Geospatial analysis of marine habitat representation for marine spatial planning around Waiheke Island, Auckland, New Zealand.

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Attestation of Authorship:

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of learning.

Signed

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ABSTRACT

This thesis compares differences in marine habitat composition for different sections of coast within 1 km of Waiheke Island located in the inner Hauraki Gulf, Auckland, New Zealand (36.800° S, 175.101° E). The maps, graphs, multivariate analyses and Marxan simulated annealing models developed consistently identify distinct differences in habitat composition among sections of coast and provide options for a representative and adequate network of complementary MPAs which include a range of habitats and associated biodiversity.

Four distinct groups of marine habitats required adequate representation in protected areas, but their distribution was limited to a relatively small number of locations. The groups were: the intertidal and subtidal boulder and gravel habitats found mainly off north-western Waiheke Island and in the Nani-Onetangi and the Pie Melon-Te Whau sections of coast; high current habitats in the Motutapu and Waiheke Island Channels; seagrass, mangrove, saltmarsh and mud flat habitats in the Rocky-Pūtiki, Kennedy-Huruhi, Awaawaroa Bay and Te Matuku Bay Marine Reserve; and the deep gravel, mud and other habitats of the Horuhoru (Gannet Rock) to Hooks Bay section of coast. There is, however, flexibility to choose areas that include other biodiversity values and also provide for social, economic and cultural values and activities.

Establishing MPAs in these locations would complement customary management and other fisheries, conservation and land management practices to help restore and protect ecosystems around the island and also contribute to objectives for the Hauraki Gulf Marine Park and national marine spatial planning.

The resulting GIS models can be used in participatory management with scientists, stakeholders, iwi and the public to help plan and assess conservation actions around Waiheke Island and in the surrounding Marine Park.

Keywords: marine protected area; reserve; GIS; Marxan, marine spatial planning.

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1 INTRODUCTION

The objective of this research project is to determine if decision support models and geographic information systems (GIS) can help prioritise marine areas around Waiheke Island for conservation and sustainable use. Analysis tools such as ArcPro (ESRI) GIS, multivariate statistics and the reserve selection modelling tool, Marxan, are used to identify areas which best represent 26 different marine habitats while minimising the area occupied by marine protected areas (MPAs) or other planning strategies. Similar biodiversity assessments have been used successfully overseas and in New Zealand, within the Exclusive Economic Zone, Territorial Sea and the Hauraki Gulf Marine Park (Breen, 2007; Leathwick et al., 2008; Mazor, Possingham, Edelist, Brokovich, & Kark, 2014; Rushdi, 2020).

The Hauraki Gulf Marine Park Act was established in 2000. It created the first comprehensive management plan to improve our knowledge of the Gulf and better protect its many values (Department of Conservation and Ministry of Fisheries, 2008). From this, the Hauraki Gulf Forum was formed and introduced reporting every three years on the state of the Hauraki Gulf environment. In the last 10 years, four reports highlighted the degradation and depletion of marine resources and species around the Hauraki Gulf (Hauraki Gulf Forum, 2011, 2014, 2017, 2020).

After working with iwi, stakeholders and a Project Steering Group to identify key issues, the Hauraki Gulf Forum and partners released Sea Change, a marine spatial plan for the Hauraki Gulf Marine Park (HGMP). The Sea Change (Tai Timu Tai Pari) project aimed to better understand and reduce pressures in the Hauraki Gulf by spatially managing a wide range of attributes (Department of Conservation and Fisheries New Zealand, 2021a).

As pressure and conflicts continue to increase from human use, having a comprehensive marine spatial plan (MSP) can help implement actions to enhance ecological resilience and avoid, remedy or mitigate environmental risks (Merrie & Olsson, 2014). One such action is developing a representative, adequate and connected network of MPAs. The Sea Change Marine Spatial Plan has proposed new marine reserves, MPA types and management approaches at different locations in the Marine Park and assessed the level of habitat representation within these (Department of Conservation and Fisheries New Zealand, 2021b; Sea Change, 2016).

This plan however, excluded the waters around Waiheke Island. This significant region of the Marine Park was not included in the Sea Change plan because of controversy around ongoing advocacy for a marine reserve network on the northern side of the island (Bing, 2015). Separate community led research, planning, consultation and implementation has continued on Waiheke Island through several groups including the Waiheke Local Council Board, Friends of the Hauraki Gulf, the Hauraki Gulf Conservation Trust, the Royal Forest and Bird Society, Ngāti Pāoa, the Waiheke Collective Marine Project and associated scientists, stakeholders and tangata whenua (Bing, 2015).

Waiheke Island needs to be included in marine spatial planning for the Hauraki Gulf, due to its diverse range of environments and habitats. These habitats provide refuge and resources for marine species to live and reproduce and ecosystem services for many life supporting, human commercial, recreational, educational and spiritual activities and values (Bing, 2015; Department of Conservation & Fisheries New Zealand, 2021). Without the adequate protection of a representative network of marine protected areas, these values cannot be conserved or restored.

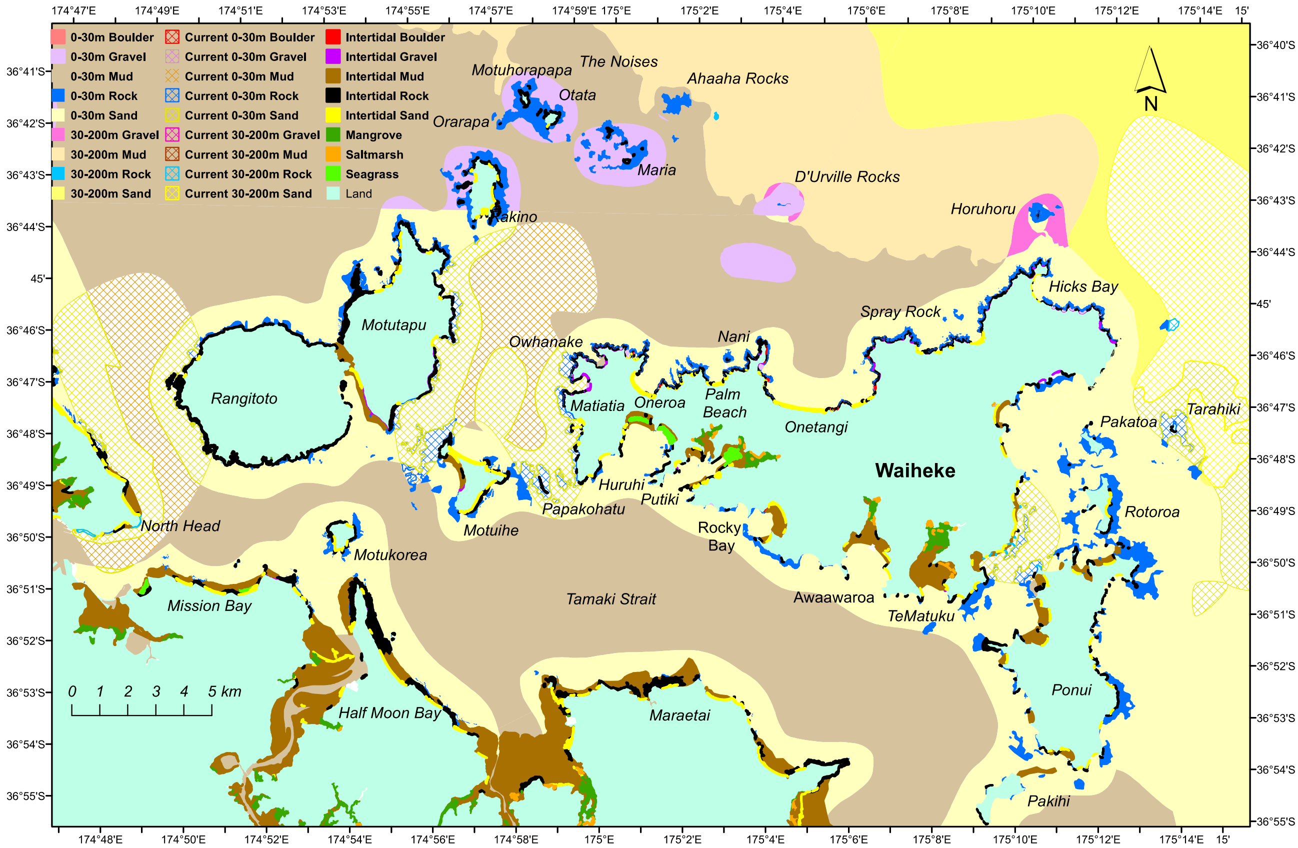

Figure 1 Habitat map of Waiheke Island with surrounding Inner Gulf Islands and the adjacent mainland coast.

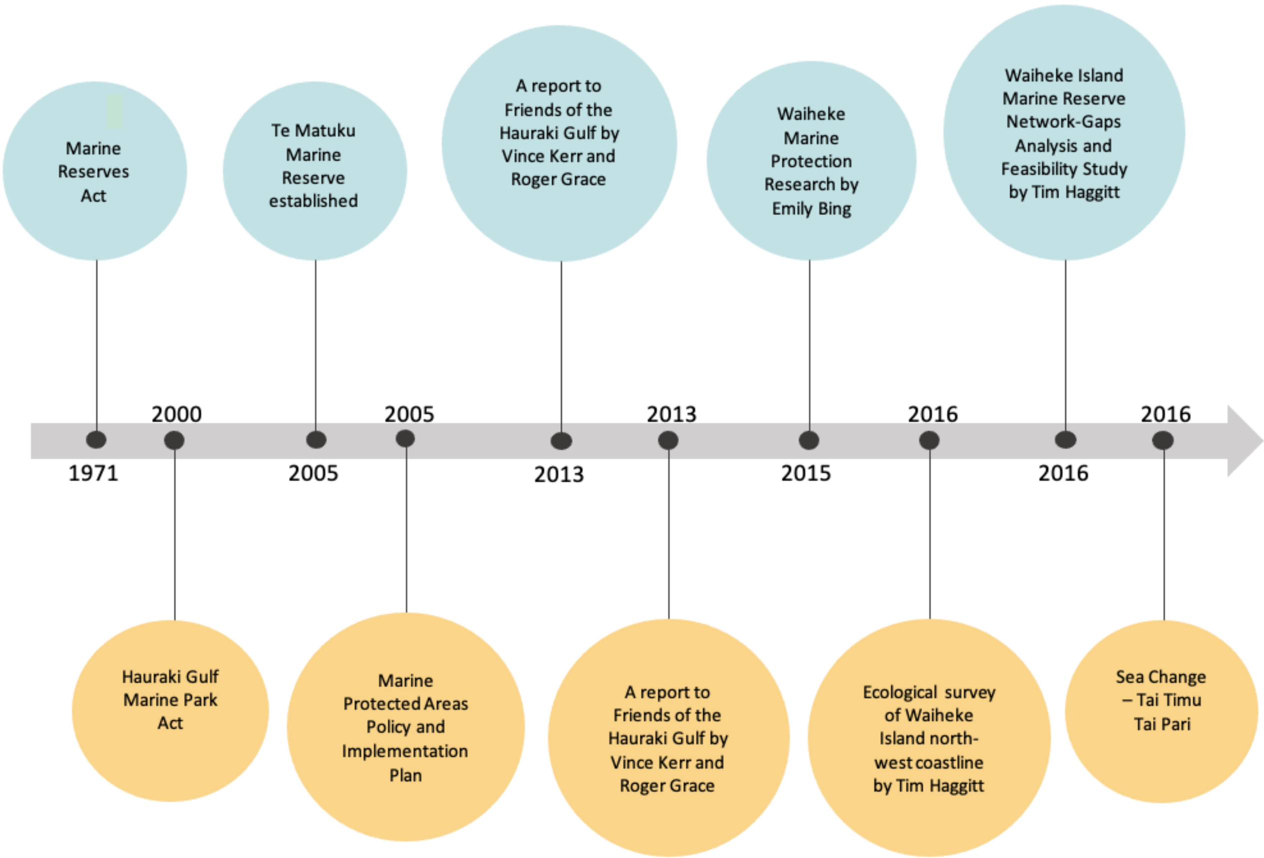

Figure 2. Timeline of key milestones for research and policy for MPAs around Waiheke Island.

1.1 Research Questions and Objectives

The key objectives of this research are to:

- Create a GIS network of broad scale planning units and associated marine habitat values to assess their potential contributions to a representative network of protected areas while minimising the overall area occupied.
- Use marine spatial planning tools like multivariate analysis and Marxan to identify complementary planning units that adequately represent all habitats.
- Compare simulation analyses with other marine biodiversity assessments for the island and with proposed MPAs and other management areas.
- Highlight areas that could contribute to a representative network of MPAs.

1.2 Thesis Structure

Chapter 1 A brief introduction to the research in this thesis.

Chapter 2 A review of current literature on the protection of marine habitats around Waiheke Island, other marine spatial planning and legislation affecting the establishment of MPAs around Waiheke Island and the Hauraki Gulf Marine Park.

Chapter 3 A description of the methods, data and software algorithms used to determine potential areas for representation and investigation.

Chapter 4 The results of spatial analyses, multivariate statistics and Marxan simulated annealing algorithms to identify complementary locations that jointly represent all habitats for the least cost in area.

Chapter 5 A discussion of results and recommendations for planning, model improvements and the integration of other data sets and input from planners and communities through public participatory GIS.

2 LITERATURE REVIEW

2.1 INTRODUCTION

This research aims to identify potential areas for marine protected areas (MPAs) around Waiheke Island from a Geographic Information System (GIS) atlas of marine habitats, statistical analysis and computer simulations in the marine spatial planning tool, Marxan. The ability of GIS to integrate, analyse and display data from many different disciplines based on joint spatial location provides powerful decision support for natural resource managers, stakeholders, communities and scientists (Mazor et al., 2014). This information can then be used by software such as the simulated annealing algorithm in Marxan to explore different scenarios for representation of marine habitats in hypothetical networks of protected areas while aiming to minimise cost (Ansong, Gissi, & Calado, 2017; Breen, 2007; Leathwick et al., 2008).

In recent years, worldwide declines in marine resources from human impacts have increased the need to reform management strategies (Bohnsack & Ault, 1996; Ministry for the Environment & Stats NZ, 2019; Worm et al., 2009). The coastal zone is one of the most valued ecosystems in the world due to its high productivity and range of ecosystem goods and services (Engelsen, Hulth, Pihl, & Sundbäck, 2008; McGlathery, Sundbäck, & Anderson, 2007). However, this interface between land and sea is vulnerable to anthropogenic pressures such as coastal development, urbanisation, agriculture, sedimentation, nutrient enrichment, other pollutants, over harvesting and climate change (Hopkins, Bailey, & Potts, 2016; Thiel et al., 2013; Zeldis & Swaney, 2018). These pressures and activities degrade ecosystems and adversely affect their resilience.

Avoiding, remedying or mitigating human impacts on populations, species, habitats, ecological communities and processes is essential to sustain ecosystem services, the heritage of future generations and the future of a productive, healthy planet (Hopkins et al., 2016).

2.2 Marine Spatial Planning

An ecosystem management approach considers the entire marine ecosystem and its interactions, including anthropogenic factors (Kirkfeldt, 2019; McLeod, 2009). It recognises the often complex, stochastic, non-linear, behaviour of ecosystem processes and the cumulative, synergistic, cascading and feedback effects of human impacts on food webs and communities (Douvere, Maes, Vanhulle, & Schrijvers, 2007). GIS geodatabases allow many different data sources and formats to be linked and simultaneously analysed in readily interpreted numerical models and map simulations. They are therefore, powerful tools for environmental decision support and marine spatial planning (Breen, 2007; Mahboubi, Parkes, Stephen, & Chan, 2015).

An integrated ecosystem-based management approach examines ecological, political and socio-economic values to enhance management for prolonged sustainability (Pavlikakis & Tsihrintzis, 2000). Government, stakeholder and community sectors working together, can pro-actively assist in decision making and identifying conflicting values, use and management (Peart, 2019). This enables decision makers to identify where resource trade-offs can be made to ensure that ecosystems are not being overexploited and are sustainable and productive (Guerry et al., 2012).

Early examples of broad scale marine spatial planning that evaluates marine habitats, species and human activities in computer optimisation models include the Great Barrier Reef Marine Park (Cocks, 1984; Cocks, Ive, Davis, & Baird, 1983) and marine parks in New South Wales, Australia (Ward & Jacoby, 1992) However, most research and applications of this approach for the next 20 years were largely restricted to planning for terrestrial protected areas in forests, deserts and mountains in Australia and around the world (Ball & Possingham, 2000; Breen, 2007).

In 2001, the terrestrial planning tool Spexan, developed by Ian Ball and Hugh Possingham at the University of Adelaide, was adapted for the 'Representative Areas' zoning plan for the Great Barrier Reef Marine Park (Ball & Possingham, 2000; Kerrigan et al., 2010). Statistical modelling and reserve planning tools integrating over 80 different reef-wide data sets were used with mapped public submissions and consultation to rezone the Park in 2004. The plan increased the area of no-take protection from 6% to 33% of the park, representing over 60 scientifically defined marine bioregions in highly protected Marine National Park zones (Breen, 2007; Merrie & Olsson, 2014).

Other marine spatial plans were also underway in the Irish and Belgium Seas (Day et al., 2002; Douvere et al., 2007; Kidd, 2013) and have now become an integral part of marine ecosystem-based management (EBM) in many regions (Day, 2008; Katsanevakis et al., 2011).

MSP identifies marine spaces and resources of importance to inform decision-making processes for effective management. Allocating certain activities in marine spaces can enhance environmental protection and ensure sustainable use of the marine environment (Ansong et al., 2017; Merrie & Olsson, 2014)..

Using MSP to recognise sites for Marine Protected Areas (MPAs) can ensure better outcomes and interconnectivity of MPAs (Dudley, 2008). Ecosystem-based marine spatial planning, incorporating network connectivity and reserve design guidelines, is a key factor in the conservation of fish stocks and biodiversity, whilst enhancing the area for native species and humans (Durante, Beentjes, & Wing, 2020; Hilty et al., 2020; Katsanevakis et al., 2011). Currently there are 108 MSP initiatives across 66 countries, with this number steadily rising (Frazão Santos et al., 2019). It has been predicted by the Intergovernmental Oceanic Commission that by 2025 MSPs could potentially cover 31 million km^2 (one- quarter) of exclusive economic zones globally (Merrie & Olsson, 2014). The MSP process emphasises integration between all sectors, but can be inhibited by diverging objectives from different stakeholders e.g. for oil and gas extraction and biodiversity conservation (Jones, Lieberknecht, & Qiu, 2016).

The impact that land-based activities have on coastal ecosystems has been highlighted for many years, but catchment areas are regularly excluded from plans (Domínguez-Tejo, Metternicht, Johnston, & Hedge, 2016). Collaborative Marine Spatial Plans ensure that the needs of a wide range of stakeholders are met. Top-down management on its own, without input from stakeholders, can alienate communities and disrupt the implementation of plans (Jones et al., 2016).

Monitoring, evaluation and modification of management strategies is essential to determine efficiency and productiveness and provide meaningful feedback to managers, stakeholders and communities. (Day, 2008; Jay, Ellis, & Kidd, 2012; Katsanevakis et al., 2011)

2.3 Marine Protected Areas

MPAs are an essential tool for conservation, aiming to decrease the loss of marine diversity caused by anthropogenic threats (Maestro, Pérez-Cayeiro, Chica-Ruiz, & Reyes, 2019). International agreements encourage countries to protect marine ecosystems through MPA establishment. New Zealand is a part of the Convention on Biological Diversity which set 20 Aichi Targets (conservation targets) to be met by 2020. Aichi Target 11 was to have 10% of New Zealand's marine space protected by MPAs (Aichi Biodiversity Targets, 2020). This target has been criticised as it is thought to have promoted marine spatial coverage instead of marine spatial planning, which ensures effectiveness of MPAs (Rovellini & Shaffer, 2020). MPAs need planning to maximise the protection of abiotic and biotic features in a marine space. Without this, protections could be placed anywhere (e.g. benthic protected areas in regions too deep to trawl), just to meet international agreement targets. Policymakers gravitate towards targets that are easily quantified and assessed, which is why coverage targets have been easier to meet, especially by redefining MPA definitions to include existing areas established for other purposes (e.g. cable zones) (Department of Conservation and Ministry of Fisheries, 2005, 2008).

The literature has highlighted that 30 to 50% coverage of ocean areas is needed by 2030 to maintain or improve ecological resilience and help sustain biological diversity under threat from human activities (IUCN, 2016; Maestro et al., 2019). Well-designed MPAs have numerous proven benefits including increases in fish stocks, biomass, connectivity and can help avoid fisheries and ecosystem collapses. MPAs now aim to protect representative ecosystems, habitats and species as well as unique, rare, commercially valuable or charismatic areas and also aim to provide ecosystem goods and services for human activities and food security (Ban, Evans, Nenadovic, & Schoon, 2015; Department of Conservation and Ministry of Fisheries, 2008). MPA allocation in New Zealand is an important management and conservation priority (Department of Conservation and Ministry of Fisheries, 2008).

2.4 New Zealand’s Marine Environment

Te moana (the ocean or sea) environment is an integral part of Aotearoa’s identity and is a source of whakapapa for Māori (Hauraki Gulf Forum, 2020). Seafaring Polynesians settled in coastal dwellings around Aotearoa and continued fishing traditions upon arrival (Hikuroa, 2017; Whaanga, Wehi, Cox, Roa, & Kusabs, 2018). Ingrained in Māori culture still today are traditions of harvesting marine invertebrates and fishing for cultural and economic purposes. The Māori Marine Economy (MME) is typically whānau (family) sized and uses a variety of traditional and commercial fishing techniques (Rout et al., 2018). Traditional practices of manaakitanga (hospitality) still include marine delicacies at tribal events such as hui and tangi (Hikuroa, 2017). Many whakataukī (proverbs) are also centred around the marine environment, which provides intergenerational mātauranga (knowledge) Māori of areas around Aotearoa (Ministry for the Environment & Stats NZ, 2019; Whaanga et al., 2018). Longstanding myths and legends are also intertwined with the marine environment (Hikuroa, 2017).

Approximately 30% of all New Zealand's biodiversity is from marine species, but gaps in this knowledge exist due to the prioritisation of commercial species (Ministry for the Environment & Stats NZ, 2019). Further comprehensive assessments are needed for marine species such as shorebirds, seabirds and marine mammals which are highly threatened, with many on the verge of extinction (Bellingham et al., 2010; Robertson & Chilvers, 2011). Non-native species are also on the rise and are directly impacting habitats by competing for resources with endemic and other native species (Ahyong et al., 2017; Ministry for the Environment & Stats NZ, 2019; Peart, 2009).

Estuaries have a variety of habitats such as mangroves, seagrass and kelp forests which act as nurseries for juveniles (Morrison, Jones, Parsons, & Grant, 2014). The three-dimensional structure of benthic plants and animals provide shelter and food for other organisms in the form of biogenic habitats (Morrison et al., 2014; Valavanis et al., 2008). Biogenic habitats support diverse trophic levels which enhances environmental resilience against disturbance events (Frank, Petrie, & Shackell, 2007). These habitats provide ecosystems goods and services such as water filtration, stabilisation of sediment, nutrient cycling and reducing coastal erosion (Grabowski & Peterson, 2007). It is important to understand the abiotic and biotic factors which influence an environment and how they affect biogenic habitats. Biogenic environments are threatened and their health is declining (Anderson et al., 2019).

Habitat degradation impacts species' migration, breeding and feeding behaviours (J Hewitt et al., 2001) and ecosystem goods and services are impacted through the loss of available biogenic habitat, though not all repercussions are known (Sunday et al., 2017).

An example of this loss is the green-lipped mussel, *Perna canaliculus* (kuku), which once dominated soft sediments in the Firth of Thames and Hauraki Gulf. Since the 1970s, mussels are now mostly found on mussel farms or rocky shores and are considered functionally extinct in the area (Anderson et al., 2019; McLeod, Parsons, Morrison, Le Port, & Taylor, 2012). It is estimated that 500 square kilometres of the Firth of Thames was covered in kuku beds, which filtered the entire volume of water in the Firth in a single day (McLeod, 2009). It is estimated that current kuku beds in the Firth would take 2 years to filter the same volume.

European settlement in New Zealand introduced widespread changes in the composition of sediments in many marine environments due to different values, perspectives and government systems (Hauraki Gulf Forum, 2020; Peart, 2007).

Activities that occur on land heavily impact coastal waters, with nutrients and sediment washed down through the catchment area to the sea (Abrahim & Parker, 2002). Coastal zones such as estuaries have experienced increases in sediment accumulation, muddiness and contaminants (Lundquist et al., 2003). These factors are also influenced by natural seasonal fluctuations and human activities (Robertson & Stevens, 2015). Water quality is also influenced by phytoplankton, turbidity, oxygen, pH and nutrient levels (Lundquist et al., 2003). Difficulties arise with assessment due to various factors such as topography and catchment areas influencing marine environments (Black, Bell, Oldman, Carter, & Hume, 2000; Boxberg, Blossier, de Lange, Fox, & Hebbeln, 2019). Management of catchments and coastal land use strongly impact coastal marine environments and the marine species that depend on them (Hunt, 2016).

2.5 The Hauraki Gulf Marine Park

The Hauraki Gulf Marine Park (HGMP) extends over 13,900 km^2 from the Waitemata Harbour, to the Hauraki Gulf, Firth of Thames and both sides of the Coromandel Peninsula (Hauraki Gulf Forum, 2020). The coast includes a wide variety of habitats including beaches, mud flats, rocky shores, estuaries, mangrove, seagrass, saltmarsh and sub-tidal reef, sand, gravel and boulders. The HGMP surrounds inner and outer islands from the Mokohinau Islands and Great Barrier Island in the north through to the islands off Whangamata to the south.

