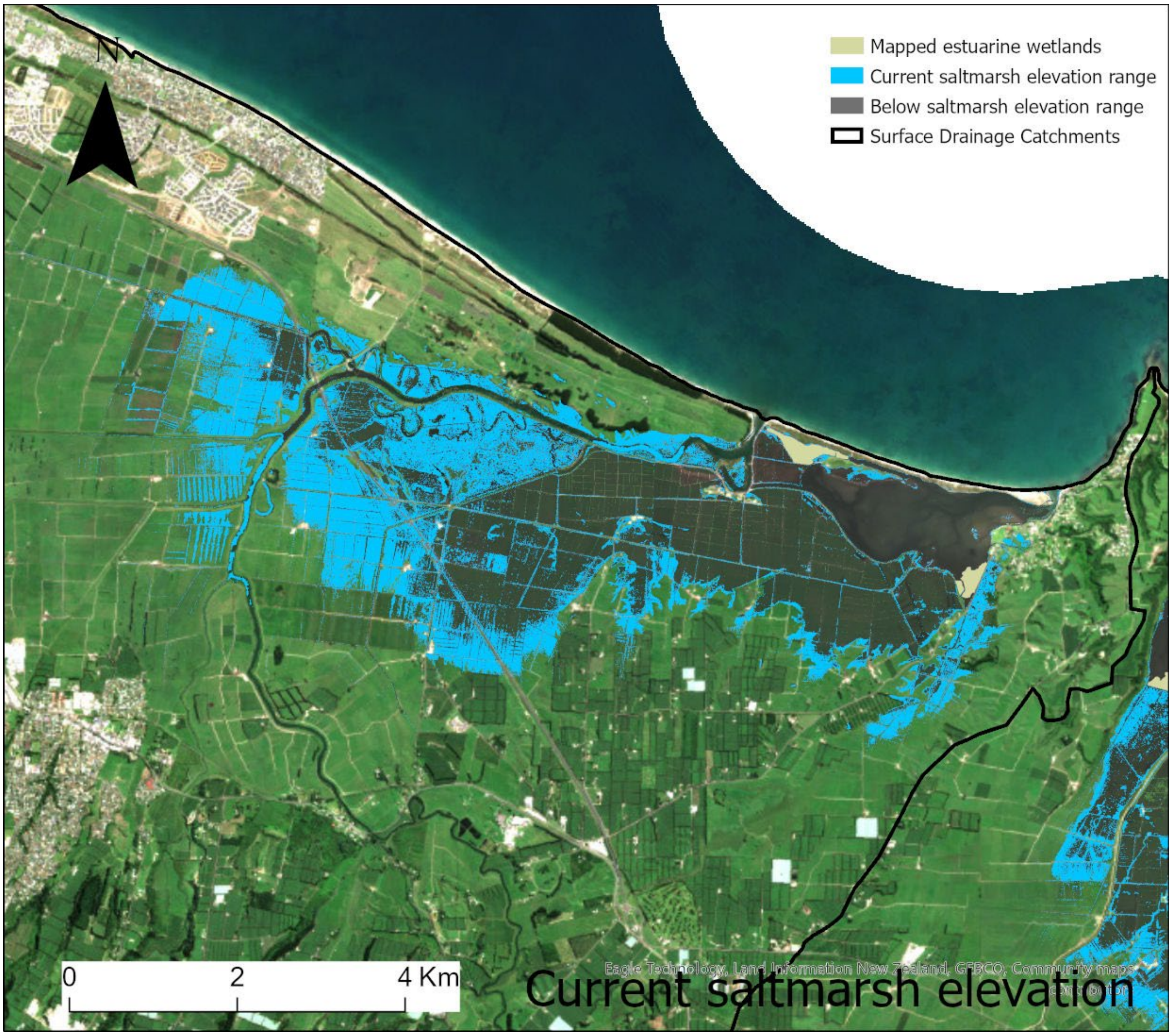

Figure 8 *Current potential saltmarsh elevation range in the Kaituna Catchment (blue), with current mapped estuarine wetlands in green, and areas of land below the elevation range in dark grey.*

Future sea level rise scenarios and saltmarsh migration

With sea level rise scenarios, overall, we see a decrease in available land with suitable elevation for saltmarsh habitat across the Bay of Plenty, from 4888 to 4490 hectares from current state to 0.6 m of sea level rise (Table 3, Figure 9). In some catchments we see potential for expansion of saltmarsh habitat, including Tauranga, Waitahanui, Rangitāiki, and Motu. In some catchments we see examples of coastal squeeze, where the total area decreases, including Kaituna, Pongakawa, Whakatāne and Ōhiwa.

As sea level rises to 0.2 m and 0.6 m, it becomes clear where the large migration pathways exist to support saltmarsh longevity into the future (Figure 9, and Appendix 3). An example of Kaituna Catchment is shown in Figure 10, where there are large areas of lowland and possible migration pathways for saltmarsh as sea levels rise. Historically large wetlands and saltmarsh was present in the Kaituna lowlands before drainage for pasture after the early 1940s, however, these low elevation areas remain, and may become a migratory pathway for saltmarsh as sea levels increase.

Table 3 Potential saltmarsh area (hectares) in elevation ranges across sea level rise scenarios split by surface drainage catchment.

	Current	0.1 m	0.2 m	0.3 m	0.4 m	0.5 m	0.6 m
Tauranga Harbour	1035	1054	1094	1180	1243	1266	1266
Kaituna	918	859	776	702	636	597	592
Pongakawa	422	365	336	320	307	293	291
Waitahanui	4	5	6	8	9	10	11
Rangitāiki	902	923	952	999	1026	1034	1054
Whakatāne	1039	1085	1074	1026	929	824	759
Ōhiwa	365	320	299	294	284	267	252
Waioeka	123	128	129	128	126	122	124
Motu	79.9	102	118	129	134	136	142
Regionwide	**4888**	**4841**	**4785**	**4787**	**4694**	**4547**	**4490**

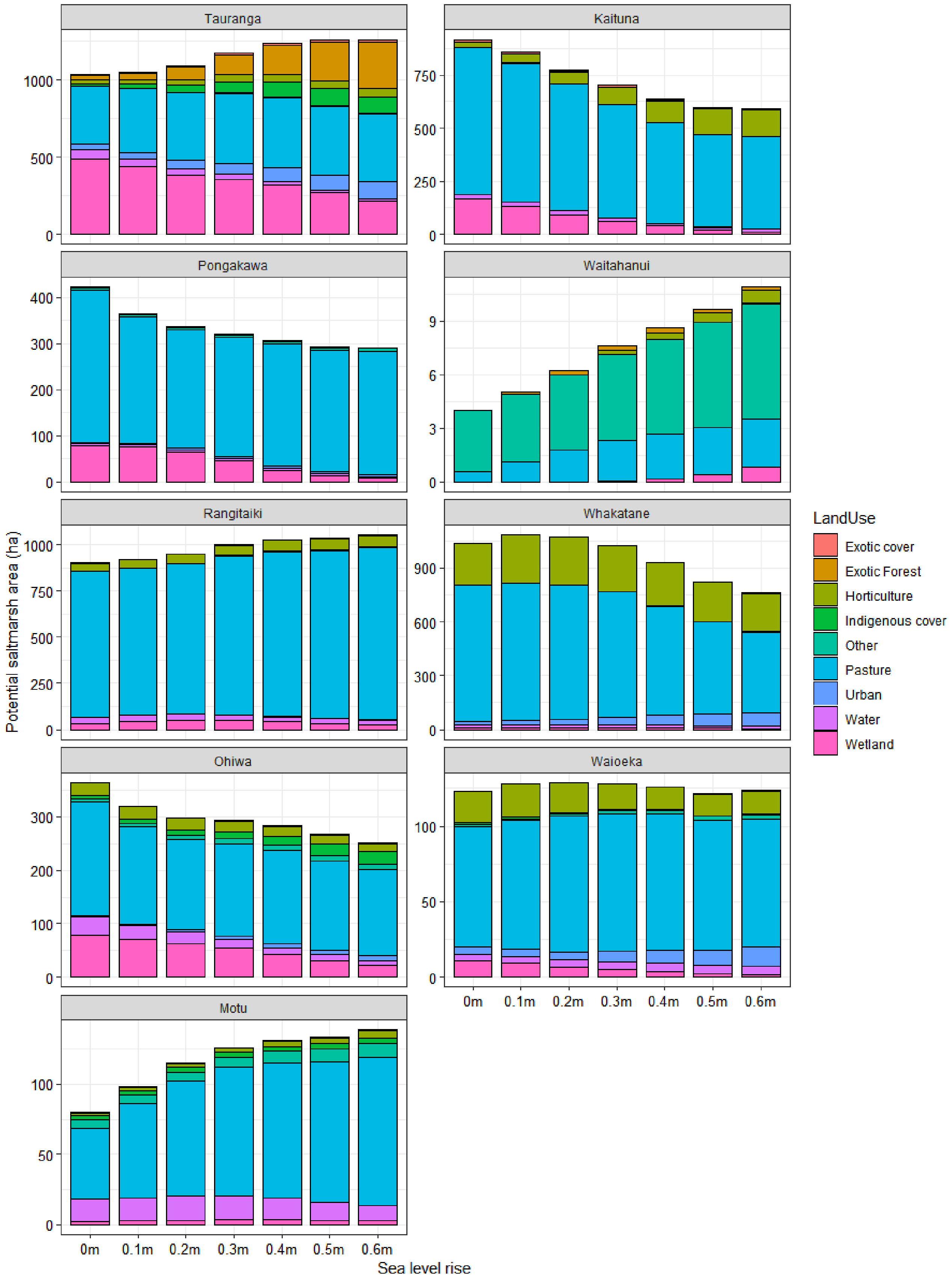

Figure 9 *Potential saltmarsh area (hectares) across sea level rise scenarios, split by surface drainage catchment and land use cover (LCDB v5).*

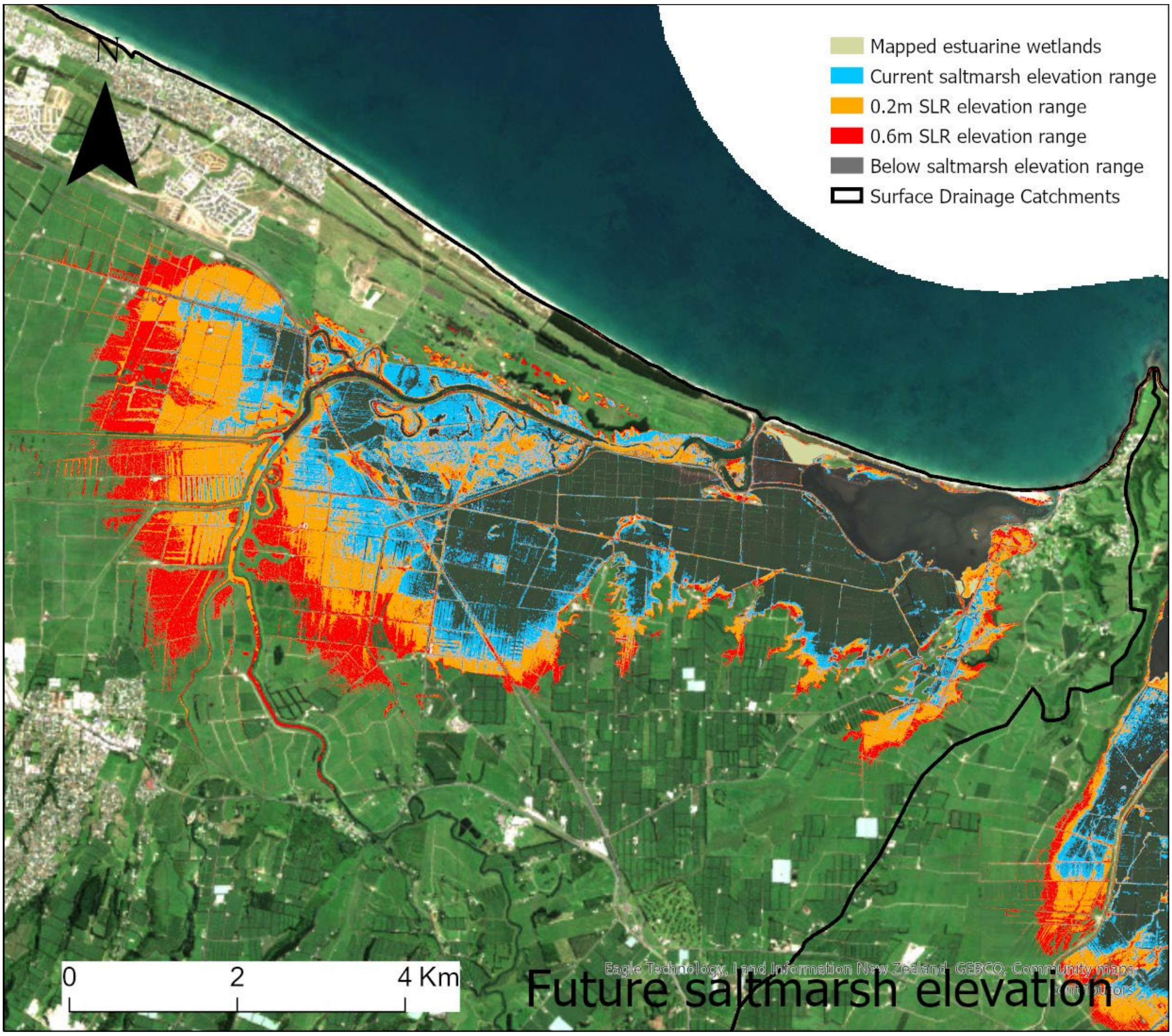

Figure 10 *Future potential saltmarsh elevation range in the Kaituna surface drainage catchment (with current elevation in blue, 0.2 m SLR in orange, and 0.6 m SLR in red), with current mapped estuarine wetlands in green, and areas of land below the current elevation range in dark grey.*

Saltmarsh restoration case studies

The Bay of Plenty Regional Council has conducted numerous restoration projects to create saltmarsh on marginal farmland. Two case studies are explored to show two likely scenarios when planning for saltmarsh restoration with the impacts of sea level rise (Figure 11). Athenree Wildlife Refuge Reserve shows an example of potential migration and expansion, whilst Wainui Repo Whenua provides an example of coastal squeeze and engineered management solutions.

