

Ecosystem service maps of Coromandel estuaries

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Prepared for Waikato Regional Council

June 2017

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Executive summary

In 2013, rapid assessment techniques were developed to map ecological habitat types in intertidal areas in 14 estuaries on the Coromandel Peninsula. The goal was to classify habitats based on key biota and functional characteristics that link to ecosystem goods and services. Ecosystem services are a way of describing the diverse array of benefits that humans derive from ecosystems. They serve as means of expressing the importance of biologically generated ecosystem functions to the benefits that support human wellbeing. Biologically generated ecosystem functions are not always obvious and appreciated by humankind; therefore, demonstrating ecosystem services can lead to better and broader environmental stewardship.

In 2014, the Department of Conservation (DOC) used a matrix-based approach to link marine habitats to ecosystem services. This operated by organising ecosystem services as columns and habitats as rows, with a habitat's relative ability to contribute to a service recorded at the intersection. A relative ranking system was used to generate matrix scores, based on information from scientific papers, reports and expert opinion.

In this report, we outline the adaptation of the DOC ecosystem service matrix approach for use in Waikato estuaries. We combined the DOC matrix with habitat maps to produce maps of ecosystem services being generated by Coromandel Peninsula estuaries. Eight services were mapped: primary production, nutrient regeneration, habitat provision, regulation by key species, sediment retention, bioremediation of contaminants, shoreline protection, and food. The primary use of the ecosystem service maps should be as a simple visual tool and a way of communicating that estuaries offer an array of benefits that support human wellbeing. All but one of the estuarine habitats in the matrix contributed highly or moderately to at least one service. Similarly, all services, except for storm protection, had greater than six habitat types making either high or moderate contributions. Confidence layers were developed that could be super-imposed on top of service maps. These were based on the type of information used to score matrix cells. Confidence was high when there was New Zealand based, peer-reviewed literature supporting the links between habitat and service. Confidence was lower when the matrix scores were based solely on expert opinion. Another caveat is that the maps depict ecosystem service 'potential'; the matrix and service maps are generated based on the assumption that the contributing habitats are in a good state of health, which is not always the case. Moreover, the maps do not reflect the demand for/use of ecosystem services and thus whether habitat patches are of sufficient size for sustainable use.

Future improvements to the matrix-mapping could include an integration of stressors into the approach, which negatively affect the production of ecosystem services. Building this into the maps would require knowledge on the distribution and concentration/severity of stressors in Waikato estuaries. Previous work by Waikato Regional Council has assessed the susceptibility of habitats to a variety of stressors including: sediments, nutrients, low oxygen, contaminants, overharvesting and effects of climate change. This could be included, allowing simple inferences about which ecosystem services might be impaired and where management intervention would be beneficial. Beyond this simple expansion, more quantitative considerations of stress would likely be beyond the scope of a matrix-based approach. Instead, further effort is needed to develop metrics and quantify individual ecosystem services, building an understanding of how services change across environmental gradients and in response to stress.

1 Introduction

In 2013, Waikato Regional Council (WRC) contracted the National Institute of Water and Atmospheric Research (NIWA), to develop rapid assessment techniques for mapping intertidal habitats. Methods were trialled in Tairua Estuary and implemented across a further 13 estuaries on the Coromandel Peninsula (Needham et al. 2013a, 2013b, Figure 1). The report by Needham et al. (2013b) gave a detailed account of the accuracy, precision and repeatability of mapping methods and descriptions of the habitat classes. Habitat classification focused on biota where the functional characteristics of the focal species could be simplistically linked to ecosystem goods and services (herein collectively referred to as *ecosystem services*) (Box 1, Table 1). The rationale was that more detailed and rigorous links between ecosystem services and habitats could be established later. Across the Coromandel estuaries, 15 different habitat classes were described (Table 2).

‘Ecosystem goods and services¹’ are a way of describing the diverse array of benefits that humans derive from the ecosystems. (Box 1, Daily 1997, Costanza et al. 1997, Boyd and Banzhaf 2007). Ecosystem ‘goods’ are the tangible resources that are extracted and utilised by humans, such as food and raw materials, whereas the ‘services’ are the abilities of ecological systems to provide favourable conditions by processing material or providing intrinsic benefits (e.g., water filtration, dampening environmental pressures). The term ‘ecosystem services’ is commonly used to mean both goods and services and we make no distinction herein. Ecosystem services can be used to identify, link and communicate the benefits that nature provides (Daily 1997, deGroot 2002, MEA 2005). This helps to form a bridge between the underpinning ecosystem functions generated by species and habitats and the benefits for humans, obtained from the marine environment (UK NEA, Haines-Young and Potschin 2010). The concept of ecosystem services can assist in the integration of environmental, social and economic concerns and allow the environment to be more visible and tractable in management decisions (MEA 2005).

In 2014, the Department of Conservation (DOC) contracted NIWA, the Cawthron Institute and the University of Auckland to assess the contribution of marine habitats to the provision of ecosystem services in the coastal environment. This collaborative effort produced an ‘ecosystem services matrix’ that characterised the benefits provided by different components of marine ecosystems (Townsend et al. 2014). The matrix operated by organising ecosystem services as columns and the biotic components of ecosystems as rows, with a component’s ability to contribute to a specific service recorded at the intersection (Table 3). This methodology had been used previously in marine systems (Potts et al. 2014) but has been more widely used in terrestrial studies (Burkhard et al. 2009, 2014, Jacobs et al. 2014). Scoring within the matrix was based on a relative ranking system, where ecosystem components were classed as having either a ‘high’, ‘moderate’, ‘low’ or ‘negligible’ contribution to ecosystem services, or marked ‘NA’ if they could not be assessed. Ranking was based on information derived from scientific papers, reports, and expert opinion. Emergent properties were included, for example, cockle beds have the capacity to stimulate primary production (Sandwell et al. 2009) and nutrient recycling (Jones et al. 2011) though their activity in the sediment.

In this report, we outline the adaptation of the ecosystem service matrix approach and its application to Waikato estuaries (Section 2). We demonstrate how the matrix can be combined with habitat maps to produce simple maps of ecosystem services in Coromandel estuaries (Section 3). These maps have strengths and limitations which need to be characterised prior to use and anchored

¹ Ecosystem services can be defined as “the direct and indirect benefits that mankind receives or values from natural or semi-natural habitats”.

within a functioning ecosystem approach. The qualities of the maps also change depending on the service of interest and spatial characteristics (Costanza 2008). These were discussed at a workshop in November 2016; with Section 4 providing a summary of key points and recommendations for map use.

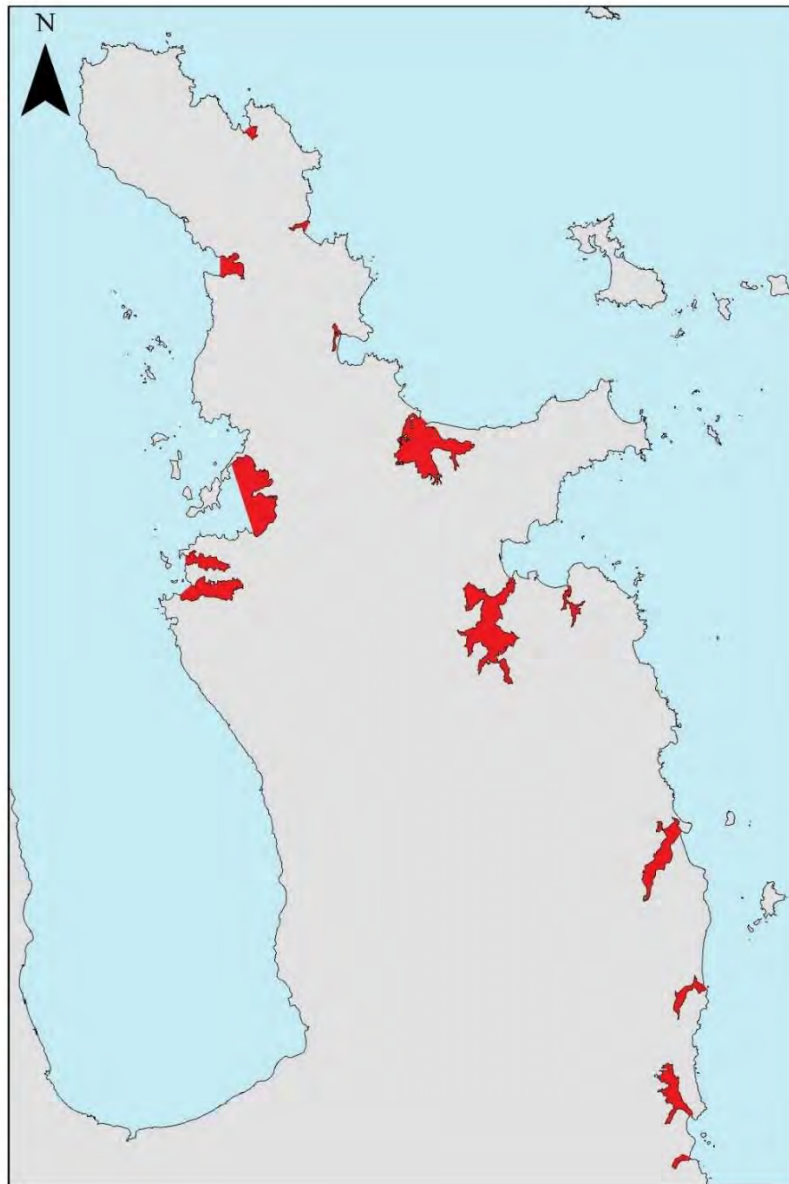
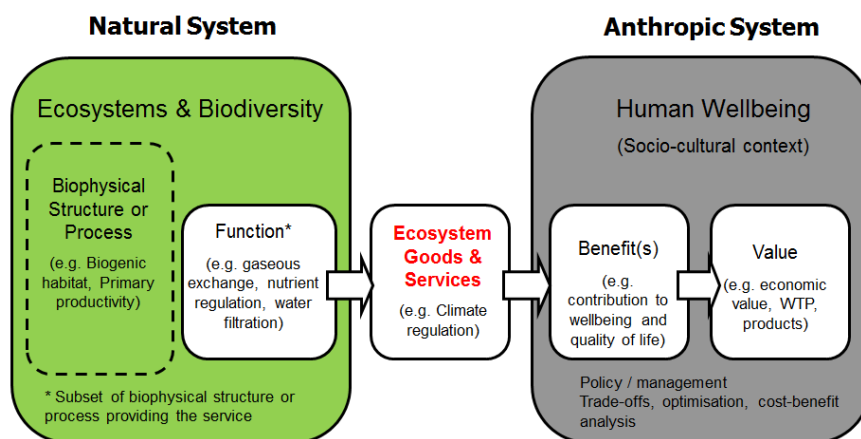


Figure 1: Map showing the estuaries (red) assessed. Starting bottom-right and working in an anticlockwise direction around the Coromandel Peninsula, the locations of intertidal habitat mapping were: Otahu estuary, Whangamata Harbour, Wharekawa Harbour, Tairua Harbour, Purangi estuary, Whitianga Harbour,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

Box 1.

Ecosystem Services

The concept of “ecosystem goods and services” allows us to articulate how ecological systems and their underlying functions support human wellbeing (de Groot 1992, Daily 1997, Daily et al. 2000). This is an important step in the management of natural resources; one that could potentially help prevent over-exploitation and the loss of biodiversity.