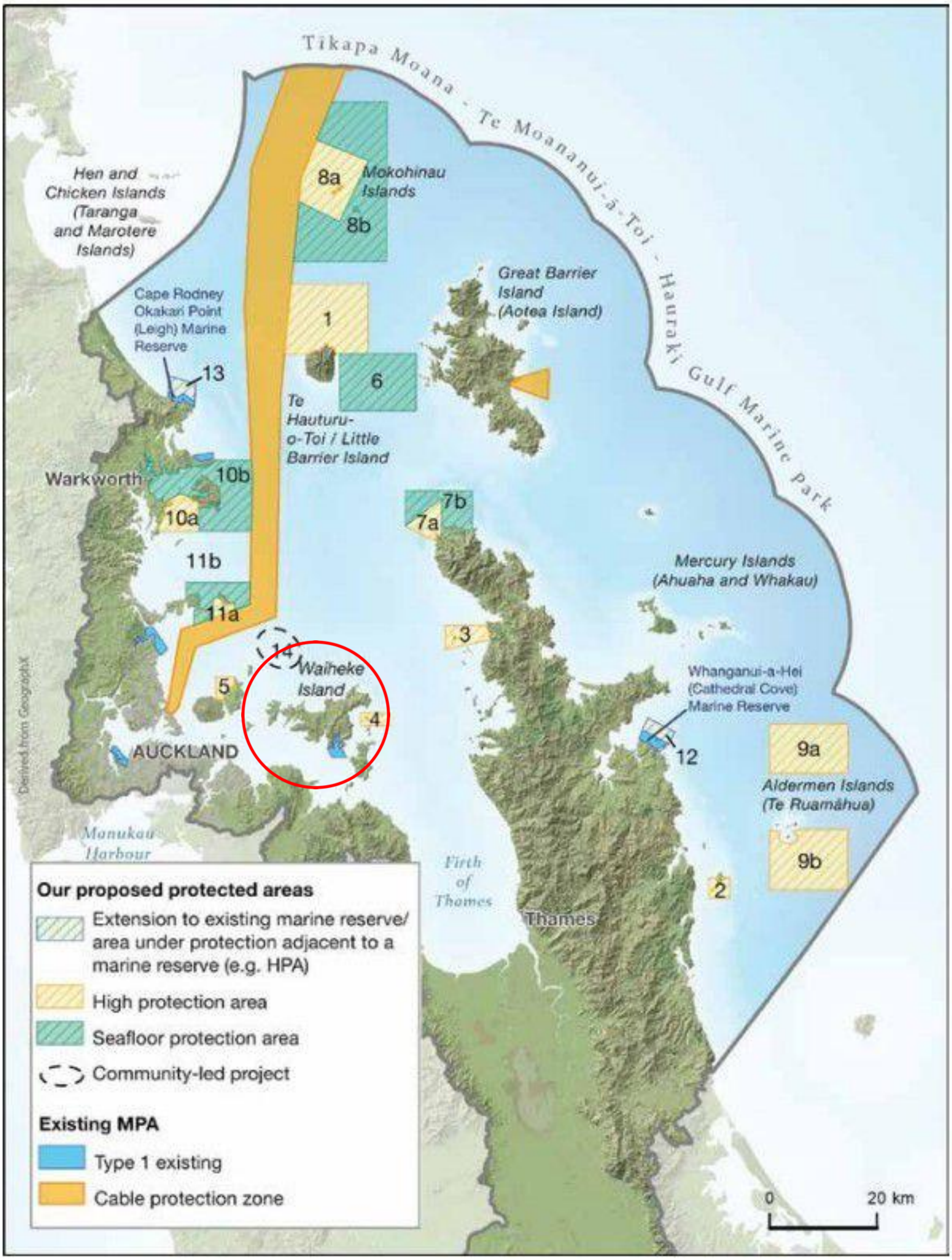

Figure 3 Hauraki Gulf Marine Park, with Waiheke Island circled in red in the centre of the map (from Department of Conservation and Fisheries New Zealand. (2021b). Revitalising the Gulf – Government action on the Sea Change Plan.

The Hauraki Gulf acts as a nursery and spawning area for a variety of fin fish and is a biodiversity hotspot for seabirds (Gaskin & Rayner, 2013; Parsons, Buckthought, Edhouse, & Lohrer, 2020). The Hauraki Gulf is a spawning and nursery ground for taonga (treasure) species such as tarakihi (*Nemadactylus macropterus*), snapper (*Pagrus auratus)* and blue cod (*Parapercis colias) (*Morrison et al., 2014). The commercial and recreational sector value native fish and shellfish species such as scallops (*Pecten novaezelandiae*), green-lipped mussels, snapper, kahawai (*Arripis trutta*) and tarakihi which inhabit the HGMP (Ministry for the Environment & Stats NZ, 2019).

Biogenic habitats in the Hauraki Gulf include kelp beds, mangroves, sea grasses, mussels, horse mussels (*Atrina zelandica*), oyster beds, dog cockles (*Glycymeris laticostatus*) and rhodoliths (Kerr & Grace, 2013). However, there are gaps in spatial inventories and baseline assessments for many biogenic habitats, which has made it difficult to assess habitat loss. Qualitative rather than quantitative information has guided much of the present arrangements for management (Haggitt, 2016a).

Since the establishment of the Hauraki Gulf Marine Park in 2000, Auckland's population has continued to increase. Human land activities such as urbanisation, forestry, transport and agriculture produce pollutants. Catchment areas have variable climates, land usage, slopes and soil compositions which can impact the type and volume of pollutants (Álvarez-Romero et al., 2014). Increased pollutant levels can be the result of drained wetlands, agricultural intensification and urban development (Dudley, 2008).

Chemicals, nutrients and sediments impact marine species, though the wider marine ecosystem effects are not fully known. Urban rivers have higher levels of contaminants, which makes marine biota more vulnerable in shallow estuaries (Álvarez-Romero et al., 2014; Dudley, 2008). Urbanisation can impact marine habitats and species, diversity, assemblages and behaviours.

The presence of toxins and pollutants can impact human uses in the area, in particular fishing, kaimoana gathering and beach closures (Ministry for the Environment & Stats NZ, 2019). Land-based activities apply excessive pressure to marine species, for instance, the range and abundance of kuku has significantly decreased in the Hauraki Gulf (McLeod et al., 2012). Kuku are filter feeders that have been impacted by increases in sedimentation, toxin levels, oxygen availability, ingested plastics and pharmaceuticals have also impacted their ability to attach themselves to rocky substrate (McLeod, 2009; McLeod et al., 2012; Webb, 2017). Declines in biodiversity can impact an ecosystems resilience to disturbance events and climate change (Micheli et al., 2012).

2.6 Marine Spatial Planning in New Zealand

New Zealand has a complex and diverse marine landscape, with ecosystems and habitats hosting a variety of native and endemic marine species. In New Zealand's Territorial Sea, Marine Protected Areas (MPA) cover 12,800 square kilometres (7.06%). Most of this area (97%) is from large offshore marine reserves in the Kermadec Islands and the Sub-Antarctic Islands (Ministry for the Environment, 2008). New Zealand is currently reforming its MPA legislation as many targets are too broad and need to be viewed in the context of New Zealand's own marine environment. This creates the opportunity to have comprehensive and collaborative science-based targets for conservation and protection of waters and coastlines (Rovellini & Shaffer, 2020).

Management plans need to support the conservation of biodiversity and ecological processes (Micheli et al., 2012). The Marine Reserve Act 1971 created legislative tools, such as no-take Marine Reserves, to conserve and preserve marine ecosystems for scientific study (Department of Conservation and Ministry of Fisheries, 2008). This authority over Marine Reserves ensures appropriate management and control of activities including tourism, fishing, moorings, extraction, marine farming, research and waste discharge points (Micheli et al., 2012).

Established in 2005, the Marine Protected Areas Policy and Implementation Plan (MPA Policy) was intended to preserve current functioning states of marine ecosystems and habitats, whilst allowing degraded habitats to recover (Department of Conservation and Ministry of Fisheries, 2005). This partnership aimed to conserve a diverse range of marine habitats be protected and manage these appropriately. Creating a comprehensive management strategy aimed to establish an interconnected network of marine protected areas rather than scattered small areas managed in isolation (Ban et al., 2017).

The MPA Policy provided marine managers guidance on processes to ensure all factors are considered when selecting new MPAs. The policy defined specific habitat types to be represented within a national network of MPAs. This habitat classification was derived from intersecting broad categories of depth, substrata and exposure as a surrogate or environmental indicators of different spatial patterns in species, habitats, processes and ecosystems.

The Marine Protected Areas Policy also set standards for MPAs in New Zealand that sought to define other MPA types, in addition to no-take marine reserves. These included partially protected areas such as cable and pipeline zones, some specific combinations of fisheries closures and other areas established under different legislation (Department of Conservation and Ministry of Fisheries, 2008). Of these *de facto* MPAs, cable zones contributed the most area to the new MPAs, but even with the addition of these areas, the percentage of coastal Territorial Sea protected on the mainland was around 1%.

A discussion paper released by the previous National Party Government proposed a *Marine Protected Areas Act*. This would allow for the development of four types of MPA: no-take marine reserves; species specific sanctuaries; benthic protected areas; and recreational fishing parks. The proposal simultaneously suggested that the Marlborough Sounds and the Inner Hauraki Gulf be declared as recreational fishing parks, although this might pre-empt any plans for any other type of MPA (Department of Conservation and Ministry of Fisheries, 2005, 2008).

Other MPAs not included in these policies include customary Māori mātaitai, taiāpure and rāhui (Fisheries New Zealand, 2021). These agreements within and among iwi can be formalised under fisheries legislation and have increased steadily in number in recent years. In a high court decision, it has also now been declared that regional councils have the power and responsibility to create MPAs for conservation and this approach is being taken by iwi and community groups for an area off Tauranga and for other locations in Northland. Regional councils are encouraged to include new MPAs and their management into regional plans.

Current marine protection types focus on the impacts of fishing activities, with other forms of protection considered on a case-by-case basis. The selection criteria of the MPA Policy ensures that existing area-specific uses are not impacted when selecting new areas to conserve and protect (Department of Conservation and Ministry of Fisheries, 2008). Widespread fishing activities, due to scale, will be impacted when new MPAs are established (Ban et al., 2015). In areas where MPAs currently do not exist, marine spatial plans can identify locations of social, economic, cultural, spiritual, political and environmental importance (Ban et al., 2015). New plans also allow for the assessment and review of previous management strategies.

2.7 The Hauraki Gulf Marine Park and Forum

The Hauraki Gulf Marine Park extends along the east coast of the North Island from Pakiri to Waihi and includes the Hauraki Gulf or Tīkapa Moana / Te Moana-nui-a-Toi, The Firth of Thames, the Coromandel Peninsula and the sea out to 12 nautical miles from the coast and many islands. Auckland is home to 34% of New Zealand's population (Hauraki Gulf Forum, 2017; Stats NZ, 2018) and much of the remaining coast and catchments for the Marine Park are grazed, cultivated, logged or urbanised.

New Zealand's increasing population impacts the rate of urban and marine development and adds commercial pressure (Hauraki Gulf Forum, 2020). This has expanded the development and use of the Marine Park and its catchments for many activities including agriculture, coastal development, ports and shipping, commercial and recreational fishing, aquaculture, customary use, conservation, research, water sports, passive recreation and education.

The Hauraki Gulf Marine Park Act 2000 established the Hauraki Gulf Marine Park and the Hauraki Gulf Marine Park Forum. The latter Forum is made up of representatives from regional and national governments, tangata whenua, stakeholder groups and Ministers from Fisheries, Māori Development and Conservation (Peart, 2019). The Hauraki Gulf Marine Park Act does not prohibit or restrict any customary, commercial or recreational activities that occur within the park. This Forum cannot make or implement decisions but advocates and promotes sustainable integrated management of the Hauraki Gulf, its islands and the catchment area.

The Forum highlights key issues and requires reports from parties regarding their management and the development of policies to target issues (Hauraki Gulf Forum, 2014). From this, the Forum amalgamates information and produces a report every three years on the environmental health of the Hauraki Gulf. This State of the Hauraki Gulf Report provides information on current goals and progress, while also identifying key management issues. In 2020, the Hauraki Gulf Forum set goals in line with Aichi Biodiversity Targets, for at least 30% marine protection and restoration of 1000sqkm of shellfish- beds and reefs.

The Hauraki Gulf Marine Park currently includes six small marine reserves: Tāwharanui, Cape Rodney-Point Okakari, Long Bay Okura, Motu Manawa (Pollen Island), Te Matuku Bay and Te Whanganui-a-hei marine reserves. Prior to the marine parks' establishment, 33 km^2 of the current 40 km^2 was already categorized as marine reserve. Approximately 744 km^2 of marine space has been allocated as a cable protection zone, which has little biodiversity significance (Hauraki Gulf Forum, 2020).

In 2011, the Forum requested a review of MSP initiatives from countries such as Australia, USA, Norway and Canada. This report concluded that the integrated management of MSP allowed for protection, preservation and enhancement of marine spaces (Hauraki Gulf Forum, 2014). Tools such as zoning could be used to allocate space and separate and control incompatible activities. Community and stakeholder consultation informed by the best available science on ecological, cultural, commercial, recreational and political values could be used to explore and assess alternative plans and incorporate local and customary knowledge and experience (Katsanevakis et al., 2011). This led to the Forum commissioning research and consultation to develop a marine spatial plan for the Hauraki Gulf Marine Park through a planning process titled “Sea Change.”

2.8 The Sea Change Marine Spatial Plan for the Hauraki Gulf Marine Park

Very little marine planning had occurred in the marine park since the 1990s, which had primarily focused on current activities, with no thought for the future (Peart, 2009), until Sea Change - Tai Timu Tai Pari, was created in December 2013 (Sea Change, 2016). The exception was policy development, habitat mapping and data collection carried out by the Auckland, Northland, Waikato and Bay of Plenty offices of the Department of Conservation which provided information for Seachange and this project.

The aim of the marine spatial plan was to limit, reverse and reduce environmental degradation to create a sustainable Hauraki Gulf Marine Park for future generations (Sea Change, 2016). A collaborative working group consisted of 14 representatives from Māori, local community groups, aquaculture, farming, commercial and recreational fishing, dairy, science and environmental agencies provided oversight for Māori and both regional and national governments to ensure stakeholders had access to appropriate administration, science and technical support (Peart, 2019; Sea Change, 2016).

An application using the Sea Sketch internet based GIS software was established to publicly display multiple map layers describing biodiversity and human activities in the

Gulf and allow stakeholders, government agencies and the public to analyse alternative options and map their own information and views. The late establishment of this MSP in New Zealand allowed for information from internationally successful MSPs to be applied through a lens specific to New Zealand (Peart, 2019).

After three years, this Marine Spatial Plan was finalised and launched in December 2016 with a holistic vision. It aimed to restore the Hauraki Gulf's mauri (essence and life force) and presented a list of goals and actions to achieve this (Department of Conservation & Fisheries New Zealand, 2021; Sea Change, 2016).

The plan proposed to create an interconnected network of different types of Marine Protected Areas, such as 11 no-take marine reserves, extensions on two current MPAs and protection of benthic areas. It targeted restoration of habitats with declining or poor health and aimed to phase out destructive fishing methods which contact the benthic zone.

It also proposed to embrace an Ahu Moana joint management approach for nearshore environments by mana whenua and other local communities with small-scale adaptive protection and management of fisheries areas based on traditional ecological knowledge (mātauranga Māori).

The plan created 13 new areas for sustainable marine farming and also aimed to limit the level of contaminants such as heavy metals, sediments and nutrients from land-based activities in catchment areas.

In December 2016, this non-statutory plan was symbolically handed to local and central governments, who have been analysing the proposal and discussing steps for implementation (Department of Conservation & Fisheries New Zealand, 2021; Peart, 2019).

The Department of Conservation and Fisheries New Zealand in June 2021 published a response to the Sea Change – Tai Timu Tai Pari - HGMP Spatial Plan. In Figure 3, eighteen new protected areas are highlighted including eleven new Highly Protected Areas (HPA) to protect and enhance marine ecosystems and communities.

However, the Seachange Plan excluded Waiheke Island from its scope due to conflicting stakeholder interests and existing council community board and non-government organisation marine planning already underway. For an interconnected network of MPAs, the waters around Waiheke Island need to be assessed and incorporated into management plans as it is a large part of the inner Hauraki Gulf. Rigorous biological surveys around Waiheke Island are needed to understand species assemblages and ensure management plans protect ecologically important areas (Wong & O'Shea, 2010).

2.1 Waiheke Island and the Hauraki Gulf Marine Park

Waiheke Island is only 30 kilometres from Auckland CBD, but has a diverse range of habitats and biophysical features surrounding its coastline (Haggitt, 2016a). Waiheke Island is the largest inner Hauraki Gulf island and is linked by strong tidal currents to nearby Motutapu, Rangitoto, Motuihe, Rakino, The Noises, Pakatoa, Rotoroa, Ponui and other islands (Figure 1). Wave action, turbidity, currents, sediment type, depth and catchment areas create a unique combination of environments in the inner Gulf and around Waiheke Island (Kerr & Grace, 2013).

Waiheke Island lies on a steep environmental gradient, from sheltered estuarine areas to high current island channels to offshore shelf habitats (Haggitt, 2016a). This connectivity is important for the dispersal and recruitment of adult and larval marine organisms, food webs and unfortunately, land-based pollutants (Francis, Morrison, Leathwick, Walsh, & Middleton, 2005).

Waiheke Island, like much of the Gulf is extremely vulnerable to land-based activities, with sedimentation causing significant impacts on the environment. Turbidity is considerably higher on the southern, eastern and western faces of the island, due to the influence of the Tamaki River, Firth of Thames and the Tamaki Strait. Whereas, the northern side of Waiheke Island is less turbid (Lundquist, Vopel, Thrush, & Swales, 2003). One of the justifications for marine reserves on the north side of Waiheke Island was so that snorkelling children and their parents and other visitors would be able to see healthy populations of fishes and invertebrates in relatively clear water (Department of Conservation & Fisheries New Zealand, 2021).

In the 1800s, Waiheke Island's kauri forest was milled and converted to pasture for farming which led to widespread erosion with diminished returns (Baragwanath, 2010). The island substratum consists of mineralised clay, silt, greywacke rock and sandstone (Grant-Mackie, 1959; Haggitt, 2016a; Hayward et al., 1997).

Along the southern side of Waiheke Island and in Whakanewha Regional Park, possum free forests of kanuka, manuka, kohekohe and taraire exist (Cameron, 2009; Department of Conservation, 2016). The southern coastline is characterised by sheltered bays with finer sediment creating different environments, whereas the northern coastline has greater wave exposure with rocky platforms and reefs (Haggitt, 2016a; Kerr & Grace, 2013). Predominantly covered by non-native grass, Waiheke Island's environment is also suitable for vineyards due to its slopes and warmer temperatures (Baragwanath, 2010). The island is a popular destination for tourism and recreation for local and overseas visitors and has a large population of residents and holiday house owners. Coastal development, marina proposals, sedimentation from runoff and stormwater, over-harvesting, kina barrens and climate change are just some of the impacts on the island's marine ecosystems. With a population of almost 10,000 residents, the island's inhabitants live close to a wide variety of marine environments (Stats NZ, 2018).

An MPA network founded on ecosystem-based management can help address many of these threats as MPAs are not just a way to manage the effects of fishing. This may require an authority with the mandate to manage across all of these activities, and to manage these areas as part of an efficient network rather than as isolated locations.

With the exception of a recently declared rāhui within one nautical mile of the island for shellfish, the Te Matuku Marine Reserve has been the only marine protected area near Waiheke Island since 2005 (Department of Conservation, 2016; Ministry for Primary Industries, 2021). Saltmarsh, mangroves, intertidal/subtidal soft sediments and rocky reefs are just some of the important habitats located within this established MPA (Haggitt, 2016a; Kerr & Grace, 2013).

The Te Matuku Marine Reserve offers protection to a wide variety of bird and marine life in a mostly undisturbed estuary, which is rare for the Auckland region (Department of Conservation, 2016; Enderby & Enderby, 2005). This 690 ha reserve encompasses Te Matuku Bay, (except the oyster farm), and extends into the Waiheke Channel and Tamaki Strait from White Bay to Otakawhe Bay and across to Kauri Point on Ponui Island.

Before European settlement, Te Matuku Bay was a place of importance for Māori, who collected kaimoana (seafood) and landed waka (canoes) in the bay. Ngāti Pāoa are the kaitiaki (guardians) and tangata whenua (people from this land) of Waiheke Island.

Ngāi Tai and Hauraki iwi also have cultural, historical and spiritual ties to Te Matuku Bay (Department of Conservation, 2016). At the head of the bay, a cemetery and school is all that remains of the first European settlement on Waiheke Island (Cameron, 2009).

This reserve has a diverse array of significant environments such as estuarine saltmarsh, mangroves, low-lying islands, intertidal mudflats, deep water, shell beaches and rocky intertidal zones (Hayward et al., 1997). Each of these habitats is host to a broad range of marine biota that contribute to ecological sequences. Muddiness has increased in the reserve due to sediment deposition theorized to be, in part, from the Wairoa embayment (Abrahim & Parker, 2002; Judi Hewitt, Edhouse, & Simpson, 2009; J Hewitt, Hatton, Safi, & Craggs, 2001).

Monitoring information for the marine reserve currently is *ad hoc* research on epifauna and infauna abundance and diversity in intertidal and subtidal zones. Unpublished data and reports from the Department of Conservation consists of georeferenced drift underwater video surveys of fishes and benthos at night, sediment grain size, infauna composition (Haggitt, 2016a), tunnel net surveys of estuarine fishes, aerial photo maps of estuarine vegetation and single beam and multibeam surveys of the deeper parts of the reserve by NIWA and the University of Waikato.

While baseline monitoring and mapping of sediments, benthic infauna, cockle beds, vegetation and fishes in the reserve has been conducted by DOC, NIWA, local schools and other organisations, this has typically occurred for short periods and largely restricted to the reserve (Haggitt, 2016a).

More recent studies outside the marine reserve include using sidescan sonar, video and SCUBA to map marine habitats off the entire north coast of the island (Kerr &

Grace, 2013), social surveys by Colmar Brunton (2015) and biodiversity assessments by Haggitt (Bing, 2015; Haggitt, 2016b). This feasibility study by Haggitt identified gaps in the current baseline knowledge of location specific habitat distributions and identified the lack of sequential monitoring of habitats over time (Haggitt, 2016b). A timeline of surveys, research and key milestones for Waiheke Island is displayed in **Error! Reference source not found.**.

This research determined more analysis is needed to ensure that Waiheke Island marine reserves complement each other and add to the existing marine reserve network in the HGMP. MPAs are needed to protect rare and diverse marine species and habitats (Department of Conservation and Ministry of Fisheries, 2005; Ministry for Primary Industries, 2017), representative ecosystems and enhance commercial, recreational and customary values for these and surrounding areas (Ministry for the Environment & Stats NZ, 2019).

This Masters research project will assess which areas within 1km of Waiheke Island would best represent each of the 26 marine habitats within a marine reserve or other management area for the least cost in the total area of the network. The resulting GIS models can also be used in participatory management with scientists, stakeholders and iwi help plan for marine conservation around Waiheke Island and the surrounding Marine Park.

3 METHODS

This research project's objective is to identify if simulation models and geographic information system (GIS) analyses can assist with the prioritisation of Waiheke Islands marine space for conservation and sustainable use. Marine spatial planning tools such as Marxan can identify areas that represent multiple habitat types, whilst minimising the coverage of marine space or other potential costs and benefits for other values and activities. Areas prioritised in these analyses will be compared with other marine biodiversity assessments for Waiheke Island and other management areas. The analyses, spatial planning tools provided and areas identified will assist planning for conservation and sustainable use around Waiheke and to help establish a representative and adequate network of MPAs for the Hauraki Gulf and New Zealand.

3.1 Study location

Waiheke Island is the largest inner Hauraki Gulf island. It is surrounded by other islands including Rangitoto and Motutapu to the west, The Noises and Rakino Island to the north-west, Motutihe to the south and Tarahiki Island (Shag Rock), Pakatoa, Rotoroa and Ponui Islands to the south-east. Channels with strong tidal currents surround the island including the Motutapu and Motuihe Channels to the west and south-west, the Tamaki Strait to the south and in the east, the Waiheke Channel which drains Tamaki Strait and mixes with water from the Firth of Thames. Waiheke Island has a coastline of 130 km and a population of 9,660 people, the most densely populated island in the Hauraki Gulf (Stats NZ, 2018). The coastline has a variety of biological and physical habitat types that are the result of complex environmental interactions (Haggitt, 2016; Wong & O'Shea, 2010).

Figure 4 Waiheke Island (published by the Department of Conservation).

3.2 Marine habitat data

Broad "surrogate" habitat categories as defined in the Marine Protected Areas policy (DOC and Ministry of Fisheries 2006) were mapped within 1 kilometre of Waiheke Island using the ArcMap Geographic Information System (GIS) to combine data from three main sources:

- a "Broad scale gap analysis of habitats and marine protected areas in the New Zealand Territorial Sea" (New Zealand Department of Conservation and Ministry of Fisheries, 2011) compiled from many other data sources (Appendix 1).
- more detailed (1:10,000) marine habitat maps of the Hauraki Gulf Marine Park digitised from aerial photos and interpreted from paper fare sheets of hundreds of depth soundings digitised by Stacey Byers, Chris Wild and Anna Wild at Auckland

Conservancy, Department of Conservation with additional coastal data from Environment Waikato, and subsequent modifications made by Vince Kerr and others.

- Finer scale habitat maps by Vince Kerr and the late Roger Grace of the entire north side of Waiheke Island to several kilometres offshore using side scan sonar and underwater video (Kerr & Grace, 2013).

Habitat codes in the three data sets were standardised and simplified for the area around Waiheke Island and the spatial data combined digitally into a single GIS coverage using the “Update” command, with priority given to the data with the highest resolution. ArcMap was used to create a 1 km buffer around the island and clip habitat data to only those areas within the buffer. The width of the 1km buffer was chosen in line with suggestions made during community consultation as part of the Department of Conservation “Future Search” planning process by the Waiheke Collective Marine Project. All data was projected into the New Zealand Transverse Mercator projection using ArcMap. Other unpublished quantitative spatial data were used from Auckland Council and their surveys of the coastline around Waiheke Island in 2013.

3.3 Spatial planning units

Using a coastline modified from Fisheries New Zealand, a 1 km marine buffer around Waiheke Island was divided into 23 coastal sections with boundaries running perpendicular to the coast from prominent coastal features such as headlands and major bays. These relatively large planning units were used to quantify habitats within broad sections of the coastline most readily recognised by stakeholders, local communities, visitors and managers. The “Tabulate Areas” command in ArcMap was used to calculate the area in hectares of each habitat type within each large planning unit.

3.4 Univariate and multivariate analysis

For each habitat type, differences in area among planning units were graphed to visually compare representation of different habitats in each region. Principal component biplots based on the correlation matrix were used to compare multivariate similarities and differences among planning units based on habitat composition using the free statistical software PAST (https://past.en.lo4d.com/windows).

3.5 Irreplaceability of planning units for habitat representation.

The free software Marxan was used to prioritise planning units according to how well they could contribute to a network of marine protected areas that included representative examples of different marine habitats for the least cost in area. Marxan uses a global search algorithm called simulated annealing that aims to choose networks of planning units that together meet targets for representation of different habitats or other conservation features while minimising costs in area occupied, boundary perimeters and other economic or social costs such as economic profit, tonnes of fish or number of licenses.

In this study, we used Marxan to simulate networks that represented 10, 20, 30 and 40% of the area of each of 20 different marine habitats while minimising the cost in the total area protected. Simulated annealing in Marxan aims to minimise the objective function outlined in Equation 1 below.

Equation 1. The objective function minimised in Marxan simulated annealing.

$\sum$site Cost + BLM x $\sum$Boundaries + $\sum$CFPF x P where:

Cost = e.g. reserve area, fish catch, number of licenses etc.

BLM = boundary length modifier to increasingly aggregate sites in a network

CFPF = Conservation feature penalty factor to weight biodiversity targets

P is Penalty or the shortfall – how much more of a feature is required to meet a target

By aiming to minimise the “penalty” or shortfall, Marxan effectively aims to meet feature targets while also minimising costs in the reserve area, length of reserve boundaries or impacts on other human activities and values. For example, if aiming to meet a 10% habitat target, but only 3% of the habitat is included in the network, there is a 7% penalty or shortfall which Marxan will attempt to reduce for each habitat depending on their shortfalls and also their potential costs to other activities and reserve design criteria.