Figure 11 Tauranga Harbour (A) and the two case study sites; Athenree Wildlife Refuge Reserve (B) and Wainui Repo Whenua (C).

Athenree Wildlife Refuge Reserve

The Waiau Wetland complex once extended over an area of ~300 ha behind the now township of Waihī Beach and up the lower reaches of Waiau River (Figure 12). The wetland consisted of a mixture of palustrine and estuarine environments, providing significant habitat for native species and an important resource for tangata whenua. By the early 2000's, extensive drainage for agricultural production had reduced the wetland extent to ~30 ha, with areas of estuarine saltmarsh and mangrove shrubland remaining around the Waiau River mouth.

Figure 12 Athenree Wildlife Refuge Reserve and Steele Road Wetland showing historical wetland coverage between 1942-1950, current extent in 2021. 2022 shows the upper wetland out towards the ocean.

In 2006, the late Snow Brown bequeathed 26 ha of pasture to Department of Conservation specifically for restoration and the Athenree Wildlife Refuge Reserve was gazetted in 2013. A collaborative restoration is being undertaken between BOPRC, Department of Conservation, Western Bay of Plenty District Council, Te Whānau o Tauwhao ki Ōtāwhiwhi, Ngāti te Wai, and Waka Kotahi. Significant restoration has been undertaken on the portions adjacent to the existing saltmarsh. Tidal inundation has been restored by removing flood protection structures and brackish ponds for wading bird species have been created in areas of higher elevation. While considerable planting has been undertaken in the higher areas, tidal areas have reverted naturally to sea rush, oioi, saltmarsh ribbonwood and a range of estuarine herbs.

The most recent project extends the restoration efforts to a 6 ha portion of the Athenree Reserve. The objective is to provide a diverse range of wetland habitat types including potential inanga rearing habitat. The site contains a range of elevations with much of the site being at or above the natural saltmarsh range, so a series of ponds and channels have been created to maximise the area of potential saltmarsh restoration. Remaining higher ground areas are expected to transition to saltmarsh gradually under future sea level rise scenarios.

The current elevation range for saltmarsh aligns well with the existing wildlife reserve and coverage of saltmarsh and mangrove (Figure 13) and includes some areas of farmland that is protected from tidal influence. As sea level rises to +0.2 m, we see an increase in the potential elevation range available for saltmarsh into an area donated for restoration activities, whilst most of the existing saltmarsh remains in a suitable elevation range. As sea level increases to +0.6 m, there may be some significant losses of saltmarsh through the existing Athenree Reserve, however, there remains space inland for migration to occur. The reconnection of hydrology to the area has provided a protected migration pathway for saltmarsh to move into.

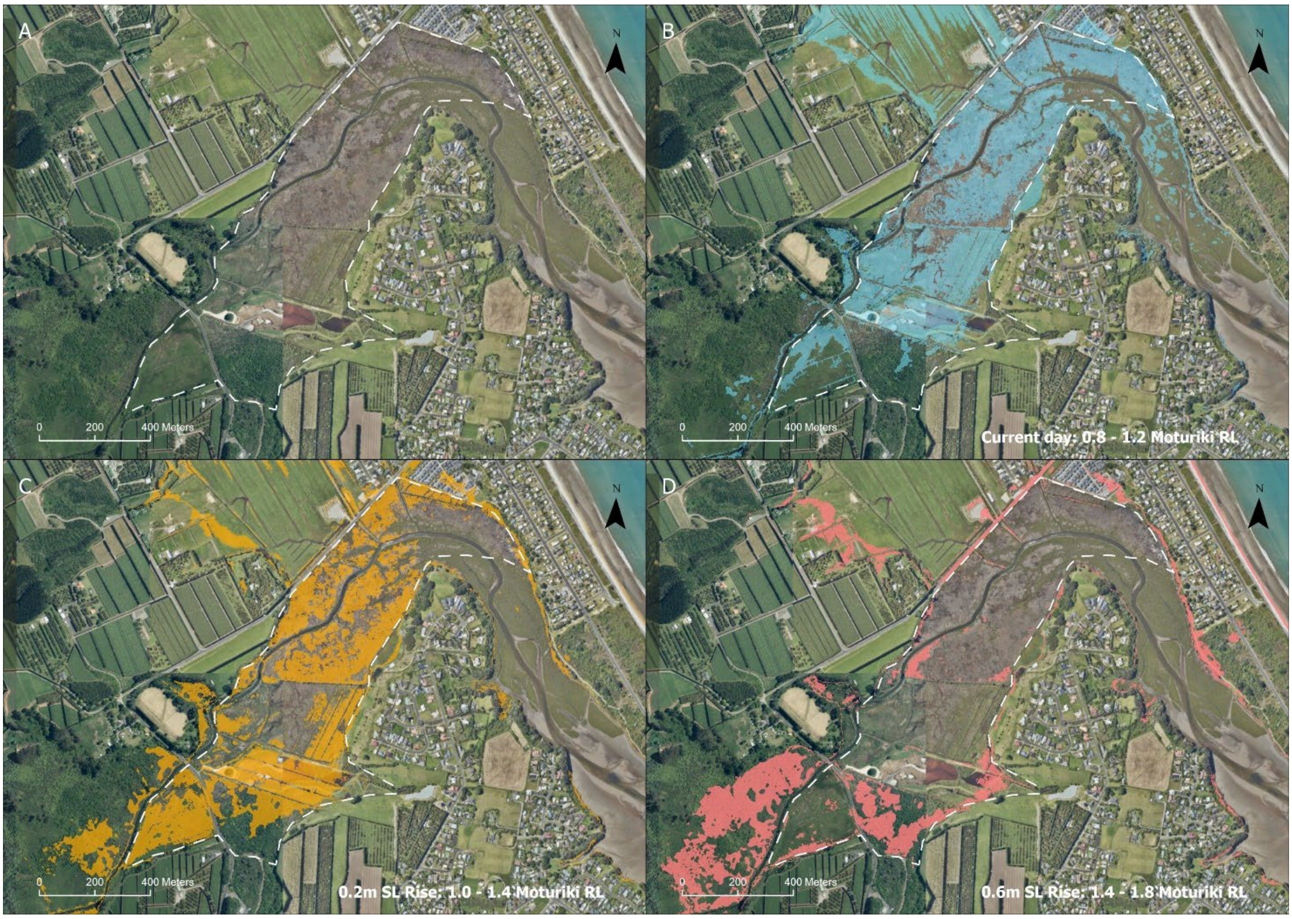

Figure 13 A: Athenree Wildlife Refuge Reserve and Steel Road Wetland (white dashed outline). B: Current day potential saltmarsh elevation range (blue). C: +0.2 m SLR elevation range (yellow). D: +0.6 m SLR elevation range (red).

Wainui Repo Whenua

Wainui Repo Whenua is 20 ha of BOPRC owned land, which is undergoing restoration from marginal pasture back to saltmarsh habitat, in partnership with Pirirākau hapū and Ngāi Tamawhariua. The area was historically saltmarsh and mangrove habitat before ~1960, when it was converted for pastoral farming, then summer grazing (Figure 14). Several culverts have since been installed which restore hydraulic connectivity between the Tauranga Harbour margin and the upper Wainui River, which was modelled to maximise the potential of the land to support saltmarsh. The restoration plan aims to plant two broad estuarine saltmarsh community types, the 'rush community' (oioi and searush) and 'saltmarsh ribbonwood community' (ribbonwood). Since planting has begun, the site has been dominated by a bachelors button community (*Cotula coronopifolia*), and high bird and fish diversity has returned to the wetland (including the Kōtuku, white heron).

The majority of site is not suited for saltmarsh restoration with based on its current elevation, thus, to provide for saltmarsh restoration at this location in its current elevation range, hydrodynamic modelling was utilised prior to restoration to identify the number of culverts and size required to obtain suitable water elevations for saltmarsh. Future SLR scenarios predict the site won't support saltmarsh (Figure 15) and indicate a squeeze will occur due to limited space for migration of saltmarsh. Although the saltmarsh elevation range is limited in future SLR scenarios, due to the water connection being restricted through numerous culverts, the hydrology at the site may provide some resilience to potential sea level rise changes and opportunities for tidal management.

This highlights that the utilisation of the future saltmarsh elevation range prior to restoration beginning may have dictated a modified approach at this site. This may have involved allowing a natural community to re-establish (i.e., an expansion of the mangrove habitat or conversion to mudflats), rather than attempting the long-term rehabilitation of saltmarsh habitat which will require active management. The two future sea level rise scenarios highlight additional areas of land where saltmarsh may begin to migrate into as water rises, and these zones can be prioritised for restoration activities or early retirement of land to support a natural inland migration process.

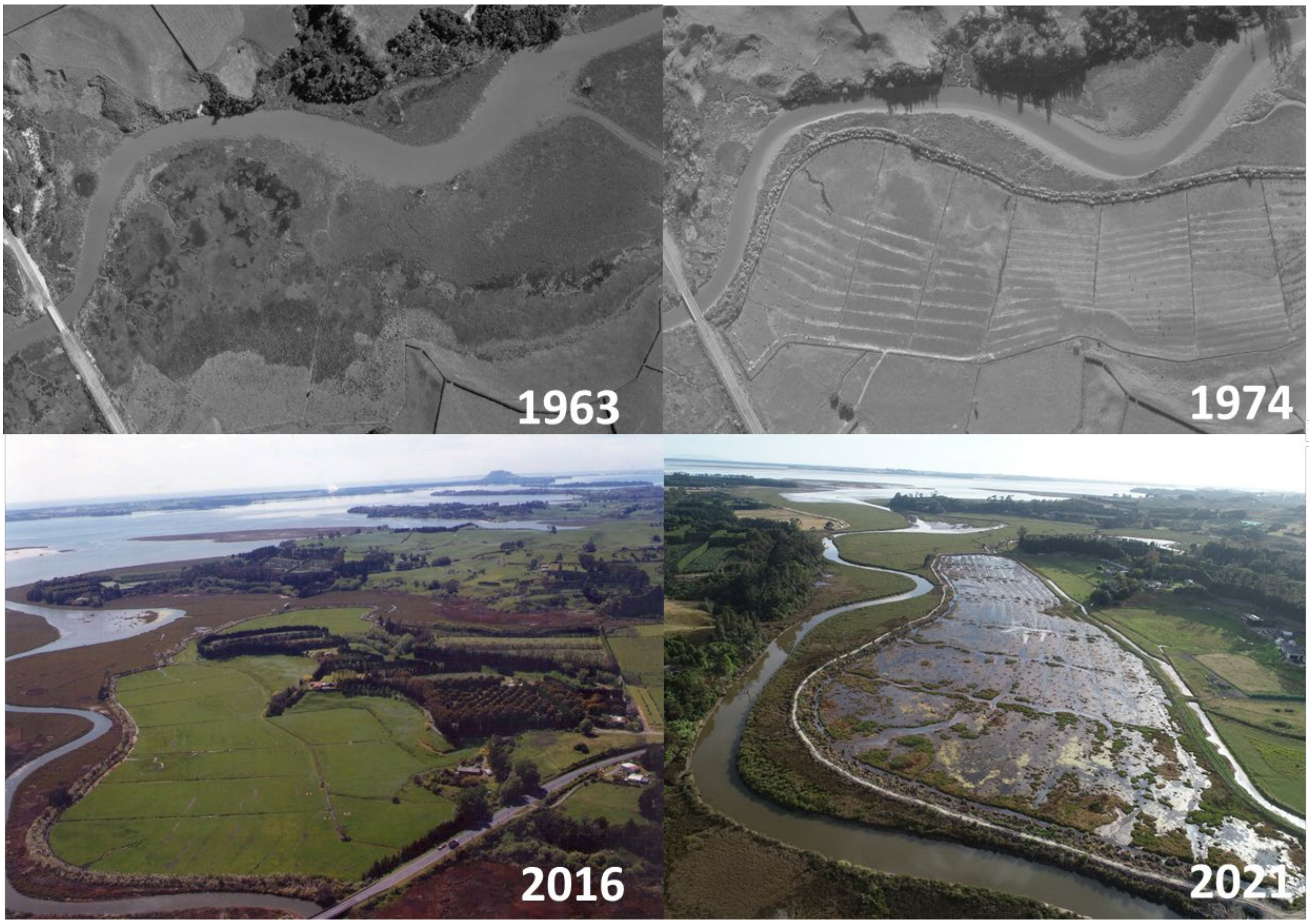

Figure 14 *Historical saltmarsh habitat at Wainui Repo Whenua in 1963, reclaimed farmland on the historical saltmarsh site in 1974 and 2016, and the saltmarsh in 2021 following tidal reconnection.*