Ecosystem service approaches are becoming more common. Studies such as Costanza et al. (1997) have highlighted how important ecosystem services are from an economic perspective. The Millennium Ecosystem Assessment (MEA 2003, 2005) has stimulated worldwide interest in this field. It deconstructs ecosystem service into 4 overarching categories:

- Provisioning services describe the array of products that can be extracted from marine ecosystems such as food, raw material or medicinal products.
- Regulation services describe the benefits obtained from the regulation of ecosystem processes.
- Supporting services are those that are necessary to produce all other ecosystem services.
- Cultural services describe the nonmaterial benefits people obtain from ecosystems.

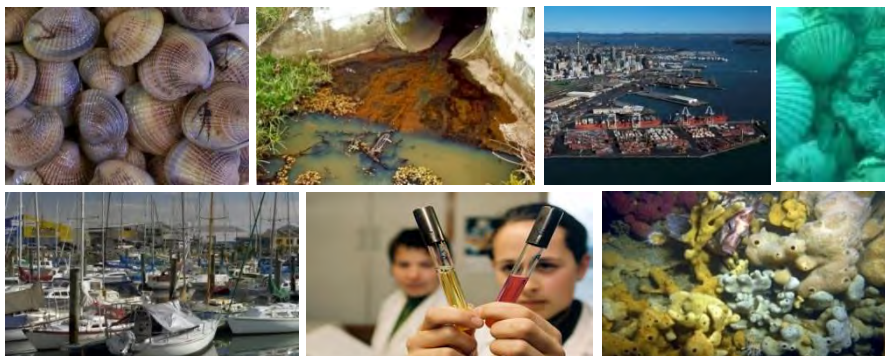


Table 1: Simplistic links between biota and goods and services from Needham et al. (2013a).

Habitat Type	Implicit Service Links
<u>Flora</u>	
Seagrass	Primary production, habitat structure, sediment stability & retention.
Mangroves	Primary production, carbon sequestration, gas and climate regulation, disturbance prevention, sediment stability & retention, habitat structure and coastal defence.
Pneumatophores	Nutrient cycling, sediment stability.
<u>Fauna</u>	
Tube worm mats	Sediment stability.
Cockle or Pipi beds	Secondary productivity, cultural harvesting, waste treatment, processing and storage, carbon sequestration.
<i>Amphibola</i> (mudflat snail / Titiko)	Cultural harvesting.
Oysters	Biogenic habitat provision, cultural harvesting, waste treatment, sediment stability & retention.
<i>Macomona</i> (wedge shell / Hanikura)	Sediment stability.
Crustacean burrows	Sediment stability and reworking rates, waste treatment, processing and storage, nutrient cycling, secondary productivity, habitat structure.
Mounds and pits	Secondary productivity, nutrient cycling, sediment stability habitat structure.

Table 2: Habitat classes from Needham et al. (2013b) and their defining characteristics.

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

2 Adaptation of the ecosystem services matrix to WRC habitats

2.1 Adjusting matrix scores

A key difference between DOC's ecosystem services matrix and the WRC mapping approach was a focus on different biotic components. WRC mapping used 'habitats' which include both biological and environmental attributes supporting particular species. Marine benthic habitat includes the sediment that species live in or on, the interstitial and overlying waters, the prevailing conditions of current, salinity and temperature, and the habitat-defining organisms living there. The DOC ecosystem services matrix focused on 'ecosystem components', which were defined as "direct and emergent properties of the character defining species", and their contribution to ecosystem services. Habitats have a broader inclusion than ecosystem components because they include the sediment environment and other species in addition to the focal species. For this reason, certain matrix scores required adjustment to encapsulate the wider definition of habitats.

Seven of the 15 WRC habitats were closely matched to ecosystem components in the DOC matrix and required only minor adaptation in some cases (i.e., minor adjustment to scores for one or two services, see Appendix A for original DOC Matrix). These were mangroves forest, cockle bed, surf clams (high density pipi), wedge shell bed (high density *Macomona*), oyster reef, soft-sediment whelk association (high density *Amphibola*) and mud crab beds (high density crabs) (Table 3). Three of the 15 WRC categories were a combination of entries: high density cockles and pipi, high density crabs and cockles, tube worms and crabs. For these habitat types, the matrix cells for each service were scored as the highest individual component; again with minor adaptation to convert to habitats (Table 3). Although not included in its defining characteristics, Needham et al. (2013b) noted that seagrass habitat in Waikato estuaries regularly contained high to medium densities of cockles. This could not be verified for all seagrass patches during mapping, but was a common feature. To make this more explicit when considering ecosystem services, the WRC habitat category was updated to 'Seagrass and high density cockles' and scored as the highest individual component of seagrass meadow and cockle beds with minor adaptation. This increased the transparency and made some elements of the scoring more logical, e.g., when seagrass habitat was scored for food provision. Only three of the 15 WRC categories required more substantial adaptation: low density deposit feeders/background, mounds and pits/mixed and pneumatophores. Pneumatophore habitat was adapted from mud crab bed scoring, as virtually all pneumatophore fringes observed during mapping were occupied by high densities of *Austrohelice crassa* or *Hemiplax hirtipes* (Table 3). The final WRC category of 'low fauna' was judged to make a negligible contribution to ecosystem services, since its defining characteristic was that key macrofauna (e.g., shellfish and decapods) were extremely sparse (on average less than 1 individual per 0.25 m² quadrat).

DOC's ecosystem services matrix took a broad and national perspective when scoring the contribution of habitats to ecosystem services, but recognised the potential for variation across local and regional scales (Townsend et al. 2014). For example, there are differences in the importance of snapper and blue cod between the north and south of the country, culturally and as a food source. Cultural identity affects our values, and the relative importance of different species or habitats in our uses of natural resources. Culture is determined by our family, upbringing and our life experiences and can differ between generations, ethnicities, religions, countries of origin, income level, location of residence and sector of society (Hoffstede 1991, Hebel 1999) and hence is inherently subjective. In

the DOC ecosystem service matrix, mud snails (high density *Amphibola*) were given a low ranking for their potential contribution to food provision. However, given the presence of mana whenua and the customary harvest of 'titiko' in the Waikato, this score was increased to a moderate contribution (Table 3).

Table 3: Ecosystem service matrix adapted for WRC habitats. Eight ecosystem services are listed: three 'habitat and supporting' services (primary production, nutrient regeneration & biogenic habitat provision); four 'regulation' services (regulation by key ecosystem component, sediment retention, bioremediation of contaminants & shoreline protection); and one 'provisioning' service (food).

Habitats	Primary production	Nutrient regeneration	Biogenic habitat provision	Regulation by key species	Sediment retention	Bioremediation of contaminants	Shoreline protection	Food
Seagrass & high density cockles	3	2	2	3	2	1	1	2
High density cockles	3	3	3	3	1	2	1	2
High density cockles and pipi	3	3	3	3	1	2	1	2
High density crabs and cockles	3	3	3	3	3	3	1	2
Mangroves	3	2	3	3	3	2	2	1
High density oyster	1	2	2	NA	2	2	1	2
Tube worms and crabs	1	3	1	1	3	3	1	1
High density crabs	1	3	1	1	3	3	1	1
Pneumatophores & mud crabs	1	2	1	1	2	2	1	1
Low density deposit feeders (Background)	1	1	1	1	1	1	1	1
High density pipi	1	1	1	NA	1	NA	1	2
High density <i>Macomona</i>	1	3	NA	3	1	1	1	1
Mounds & Pits (Mixed)	1	1	1	1	1	1	1	1
High density <i>Amphibola</i>	1	1	NA	3	1	NA	1	1
Low Fauna	1	1	1	1	1	1	1	1

Scale of ES supplied by the habitat		'Confidence' in evidence
	High contribution	3 NZ focused, peer-reviewed literature.
	Moderate contribution	2 NZ focused, reports, grey literature, overseas literature.
	Low contribution	1 Expert opinion.
	No/negligible contribution	NA Not assessed.

2.2 Service selection

Not all the 16 ecosystem services included in DOC's matrix were suitable for spatial adaptation and conversion into maps. The services of gas balance and carbon sequestration & storage were excluded because they do not have obvious local benefits²; reducing the use of any maps produced. For both these services and also the formation of sediments, it was recognised that they operate over spatial scales much larger than Waikato estuaries. Habitats found in Waikato estuaries did not have strong links to the provision of raw materials or biochemical/medicinal resources (none made high contributions and few made moderate contribution, Appendix A) so these services were not included in mapping. The cultural services of leisure and ecotourism and spiritual and cultural wellbeing were excluded from consideration due to complex spatial relationships. While there are values associated with specific habitats e.g., high value of 'taonga' shellfish, place and identity are overriding factors in determining how important a specific location is. Creating maps without a consideration of place would reduce the credibility of maps produced solely on habitat presence. The eight services selected for mapping were: primary production, nutrient regeneration, habitat provision, regulation by key species, sediment retention, bioremediation of contaminants, shoreline protection and food:

Supporting services:

Primary production: This is the activity of plants, algae and microbes using solar radiation to create organic compounds from inorganic constituents (Tait and Dipper 1998). This is an important source of energy that underpins many marine food-webs. Rates of primary production vary across habitats, depending on the types of species present and environmental conditions (Cahoon 1999).

Nutrient regeneration: This is the breakdown and conversion of organic matter into inorganic nutrients by the activities of marine species. Sediments are the most active area for organic matter remineralisation, but this process also takes place in the water column (Sundbäck et al. 2003). Remineralisation is typically a microbially mediated process, but rates of nutrient exchange are influenced by benthic and pelagic fauna and sediment type (Fenchel and Bernard 1996).

Biogenic habitat provision: Marine species, through their physical structures or activities, provide important living spaces for other organisms (Holt et al. 1998). These living spaces are often, but not limited to, emergent structures in the water column that create complex vertical relief.

Regulating services:

Regulation by key species: Key species are able to control the abundances of other plants and animals through their activities and in some cases predation. Thus, populations, food-webs, community composition and ecological functioning are controlled and regulated by strongly interacting 'key' or 'keystone' species.

Sediment retention: When in sufficient densities, biota can prevent the erosion of sediments and increase sediment deposition (Thrush et al. 1996, Lelieveld et al. 2004). The most obvious estuarine example is mangroves which can trap sediment in the upper intertidal. This service also includes biota that reduce sediment resuspension.

Bioremediation of contaminants: Human activities can introduce contaminants into the marine environment including sediments, chemicals e.g., heavy metals and hydrocarbons, microbes/pathogens and nutrients (Oviatt et al. 1986, 1993). Marine organisms can mitigate possible impacts

² Non-proximal spatial characteristics - the benefit from a service does not depend on a person's proximity to it (Costanza 2008).

Shoreline protection: Biogenic structures formed by various marine habitats can mitigate environmental disturbances such as storm surges and wave action (Danielsen et al. 2005). Biogenic structures modify flow by dissipating energy which can reduce erosion during these events and protect coastal infrastructure (Fonseca and Calalan 1992).

Food: Marine ecosystems contain species that can be extracted for human consumption.

Each matrix cell contains a numeric indicator reflecting the confidence in the assigned score. Where there was a New Zealand focused, peer-reviewed scientific study that underpinned a service score, confidence was high and the cell was rated as a '3'. A confidence level of '2' indicated support from sources that were either not peer-reviewed or were external to New Zealand. Supporting literature is provided in Appendix B. A confidence level of '1' indicated that evidence for a service score was based solely on expert opinion. Only in a few cases could expert opinions not be offered in the absence of other information sources. Three habitats were judged based on expert opinion alone: LD deposit feeders/background, mounds and Pits/mixed and low fauna.