Marxan aims to iteratively minimise the objective function by randomly adding, subtracting and/or swapping planning units many thousands of times, increasingly accepting into the network those planning units that best minimise the objective function. In the early global search stage of simulations, both “good” and “bad” changes are accepted (high annealing “temperature”) and this helps avoid the algorithm being trapped in local minima and failing to seek more efficient solutions.

As the algorithm progresses, only improvements are increasingly accepted (cooling annealing temperatures). For about 20 conservation targets and several thousand planning units, Marxan can complete over 100,000 iterations to generate a ‘near optimal’ solution within a few seconds. While Marxan will not produce a single perfectly optimal solution necessarily (as can be done for small problems using linear integer programming) it can quickly provide, for example, 100 near optimal solutions. This can provide a range of alternative management strategies which all meet biodiversity goals for similar cost. The range of designs can provide flexibility to accommodate other social, economic and cultural values, ecological reserve design and viewpoints.

The frequency of occurrence of each plan unit in solutions from repeated simulations can be used to map the "irreplaceability" of each plan unit as the number of times the unit reoccurs, in for example 100 different solutions.

Pressey et al. (1994) define this value as 'irreplaceability':

"...the likelihood that an area will be required as part of a conservation system that achieves the set of targets";

or "...the extent to which the options for achieving the set of targets are reduced if the area is unavailable for conservation."

"If an area is totally irreplaceable, then no matter how a system of conservation areas is designed for a region, it will have to include that area. Put the other way, if that area loses its conservation values, one or more of the conservation targets for the study area will become unreachable."

The potential complementary value of a planning unit in meeting targets will change as each new site contributes additional features to the network. Complementarity is how different planning units can work together to meet targets for all conservation features, because a planning unit chosen primarily to represent a particular habitat will also contribute to goals for other habitats present in the unit. This means that it is not just the richest planning units with many habitats that is necessarily chosen, because often, combinations of other sites can, together, meet targets for a lesser cost (Pressey, Johnson, & Wilson, 1994).

For a few planning units and conservation features (i.e. <10) the most complementary network of sites can be identified by inspection. For more than a few units and features there are many thousands of permutations, and this is why iterative, machine learning algorithms, like Marxan, which rapidly assess millions of network permutations, are required to choose the most complementary networks.

Other settings in Marxan can be used specify other network characteristics such as minimum reserve size, minimum replication of conservation features in different reserves, minimum distance between reserves, the mandatory inclusion or exclusion of particular planning units from network solutions and the identification of different zones for different activities and objectives.

In this study, Marxan aimed to identify which of 23 large planning units could most efficiently include 10, 20, 30 and 40% of the area of each of 20 different marine habitats for the least cost in area. Marxan was run for scenarios which ignored the existence of the Te Matuku Marine Reserve and also for scenarios where the marine reserve was included as mandatory in all network solutions. One million iterations with 10,000 temperature decreases were used to generate each near optimal solution. One hundred near optimal solutions were run for each combination of percentage targets, either with or without Te Matuku Bay included as a mandatory part of the network. Each provided two outputs: the best near optimal solution from one hundred runs and also the number of times a planning unit occurred in solutions from a total of 100 runs (irreplaceability). These outputs from Marxan were imported into ArcMap, joined to the polygon file for the planning units, and used to map the best planning unit solutions and ‘irreplaceability’ (frequency of planning unit occurrence in solutions) for different areas within 1km of Waiheke Island.

4 RESULTS

This results section of this thesis maps, describes and quantifies the area of 20 different marine habitats within 23 sections of coast around Waiheke Island; compares multivariate differences in habitat composition among these broad scale planning units; and then maps the relative irreplaceability of different areas, based on how well they complement other planning units in representative and adequate hypothetical MPA networks.

Broad scale planning units within 1km of Waiheke Island overlaid on mapped marine habitats in Figure 5, show clear differences around the island in habitat composition and highlight areas where relatively rare, irreplaceable habitats occur. In Figure 5, detailed marine habitat maps for each of the 23 broad scale planning units, are shown in an interactive atlas (ArcPro map series pdf). Double clicking on Figure 6 will open the pdf and clicking the down arrow will step through high resolution images of each planning unit. The map legend shows colours, shades and patterns of different marine habitats at different depth ranges i.e. shades of red for boulder, purple for gravel, yellow for sand, brown for mud, blue or black for rock and cross hatching for high current areas. For each marine habitat, bar charts in Figure 8 to Figure 26 show the area in hectares across all broad scale planning units. The figures quantify the extent and distribution of common and rare marine habitats around the island, providing an intuitive view of which planning units, best represent the full diversity of habitats for the least cost in area. Summaries of which planning units are likely to contribute most to a representative network are described for each habitat in the planning sections below. The areas (ha) of different habitats in different broadscale planning units are listed in Table 1 (Appendix 1).

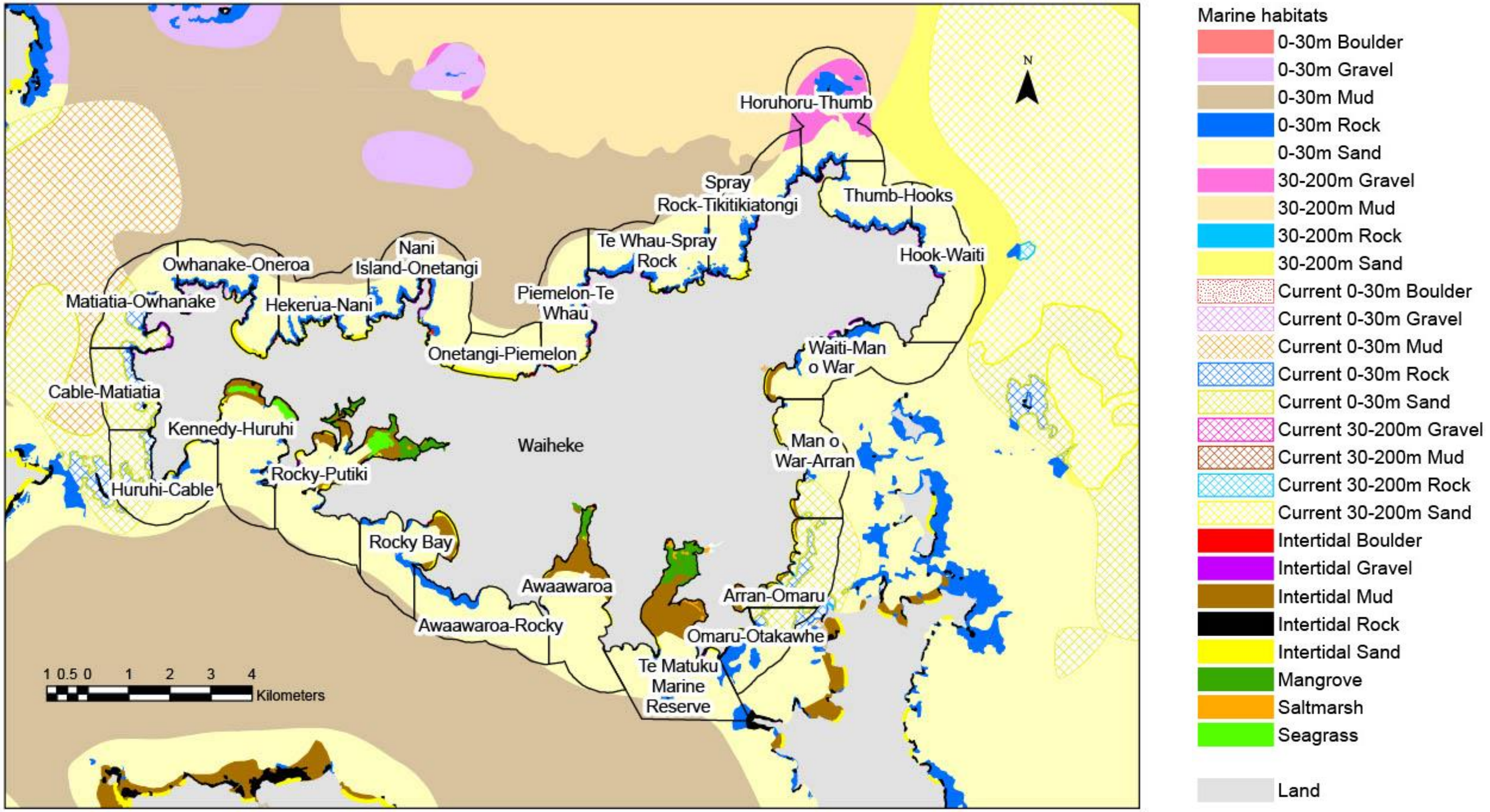

Figure 5 Waiheke Island sectioned into 23 sections by physical landmarks overlaid on the distribution of marine habitats around the island.

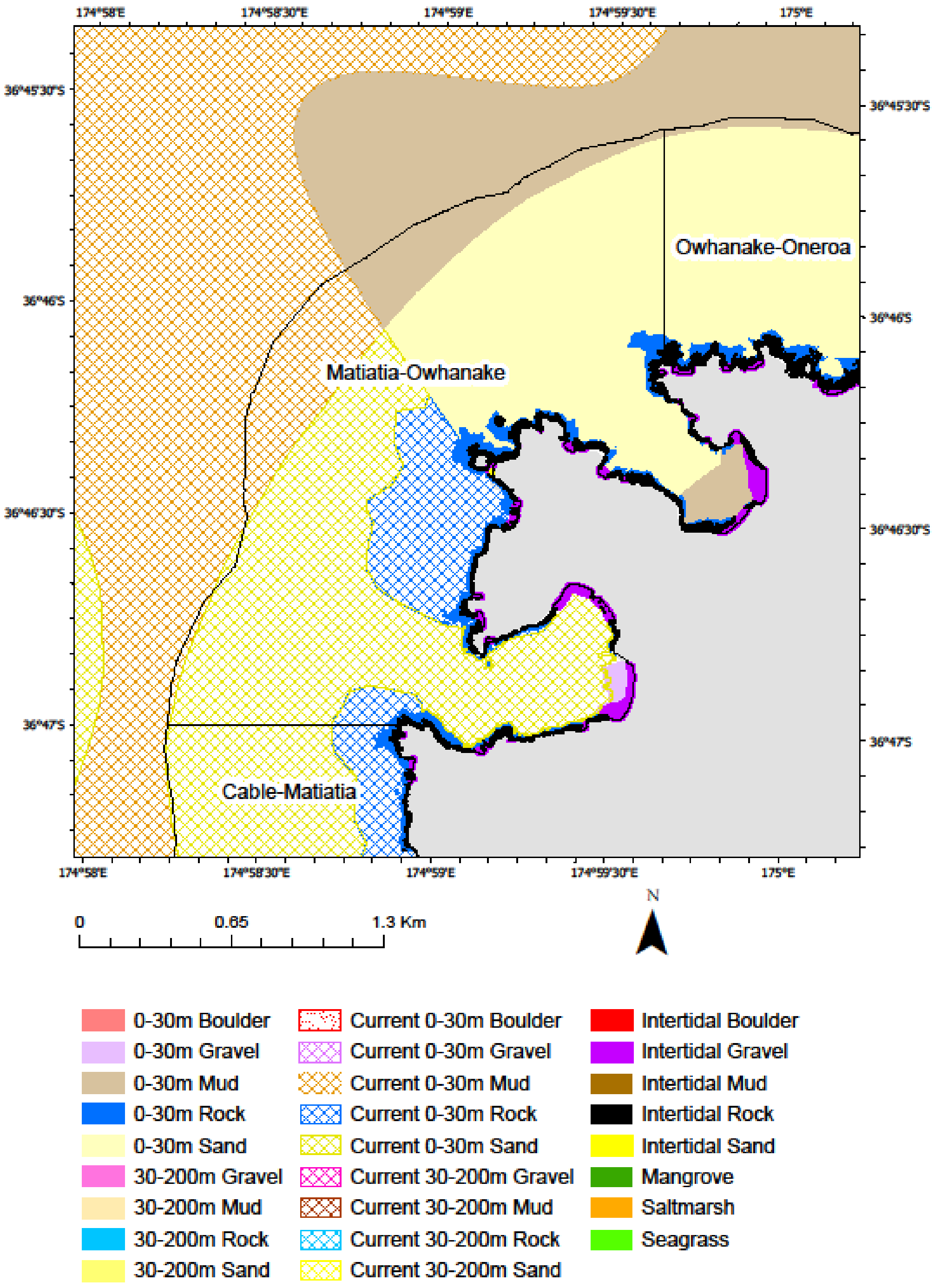

Figure 6. Atlas of marine habitats mapped for each planning unit within 1 km of Waiheke Island. Double click on the figure and then click and arrow down on the linked pdf map menu to cycle through a tour of fine scale habitat maps for each individual plan unit.

4.1 Boulder habitats

Small intertidal boulder beaches were limited mainly (with the exception of Rocky Bay) to a few locations on the northern side of the island (Figure 7). Nani Island-Onetangi included the largest area of this habitat (1.6 ha). Together with the Piemelon-Te Whau and Owhanake-Oneroa planning units, these sections of coast included most of the intertidal and subtidal boulder habitat around the island (Figure 7, Figure 8). Rocky Bay is unique on the southern side of the island in having 0.3 ha of intertidal boulder habitat.

4.2 Gravel habitats

Intertidal gravel habitats occurred mainly along the northern side of the island around to Man ‘o War Bay in the east (Figure 9). The Matiatia-Owhanake section (4.2 ha) and adjacent Owhanake-Oneroa sections included the largest area of this habitat. However, sections east of Onetangi consistently included significant areas of gravel beach and Te Matuku Marine Reserve also included intertidal gravel along an estuarine shell bank and beaches exposed to current at the mouth of the Waiheke Channel. On the south-western side of the island, small areas of intertidal gravel occurred only in the Rocky-Pūtiki section and Cable-Matiatia sections (Figure 9).

The north side of Waiheke Island included almost all the areas of 0-30m gravel (Figure 10), with the largest areas found in the Matiatia-Owhanake (1.6 ha), Owhanake-Oneroa, Noni Island-Onetangi and the Thumb Point to Hooks Bay sections. A small area in the Rocky-Pūtiki Bay (0.2 ha) section is the only area of 0-30m gravel mapped on the southern side of the island.

The north-eastern extremity of the island had the only mapped areas of subtidal gravel habitats between 30 and 200m (210 ha, Figure 11) between Spray Rock, Horuhoru (Gannet Rock) and Thumb Point. Gravel varies depending on location and size, it may in some instances include other categories such as shells, shell hash and shell grit and other skeletal sediments as well as terrestrial gravels. In the area between Thumb Point and Horuhoru, areas of coarse sediment or reef were evident in surveys by Kerr and Grace (2015). Previous underwater drop videos recorded by the Department of Conservation in 2007 (pers. comm. D. Breen) show large accumulations of *Glycymeris laticostata* dog cockle shells near Horuhoru. These robust shells last for many years providing biogenic habitat for many invertebrates and substrata for sponges, corals, bryozoans other filter feeders and fishes to colonise (Anderson et al., 2019; Sunday et al., 2017).

4.3 Rock habitat

Intertidal rock habitats were found around the entire Waiheke coast but were most extensive on the north side of the island. The Nani Island-Onetangi (15.5 ha) and Owhanake-Oneroa (14.6 ha) sections included the largest areas of intertidal rocky shores although most northern sections on the island included significant areas of this habitat and smaller areas were present in many sections on the southern side of the island (Figure 12).

Large areas of 0-30m rocky reef occurred around the island with the largest areas in the Omaru-Otakawhe (60.1 ha) and the Horuhoru-Thumb sections (58.7 ha; Figure 13).

Other sections with large areas of rocky reef at this depth range occurred in high current areas including the Arran-Omaru (43.2 ha) and adjoining sections of the

Waiheke Channel and on the north-eastern side of the island, Matiatia-Owhanake (40 ha), Cable-Matiatia (37 ha) and Huruhi-Cable Bay (41.6 ha) on the Motutapu Channel (Figure 14).

The only areas within 1km of the Waiheke Island coast with high current 30-200m rocky reefs occurred in the Man o' War-Arran (1.6 ha) and Arran-Omaru (0.2 ha) sections in the Waiheke Channel on the eastern side of the island (Figure 15).

4.4 Sand habitats

Intertidal sandy beaches were found around most of the Waiheke Island coast (Figure 16), with the Onetangi-Piemelon (13.8 ha) and Owhanake-Oneroa (11.1 ha) sections including the largest area of this habitat. Awaawaroa-Rocky, Hook-Waiti, Horuhoru-Thumb and Matiatia-Owhanake (0.01ha) included the smallest area of this habitat (Figure 16).

The 0-30 m sand habitat category is present in all sections around the island (Figure 17) occupying areas up to 400 ha with the exception of the Arran-Omaru section which is classified entirely as high current 0-30m sand.

High current 0-30 m sand (Figure 19) was found primarily at the north-west end of the island in the Matiatia-Owhanake, Cable-Matiatia and Huruhi-Cable sections of the Motutapu Channel and in the Arran-Omaru (238.8 ha) section in the Waiheke Channel (Figure 19) at the south-eastern end of the island.

Almost all of the 30-200m sand habitat within 1 km of the island occurred in the Hook-Waiti section where the waters of the Waiheke Channel and the Firth of Thames flow out into the open Hauraki Gulf (29.1 ha; Figure 18).

4.5 Mud habitats

Intertidal mud flats only occurred on the southern side of the island, but in most sections between Waiti and Huruhi. The Te Matuku Marine Reserve included the most area of this habitat (147.6 ha) but large areas were also present in the Rocky Bay-Pūtiki (70 ha) Bay section and Awaawaroa Bay (60 ha, Figure 20).

The 0-30 m mud habitat was only found off the northern side of the island between Matiatia and Tikitikiatongi and between Te Matuku Bay and Huruhi on the southern side of the island. The Nani-Onetangi section included the largest area of this habitat off the northern coast (134.3 ha) and Te Matuku Marine Reserve the largest area (62.4 ha) off the southern coast (Figure 21).

The Horuhoru-Thumb (80 ha) and Spray Rock-Tikitikiatongi (21.4 ha) sections were the only areas to include the 30-200 m mud habitat (Figure 22). The Matiatia-Owhanake (29 ha) and Cable-Matiatia sections (9 ha) were the only sections to include high current 0-30m mud habitats (Figure 23).

4.6 Mangrove, Saltmarsh and Seagrass habitat

The Te Matuku Marine Reserve (51.1 ha), Rocky-Pūtiki (40.13 ha) and Awaawaroa (11 ha) sections were the only areas to include substantial mangrove habitats (Figure 24). Research using tunnel nets to catch and release fishes from mangroves in Te Matuku Marine Reserve and Pūtiki Bay indicate that these areas are used by native fishes including snapper (*Pagrus auratus*), Jack mackerel (*Trachurus novaezelandiae*), Anchovies (*Engraulis australis*), Kahawai (*Arripis trutta*), Goatfish (U*peneichthys lineatus*) and other species (Haggitt, 2016b; Morrison et al., 2014).

Saltmarsh occurred mostly on the southern side of Waiheke Island, mainly in the Te Matuku Marine Reserve (4.6 ha), Rocky-Pūtiki (2.7 ha) and Awaawaroa Bay (1.8 ha) sections (Figure 25).

Seagrass beds were only mapped in the Rocky-Pūtiki (17.2 ha) and Kennedy-Huruhi (16 ha) sections (Figure 26). These represent substantial areas of productivity and important habitat for the juveniles and adults of many species. The areas are particularly vulnerable to coastal development and sedimentation from the island and mainland but have received little attention until recent concerns over the impacts of a marina being built at Kennedy Point.

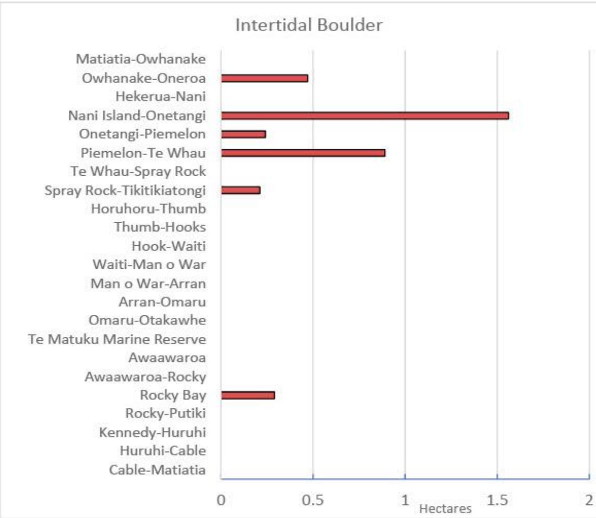

Figure 7 Area (ha) of intertidal boulder.

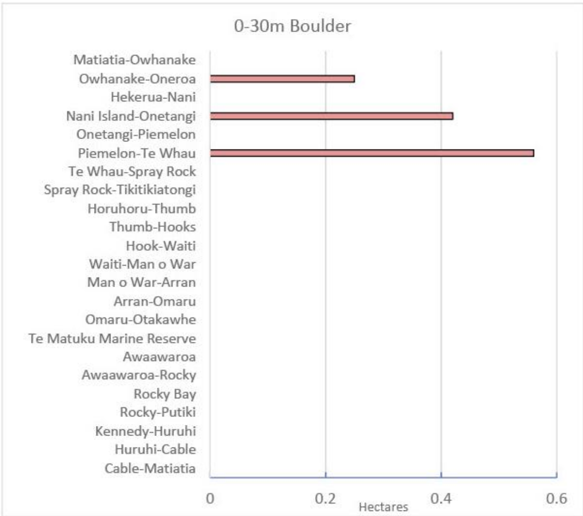

Figure 8 Area (ha) of 0-30m boulder.

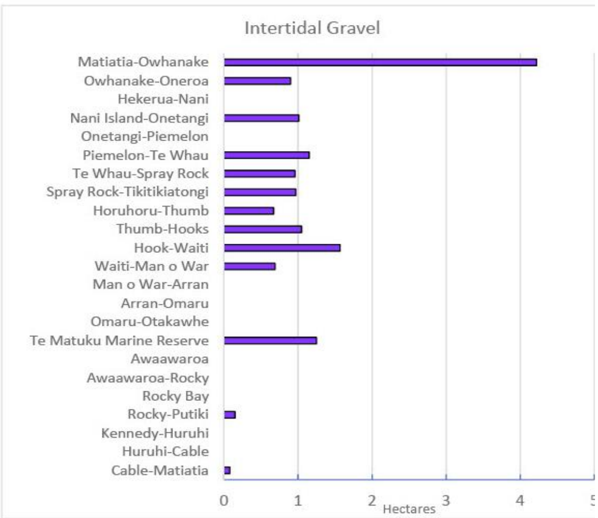

Figure 9 Area (ha) of intertidal gravel.

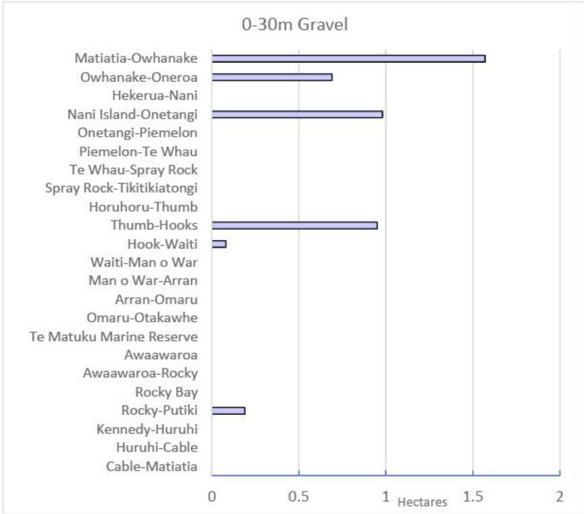

Figure 10 Area (ha) of 0-30m gravel.

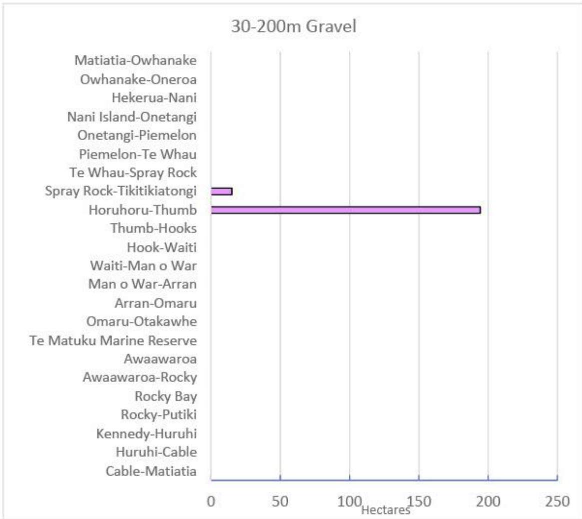

Figure 11 Area of 30-200m gravel.

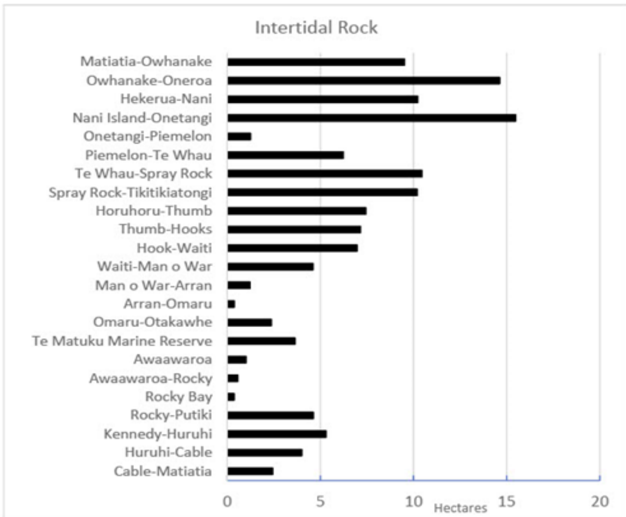

Figure 12 Area (ha) intertidal rocky shore.

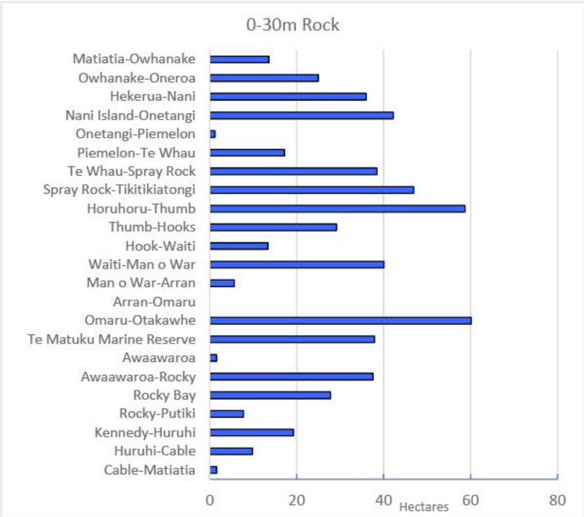

Figure 13 Area (ha) 0-30m rocky reef.