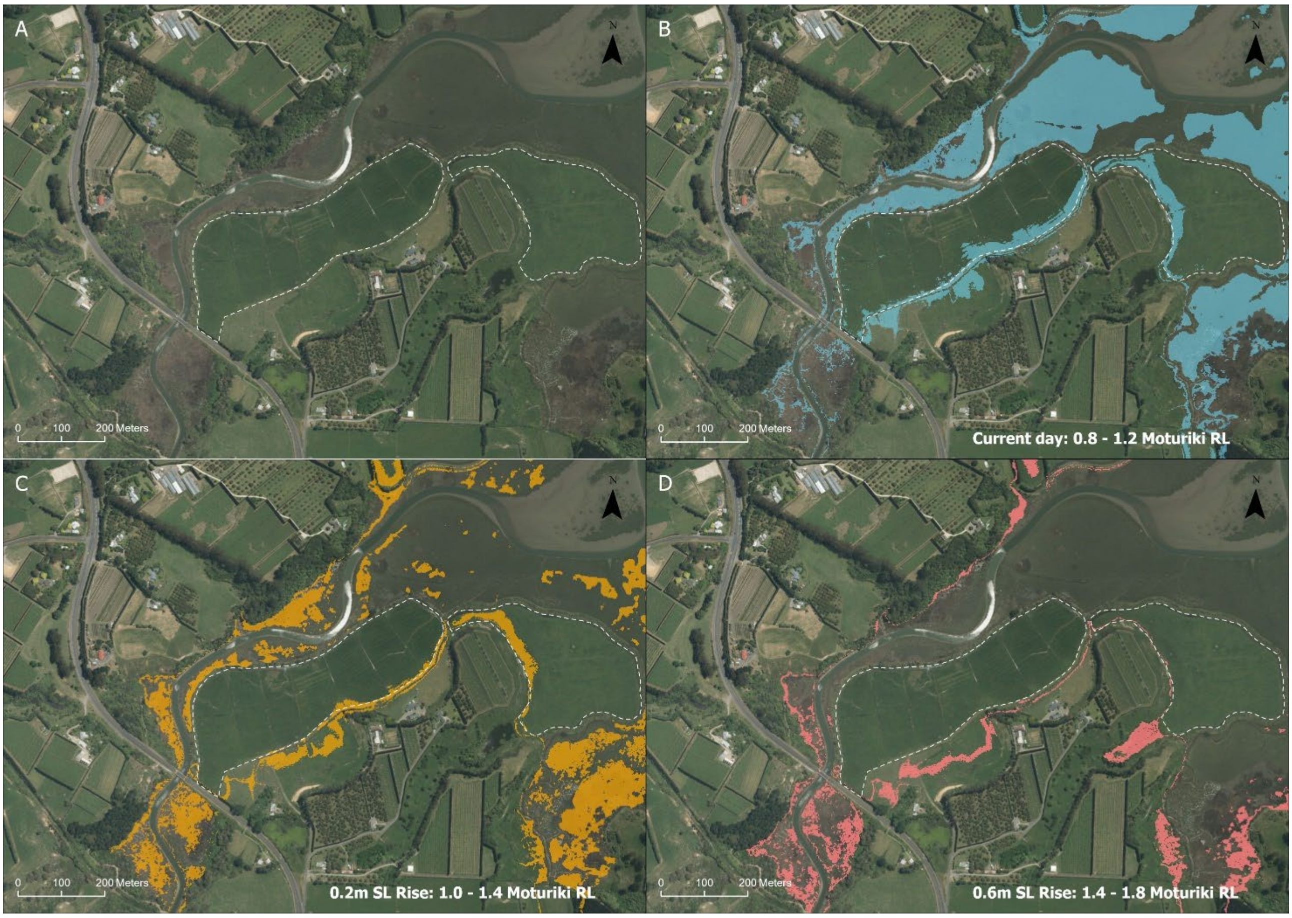

Figure 15 *Wainui Repo Whenua (white dashed outline). B: Current day potential saltmarsh elevation range (blue). C: +0.2 m sea level rise elevation range (yellow). D: +0.6 m sea level rise elevation range (red).*

Discussion/Matapakitanga

The spatial mapping exercise presented here has provided a basis to assess current saltmarsh extent, identified potential elevation ranges for saltmarsh restoration, and modelled future scenarios for saltmarsh under sea level changes. Significant areas of land have been identified to fall within the current potential saltmarsh elevation range that are currently in use for alternate land uses and have barriers or mechanisms in place to stop water intrusion. Much of the current potential saltmarsh areas are currently in use for pastural farming (67%), much of which was previously drained wetland for this purpose. These areas are potential sites for saltmarsh restoration projects, but further site-specific investigations will be necessary, relating to hydrology and salinity requirements. Significant areas were identified that fall below the preferred elevation range of saltmarsh (greater than that identified for saltmarsh restoration), however these may be important locations on the marginal edges of the estuary and may provide a space for change into open tidal flats or mangrove habitat. Mapping outputs have highlighted two divergent scenarios for saltmarsh under sea level rise: increases through landward expansion or decreases in saltmarsh through coastal squeeze.

The latest IPCC report has highlighted that we have locked in 1.5°C of warming by 2100, with corresponding sea level rise of 0.26 m – 0.77 m, and continued sea level rise beyond that horizon (Allen et al. 2018). This work has highlighted the importance of considering climate change adaptation, and more specifically managed realignment when undertaking saltmarsh restoration projects and has provided a means to do so. In a scenario, such as Athenree Wildlife Refuge Reserve, where there are opportunities for inland migration of salt marsh with increasing sea levels, identification of land areas and early planning can support this process. Strategic planning can support natural inland migration and ensure that the existing mechanisms for biodiversity protection can be amended to extend inland as migration occurs. In the case of Wainui Repo Whenua, where there is little opportunity for inland migration of saltmarsh, alternative considerations must be examined. The saltmarsh elevation mapping highlighted that saltmarsh at this location will become squeezed against the land topography with even small changes (+0.2 m) in sea level. Under this scenario, it may be important to manage stakeholder expectations of what restoration looks like. Site management may be different – i.e., tidal restriction by culverts, and additional land will be required to ensure saltmarsh continuation in this zone. In highly urbanised areas, retainment of saltmarsh habitat may not be feasible due to hard structures preventing landward migration, and future discussions with the community will need to find a middle ground between providing space for protecting natural resources and/or adaptation of the built environment and communities (Swales et al. 2020).

Estuarine wetland monitoring will help us determine whether Bay of Plenty saltmarsh wetlands can adapt to rising sea levels, or if mitigation is required. Rod Surface Elevation Tables (RSET) have been installed at several sites (Athenree in Tauranga Harbour, and Nukuhou in Ōhiwa Harbour) to measure relative elevation change of wetland sediments resulting from sediment accretion, consolidation, and subsidence. Rod Surface Elevation Tables provide highly accurate measurements of sediment elevation within wetlands over long periods of time. A comparison between measured accretion rates and relative SLR indicates whether a saltmarsh can adapt to rising waters. The monitoring of estuarine wetlands will further our understanding of the potential impacts of climate change and allow adaptive management. At these sites there is also vegetation monitoring to enable changes in wetland vegetation to be monitored over time. The Future Coasts Aotearoa[9] programme aims to investigate the physical impacts of sea level rise on existing saltmarsh habitats, including wetland and tidal resolution using detailed modelling techniques. They plan to develop tools and methods to support options for managed realignment, utilising some case studies located in the Bay of Plenty.

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[9] https://niwa.co.nz/natural-hazards/research-projects/future-coasts-aotearoa

Saltmarsh can play a significant role in storage of carbon and support future climate carbon reduction goals. Restored wetlands, in particular those being converted from pasture, will take time to reach their carbon storage potential (Burden *et al.*, 2013). In New Zealand, the current knowledge of carbon stocks and potential value of blue carbon ecosystems including saltmarsh has been investigated (Weaver et al. 2022). They have identified ‘blue carbon’ credits that could be marketed at a local and national level for voluntary carbon off-setting. This could enable coastal blue carbon to function as a potential funding mechanism for coastal ecosystem conservation and restoration. Sea level rise will also pose a significant risk to carbon storage and sequestration of saltmarsh habitats; thus, it will be critical to understand potential lifetimes of restoration projects if carbon storage goals are at the forefront. The Nature Conservancy is leading a programme of work around restoration of marginal farmland into saltmarsh to support climate resilience, and a roadmap for the delivery of carbon credits. BOPRC is actively participating in this research with case study sites in our region.

Another assessment tool is the New Zealand Sea Level Rise project which maps vertical land movement across New Zealand coastlines every 2 km using satellite imagery[10]. For the Bay of Plenty Region, it highlights that there is variation in vertical land movement; decreasing in some areas whilst in others it is increasing, providing resilience to SLR. This may also help with prioritisation of areas where impacts are likely to be the first to be evident due to subsidence via vertical land movement (e.g., from tectonic plate movements). These regions are also likely to be where we see the greatest risk from coastal hazards. Intertidal vegetation including saltmarsh and mangroves can help reduce wave run up at the coast through attenuation of short period wave energy. Thus, saltmarsh restoration projects may also provide additional benefits for protection of land and infrastructure in suitable areas.

Ultimately there are still many unknowns regarding the rate of climate change/SLR and what impacts it will have on saltmarsh habitats, however, there is need for immediate action, utilising the best available information. The case studies presented here are only two of the many saltmarsh restoration programmes occurring throughout the Bay of Plenty, and the saltmarsh elevation modelling will support our restoration activities to be climate change resilient. Further work is required to prioritise our restoration efforts based on SLR risk, and further develop management and policy options to support a broad range of future climate scenarios. Our work continues to put biodiversity values at the forefront to support extensive restoration projects on marginal coastal land, where coastal adaptation is required to support the future of functioning coastal ecosystems.

[10] https://www.searise.nz/maps

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Appendices/Ngā Āpitihanga

Appendix 1
RTK Survey

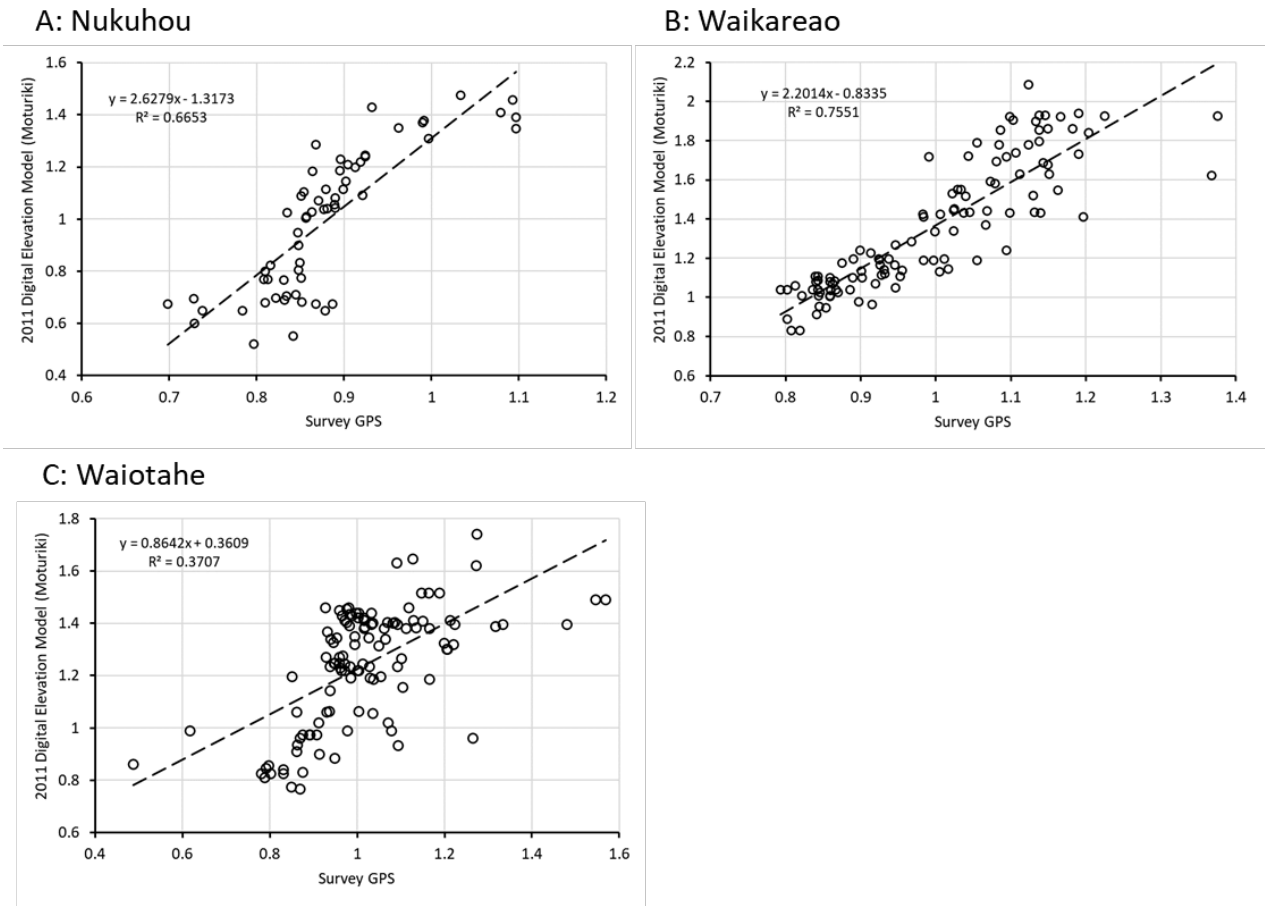

Figure 16 *Difference in elevation measure between the 2011 LiDAR digital elevation model and the RTK GPS survey in three saltmarshes across the Bay of Plenty.*