Ecosystem service maps were produced in ARCMAP 10.2.1 by incorporating the adapted matrix into the attributes table of the WRC Habitat map shapefile. Each service was individually selected as the 'value field' (the attribute that is displayed on the map) with colour used to demonstrate the contribution to service (Figure 2). Eight separate ecosystem service maps were produced for each estuary (Section 3).



3 Ecosystem Service maps for Coromandel estuaries

Below are habitat maps of Coromandel estuaries from Needham et al. (2013b) and the associated ecosystem service maps.

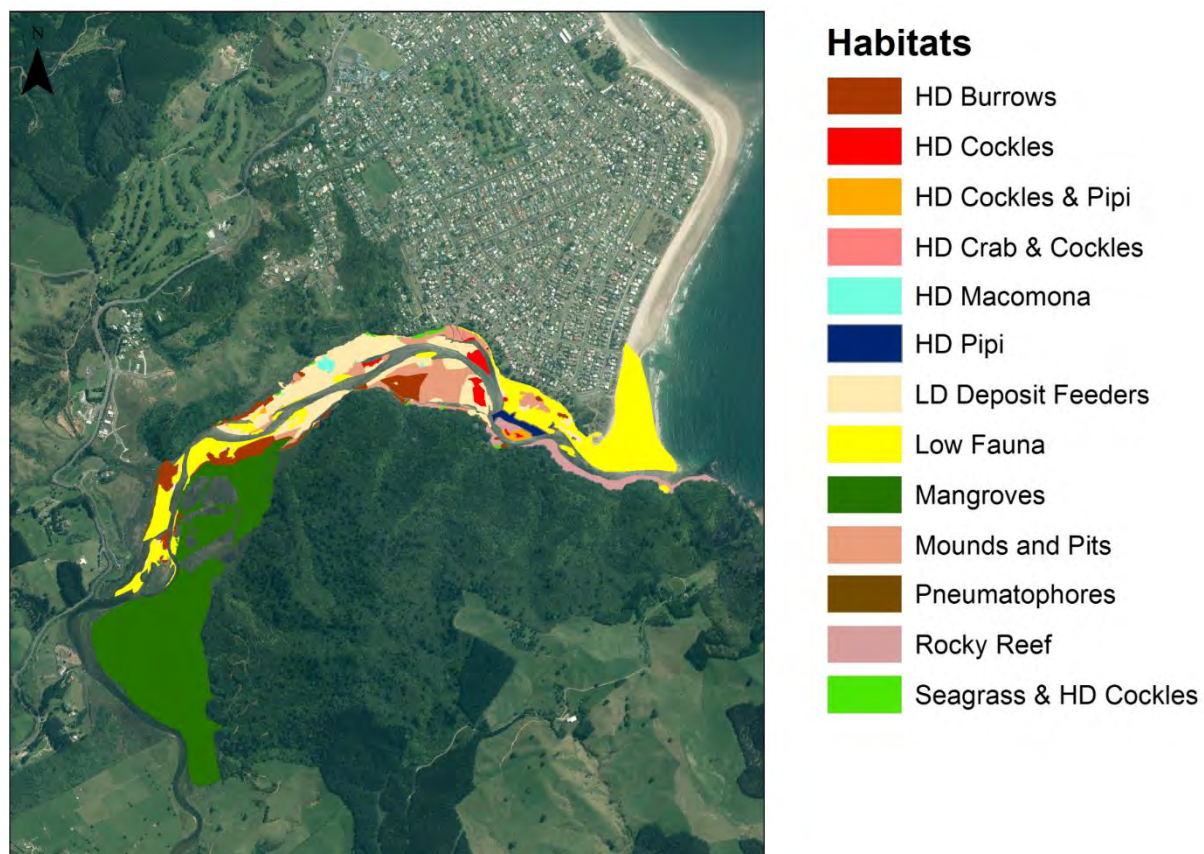


Figure 3: Habitat map of Otahu estuary.

Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat



Figure 4: Ecosystem service maps of Otahu estuary.

Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention



Figure 4 Continued: Ecosystem service maps of Otahu estuary.

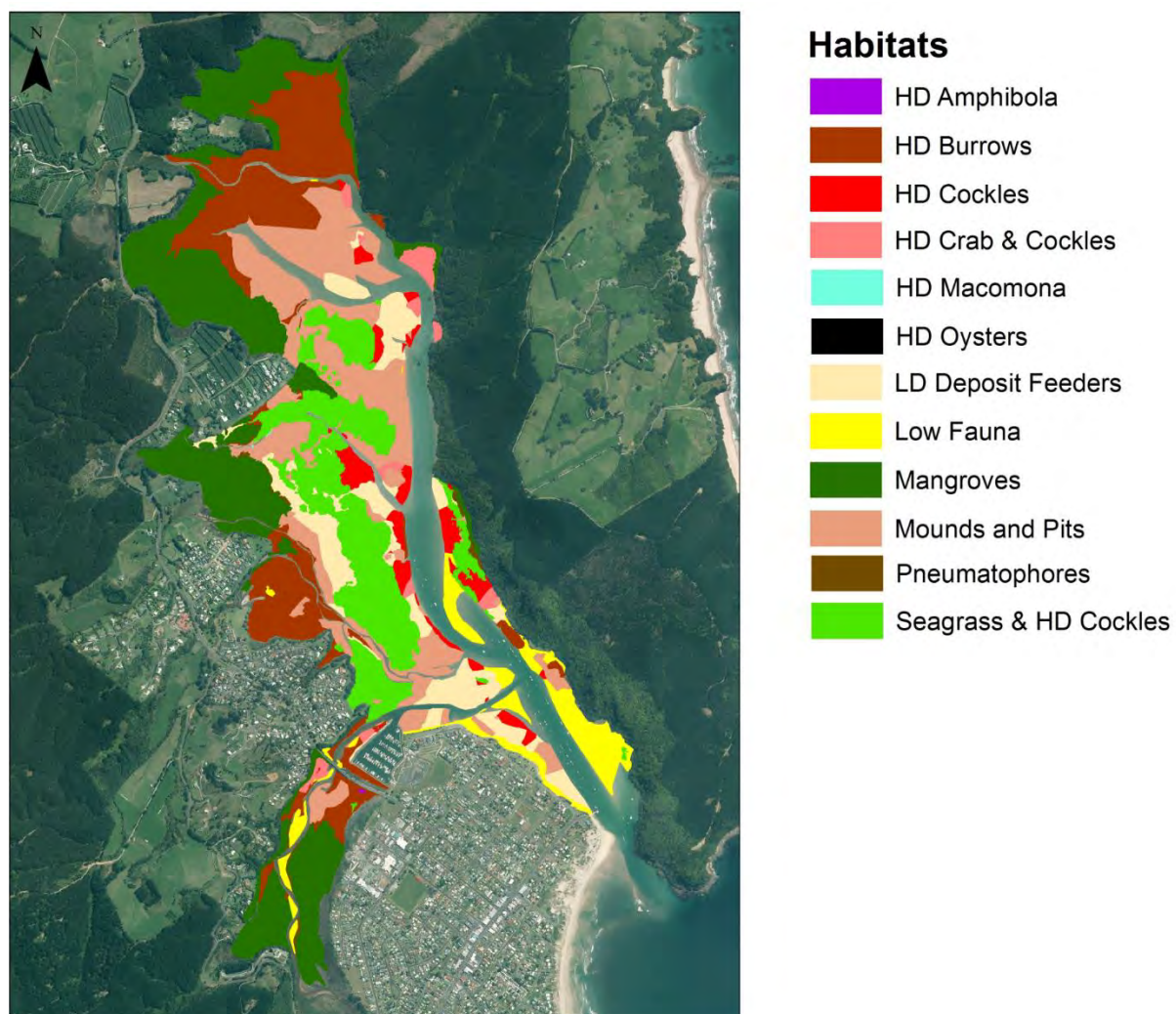
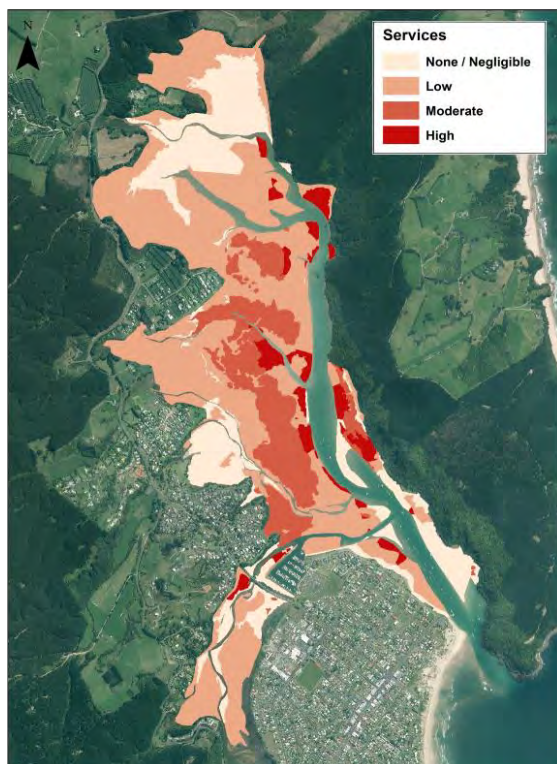
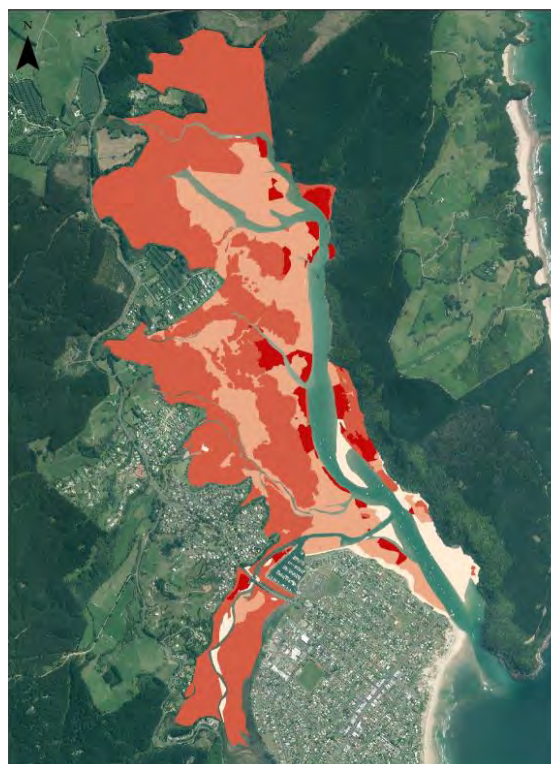


Figure 5: Habitat map of Whangamata Harbour.