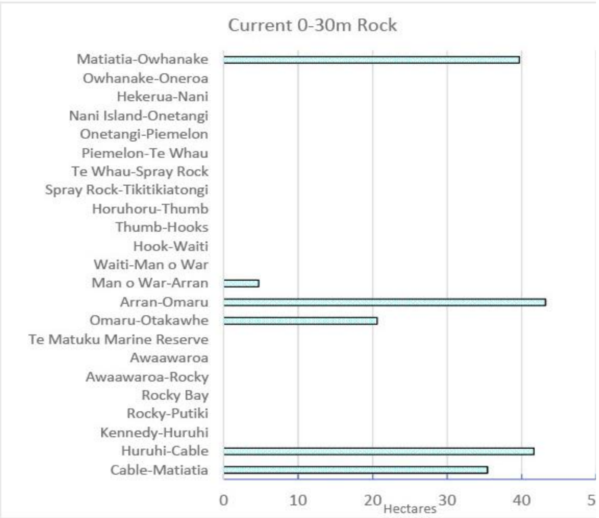

Figure 14 Area (ha) of 0-30m high current rock.

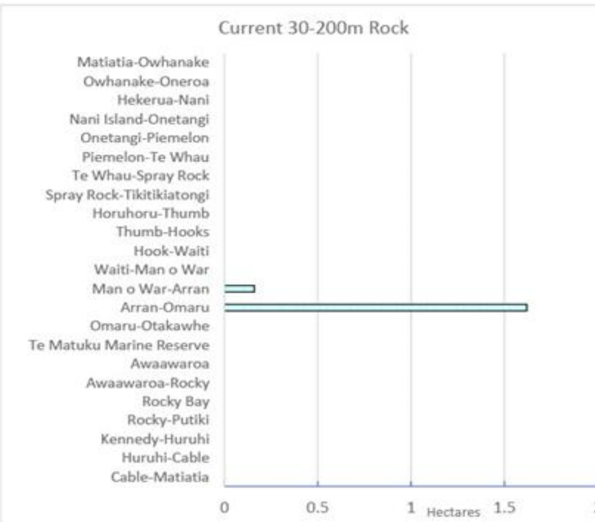

Figure 15 Area of 30-200m high current rock.

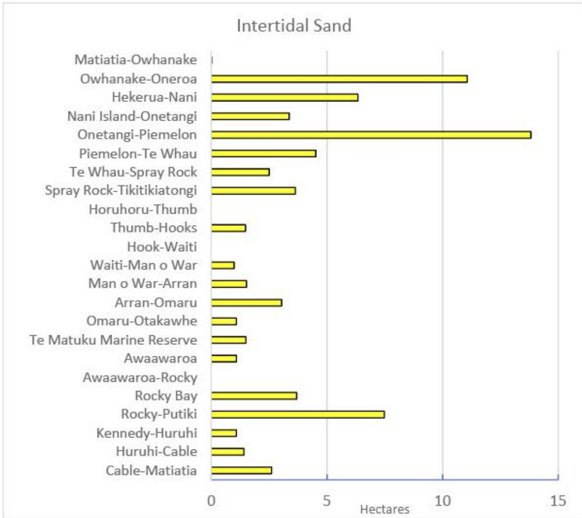

Figure 16 Area (ha) intertidal sandy beach.

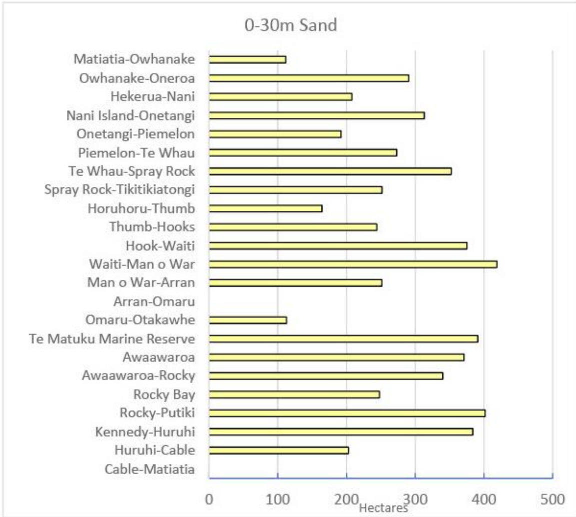

Figure 17 Area (ha) of 0-30m sand.

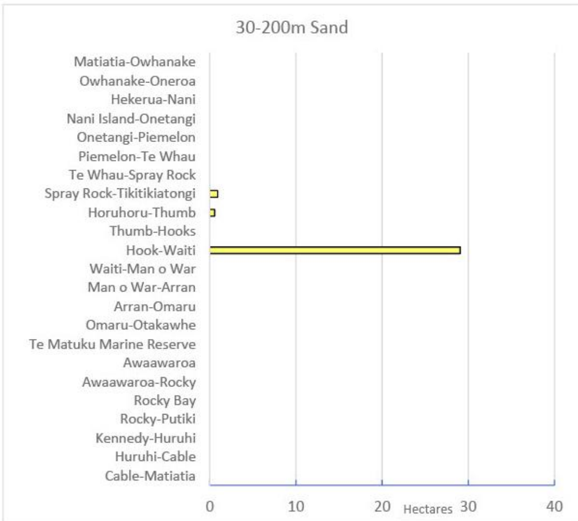

Figure 18 Area (ha) of 30-200m sand.

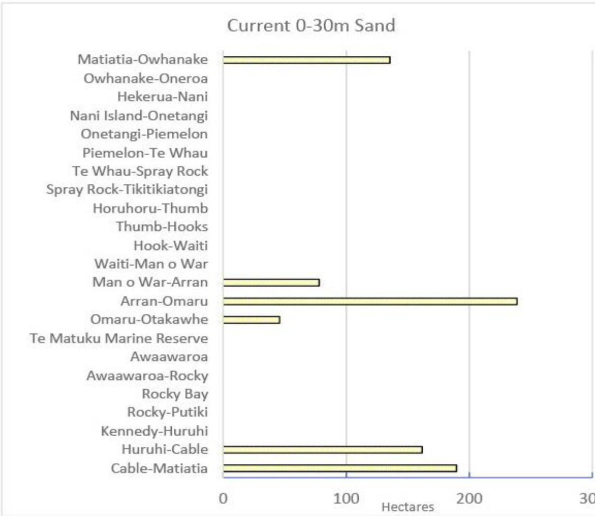

Figure 19 Area (ha) of 0-30m high current sand.

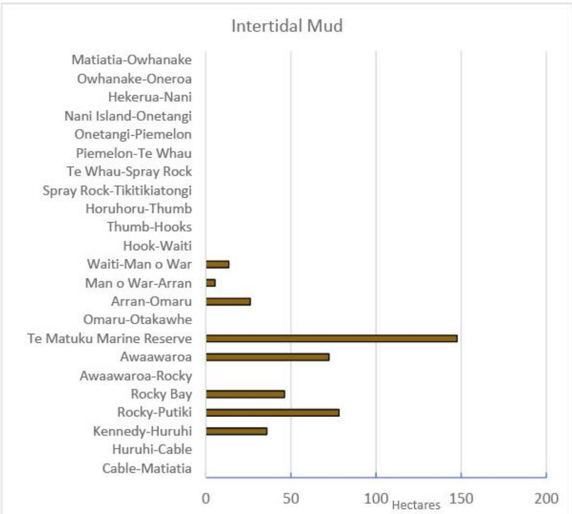

Figure 20 Area (ha) of intertidal mud habitat.

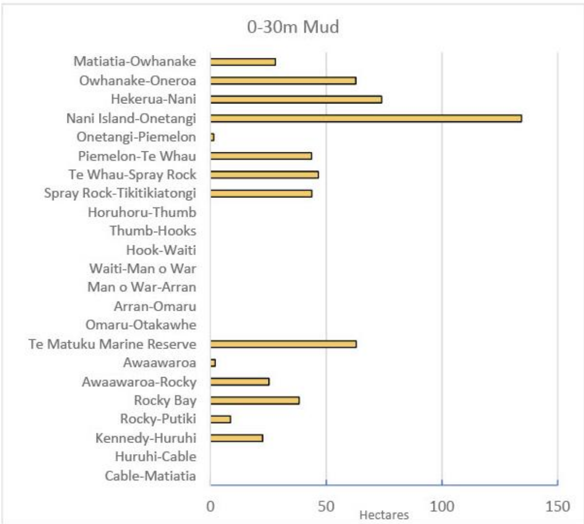

Figure 21 Area (ha) of 0-30m mud.

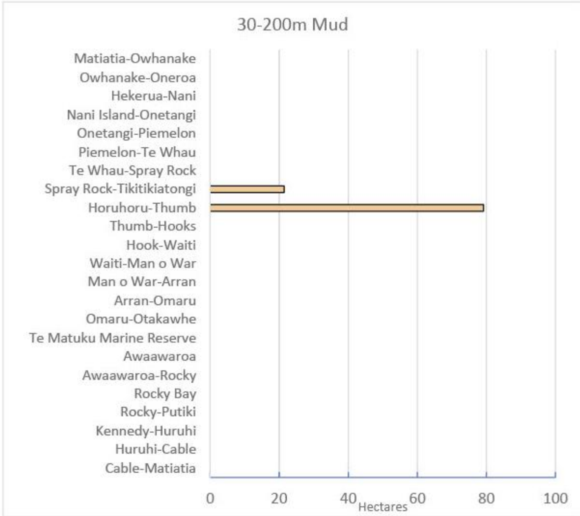

Figure 22 Area (ha) of 30-200m mud.

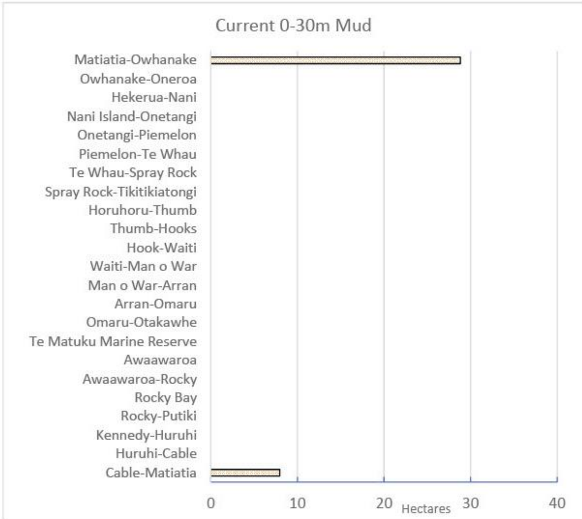

Figure 23 Area (ha) of 0-30m high-current mud.

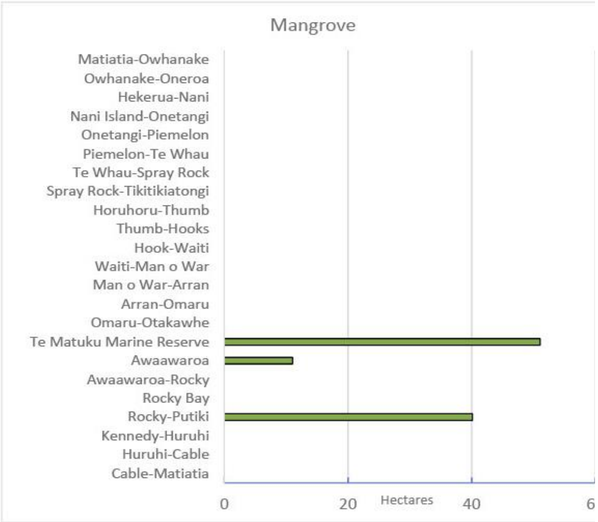

Figure 24 Area (ha) of mangrove.

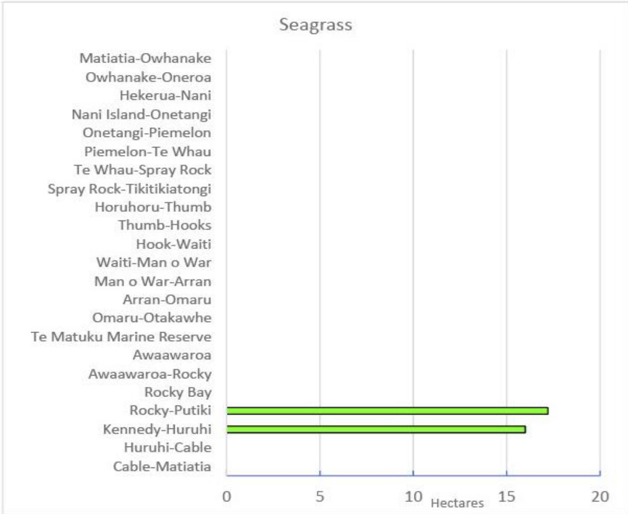

Figure 26 Area (ha) of seagrass.

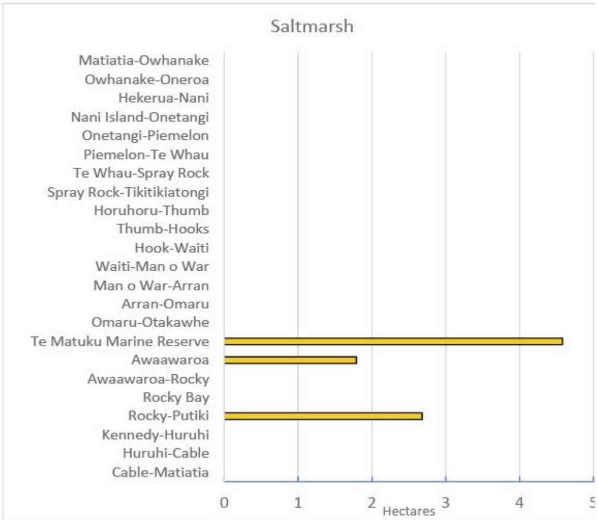

Figure 25 Area (ha) of saltmarsh.

4.7 Principal component analysis of habitat composition in planning units

The principal components analyses (PCA) in Figure 27 and Figure 28 are based on a multivariate correlation matrix among different planning units. The matrix values reflect similarities among paired sections of coast based on the relative proportions of different habitats. The use of the correlation matrix means that small and large areas of habitat and planning unit are treated more equally than if a covariance matrix was used. The latter use of absolute areas of habitat would give greater weight to common habitats and mask the contributions of rarer habitats covering smaller areas. This would provide a less representative selection of areas.

The first two principal components for each section of coast are scored on the x and y axes, respectively, in the ordinations in Figure 27. These axes reflect the largest multivariate differences in habitat composition among different sections of coast. Sections that are occupy similar positions in the ordination have similar habitat compositions while those far apart are most different in habitat composition. The further a planning unit is away from the centre of the ordination, the more unique that planning unit tends to be in its habitat composition. One approach to selecting representative areas of biodiversity is to select areas from different parts of the multivariate ordination to include a range of different habitats.

The PCA biplot (Figure 27) also plots the habitats that contribute most to the differences among sections as lines of different lengths and directions originating from the centre of the plot. Planning units that lie further along a habitat vector (measured to the planning unit along a tangent to the habitat line) include a greater proportion of that habitat. Long habitat vectors indicate habitats that contribute most to distinguishing sections of coast from each other.

The ordination reduces the number of possible multivariate dimensions in the data to those that explain the most variance. In Figure 27, the first two principal components explain, respectively, 21% and 22% of the variance among sections of coast.

The differences among sections of coast are prominent for three main groups. The first is a group distinguished by high current rock and sand habitats evident on the left-hand side of the ordination. It includes the planning units Arran-Omaru, Cable-Matiatia, Matiatia-Owhanake and Huruhi-Cable. In the top right-hand side of the ordination, the, Owhanake-Oneroa, Pie Melon-Te Whau and particularly the Nani Island-Onetangi sections are distinguished by boulder, gravel and rock habitats. In the bottom, right-hand side of the ordination, Te Matuku Marine Reserve and the Rocky-Pūtiki and Kennedy-Huruhi sections are distinguished by intertidal mud, mangrove, saltmarsh and seagrass. While three of these habitats are present in the Te Matuku Marine Reserve, seagrass has only been mapped in the Rocky- Pūtiki and Kennedy-Huruhi sections which remain unprotected. The Rocky- Pūtiki section is the only planning unit to include all these habitats.

In Figure 28, the third principal component (y-axis) explains another 16% of the variance, together explaining a total of 59% of the variance for the first three components. Additional principal components include successively smaller amounts of variance. The main difference between Figure 28 and the previous ordination is the distinctive habitat composition of the Horuhoru-Thumb planning unit at the bottom of the ordination which includes relatively large areas of 30-200m gravel, 30-200 m mud and 0-30 m rock. Looking at the most extreme locations on the ordination, the most distinctive sections of coast include the Arran-Oamaru, Matitatia-Owhanake, Nani Island-Onetangi, Rocky-Pūtiki, Te Matuku Bay Marine Reserve and Horuhoru (Gannet Rock)-Thumb Point planning units.

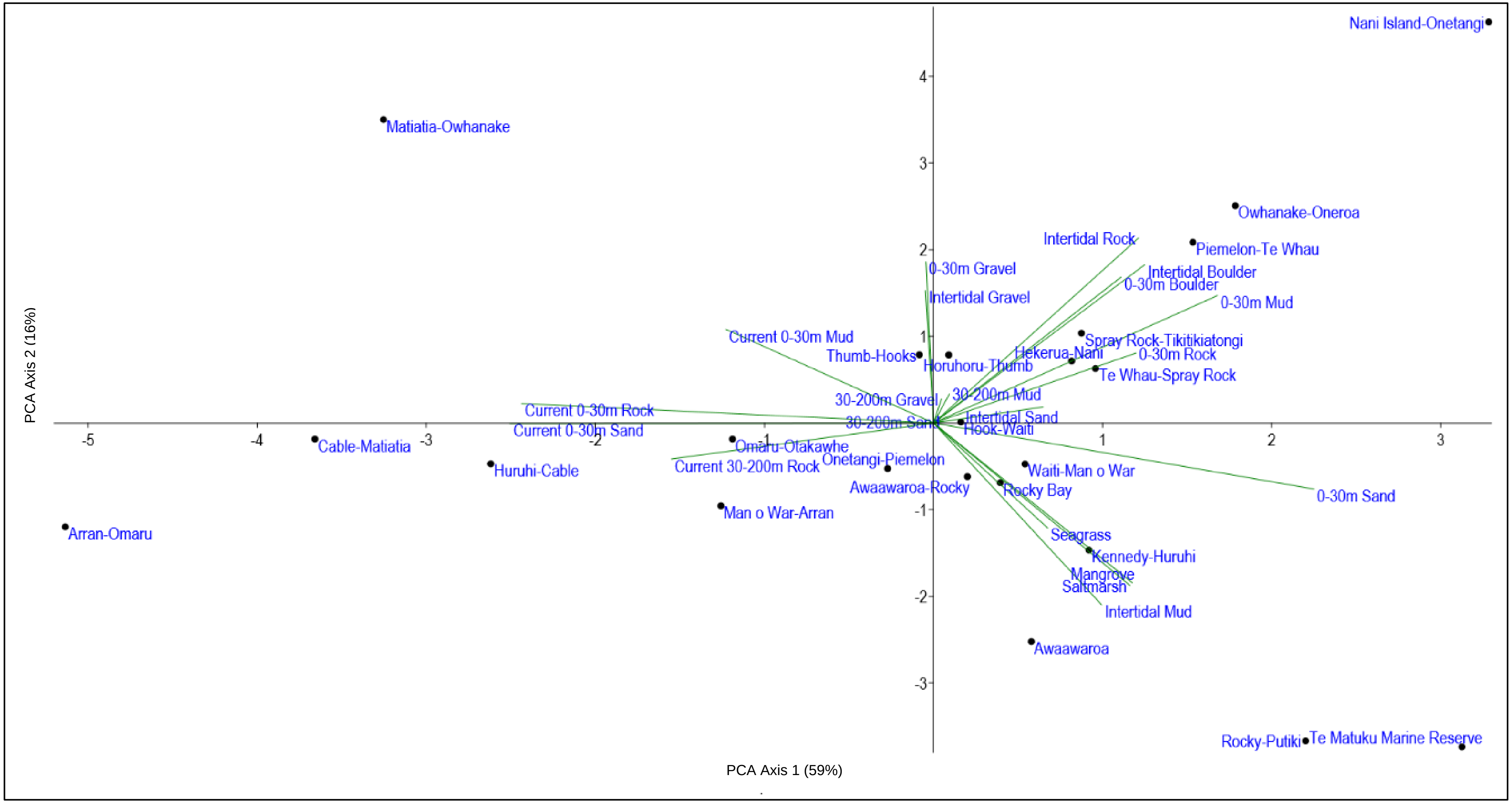

Figure 27 Components 1 and 2 of a principal components (PCA) analysis of habitat diversity in each of the 23 planning units.

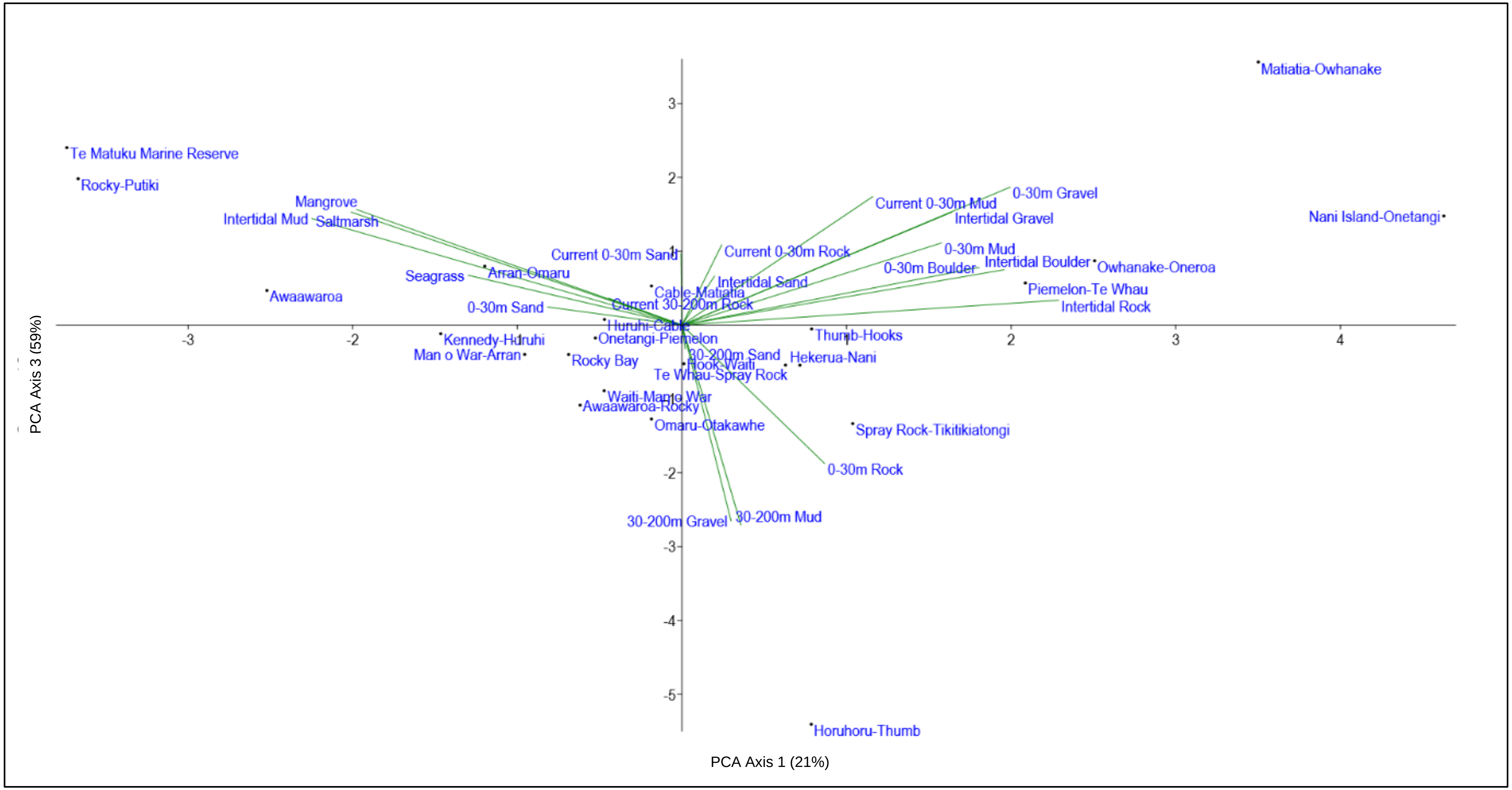

Figure 28 Components 1 and 3 of a principal components (PCA) analysis of habitat diversity in each of the 23 planning units.

4.8 Marxan simulated annealing models.

Marxan analyses explored the ‘best’ solutions from a 100 runs and highlighted areas that would, together, most efficiently represent 10, 20, 30 or 40 % of each habitat for the least overall area. These simulations were run with (Figure 30) and without (Figure 29) the inclusion of the Te Matuku Bay Marine Reserve as a mandatory part of the network. Maps on the left-hand of the figures show the single best solution from 100 runs of the simulated annealing algorithm. Maps on the right-hand side show the number of times a planning unit is selected from 100 runs. Simulation results for different habitat targets run from 10 to 40 % down each page.

In Figure 29, Te Matuku Marine Reserve is not automatically included in the network. For habitat targets of 10%, the areas included in the “best” solution or in over 90 out of 100 repeat solutions were the Cable-Matiatia, Nani Island-Onetangi, Horuhoru-Thumb, Hook-Waiti, Arran-Omaru, and Rocky-Pūtiki sections. As habitat targets increased to 30 and 40% additional sites important for habitat representation were highlighted in either the best solution from 100 simulations or appearing in over 60 % of solutions from the algorithm. In addition to the above sections of coast, the Matiatia-Owhanake, Owhanake-Oneroa, Rocky Bay, Awaawaroa Bay and Omaru-Otakawhe, Pie Melon-Te Whau, Onetangi and Hekerua-Nani Island became increasingly efficient at contributing to a representative network of habitats. However, the generally lower occurrence of these sections in Marxan solutions indicates there is flexibility in the choice of planning units able to meet habitat targets.

In Figure 30, the existing “no-take” marine reserve at Te Matuku Bay is included as a mandatory planning unit and its contribution to habitat representation taken into account when selecting other complementary planning units. For the 10 % target scenario, sections included in a “best” solution from 100 runs or occurring in greater than 90 % of solutions were Horuhoru-Thumb, Hook-Waiti, Arran-Omaru and (by default) Te Matuku Bay. Assuming the inclusion of Te Matuku Bay, sections of coast occurring in greater than 70 solutions also included the Cable-Matiatia, Owhanake-Oneroa and the Kennedy-Huruhi sections of coast. As targets increase to 30 and 40%, additional planning units also contribute towards habitat goals including Matiatia-Owhanake, Nani-Onetangi, Rocky-Pūtiki, Hekerua-Nani, Onetangi-Pie Melon and Pie Melon-Te Whau although options here are more flexible.