Appendix 2
Regional site maps – Current saltmarsh potential

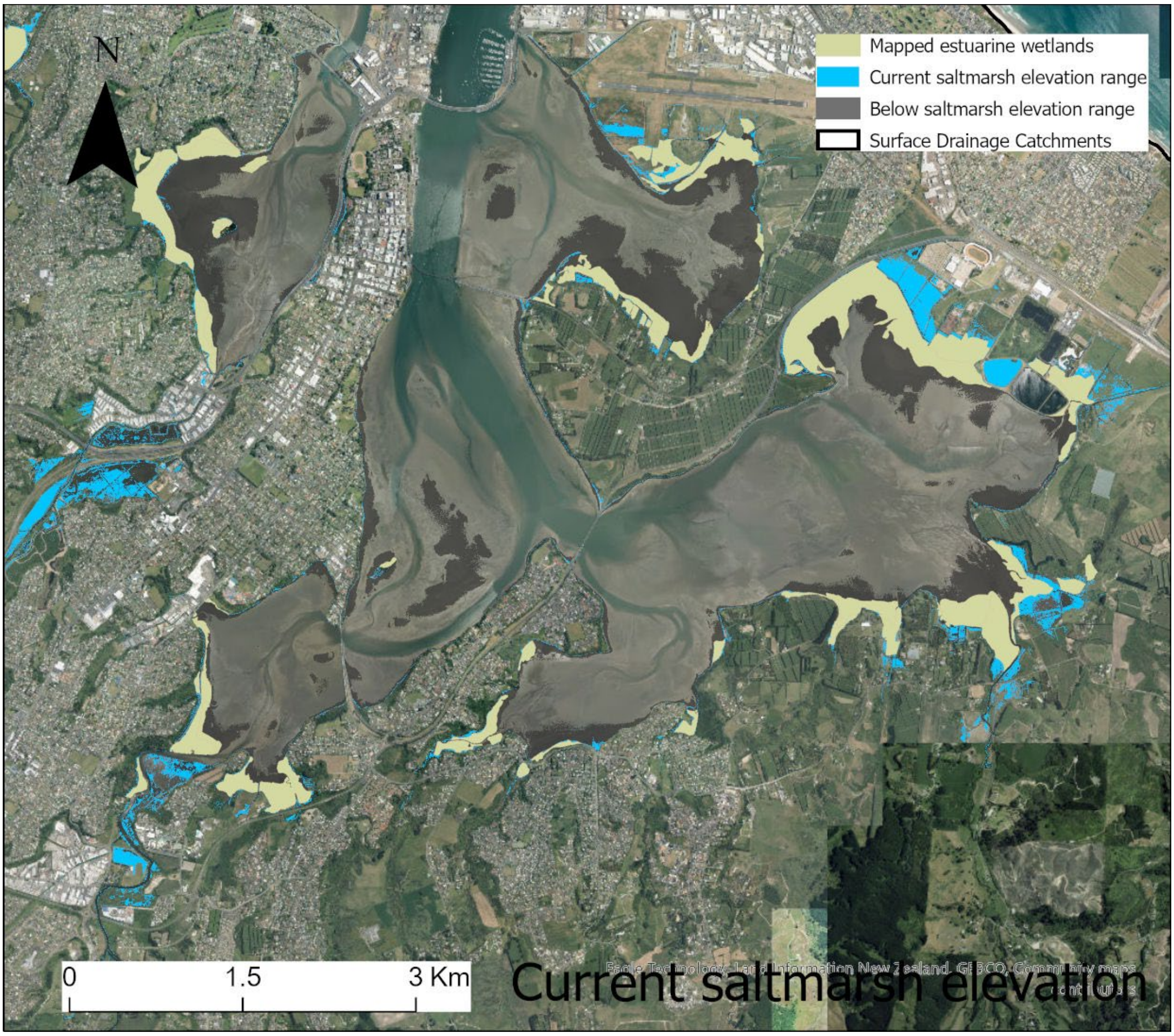

Figure 17 *Tauranga CBD: Current potential saltmarsh elevation range (blue), with current mapped estuarine wetlands in green, and areas of land below the elevation range in dark grey.*

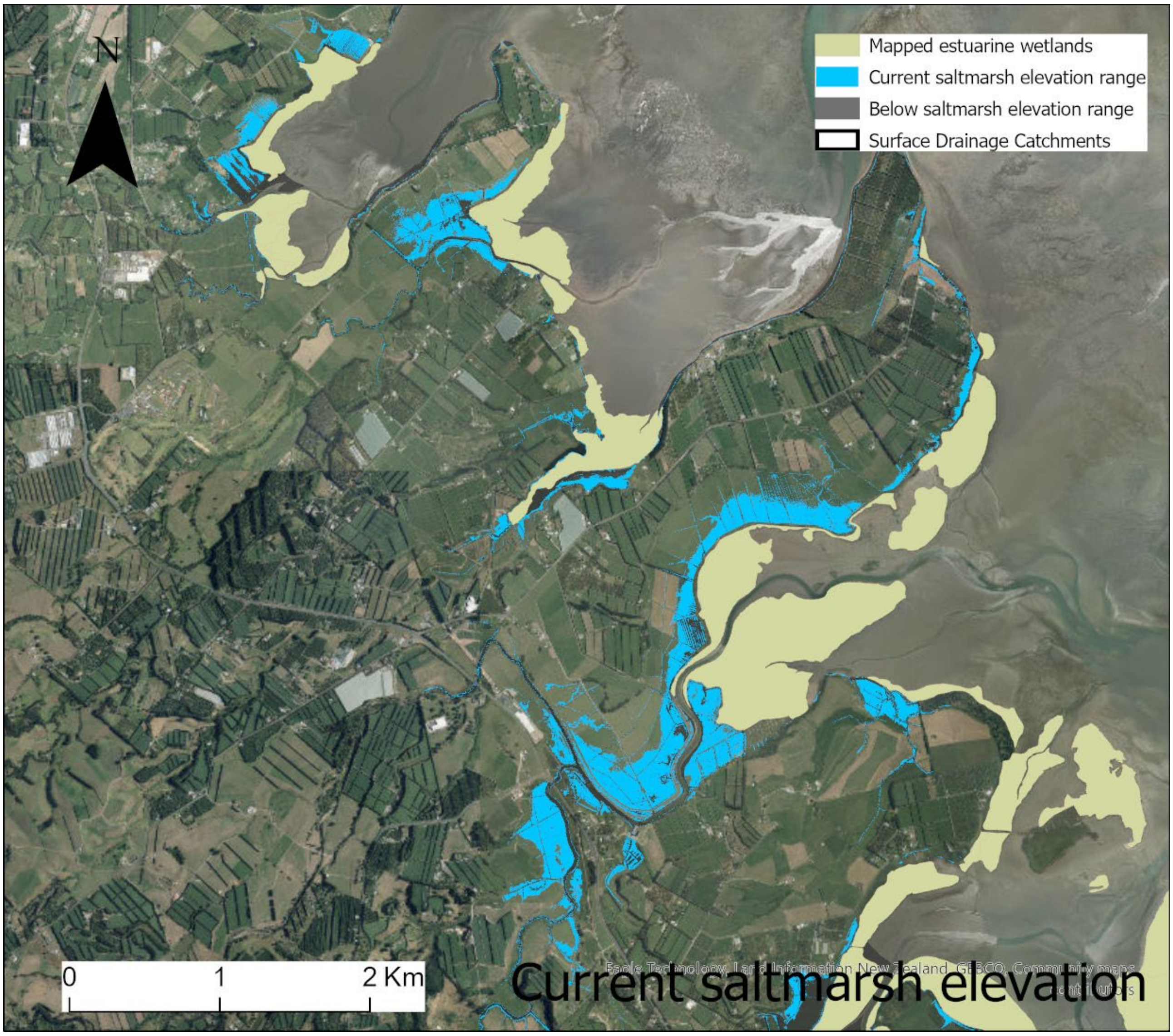

Figure 18 *Tauranga mid harbour: Current potential saltmarsh elevation range (blue), with current mapped estuarine wetlands in green, and areas of land below the elevation range in dark grey.*

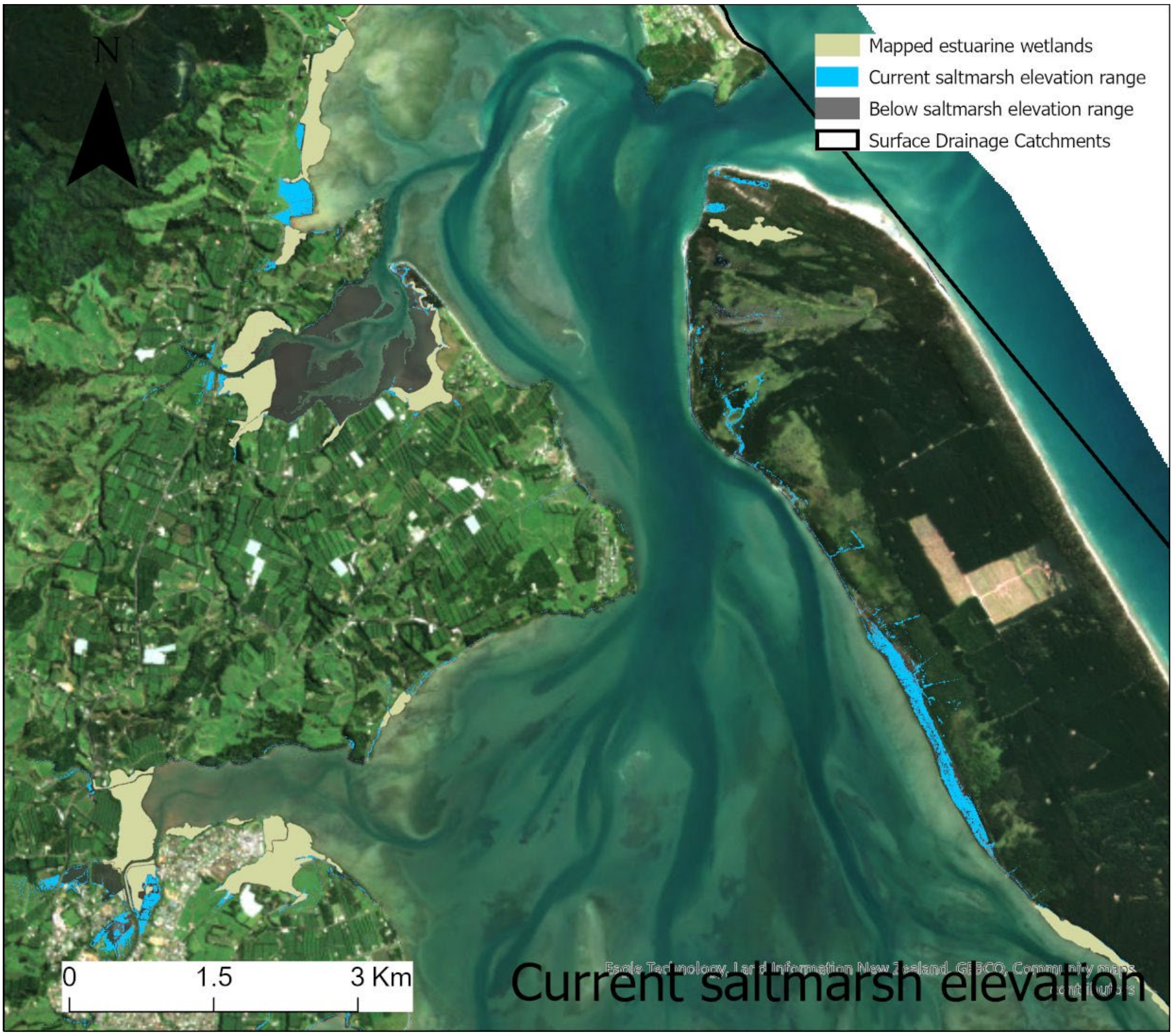

Figure 19 Tauranga north: Current potential saltmarsh elevation range (blue), with current mapped estuarine wetlands in green, and areas of land below the elevation range in dark grey.