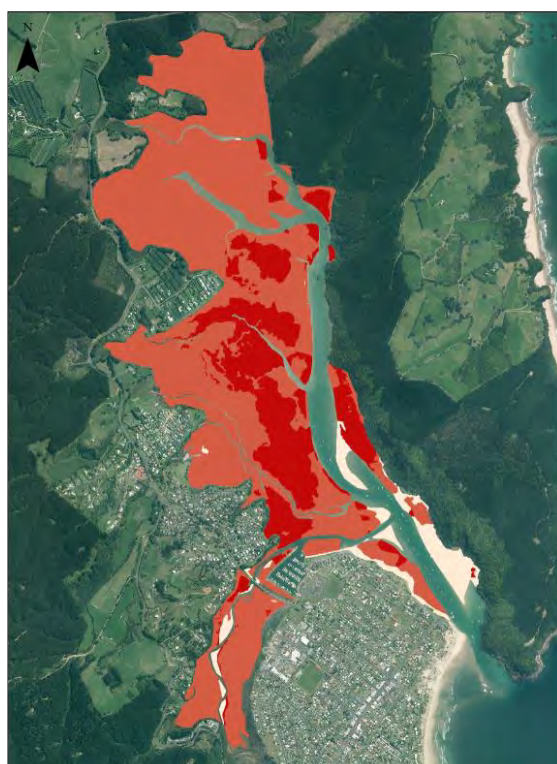
Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat

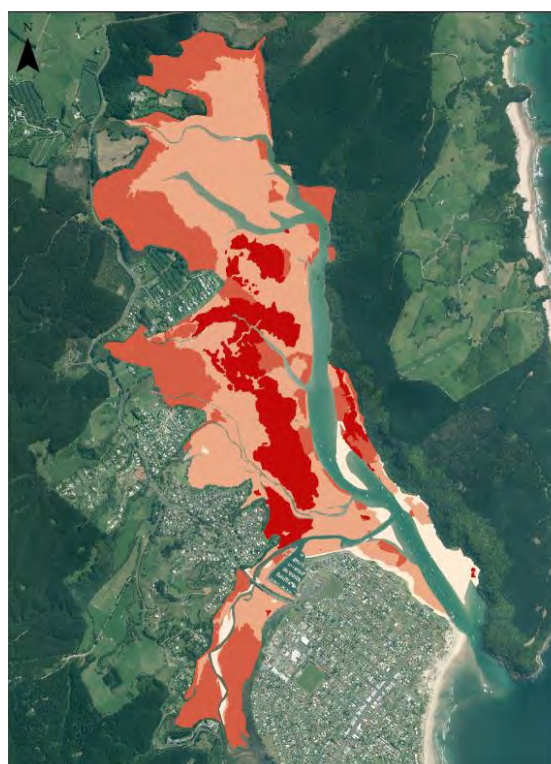
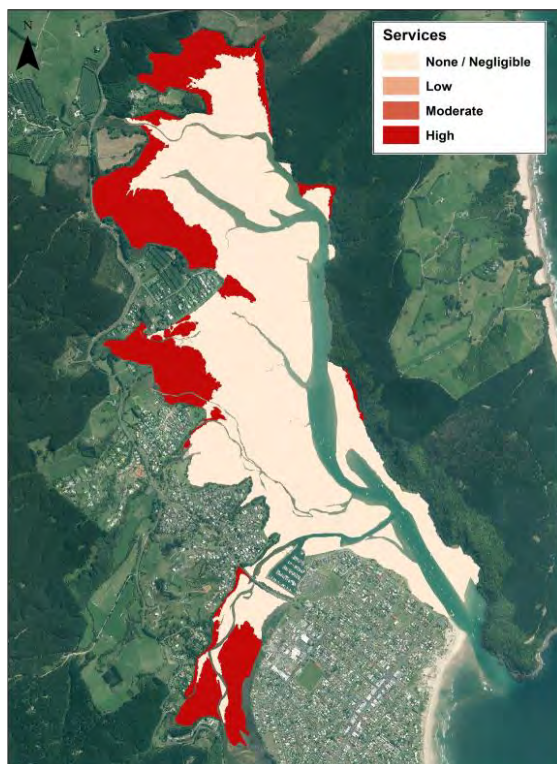
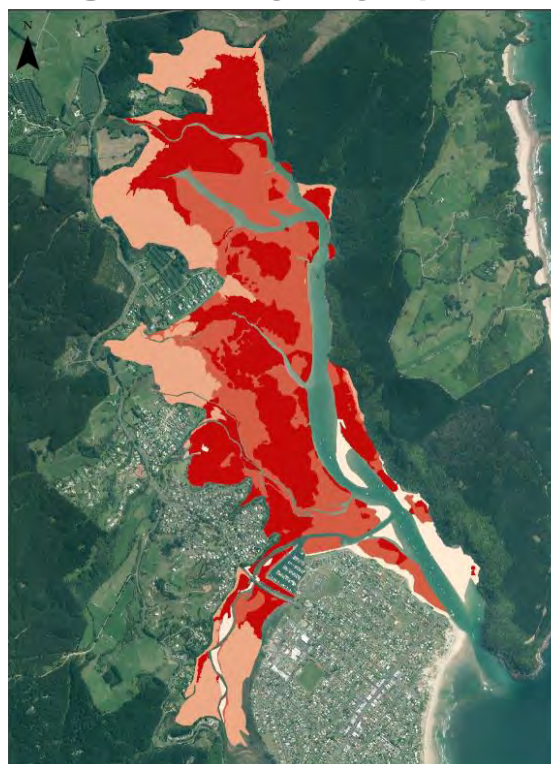


Figure 6: Ecosystem service maps of Whangamata Harbour.

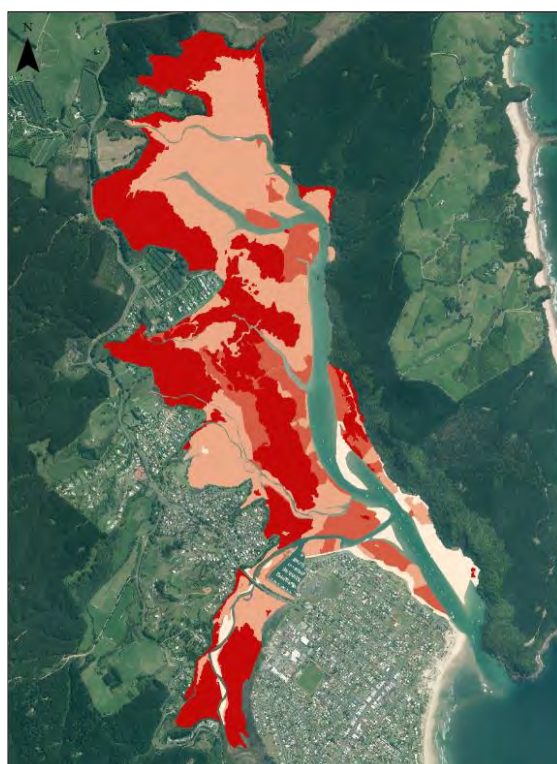
Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention

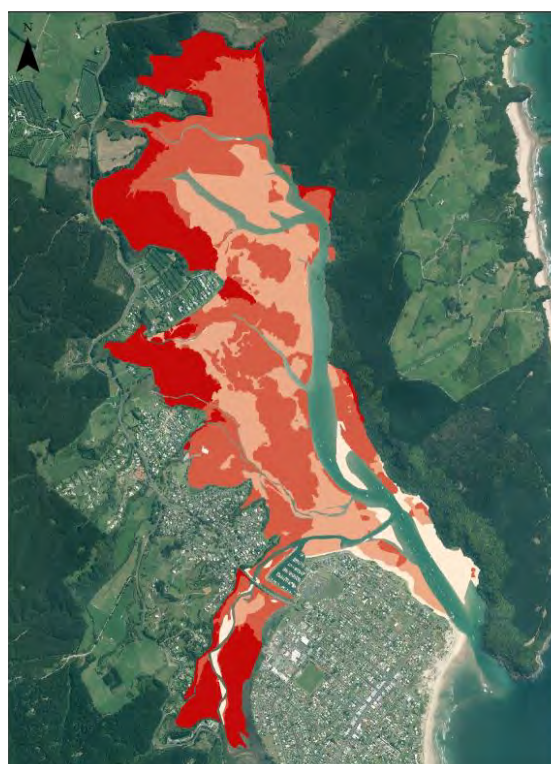


Figure 6 Continued: Ecosystem service maps of Whangamata Harbour.

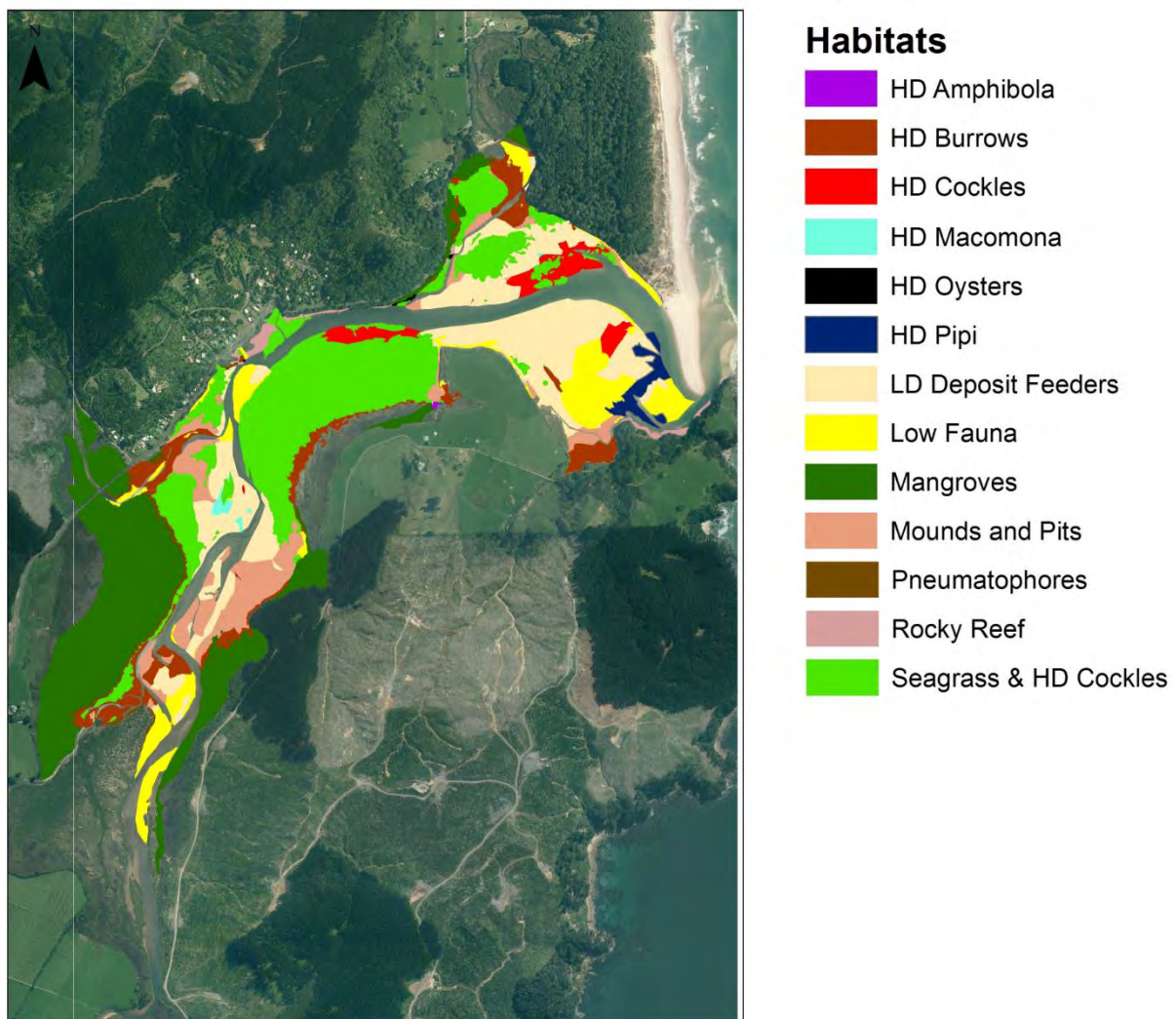
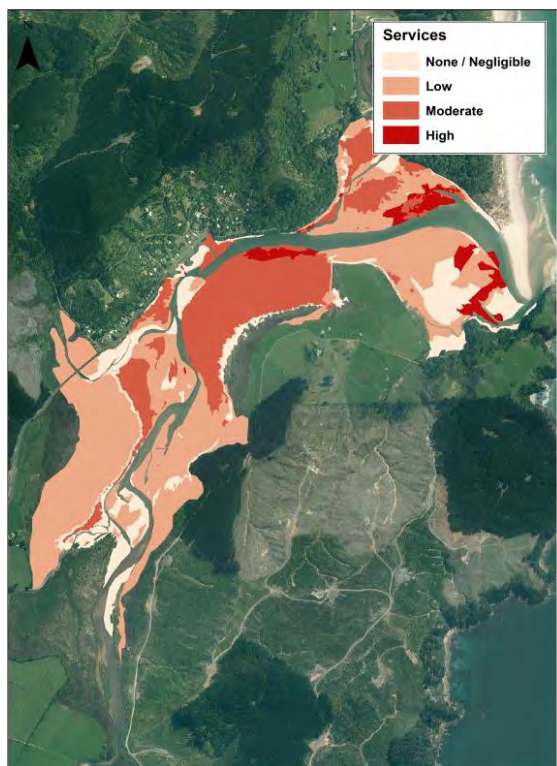
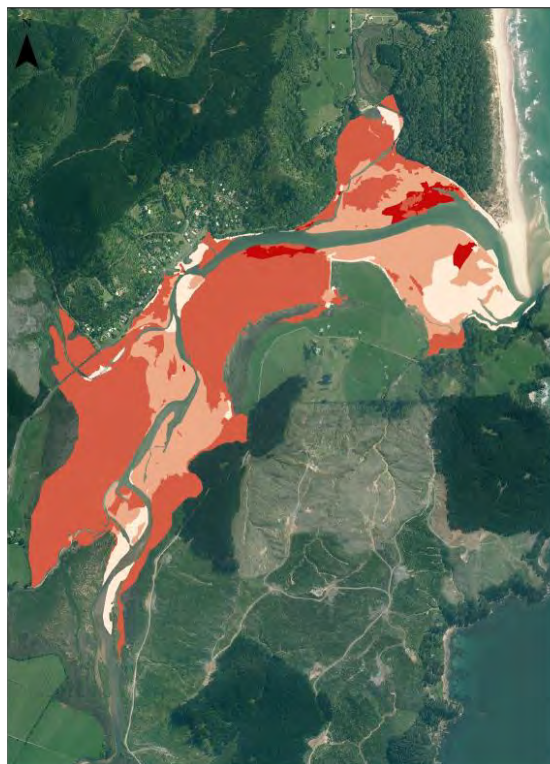