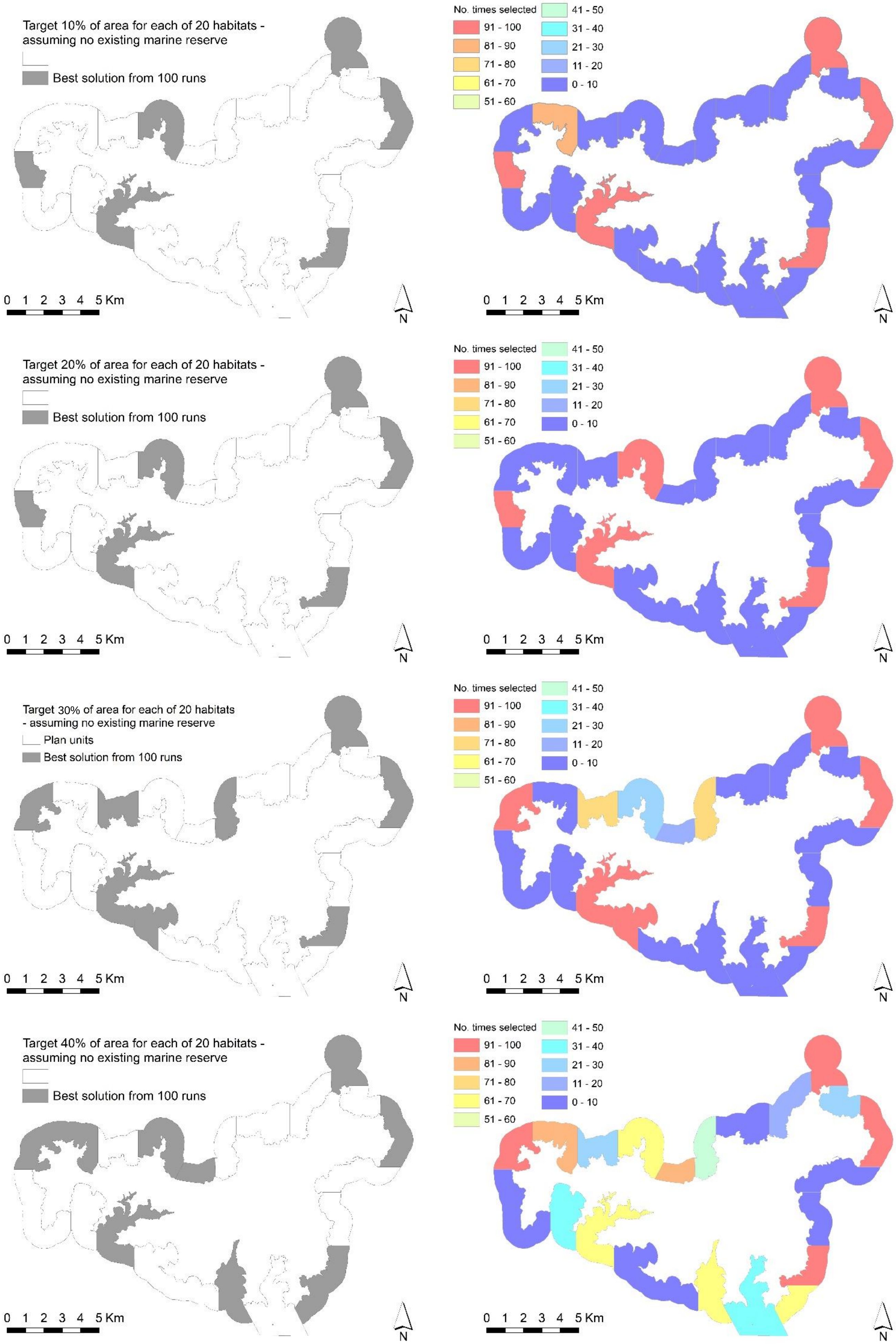

Figure 29 Best solution from 100 simulations (left) and the number of times a plan unit occurs in 100 Marxan solutions (right) ignoring the reserve status of Te Matuku Marine Reserve. The simulations aim to meet targets (top to bottom) of 10, 20, 30 and 40% of each of 20 marine habitat classes while minimising cost in area.

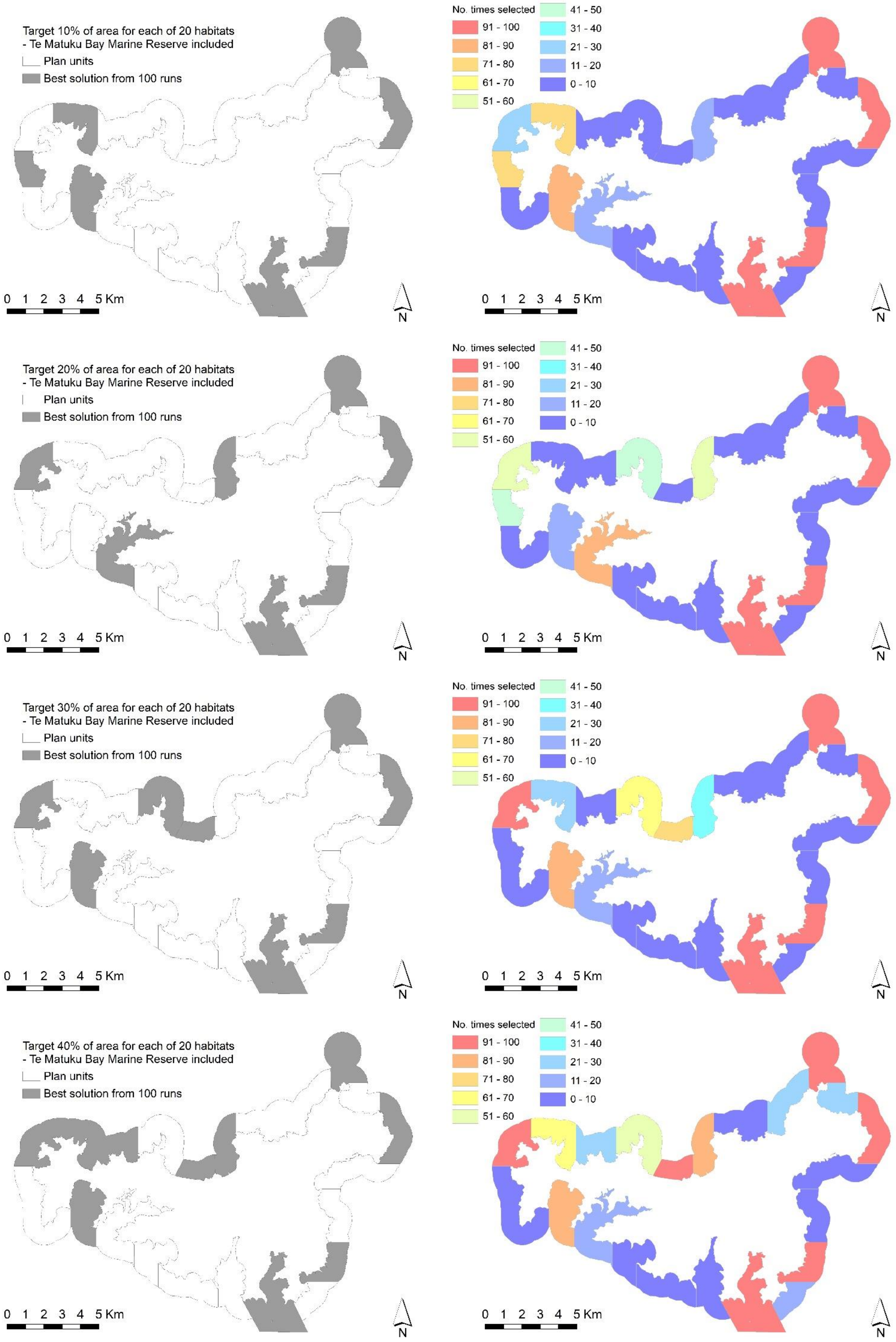

Figure 30 Best solution from 100 simulations and number of times a plan unit occurs in 100 Marxan solutions assuming the mandatory inclusion of Te Matuku Marine Reserve in all solutions. The simulations aim to meet targets (top to bottom) of 10, 20, 30 and 40% of each of 20 marine habitat classes while minimising cost in area.

5 DISCUSSION

This thesis compares differences in habitat composition for different sections of coast within 1 km of Waiheke Island. The maps, graphs, multivariate analysis and Marxan simulated annealing results consistently identify distinct differences in habitat composition among sections of coast and how a representative network of complementary MPAs could include a range of habitats and the biodiversity they include. This information was used to highlight locations of spatial importance for potential MPA selection.

In a fully representative network, both common and rare habitats are considered important, and it is how MPAs together contribute across all habitats that matters. However, there were four distinct groups of habitats requiring representation, with some present at a limited number of locations. The groups were: the intertidal and subtidal boulder and gravel habitats found mainly off north-western Waiheke Island and in the Nani-Onetangi and Pie Melon-Te Whau sections; high current habitats in the Motutapu and Waiheke Channels; the seagrass, mangrove, saltmarsh and mud flat habitats in the Rocky-Pūtiki, Kennedy-Huruhi, Awaawaroa Bay and Te Matuku Bay sections; and the deep gravel, mud and other habitats of the Horuhoru (Gannet Rock) to Hooks Bay section.

Establishing MPAs in these locations would, together with other forms of customary, fisheries, conservation and land management practices, assist in the restoration and protection of ecosystems around the island and the larger Hauraki Gulf Marine Park.

5.1 Potential marine protected areas

A recent feasibility study by Haggitt in 2016, assessed reef fish, rocky reef and soft sediment research on the coastline of Waiheke Island. The study was conducted to gather baseline data to support the establishment of no-take marine reserves and identify gaps in knowledge. The report suggests locations for MPAs in locations similar to those suggested in this study, including sections of the Matiatia-Owhanake, Owhanake-Oneroa, Rocky Bay, Rocky Bay to Pūtiki Bay planning units and between Oneroa and Enclosure Bay. Areas identified in this study outside of the above proposed locations include sections at the eastern end of the island between Horuhoru (Gannet Rock) and Hooks

Bay, in the Waiheke Channel, and also between Nani Island and Onetangi. This research determined that some additional protection may be required to represent all habitats.

Following his analysis in 2016, the Hauraki Gulf Conservation Trust contracted Tim Haggitt to carry out a comprehensive qualitative and quantitative survey of the area from Matiatia Bay to Enclosure Bay (Haggitt, 2016b).

The primary findings from this survey were:

- that an area, from Matiatia Bay to Hakaimango Point would be the most beneficial location for a no-take marine reserve, based on five potential reserves designated by Waiheke Island's Local Area Board.
- the existence of biogenic habitats such as bivalve beds, invertebrates and macroalgae
- diverse invertebrates such as ascidians and sponges ranging from moderate to high abundances in the surveyed area
- a high abundance of macroalgae above 8m between Matiatia Bay and Hakaimango Point
- a reduced number of urchins between Matiatia and Hakaimango Point
- increasing abundance of urchins towards Enclosure Bay.
- low reef fish abundance and diversity, but consistent with data from other inner Hauraki Gulf assessments
- recreationally targeted species such as kingfish, snapper and kahawai
- widespread rocky reef habitat suitable for lobsters but no lobsters were observed
- soft-sediment habitat varied in type and abundance across the area surveyed
- coarse sediment and shell fragments beside subtidal rocky reef in the Motutapu Channel, off the north-western coast
- bivalve beds supporting a diverse array of encrusting red algae and sponge communities
- moderate densities of scallops (*Pecten novaezelandiae*) in sandy substrata in Matiatia Bay
- abundant infaunal communities of crabs, shrimp and worms in sand off Hakaimango Point
- the north and western coasts had both soft-sediment and subtidal rocky reef habitats.

This Hakaimango-Matiatia Marine Reserve would span 2,500 ha, which would make it the largest no-take reserve in the Hauraki Gulf. Haggitt's two reports provide crucial information for marine spatial planning around Waiheke Island and the theoretical simulations in this study, support his findings. These and several previous studies (e.g. (Bing, 2015; Kerr & Grace, 2013) provide a solid foundation to establish a more representative network of MPAs around Waiheke Island.

5.2 Limitations

Marxan is widely recognised around the world as a conservation planning software (Watts et al., 2009). Some of the restraints of this decision support tool, is how time consuming it can be, sometimes taking months or years which can be financially expensive. Delays in projects from time and cost can create problems for marine spatial planning as environments change and so do the interests of stakeholders (Støttrup, Dinesen, Janßen, Gillgren, & Schernewski, 2017). There can also be lack of comprehension and distrust with the use of decision support tools from stakeholders, which can impact the use of these tools (Janßen, Goeke, & Luttmann, 2019). It is important for tools to be correctly recognised and for the costs involved to decrease, which will help the success of decision support tools.

There are five key features that ensure the success and productivity of a marine protected area, these are: enforced, older than ten years, no-take, isolated (typically by sand or water) and their size (Edgar et al., 2014). When designing effective MPAs it is important to consider the size of the area protected. Small marine reserves can be impacted by fishing activity in surrounding waters, which can affect recruitment and ecosystem resilience. A larger no-take reserve with an unfished population is likely to be less impacted from fluctuations in anthropogenic and environmental factors. Unfished marine reserves typically have four or more key features which can result in an increased large fish biomass and is fourteen times more likely to have apex predators like sharks compared to fished areas (Edgar et al., 2014).

5.3 Summary

The maps, figures, geospatial data and models provided here aim to assist managers, stakeholders, iwi and communities to visualise patterns in habitat protection, identify gaps and innovative solutions and assess the potential outcomes of different decisions and viewpoints.

The research shows how to represent adequate areas of different habitats while minimising the total area of the network. In this study, we used relatively large planning units comprising sections of coast out to 1 km from shore. This was done to provide a relatively small number of broad scale representations of different parts of the island that could be easily recognised by the public, summarised graphically and viewed easily as high resolution maps and basic simulations. The larger units also have a greater chance of including a range of different habitats and include prominent landmarks which can assist in discussions.

Smaller hexagonal planning units can also be used to progressively identify representative areas at finer spatial resolutions as when selecting a single large planning unit, it is possible to overshoot habitat targets, including more areas of some habitats than are not necessarily required. Smaller planning units are more likely to precisely meet targets and also allow the addition and removal of planning units from hypothetical MPAs with more precision.

The use of broad scale habitat surrogates to represent patterns in biodiversity is an approximate way to map large areas consistently but requires more information on ecological, economic, social and cultural values. Survey data on species distributions and community assemblages can significantly add to our understanding of marine environments. They can also be used to support and test more approximate surrogates and can potentially be used as indicators for other associated species that may not have been surveyed. It is important therefore, to not rely on computer simulations of desktop data and to conduct underwater surveys of the kind conducted by Haggitt (2016ab).

5.4 Future planning

Community engagement is critical in decision making as local people are the ones frequenting the area and are also the people strongly invested in and worried for the health of the marine area. Actively engaging with iwi, stakeholders and the public allows managers and scientists to inform and be informed by local knowledge, values and perceptions. The sustainability of these areas is an important long-term goal for all stakeholders, due to the proximity to Auckland and the impact Waiheke Island has on the greater Hauraki Gulf Marine Park.

Ideally, the kinds of information presented here can be used in community workshops and in GIS based interactive web sites that display and record data from the public and allow the consequences of their own network designs to be displayed, saved and modified through ongoing consultation. This holistic approach includes stakeholders and users and is critical for the success of any marine protected area.

A number of key organisations and scientists have been involved in marine spatial planning for Waiheke Island. Initial funding and impetus came from the Hauraki Gulf Conservation Trust and the Royal Forest and Bird along with consultation by The Friends of the Hauraki Gulf and more recently the use of the 'Future Search' Planning tool and hui organised by the Waiheke Collective Marine Group.

As of December 1st 2021, a new no-take rāhui has been placed around Waiheke Island protecting kaimoana such as green-lipped mussels, pāua, scallops and crayfish. This has recently been legislated and actioned and is now enforceable by law for two years. Ngāti Pāoa and community groups advocated for the closure for particular species and have so far received a great response from others in the community.

In addition, a marine reserve proposal for the Matiatia to Haikaimango Point area identified by Haggitt has been submitted to the Government by the Friends of the Hauraki Gulf and the official consultation showed over 90% support for the reserve. Key stakeholders will need to work together to create an interconnected marine reserve network in the Hauraki Gulf. Working with realistic geographic information on specific network designs is one way for stakeholders to effectively cooperate and share their knowledge, intuition and views in a practical and effective way.

6 CONCLUSION

Anthropogenic activities in the Hauraki Gulf have increased the demand for effective management tools that consider and manage a broad range of ecological and social values. Creating a network of MPAs around Waiheke Island will not only enhance the value of the local area but will have flow on effects into the wider Gulf and Coromandel. MPAs have been suggested for areas that lie adjacent to some of the biggest recreational fishing grounds in New Zealand. The ability of even small marine reserves to provide juveniles and adults to surrounding fished areas has now been demonstrated in Australia and New Zealand (Le Port et al., 2017).

Establishing MPAs near recreational fishing locations can provide large numbers of recruits to support the biodiversity and productivity of fisheries in the surrounding area. New Zealand needs to establish and create more interconnected network of MPAs to meet global marine conservation goals of 30% protection by 2030. Ecosystem stability is crucial for protecting species and habitats, especially with the continued pressure from human activities. This thesis provides additional support for the establishment of MPAs around Waiheke Island, helps to fill the gap left by the Sea Change planning process and provides ways to support more inclusive community consultation.

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8 APPENDIX 1

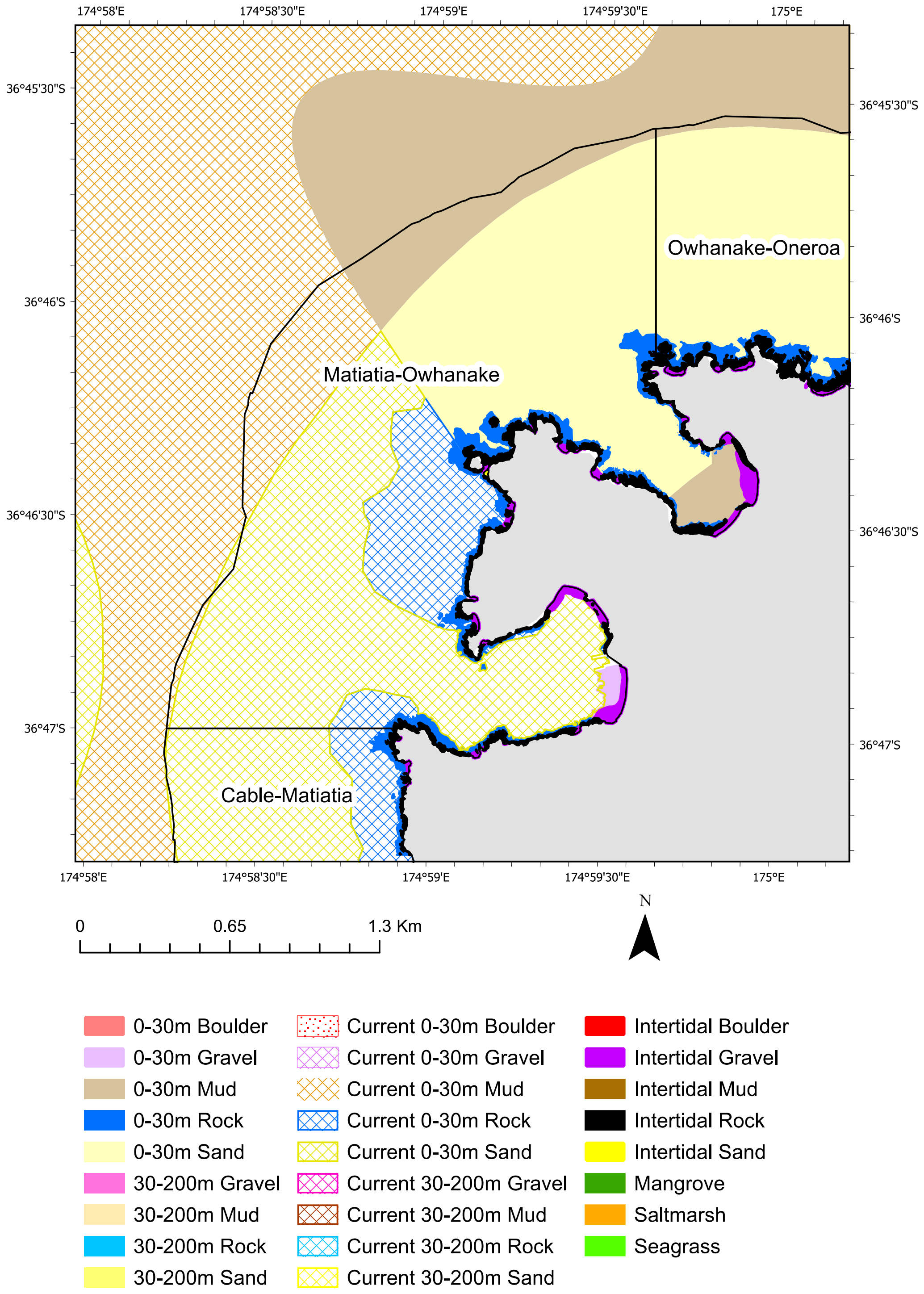

Figure 31 Marine habitats from Matiatia-Owhanake.

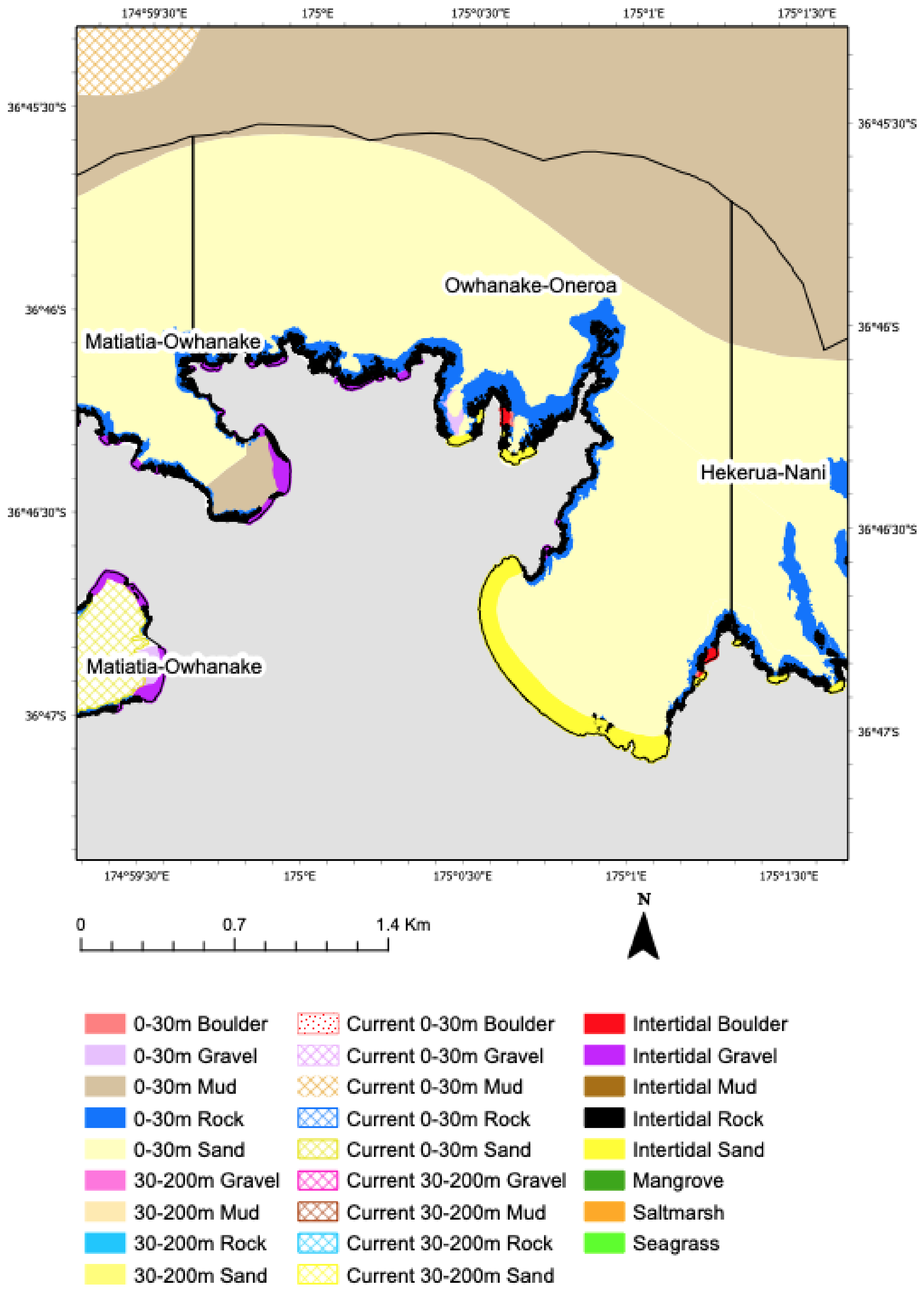

Figure 32 Marine habitats for Owhanake-Oneroa.

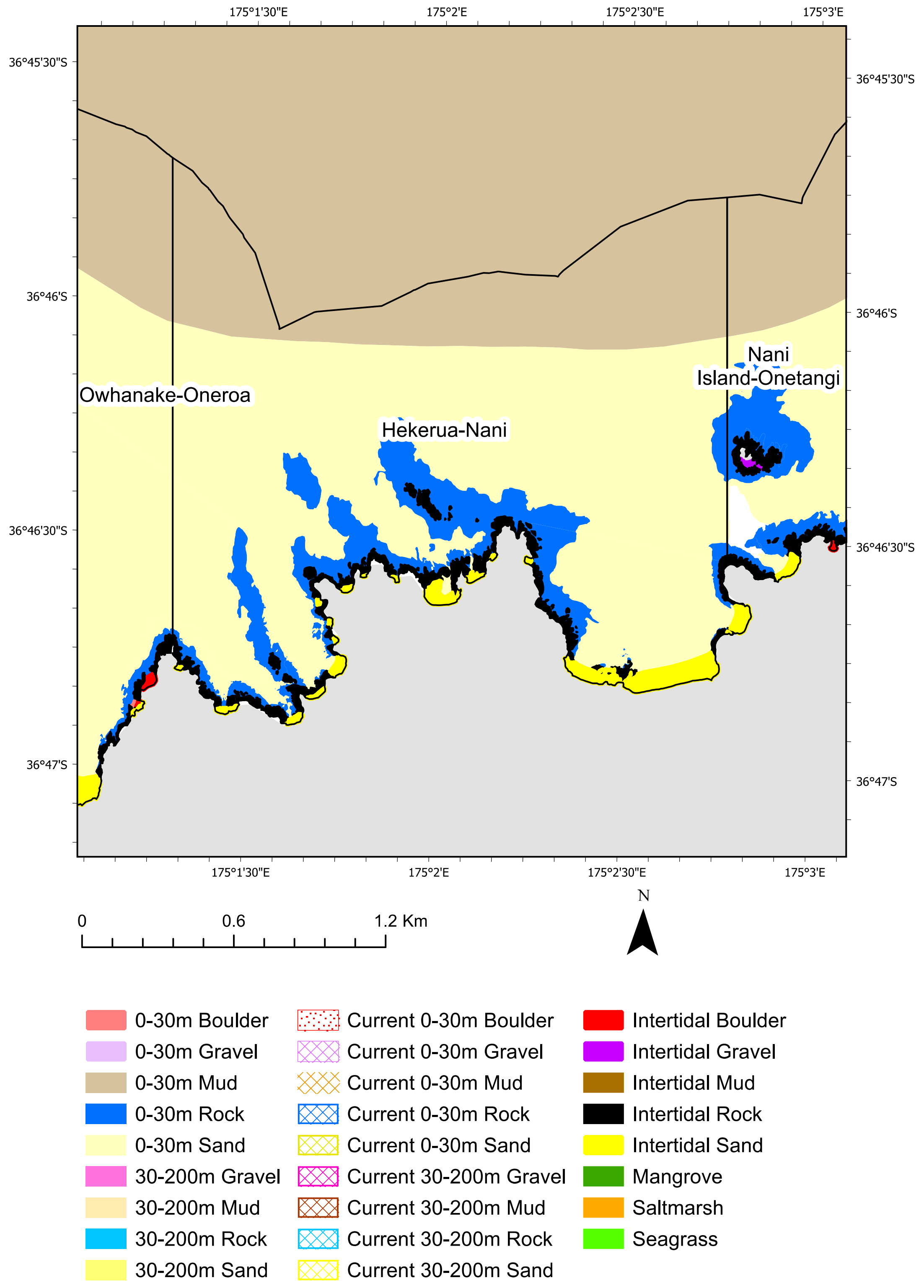

Figure 33 Marine habitats for Hekerua-Nani Island.