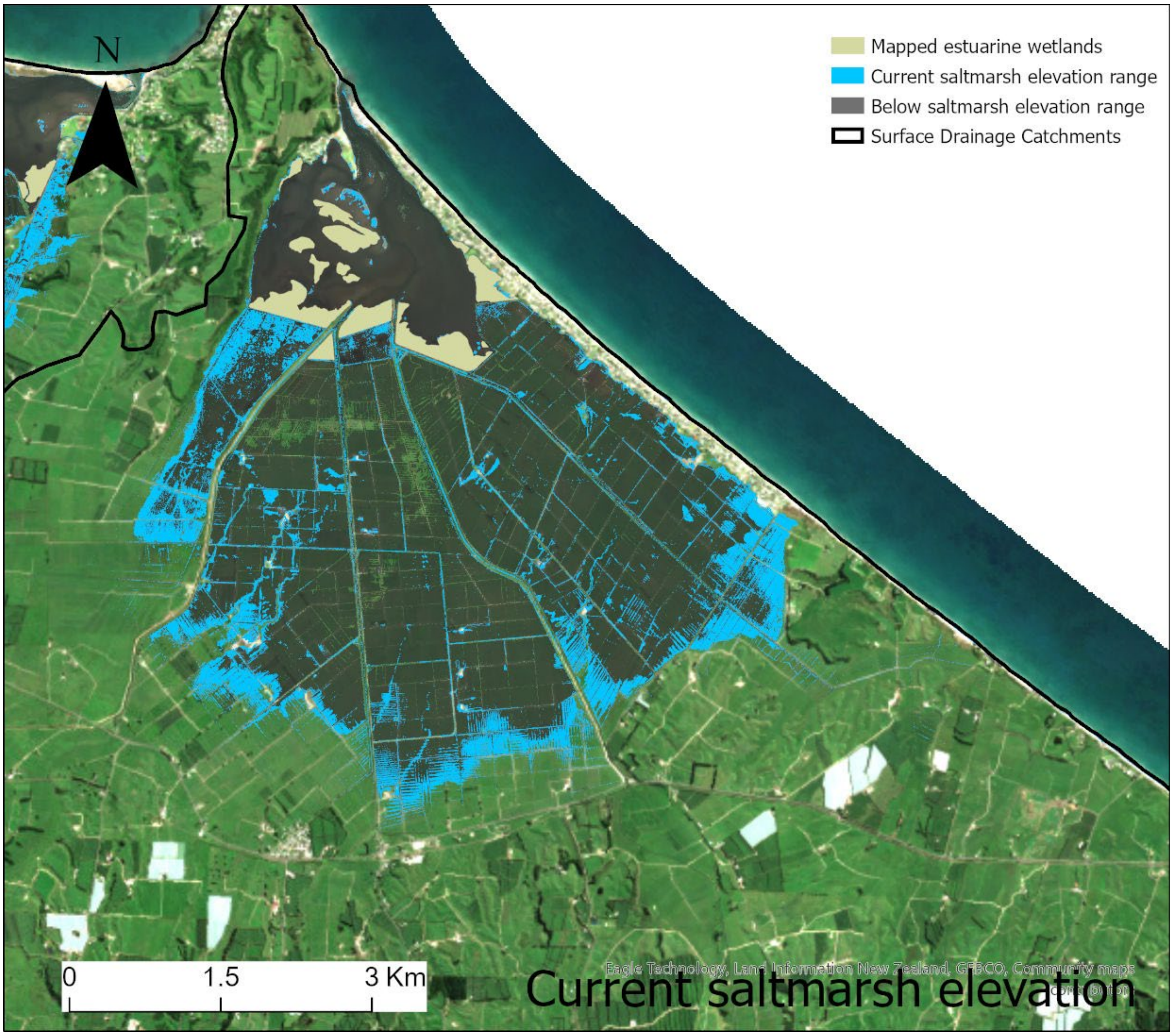

Figure 20 *Pongakawa Catchment: Current potential saltmarsh elevation range (blue), with current mapped estuarine wetlands in green, and areas of land below the elevation range in dark grey.*

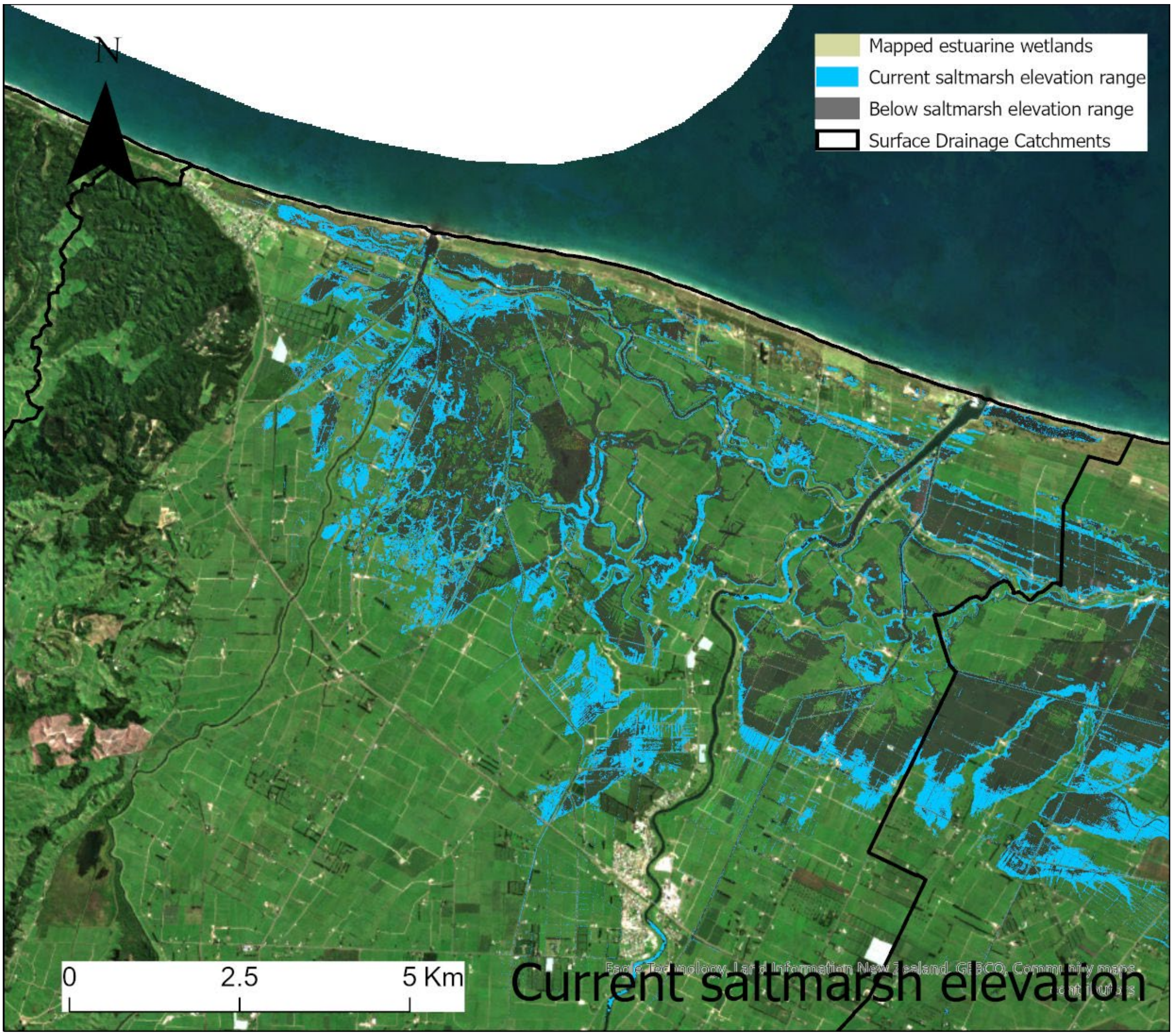

Figure 21 Rangitāiki Catchment: Current potential saltmarsh elevation range (blue), with current mapped estuarine wetlands in green, and areas of land below the elevation range in dark grey.

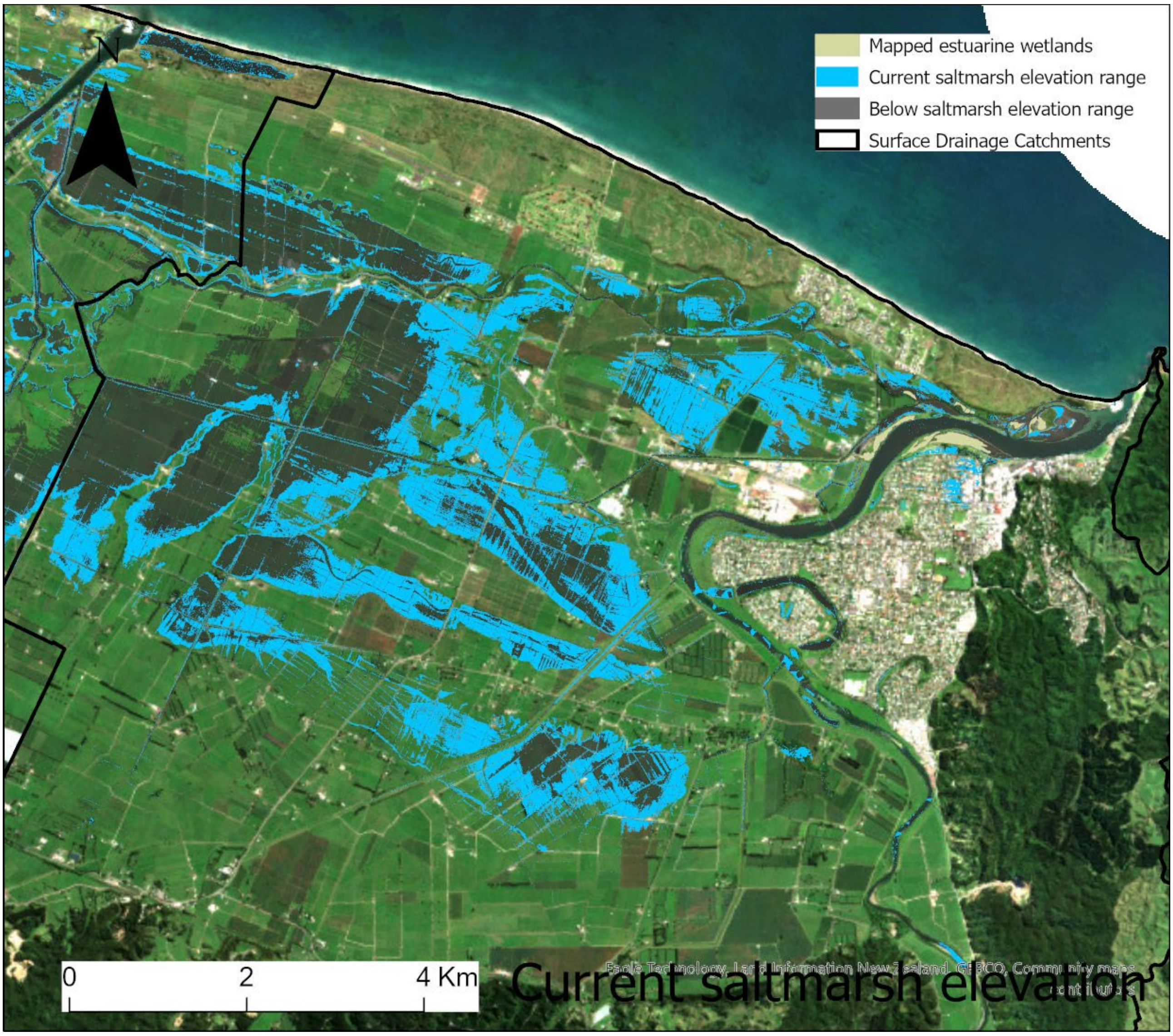

Figure 22 Whakatāne Catchment: Current potential saltmarsh elevation range (blue), with current mapped estuarine wetlands in green, and areas of land below the elevation range in dark grey.

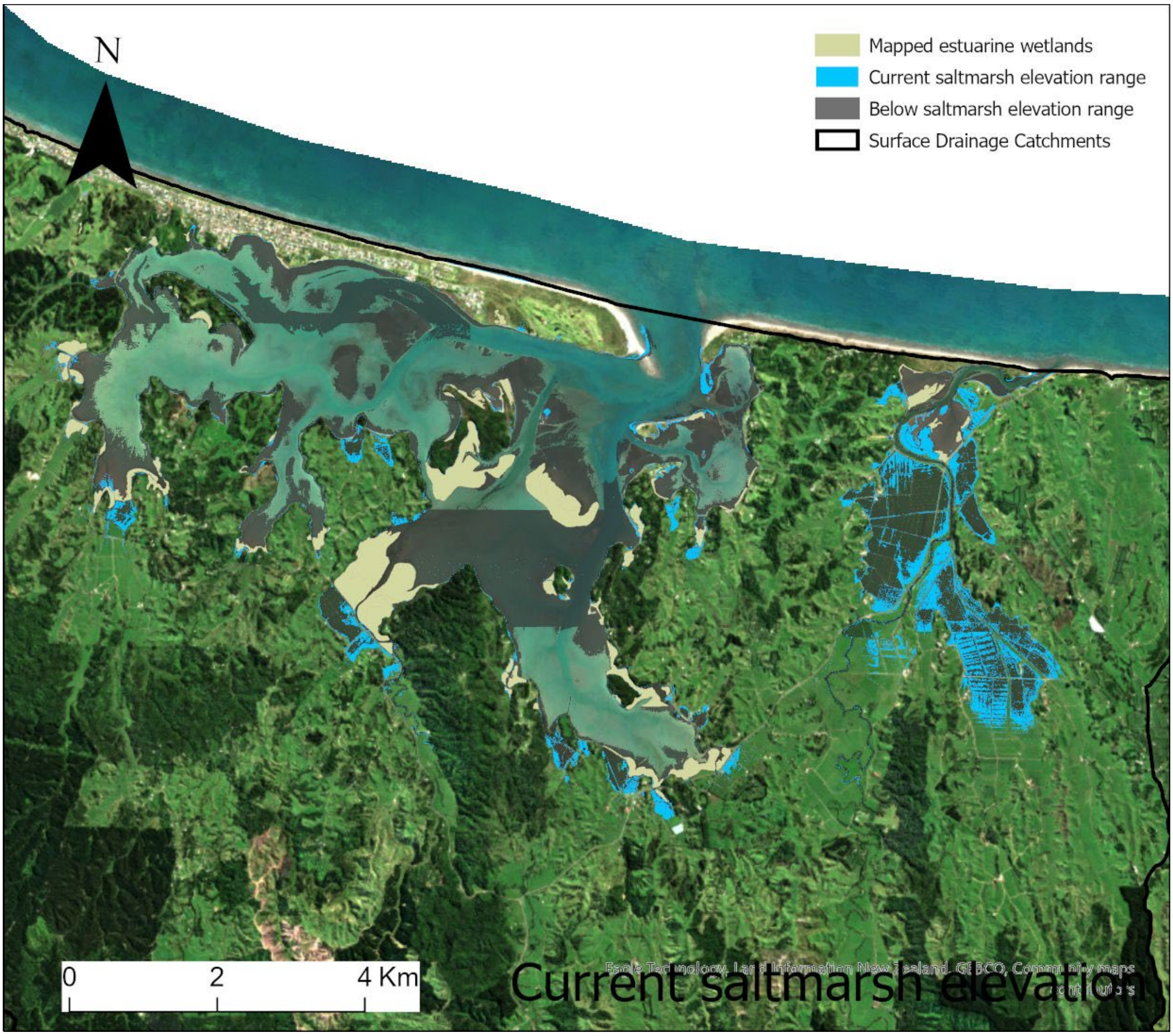

Figure 23 Ohiwa Catchment: Current potential saltmarsh elevation range (blue), with current mapped estuarine wetlands in green, and areas of land below the elevation range in dark grey.