Figure 7: Habitat map of Wharekawa Harbour.

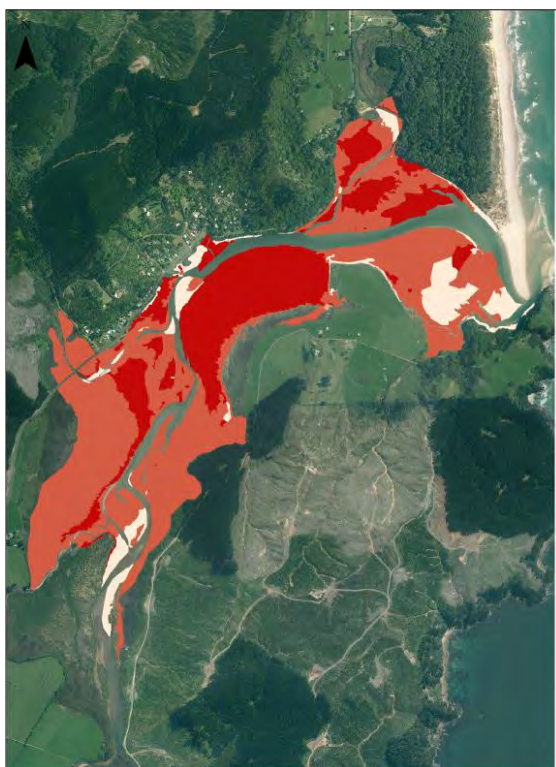
Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat

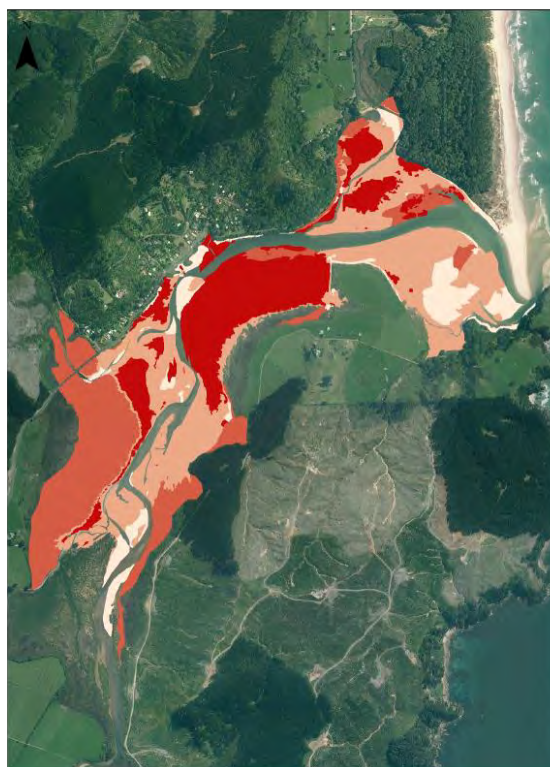
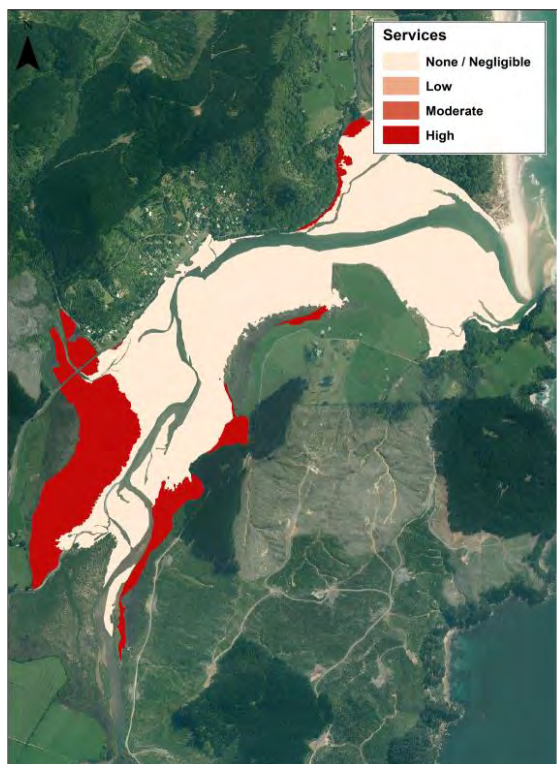
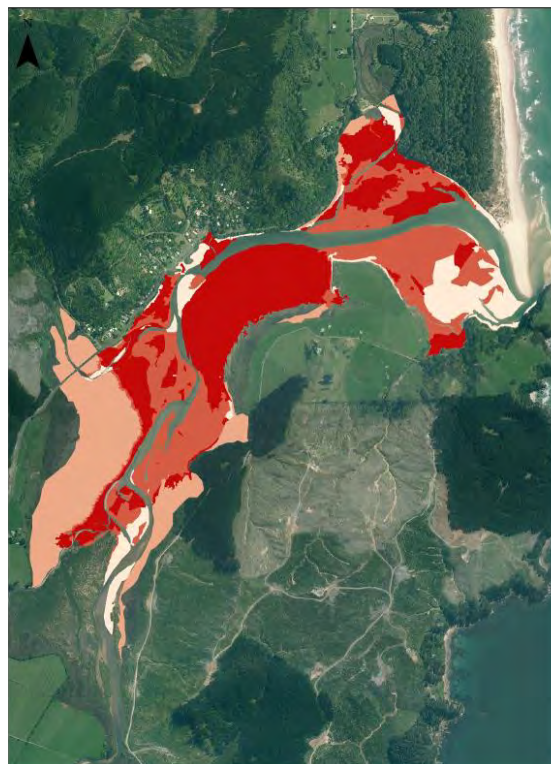


Figure 8: Ecosystem service maps of Wharekawa Harbour.

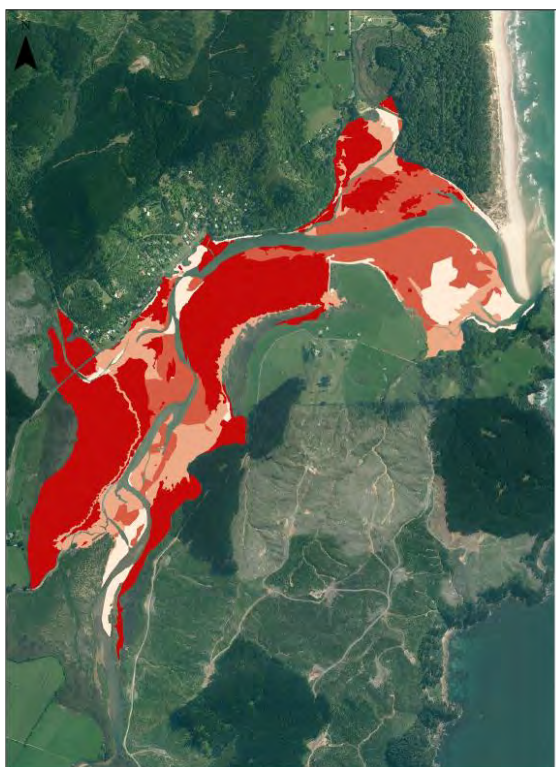
Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention

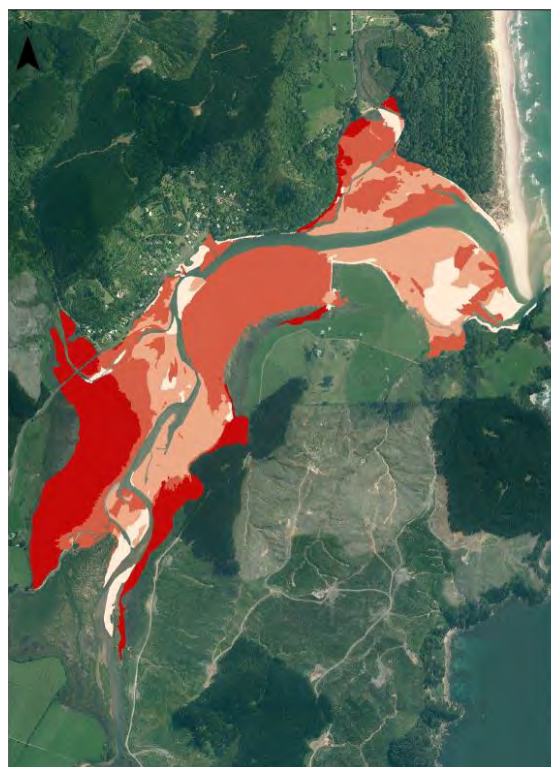


Figure 8 continued: Ecosystem service maps of Wharekawa Harbour.