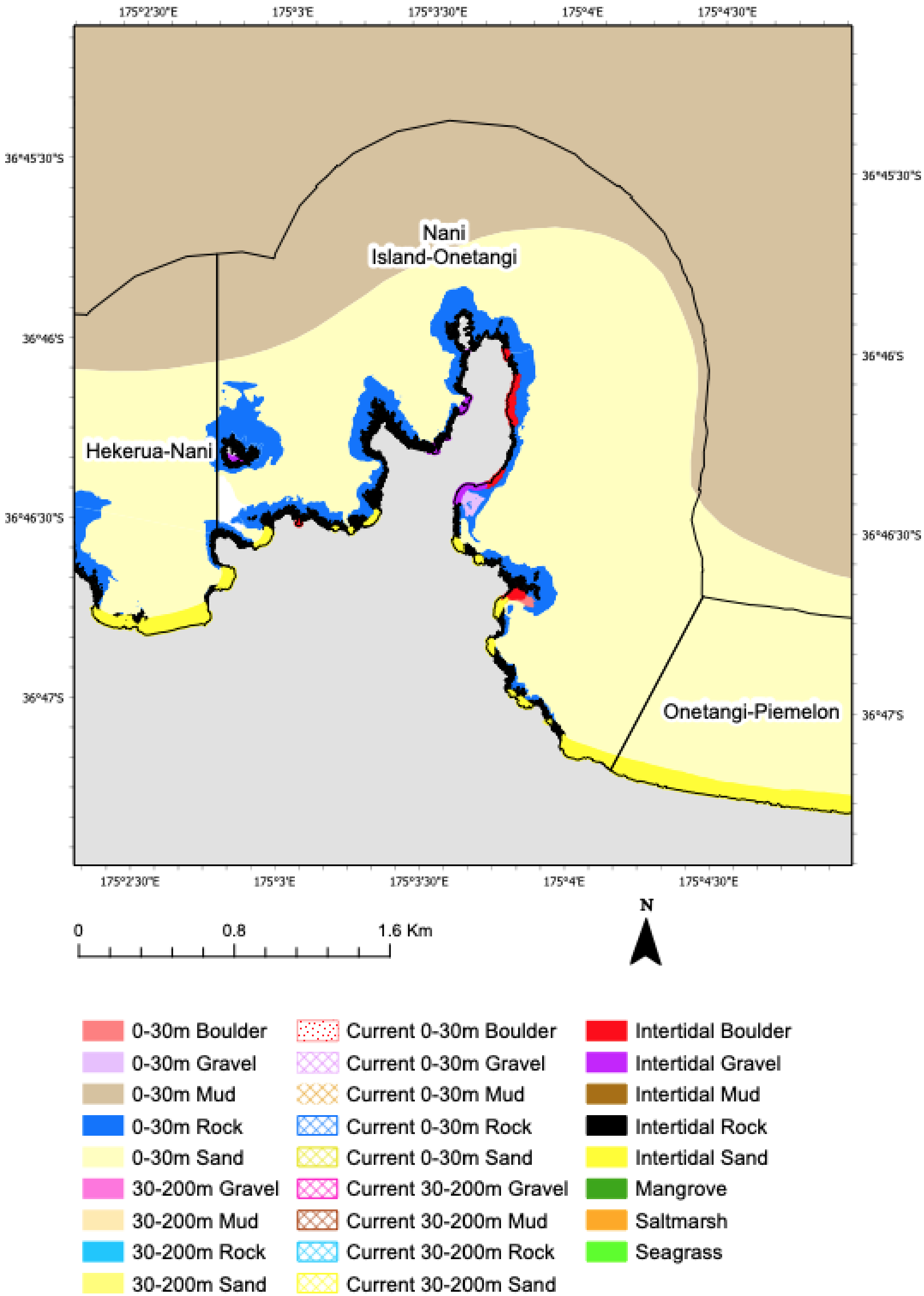

Figure 34 Marine habitats for Nani Island- Onetangi.

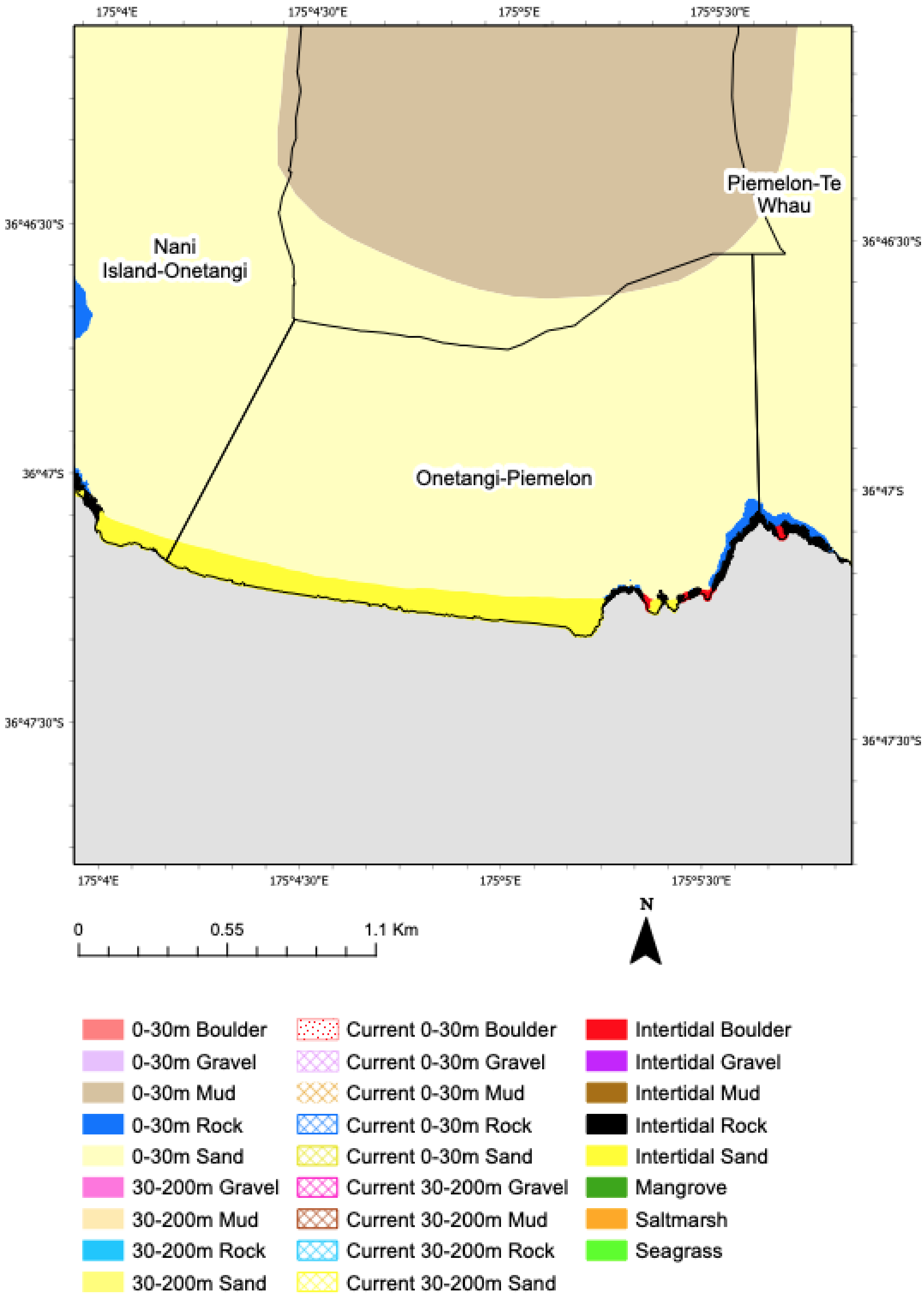

Figure 35 Marine habitats for Onetangi-Pie Melon Bay.

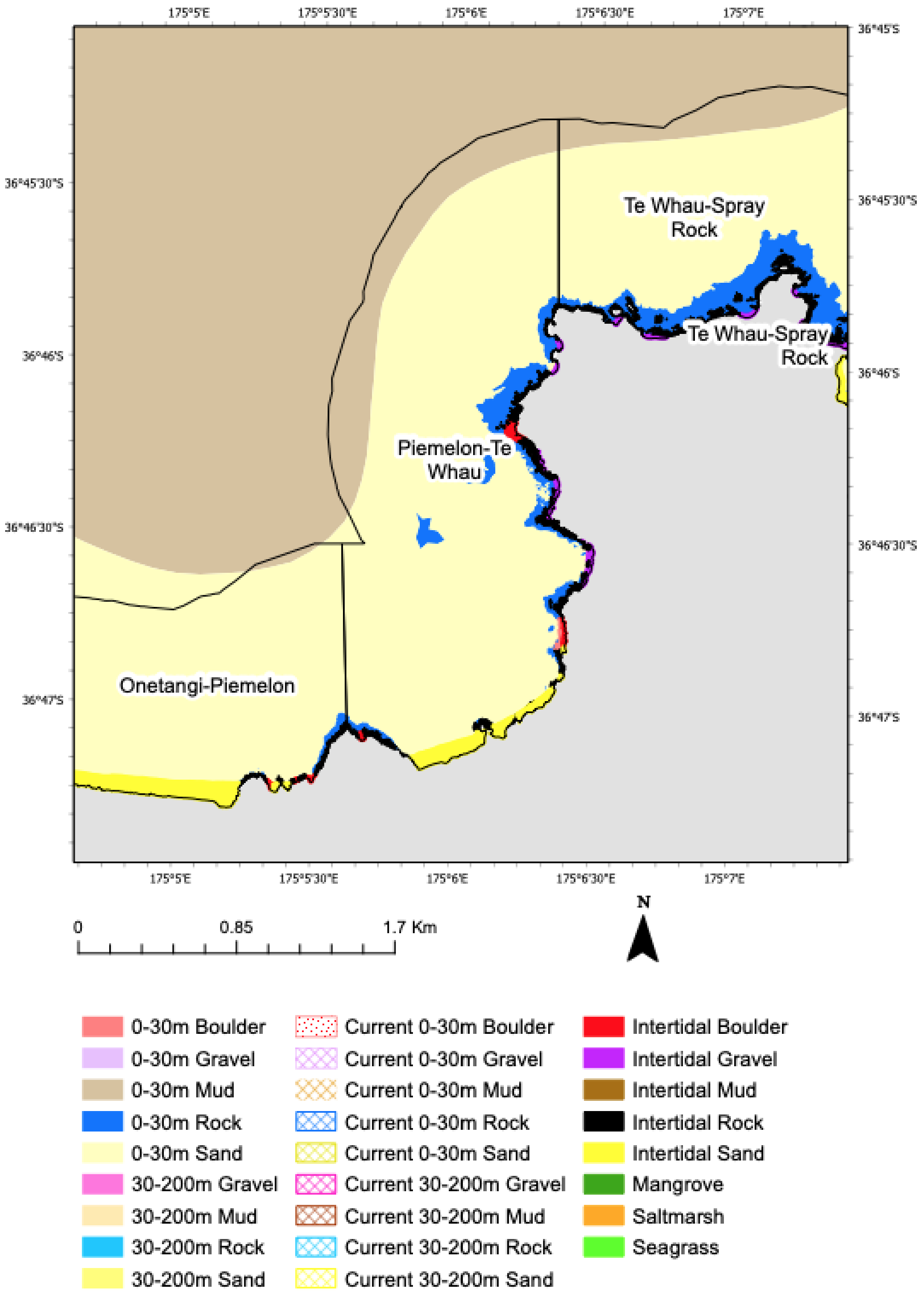

Figure 36 Marine habitats for Pie Melon Bay-Te Whau Point.

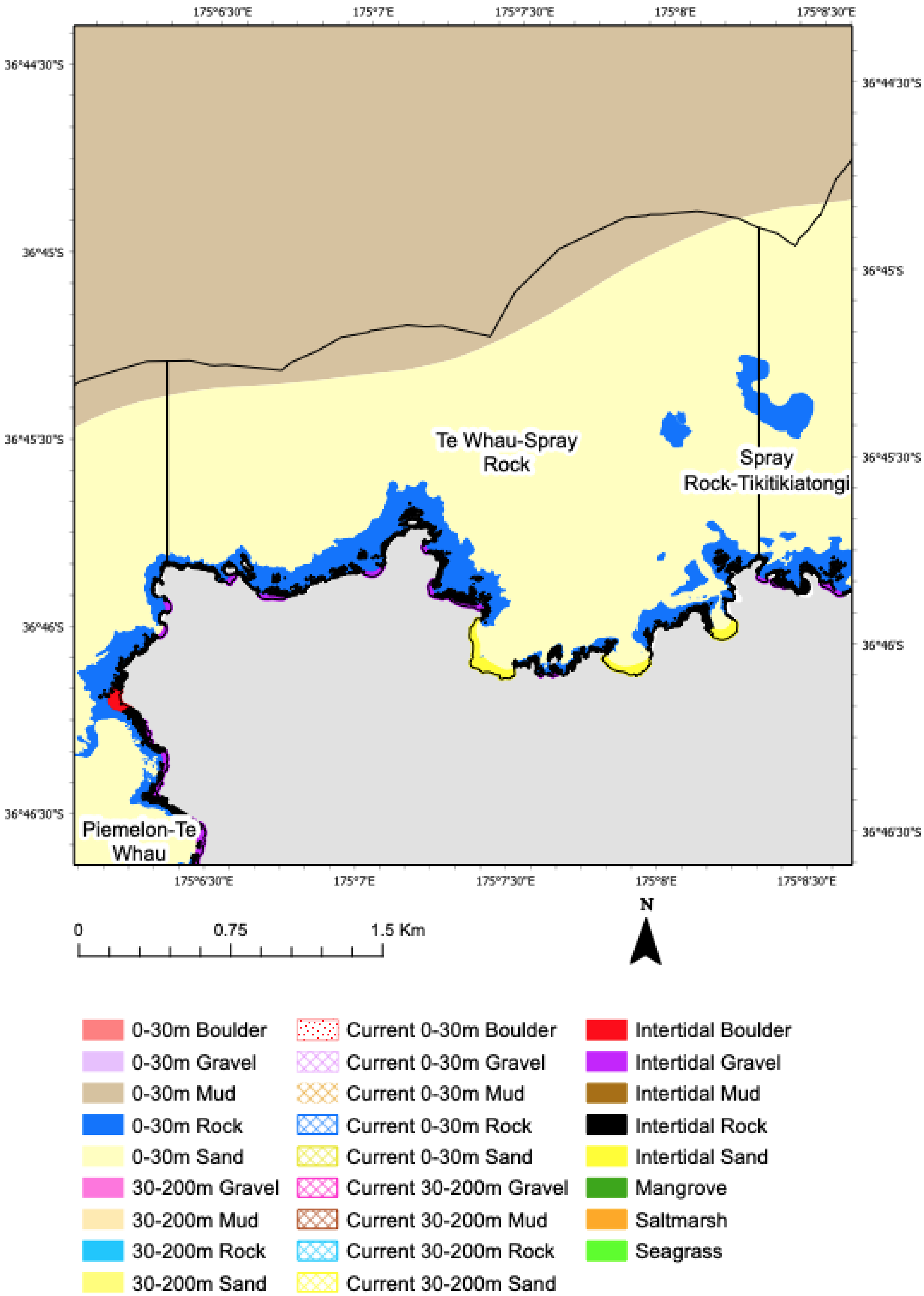

Figure 37 Marine habitats for Te Whau-Spray Rock.

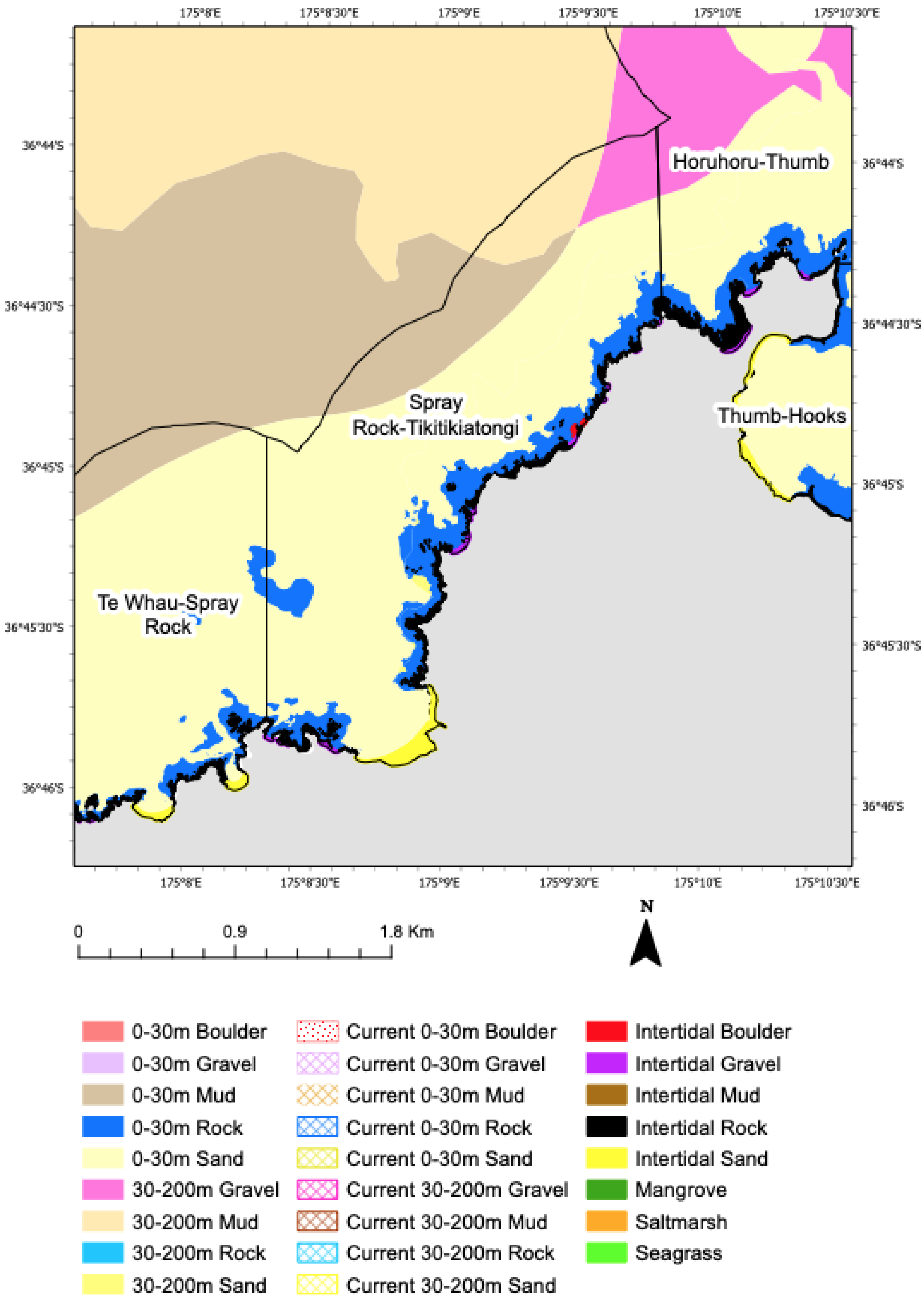

Figure 38 Marine habitats for Spray Rock-Tikitikiatongi Point.

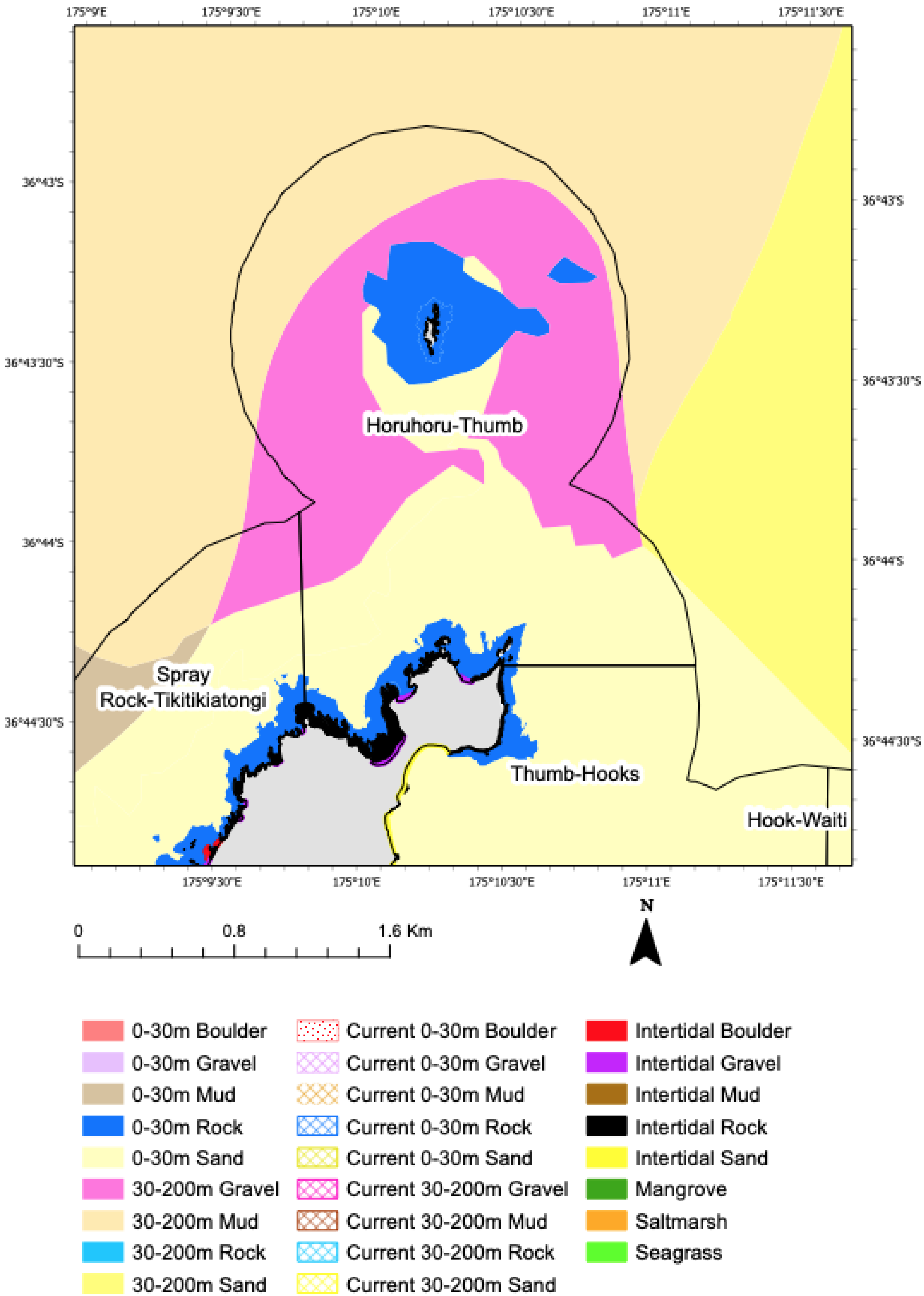

Figure 39 Marine habitats for Tikitikiatongi Point to Te Patu (Thumb Point).

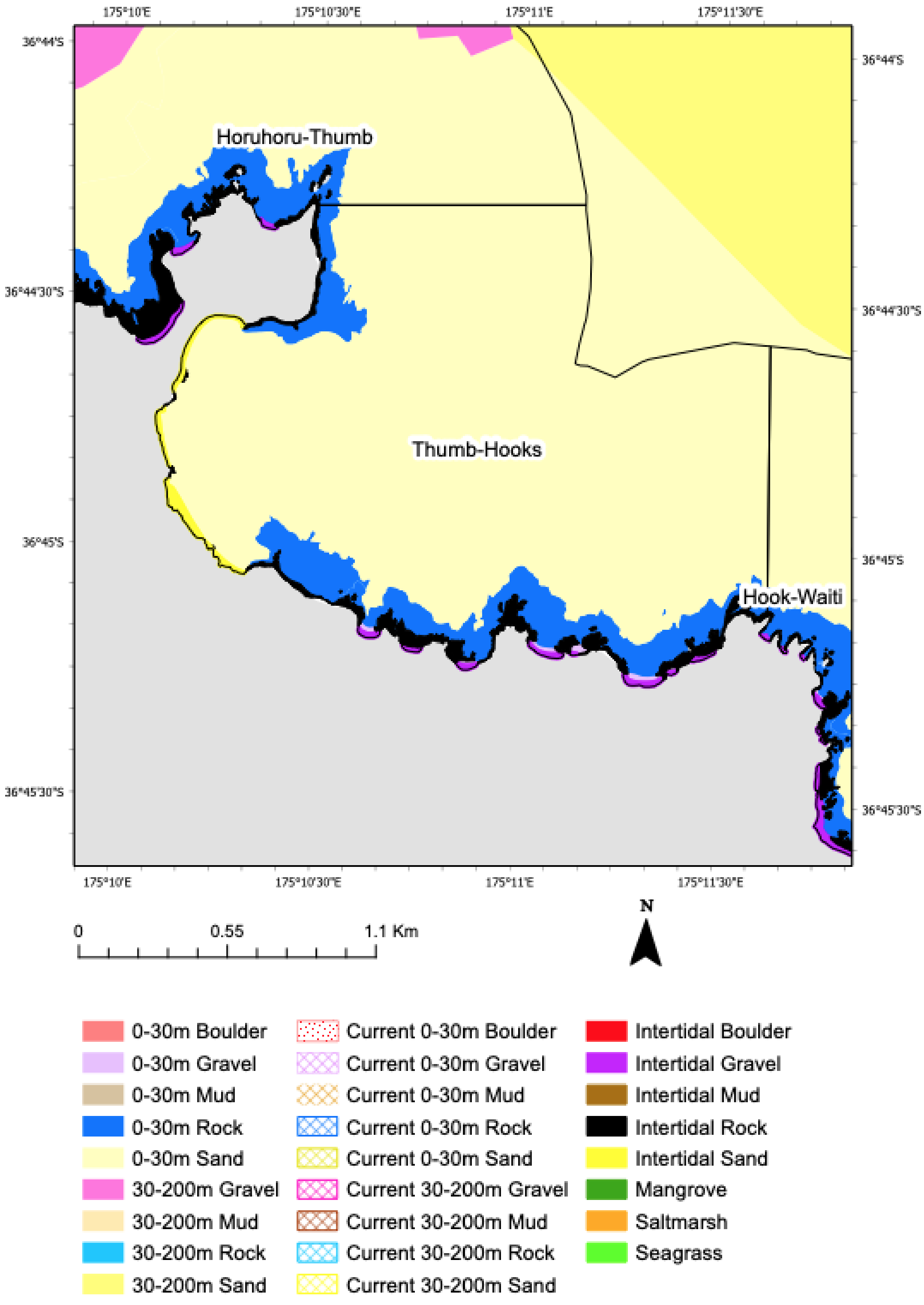

Figure 40 Marine habitats for Thumb Point-Hooks Bay.