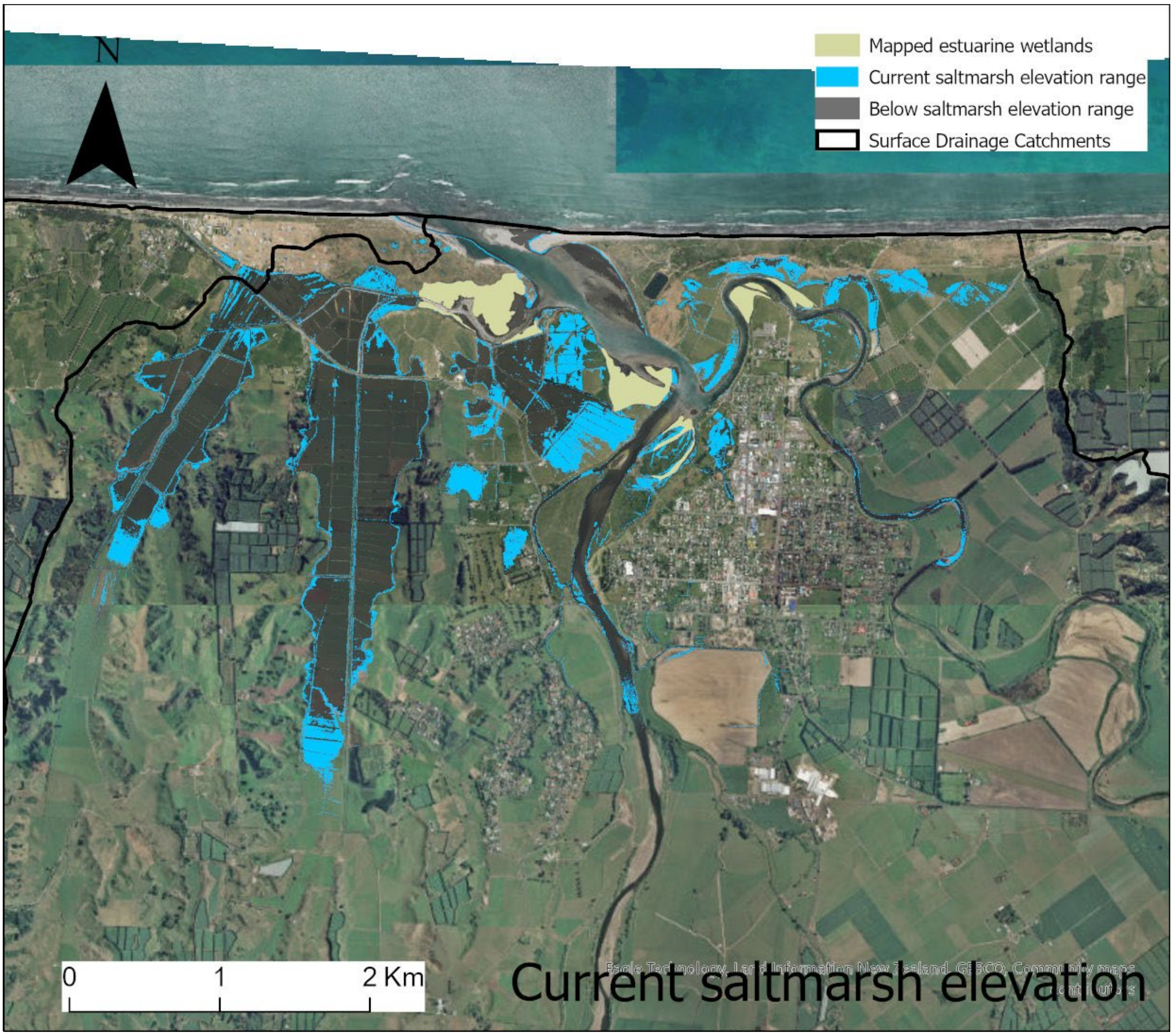

Figure 24 *Waioeka Catchment: Current potential saltmarsh elevation range (blue), with current mapped estuarine wetlands in green, and areas of land below the elevation range in dark grey.*

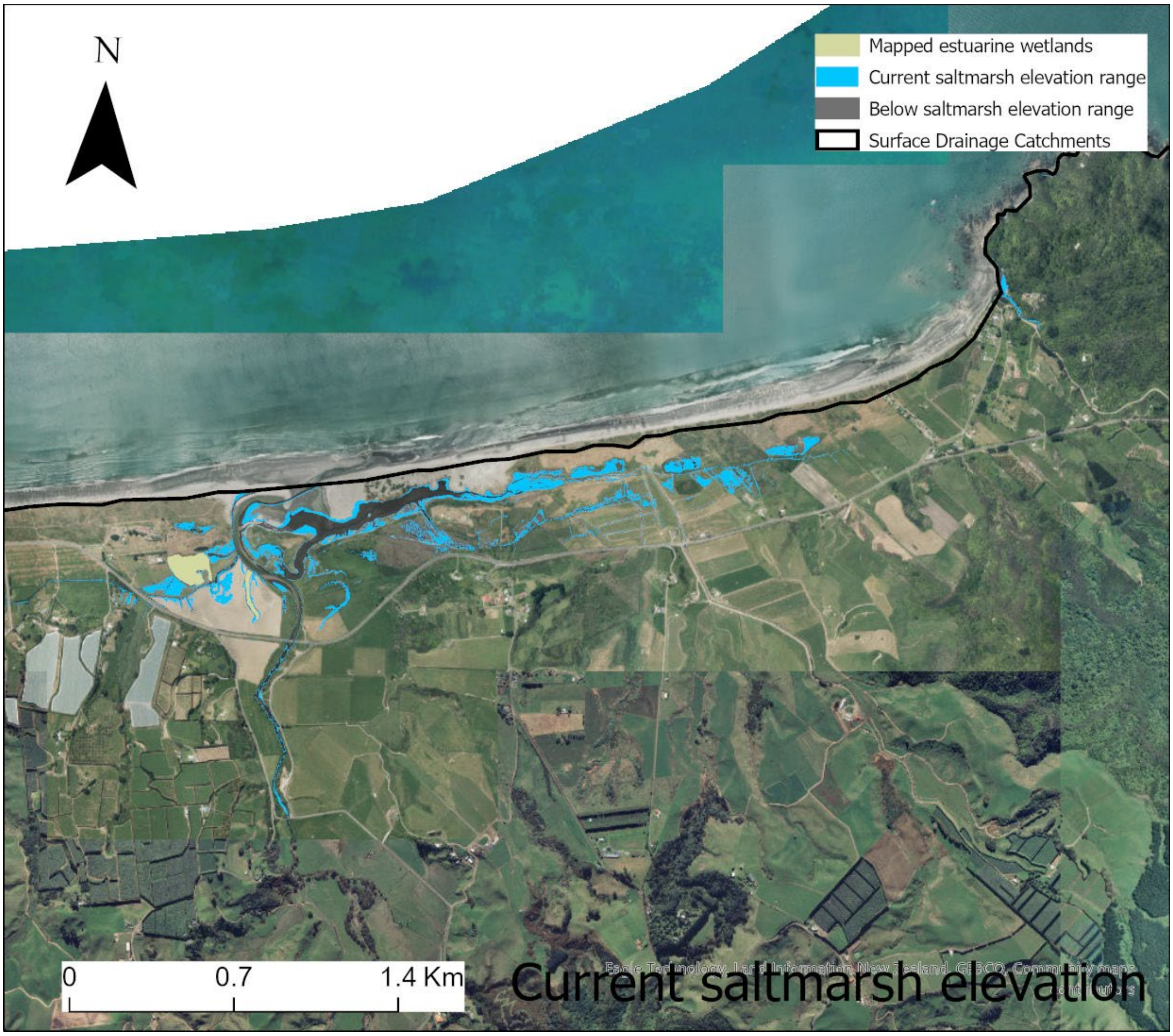

Figure 25 *Motu south: Current potential saltmarsh elevation range (blue), with current mapped estuarine wetlands in green, and areas of land below the elevation range in dark grey.*

Appendix 3
Regional site maps – Sea level rise

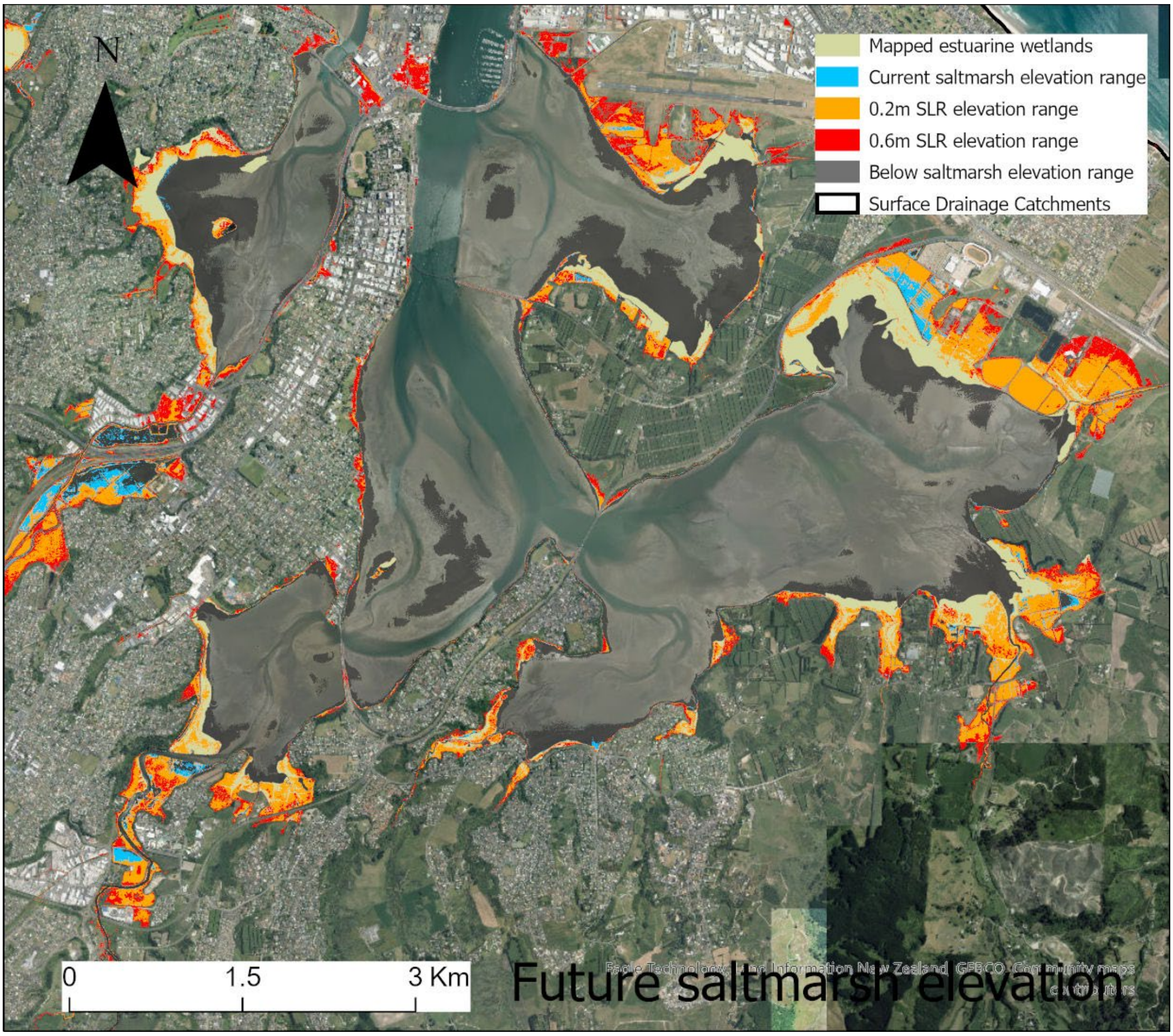

Figure 26 *Tauranga CBD: Future potential saltmarsh elevation range (with current elevation in blue, 0.2 m SLR in orange, and 0.6 m SLR in red), with current mapped estuarine wetlands in green, and areas of land below the current elevation range in dark grey.*