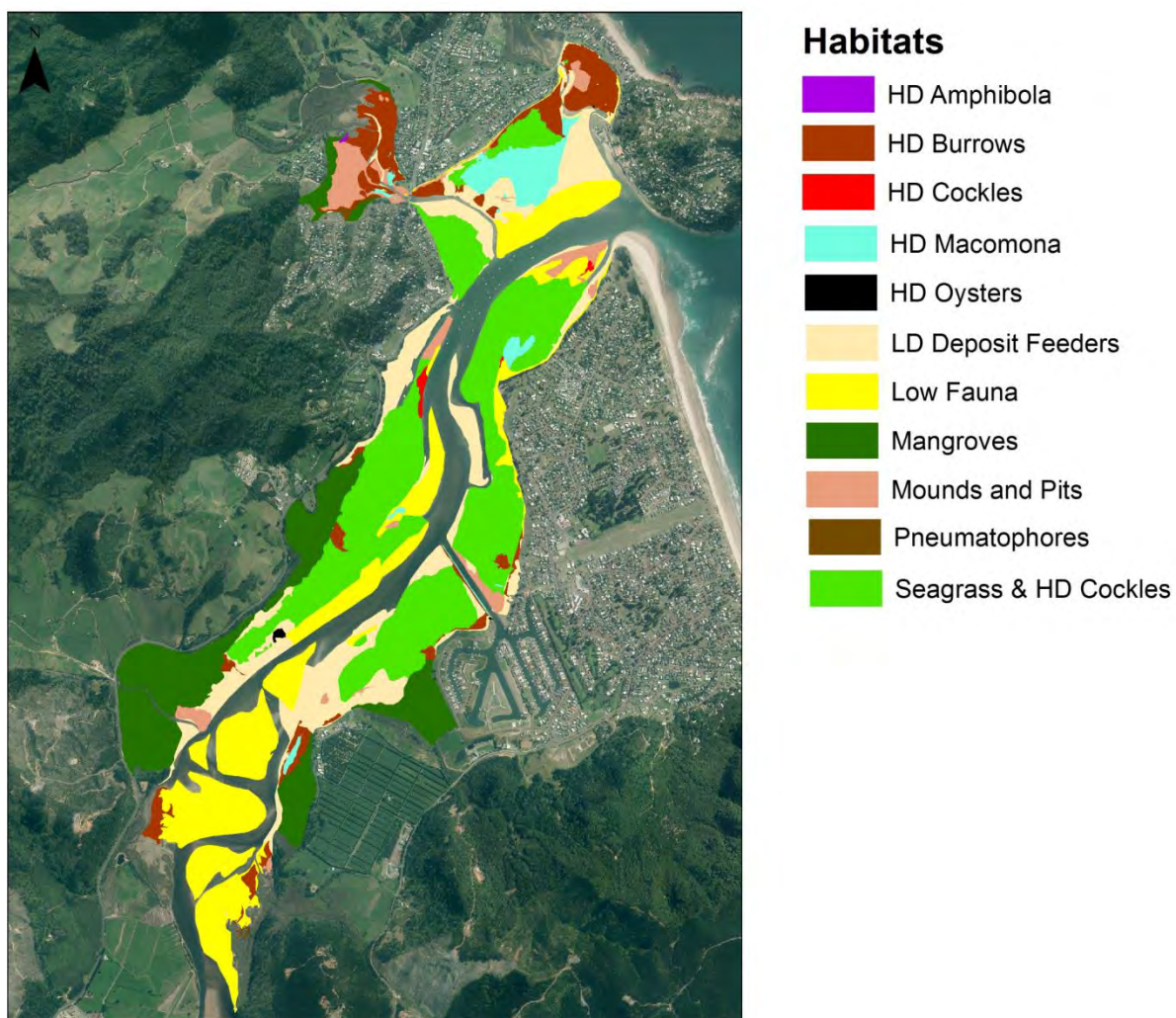
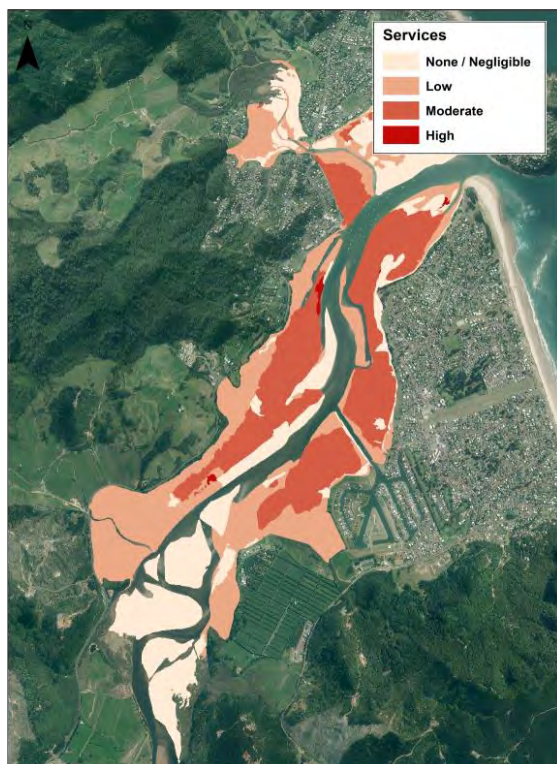


Figure 9: Habitat map of Tairua Harbour.

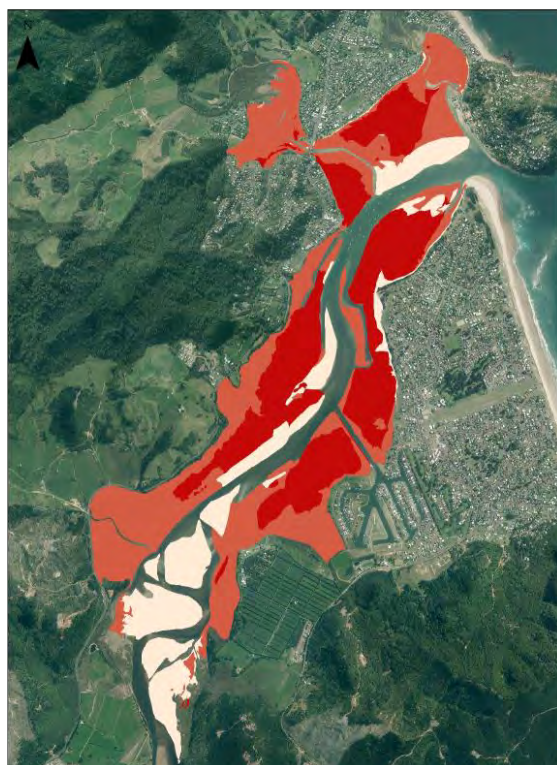
Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat

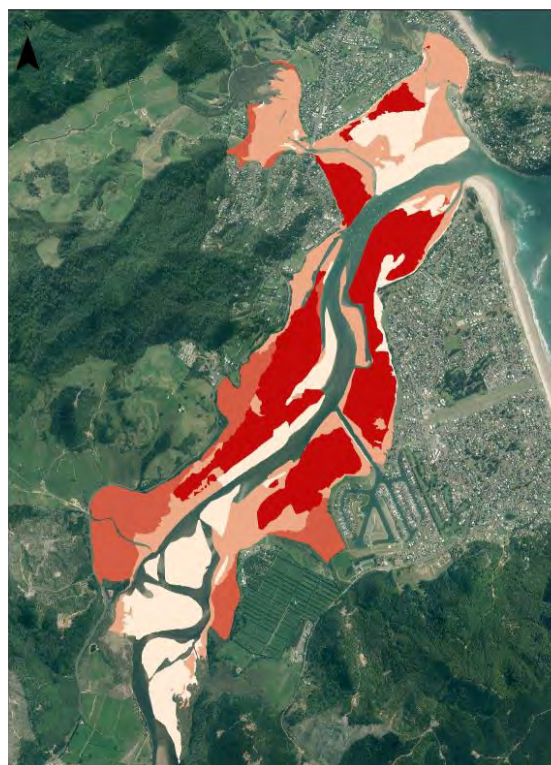
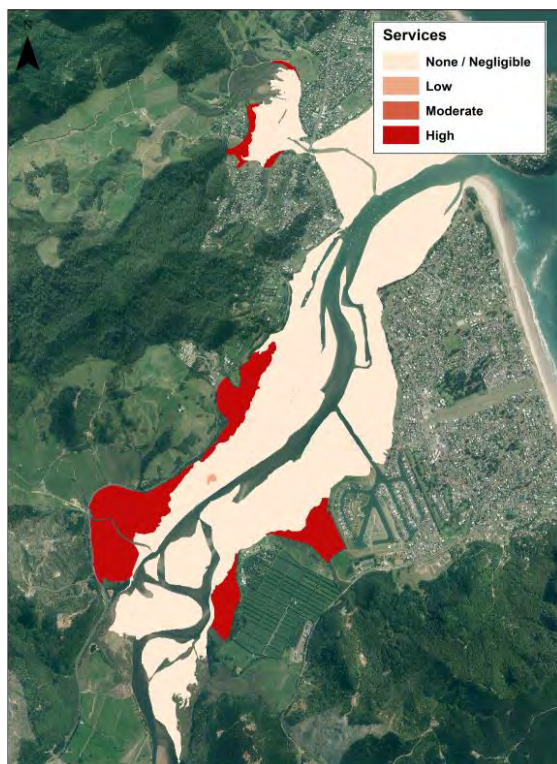
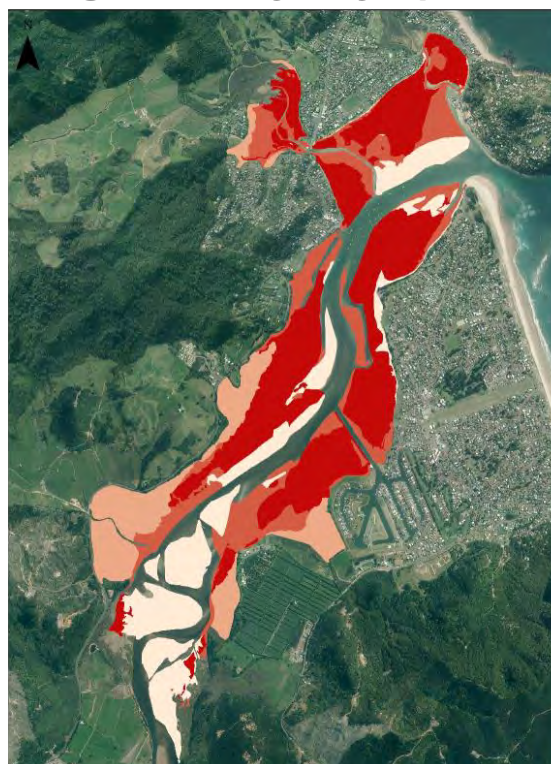


Figure 10: Ecosystem service maps of Tairua Harbour.