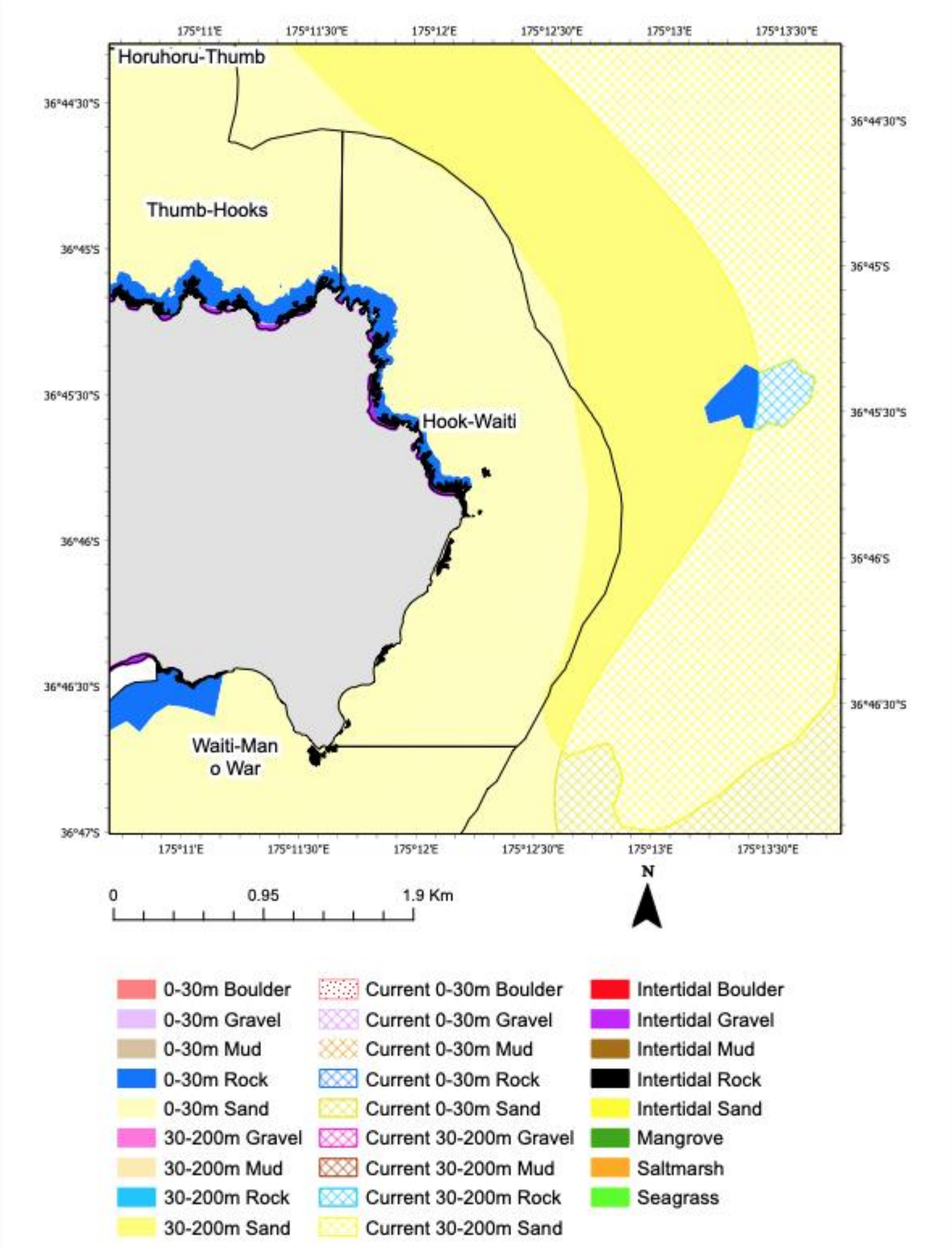

Figure 41 Marine habitats for Hooks Bay to Waiti Bay.

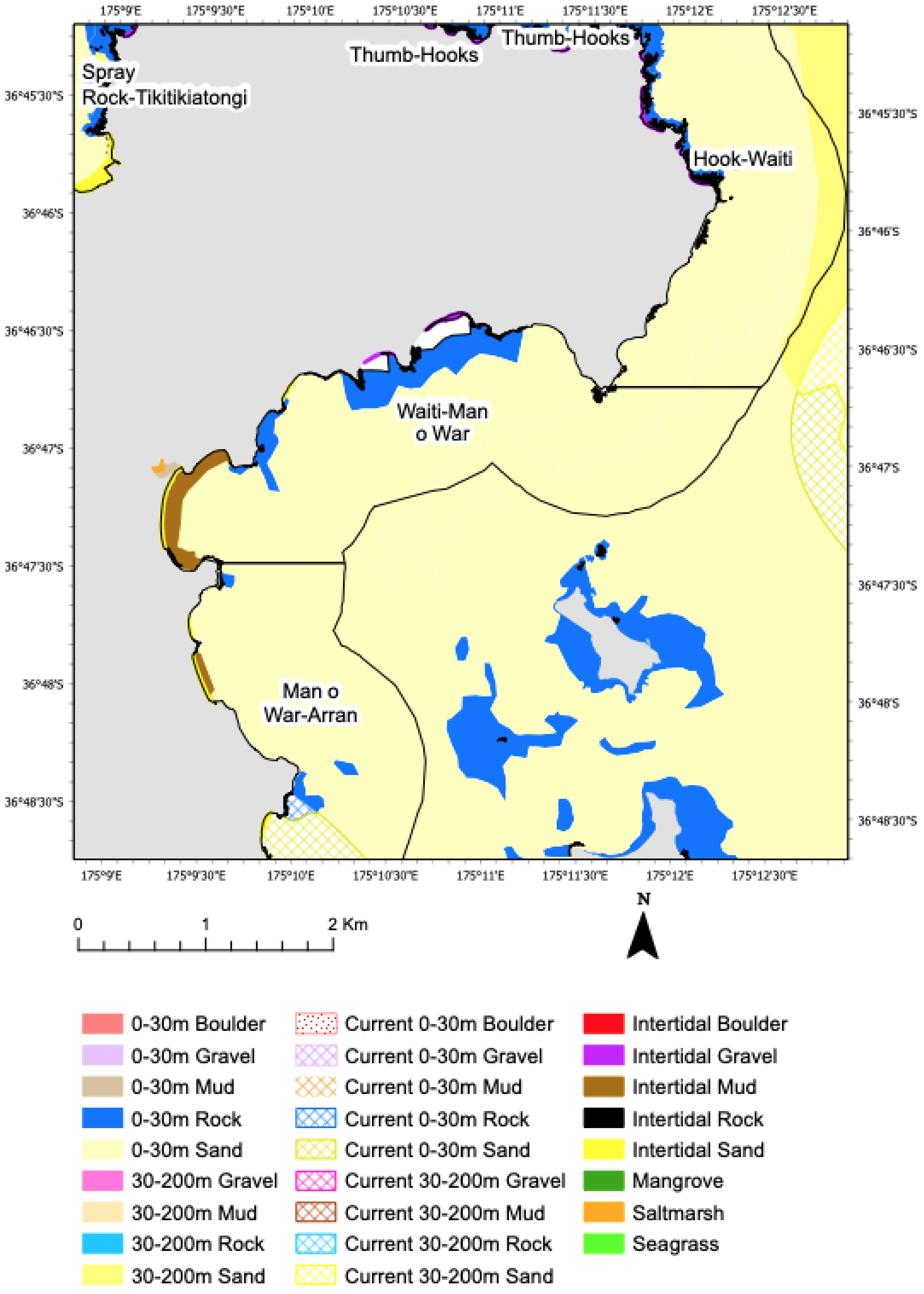

Figure 42 Marine habitats for Waiti Bay-Man o' War Bay.

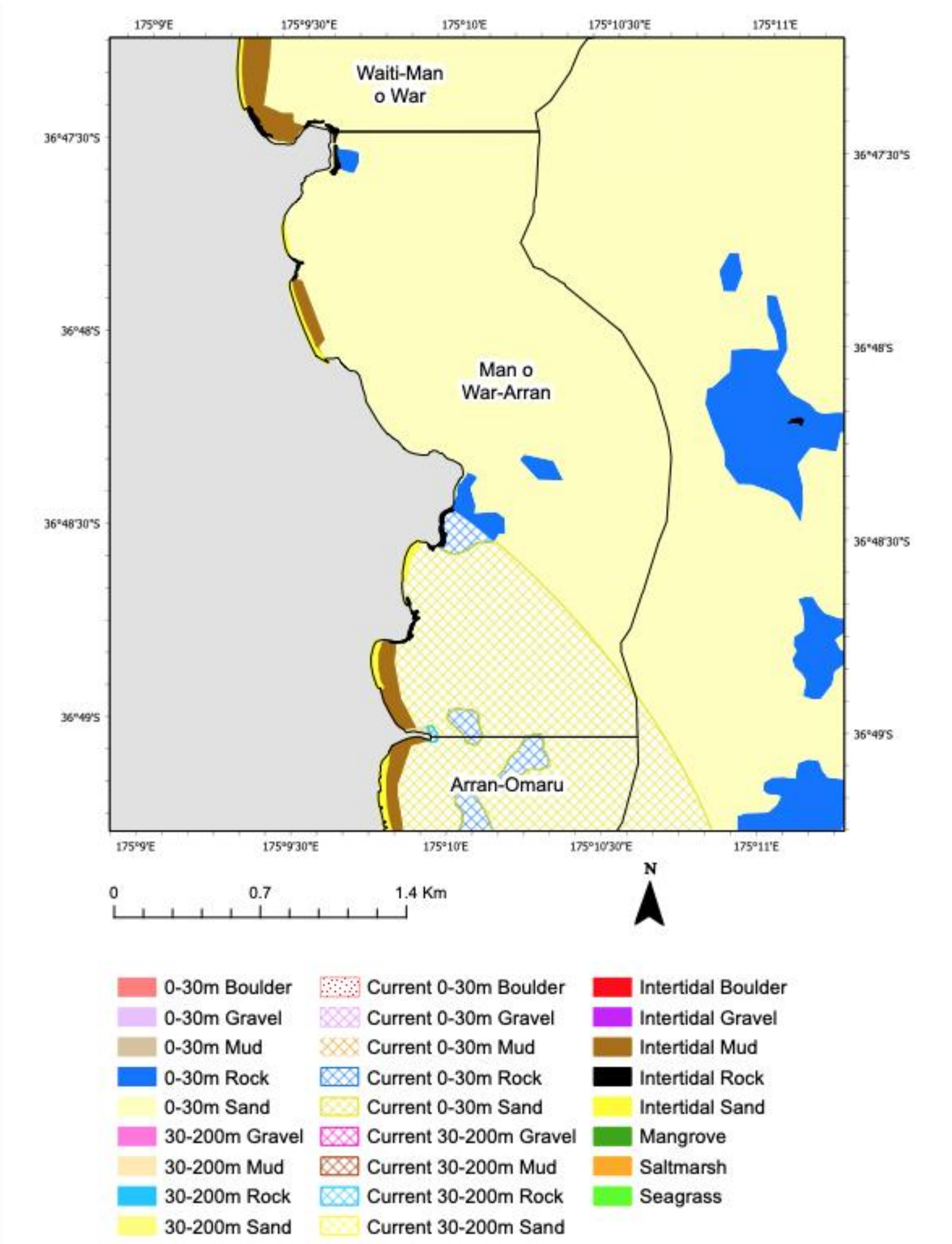

Figure 43 Marine habitats for Man o' War Bay-Arran Bay.

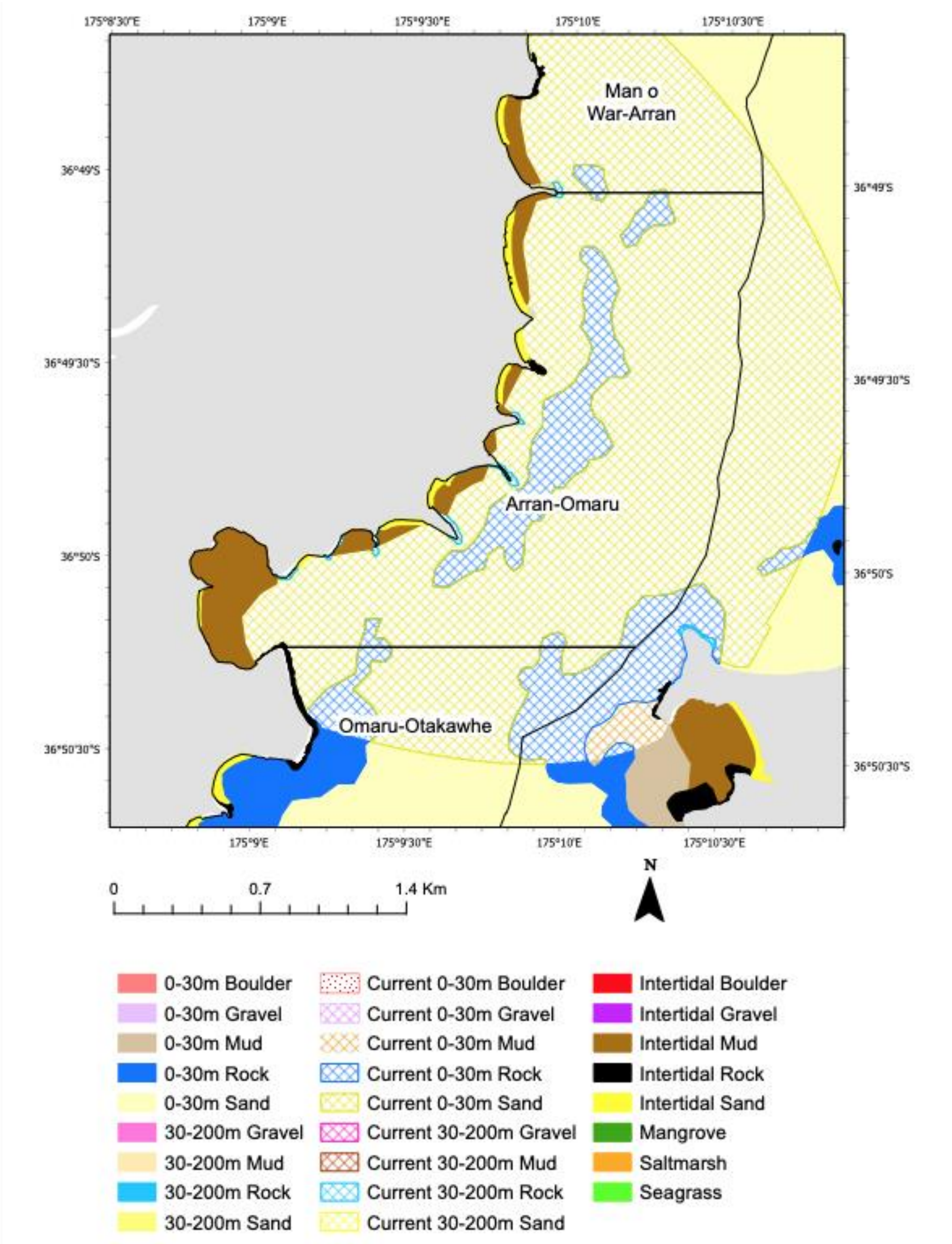

Figure 44 Marine habitats for Arran Bay-Omaru Bay.

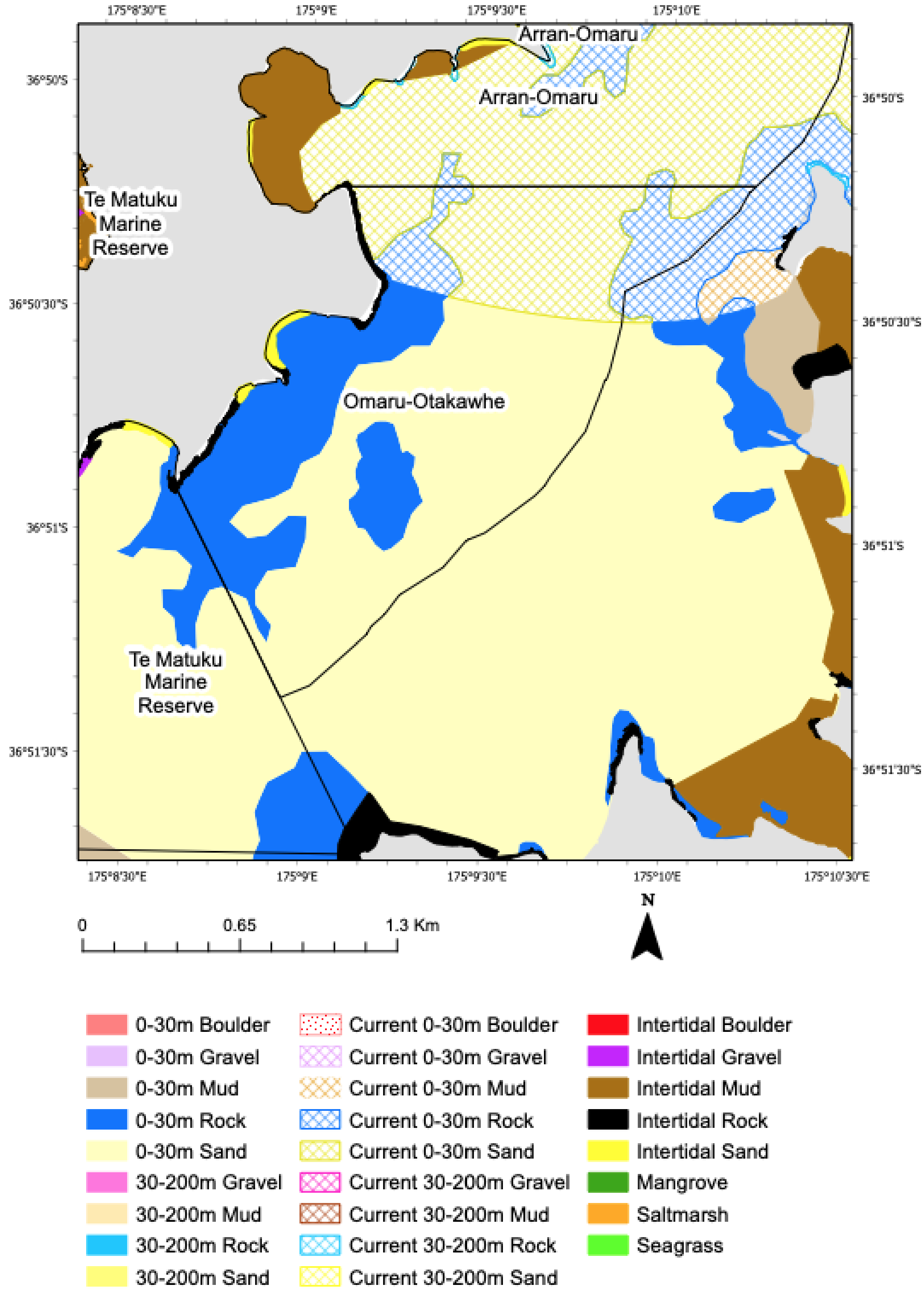

Figure 45 Marine habitats for Omaru Bay-Otakawhe Bay.

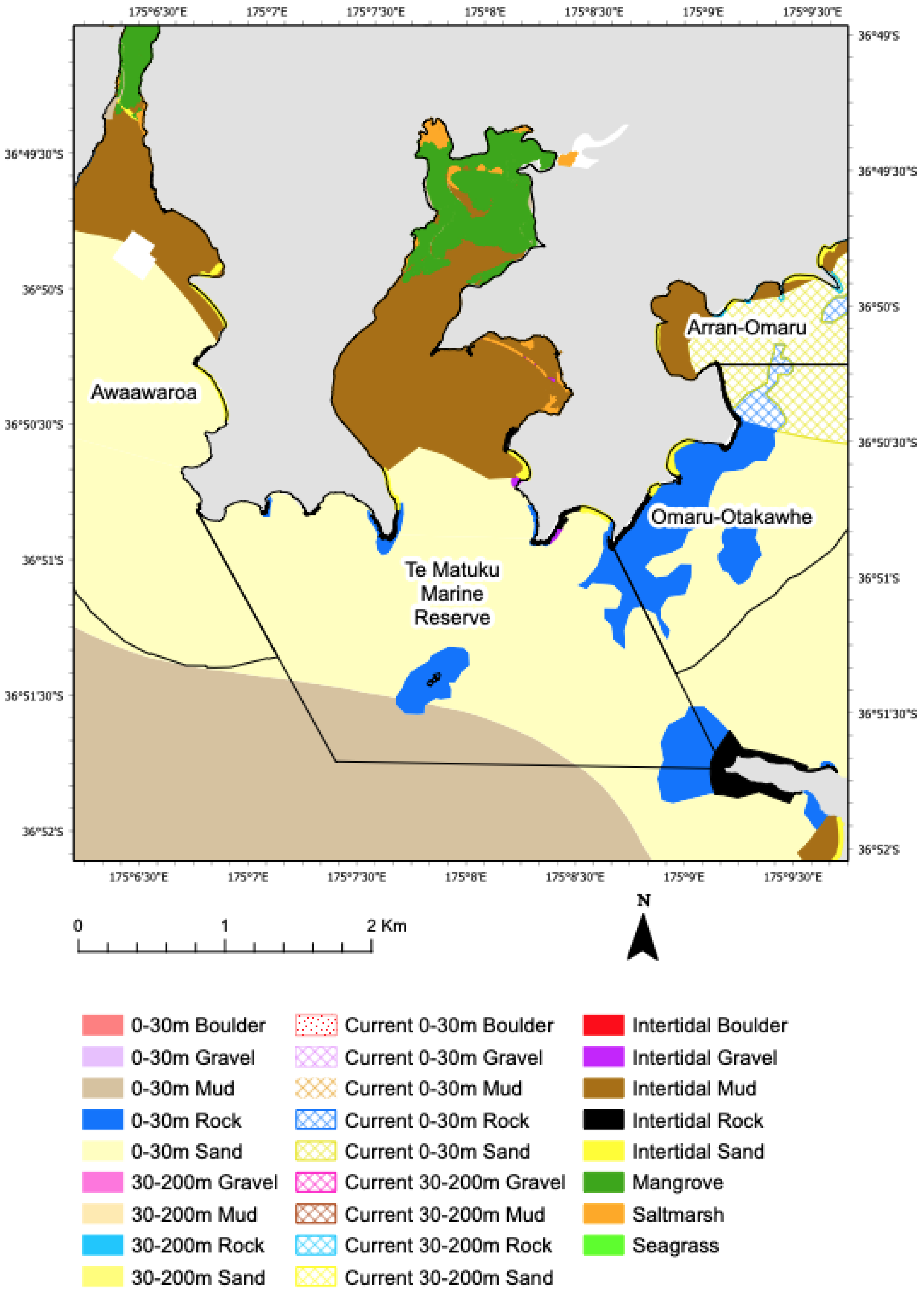

Figure 46 Marine habitats for Te Matuku Marine Reserve.

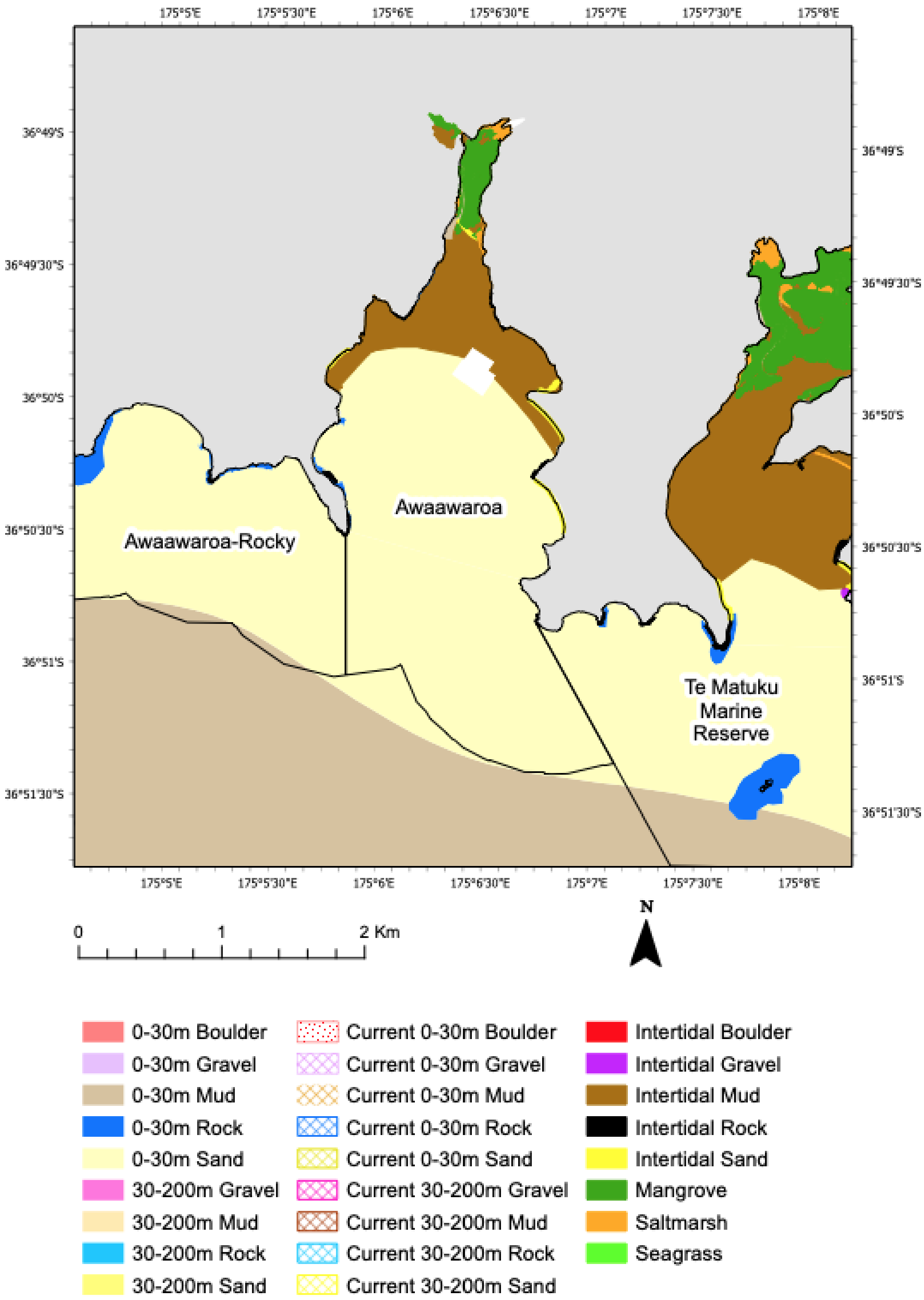

Figure 47 Marine habitats for Awaawaroa Bay.