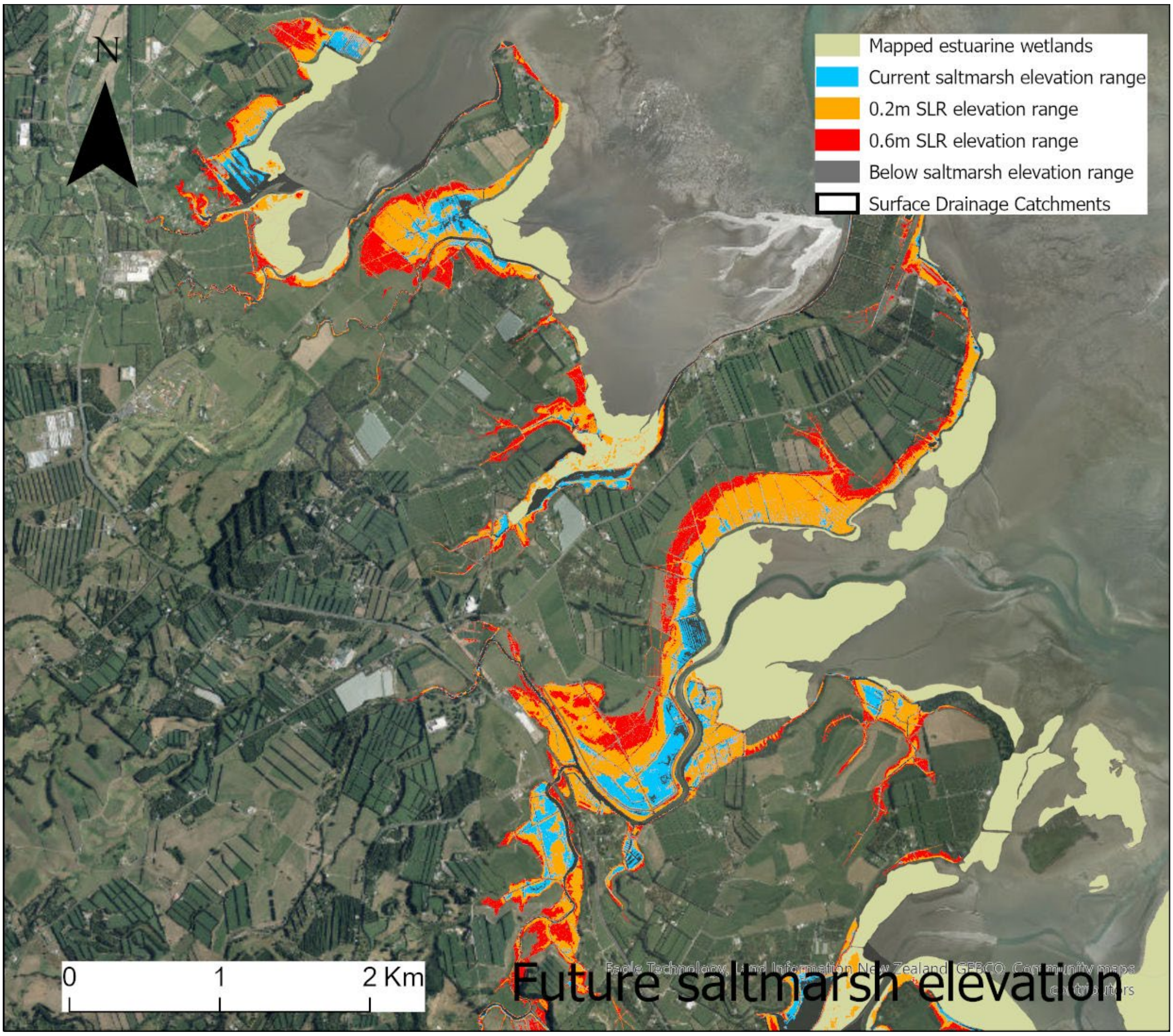

Figure 27 *Tauranga mid: Future potential saltmarsh elevation range (with current elevation in blue, 0.2 m SLR in orange, and 0.6 m SLR in red), with current mapped estuarine wetlands in green, and areas of land below the current elevation range in dark grey.*

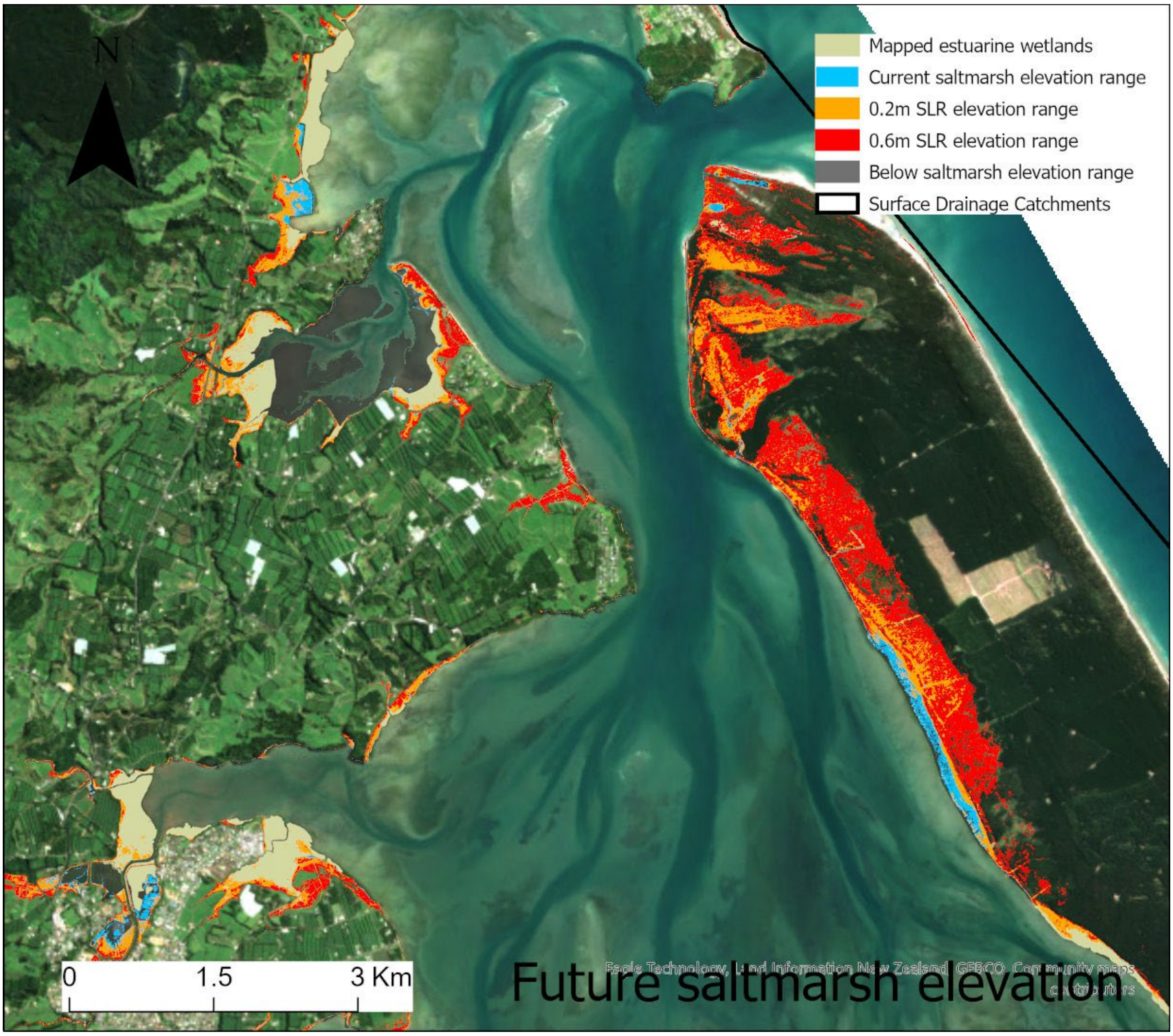

Figure 28 *Tauranga north: Future potential saltmarsh elevation range (with current elevation in blue, 0.2 m SLR in orange, and 0.6 m SLR in red), with current mapped estuarine wetlands in green, and areas of land below the current elevation range in dark grey.*

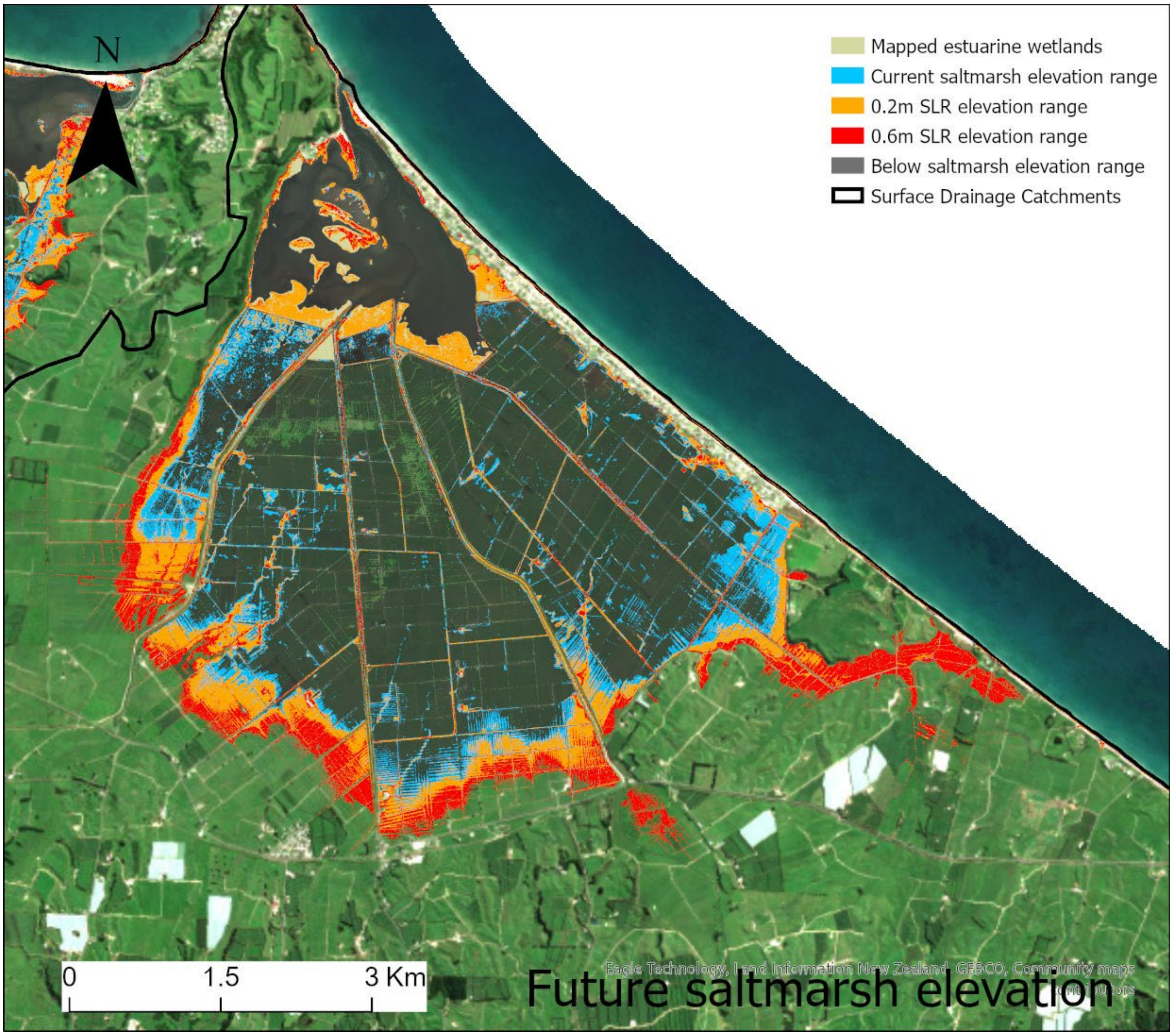

Figure 29 *Pongakawa Catchment: Future potential saltmarsh elevation range (with current elevation in blue, 0.2 m SLR in orange, and 0.6 m SLR in red), with current mapped estuarine wetlands in green, and areas of land below the current elevation range in dark grey.*

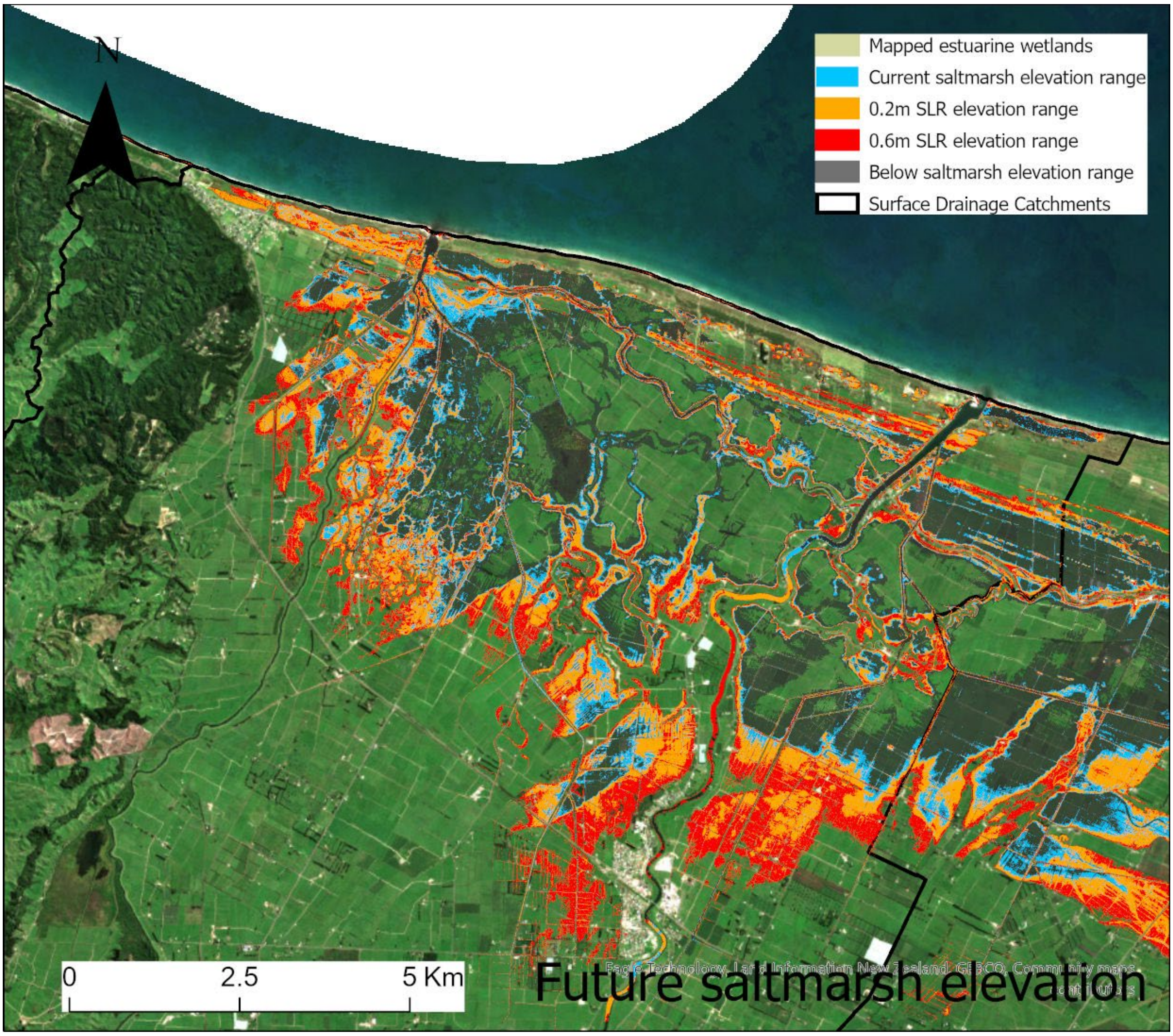

Figure 30 *Rangitāiki Catchment: Future potential saltmarsh elevation range (with current elevation in blue, 0.2 m SLR in orange, and 0.6 m SLR in red), with current mapped estuarine wetlands in green, and areas of land below the current elevation range in dark grey.*