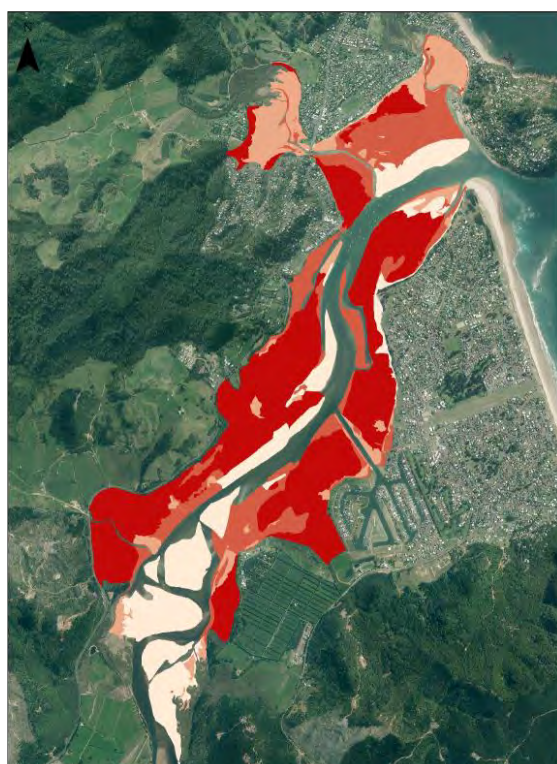
Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention



Figure 10 continued: Ecosystem service maps of Tairua Harbour.

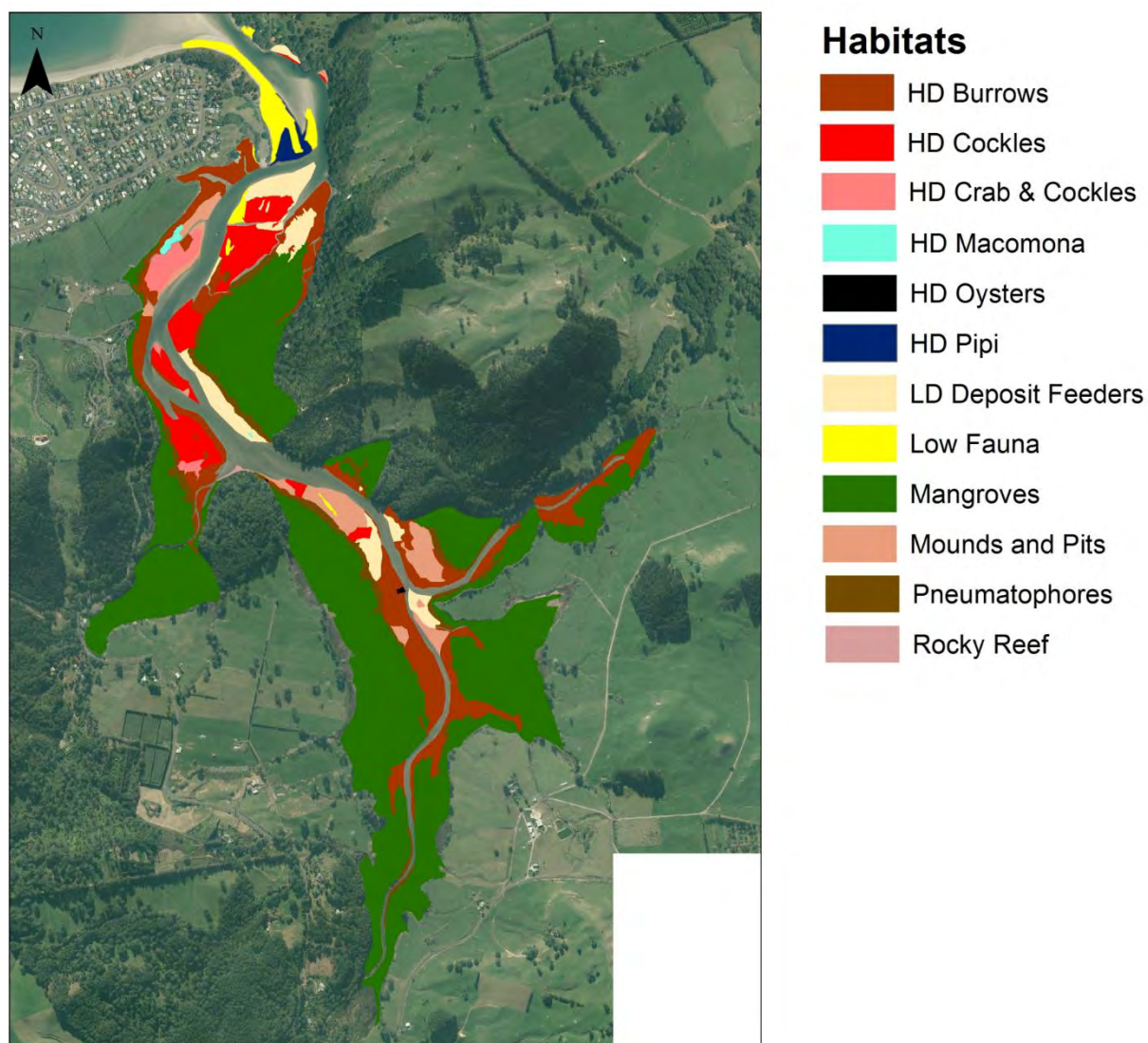
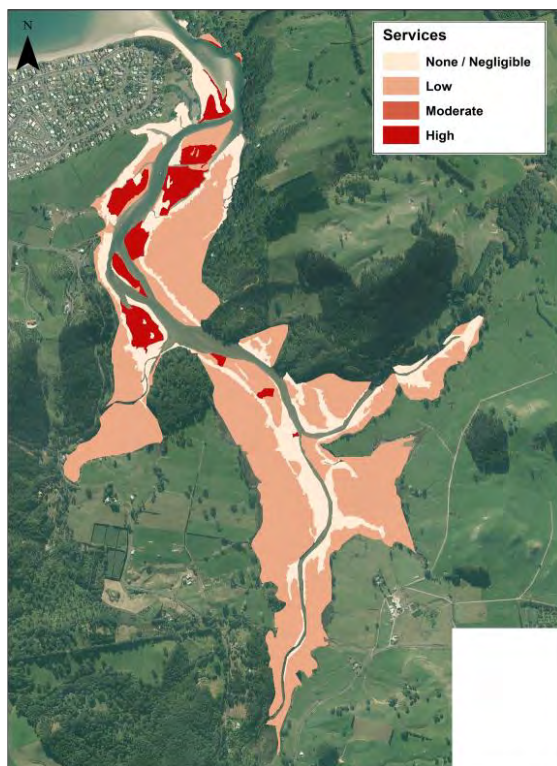
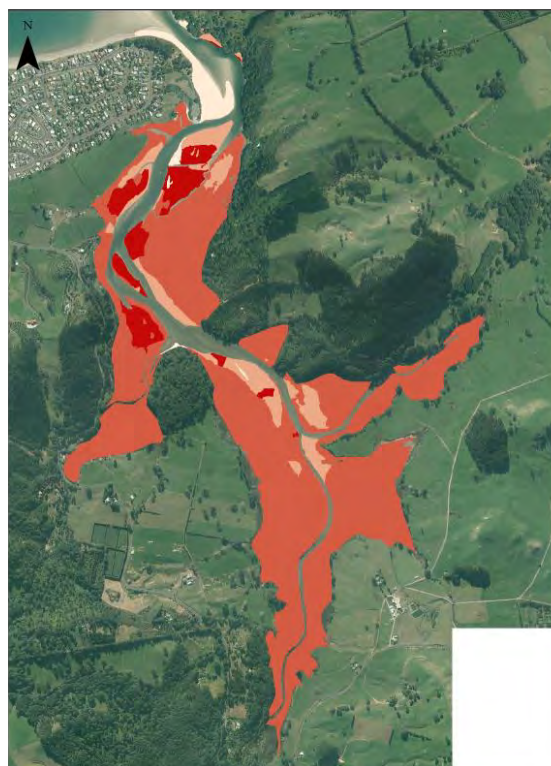


Figure 11: Habitat map of Purangi estuary.

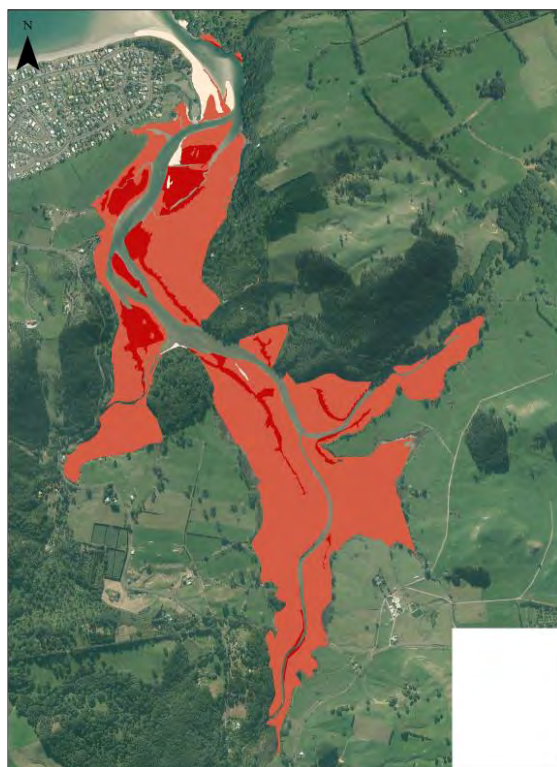
Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat

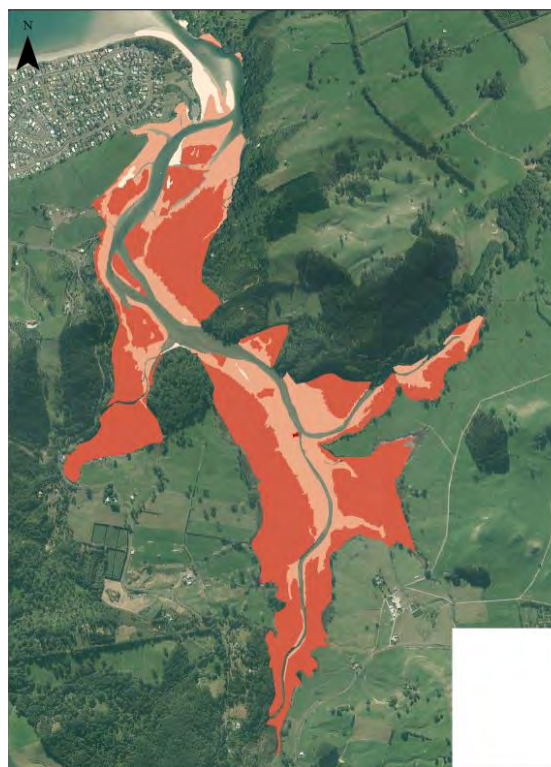
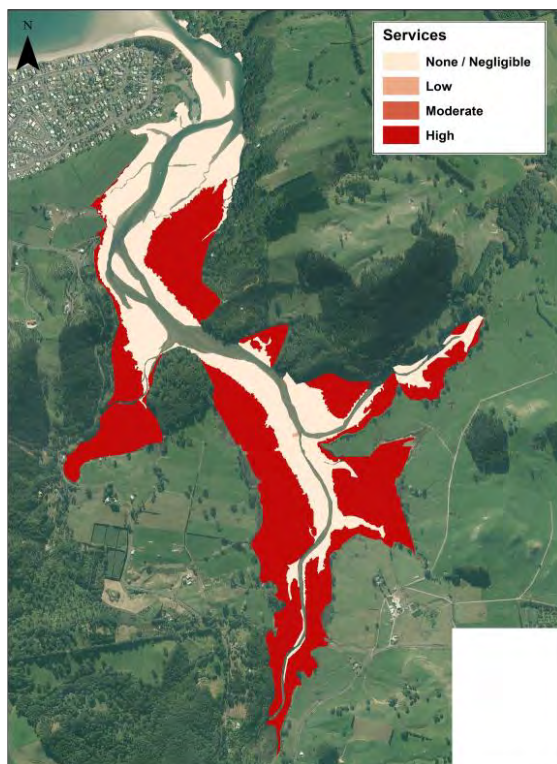
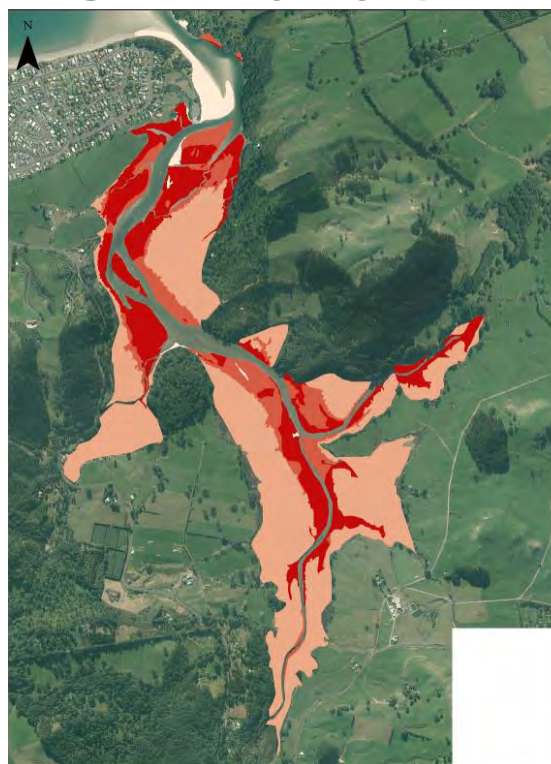