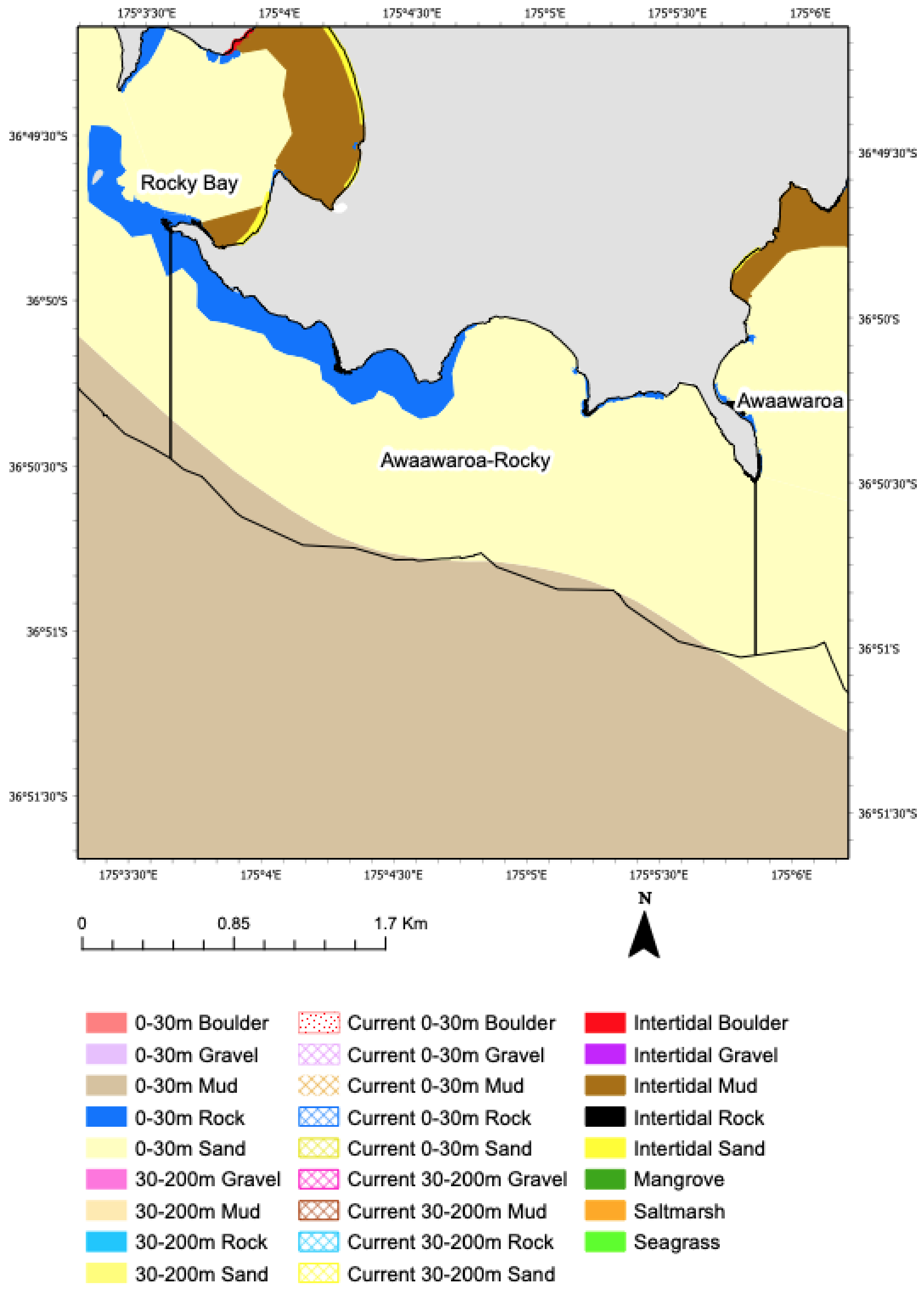

Figure 48 Marine habitats for Awaawaroa-Rocky Bay.

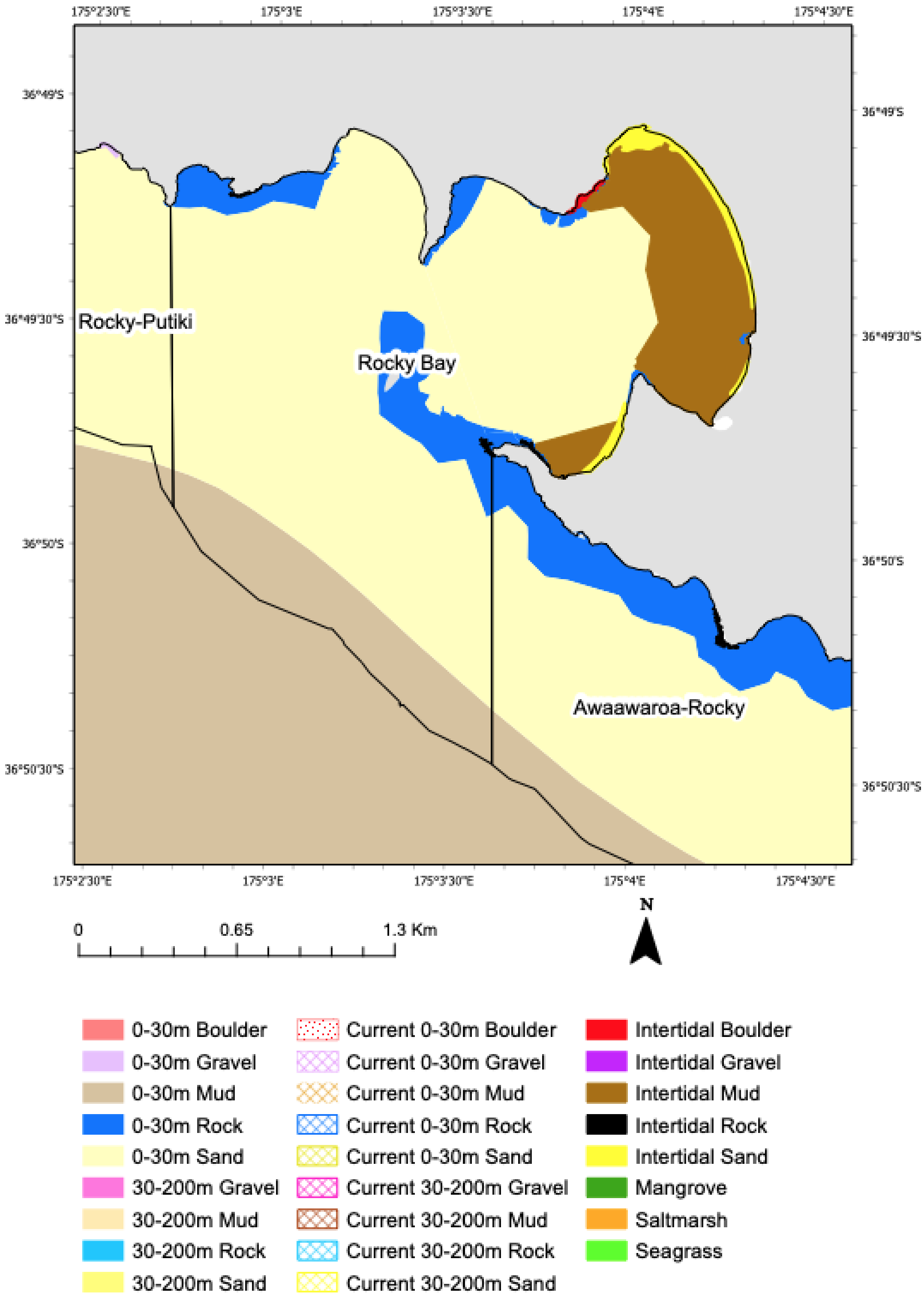

Figure 49 Marine habitats for Rocky Bay.

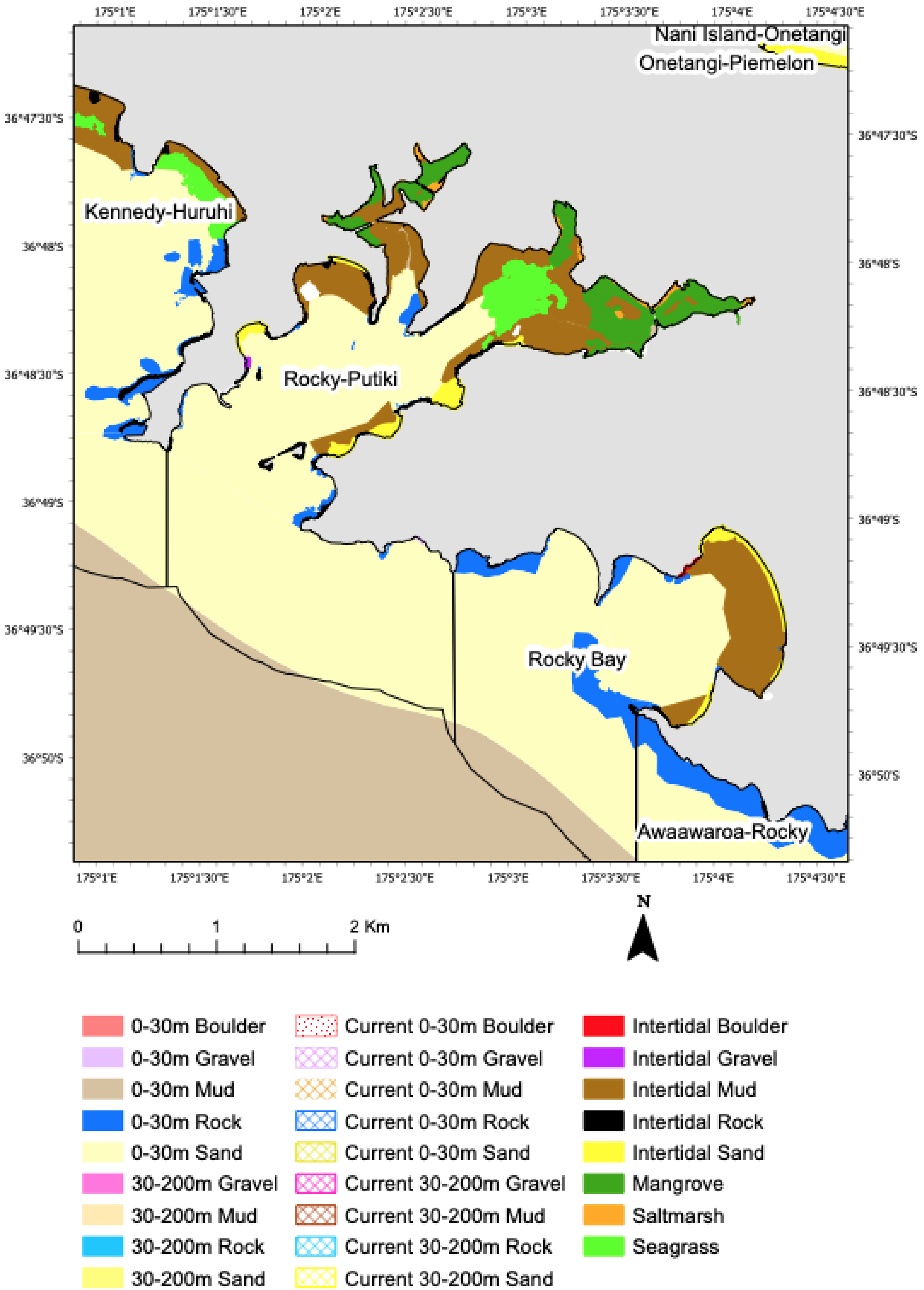

Figure 50 Marine habitats for Rocky Bay-Pūtiki Bay.

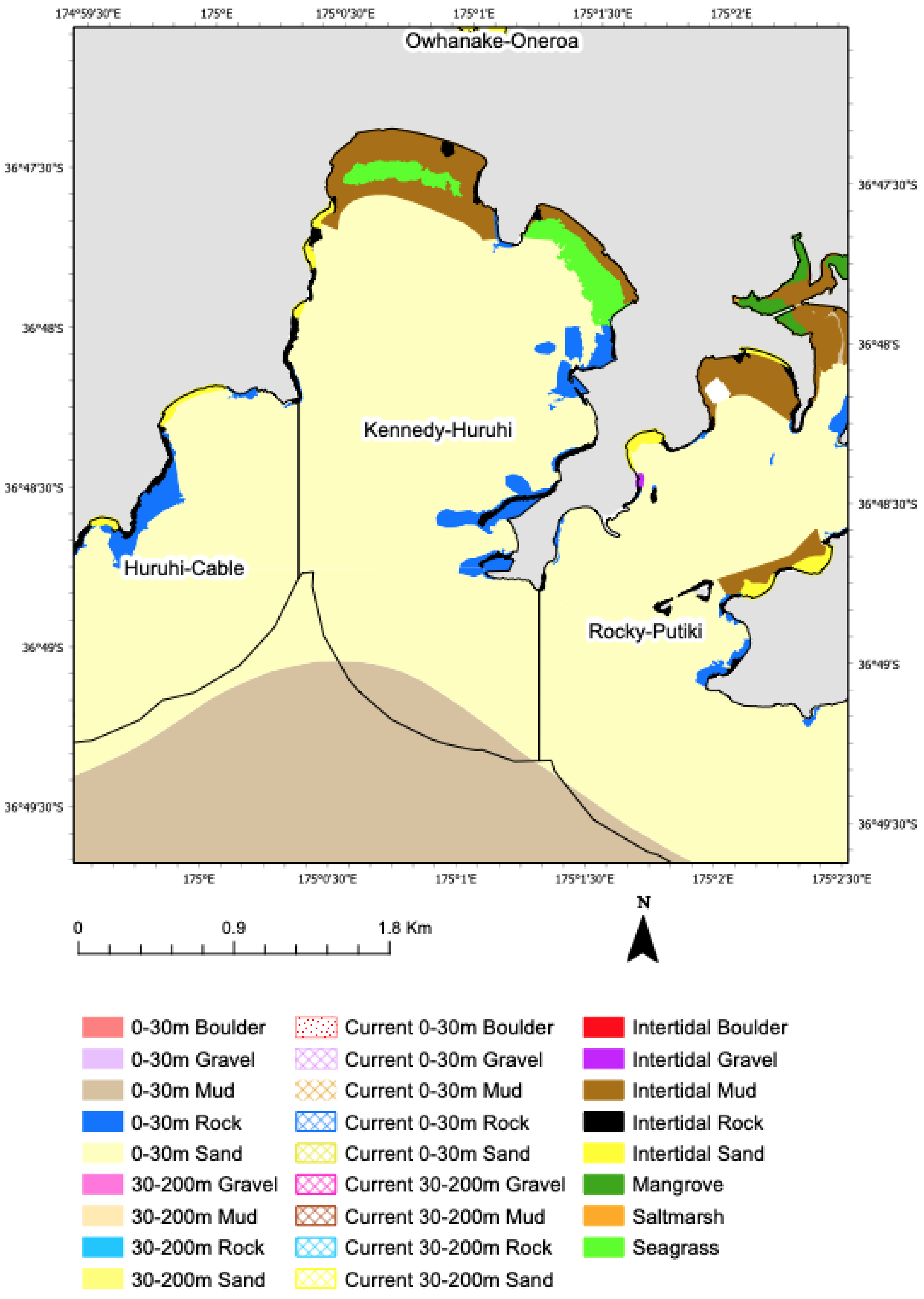

Figure 51 Marine habitats from Kennedy Point-Huruhi Bay.

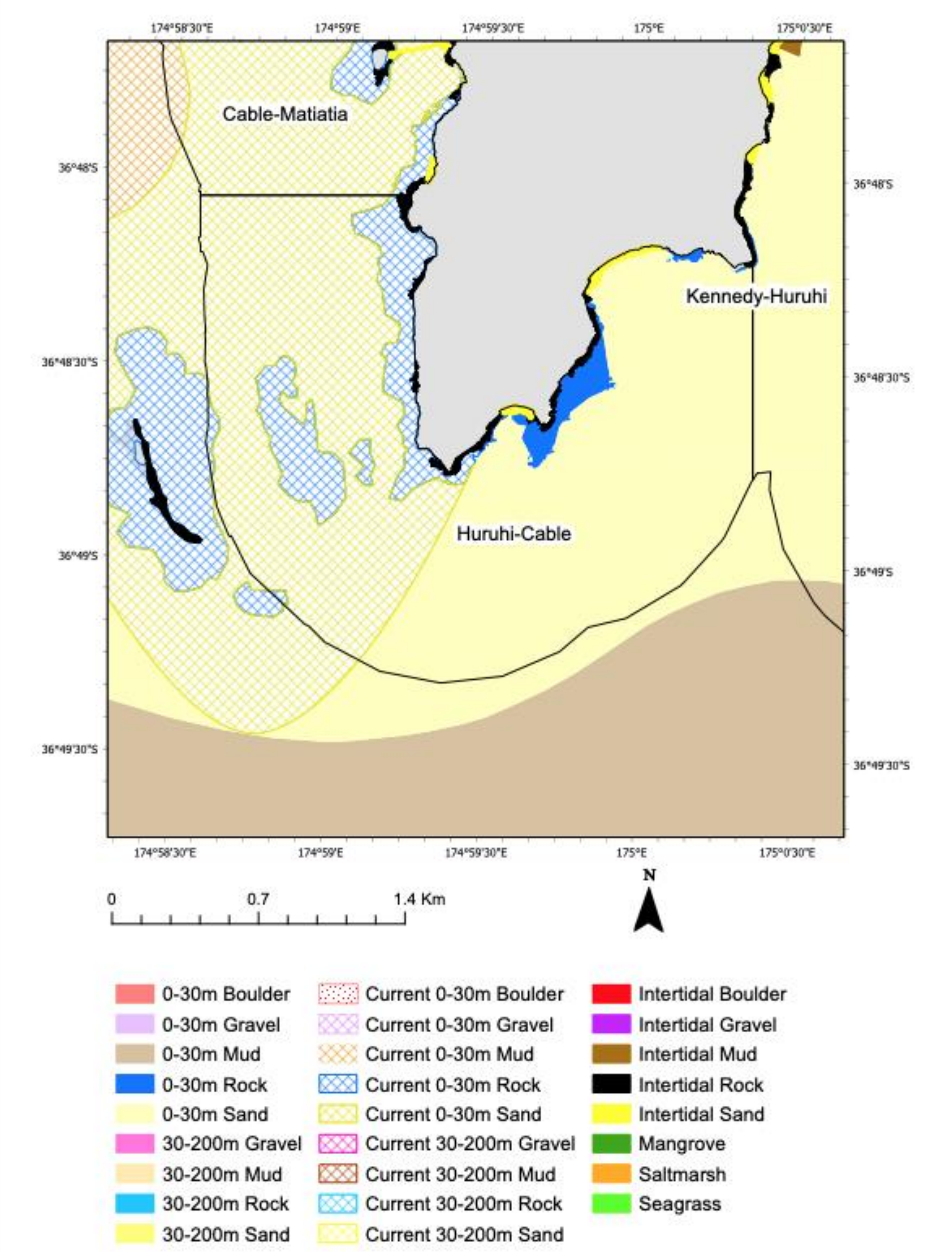

Figure 52 Marine habitats for Huruhi Bay-Cable Bay.

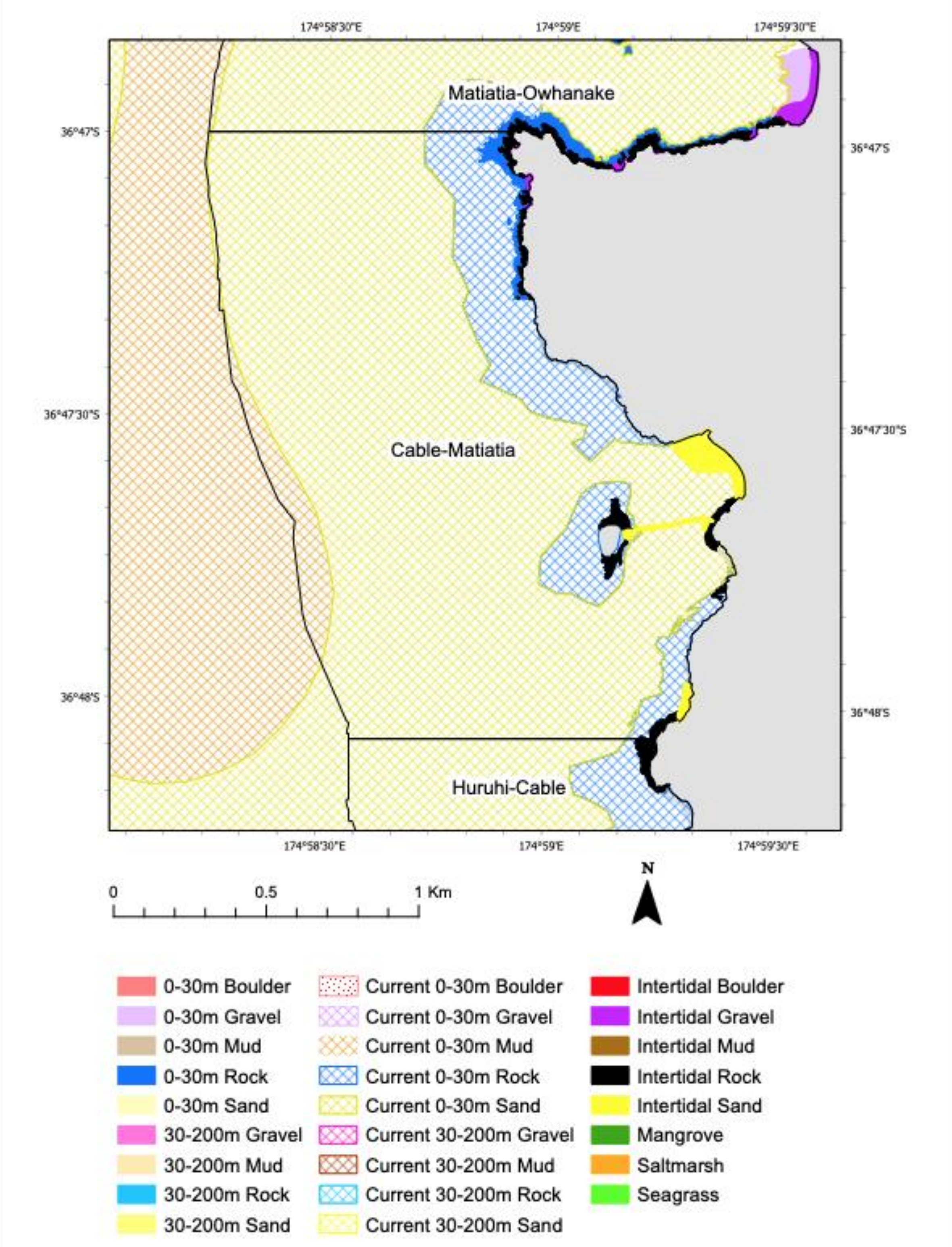

Figure 53 Marine habitats from Cable Bay-Matiatia.

Table 1 Summary of habitat areas (hectares) per planning unit.

Order	Plan Units	Intertidal Mud	Intertidal Sand	Intertidal Gravel	Intertidal Boulder	Intertidal Rock	0-30m Mud	0-30m Sand	0-30m Gravel	0-30m Boulder	0-30m Rock	30-200m Mud	30-200m Sand	30-200m Gravel	Current 0-30m Mud	Current 0-30m Sand	Current 0-30m Rock	Current 30-200m Rock	Mangrove	Saltmarsh	Seagrass	Total Area (ha)
23	Cable-Matiatia	0	2.61	0.08	0	2.44	0	0	0	0	1.57	0	0	0	7.95	189.55	35.4	0	0	0	0	239.6
22	Huruhi-Cable	0	1.41	0	0	3.99	0	202.85	0	0	9.8	0	0	0	0	161.6	41.66	0	0	0	0	421.31
21	Kennedy-Huruhi	35.79	1.08	0	0	5.3	22.58	383.7	0	0	19.23	0	0	0	0	0	0	0	0	0	15.99	483.67
20	Rocky-Pūtiki	78.2	7.48	0.15	0	4.62	8.68	401.7	0.19	0	7.73	0	0	0	0	0	0	0	40.13	2.68	17.2	568.76
19	Rocky Bay	46.21	3.69	0	0.29	0.37	38.3	247.87	0	0	27.75	0	0	0	0	0	0	0	0	0	0	364.48
18	Awaawaroa-Rocky	0	0	0	0	0.57	25.29	340.12	0	0	37.56	0	0	0	0	0	0	0	0	0	0	403.54
17	Awaawaroa	72.26	1.09	0	0	1.01	2.04	370.98	0	0	1.6	0	0	0	0	0	0	0	11.04	1.79	0	461.81
16	Te Matuku Marine Reserve	147.56	1.5	1.25	0	3.64	62.97	391.1	0	0	37.84	0	0	0	0	0	0	0	51.06	4.58	0	701.5
15	Omaru-Otakawhe	0	1.08	0	0	2.37	0	112.68	0	0	60.14	0	0	0	0	45.79	20.62	0	0	0	0	242.68
14	Arran-Omaru	26.1	3.04	0	0	0.38	0	0	0	0	0	0	0	0	0	238.77	43.19	1.62	0	0	0	313.1
13	Man o War-Arran	5.4	1.52	0	0	1.22	0	251.35	0	0	5.65	0	0	0	0	78.04	4.72	0.16	0	0	0	348.06
12	Waiti-Man o War	13.59	0.99	0.69	0	4.61	0	418.74	0	0	40.09	0	0	0	0	0	0	0	0	0	0	478.71
11	Hook-Waiti	0	0	1.57	0	6.97	0	375.28	0.08	0	13.38	0	29.05	0	0	0	0	0	0	0	0	426.33
10	Thumb-Hooks	0	1.48	1.05	0	7.15	0	244.06	0.95	0	29.15	0	0	0	0	0	0	0	0	0	0	283.84
9	Horuhoru-Thumb	0	0	0.67	0	7.45	0	164.29	0	0	58.67	79.17	0.56	194.26	0	0	0	0	0	0	0	505.07
8	Spray Rock-Tikitikiatongi	0	3.63	0.97	0.21	10.2	43.78	251.7	0	0	46.89	21.39	0.9	14.99	0	0	0	0	0	0	0	394.66
7	Te Whau-Spray Rock	0	2.51	0.96	0	10.45	46.61	352.34	0	0	38.46	0	0	0	0	0	0	0	0	0	0	451.33
6	Piemelon-Te Whau	0	4.52	1.15	0.89	6.23	43.61	273.11	0	0.56	17.17	0	0	0	0	0	0	0	0	0	0	347.24
5	Onetangi-Piemelon	0	13.82	0	0.24	1.25	1.48	192.13	0	0	1.2	0	0	0	0	0	0	0	0	0	0	210.12
4	Nani Island-Onetangi	0	3.37	1.01	1.56	15.49	134.32	313.25	0.98	0.42	42.17	0	0	0	0	0	0	0	0	0	0	512.57
3	Hekerua-Nani	0	6.34	0	0	10.22	73.93	207.67	0	0	35.95	0	0	0	0	0	0	0	0	0	0	334.11
2	Owhanake-Oneroa	0	11.07	0.9	0.47	14.62	62.8	290.53	0.69	0.25	24.96	0	0	0	0	0	0	0	0	0	0	406.29
1	Matiatia-Owhanake	0	0.01	4.22	0	9.51	28.04	111.7	1.57	0	13.6	0	0	0	28.81	135.51	39.67	0	0	0	0	372.64