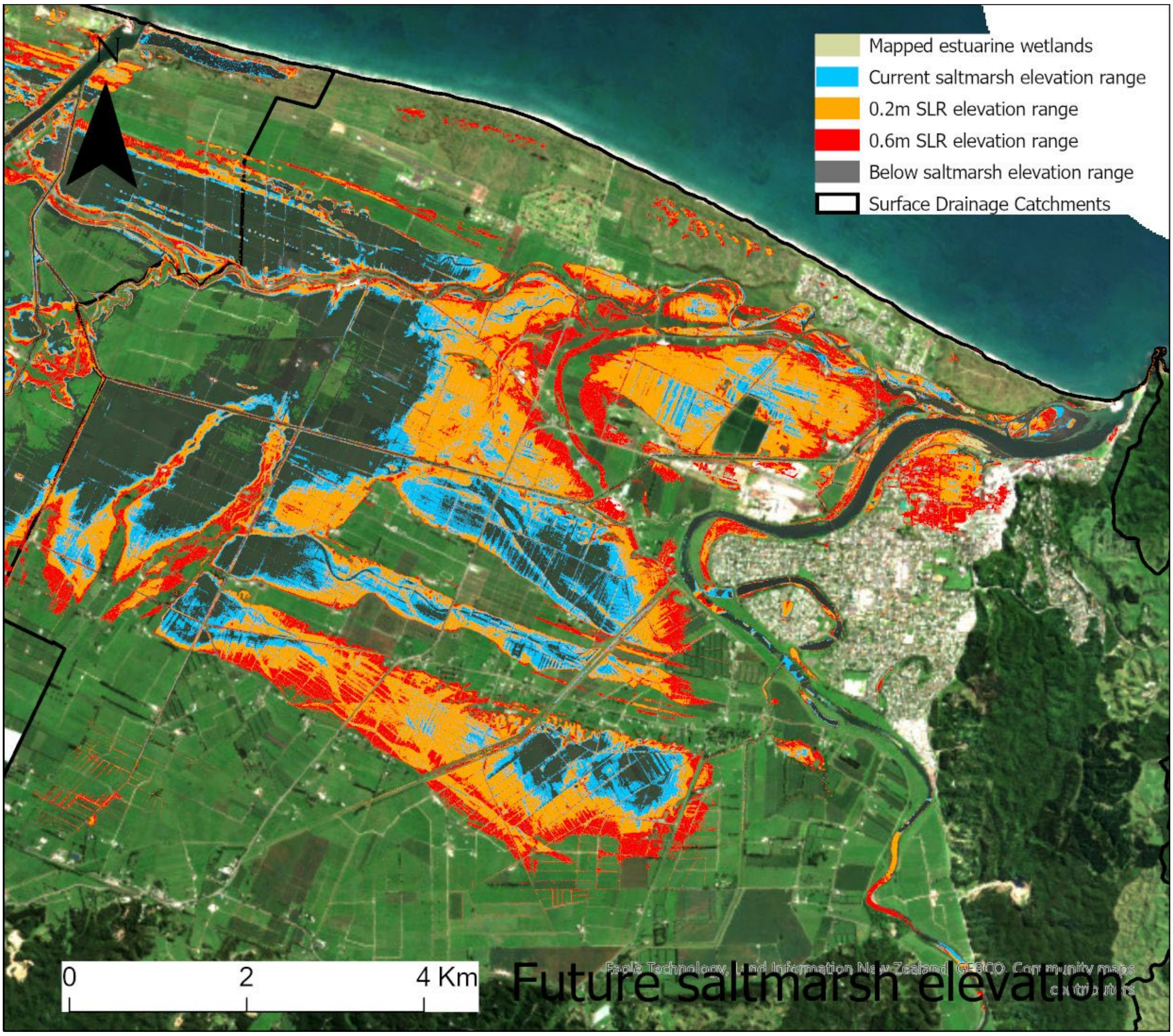

Figure 31 Whakatāne Catchment: Future potential saltmarsh elevation range (with current elevation in blue, 0.2 m SLR in orange, and 0.6 m SLR in red), with current mapped estuarine wetlands in green, and areas of land below the current elevation range in dark grey.

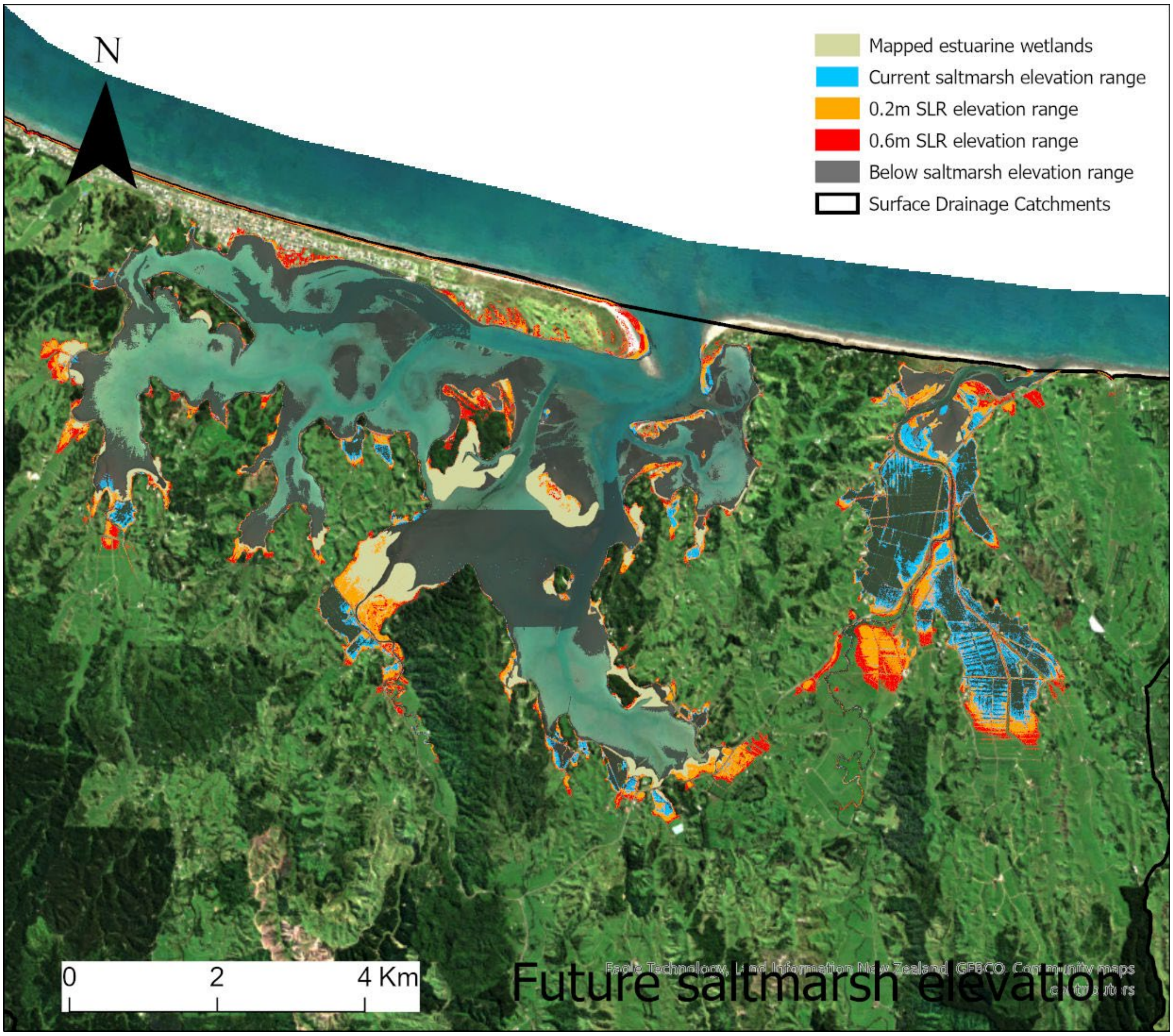

Figure 32 Ohiwa Catchment: Future potential saltmarsh elevation range (with current elevation in blue, 0.2 m SLR in orange, and 0.6 m SLR in red), with current mapped estuarine wetlands in green, and areas of land below the current elevation range in dark grey.

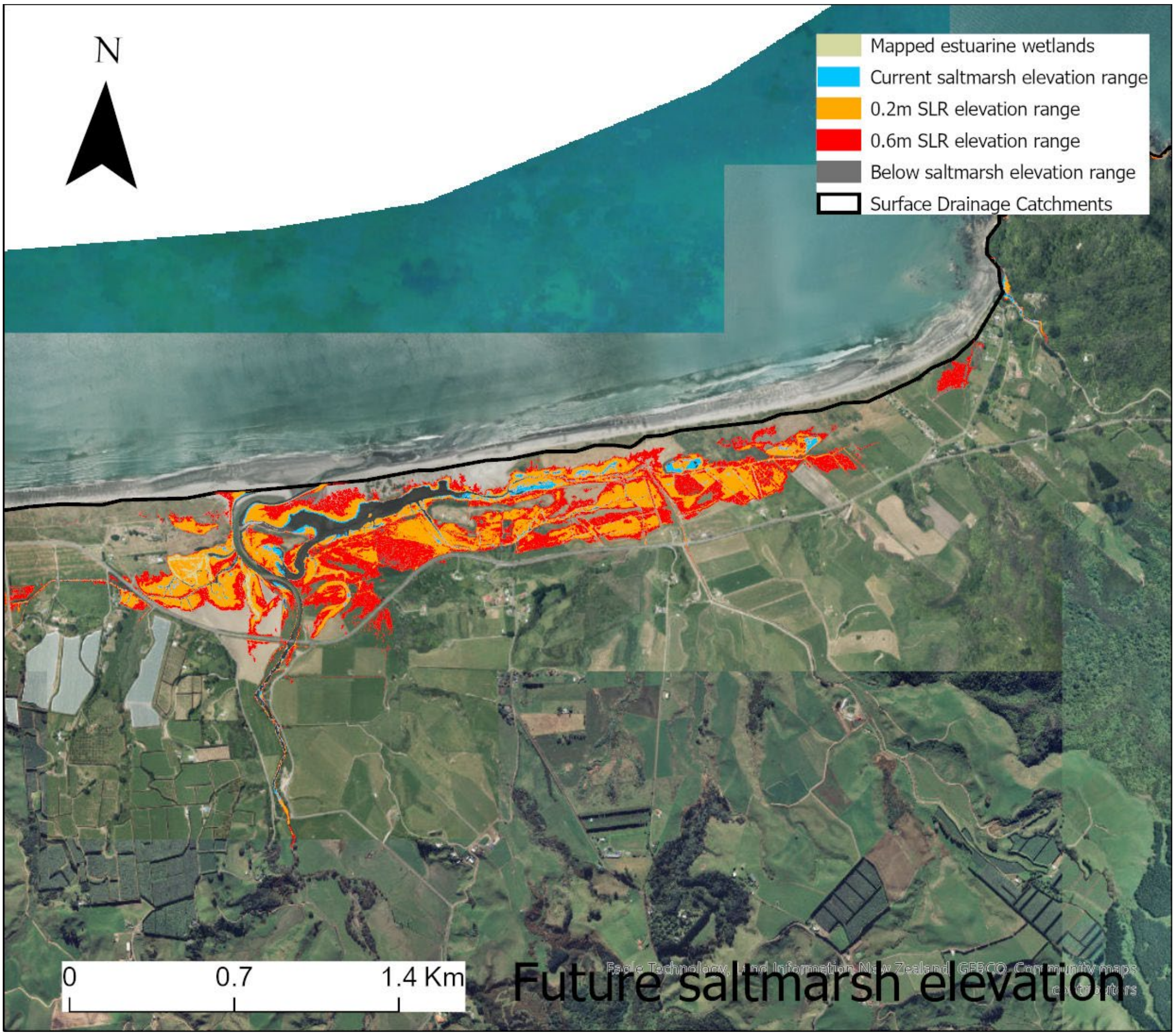

Figure 33 *Motu south: Future potential saltmarsh elevation range (with current elevation in blue, 0.2 m SLR in orange, and 0.6 m SLR in red), with current mapped estuarine wetlands in green, and areas of land below the current elevation range in dark grey.*