Figure 12: Ecosystem service maps of Purangi estuary.

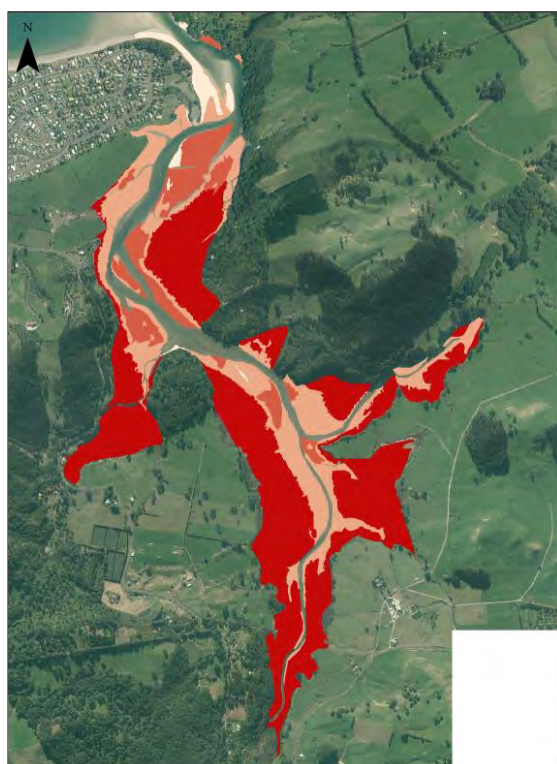
Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention

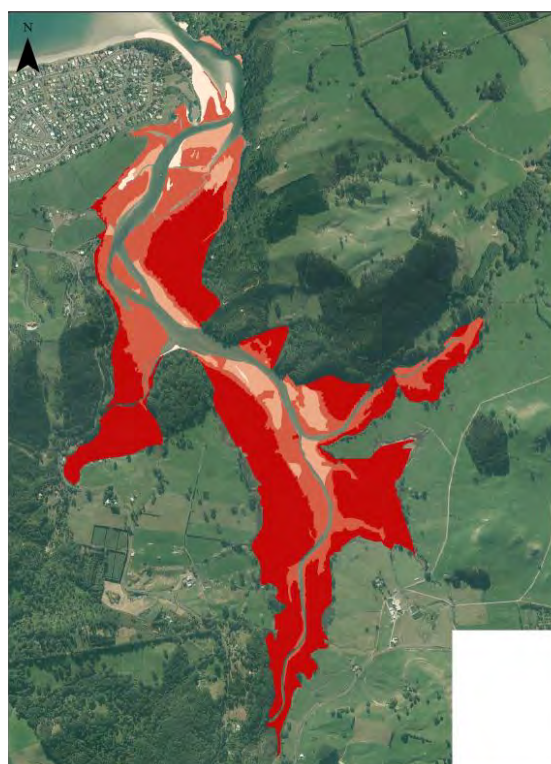


Figure 12 continued: Ecosystem service maps of Purangi estuary.

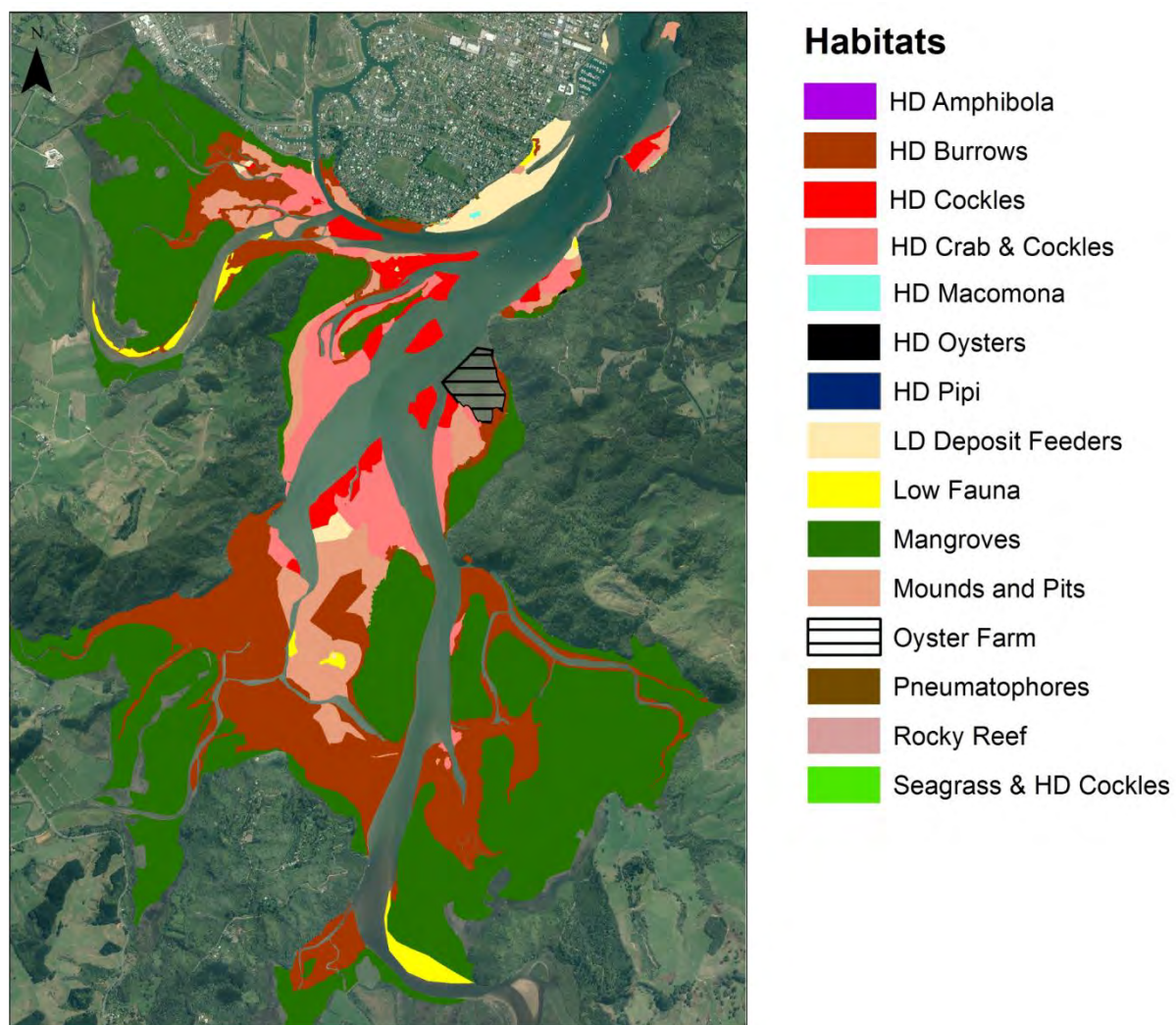
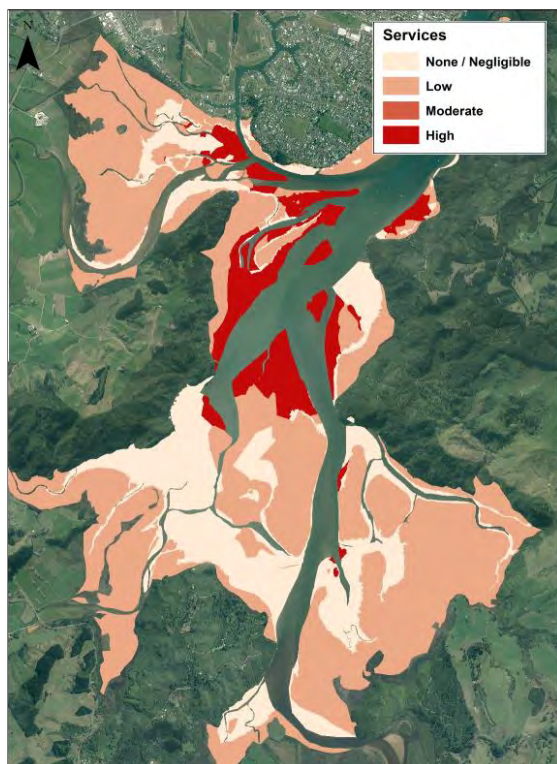
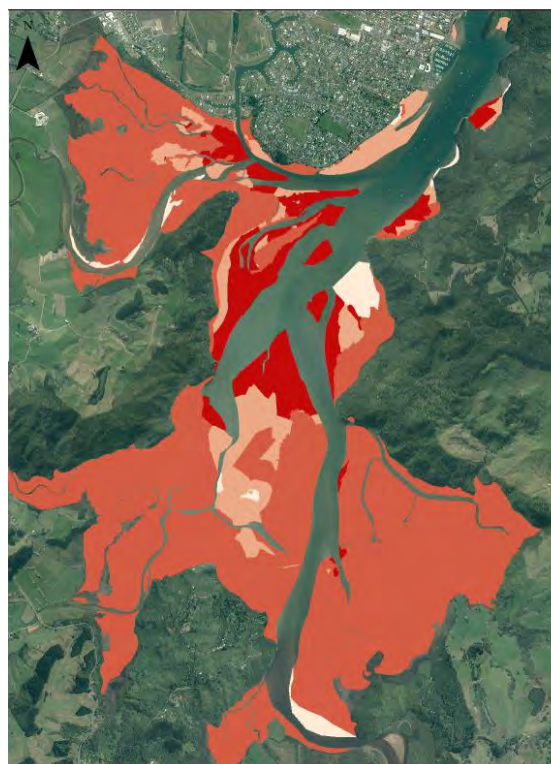


Figure 13: Habitat map of Whitianga Harbour.

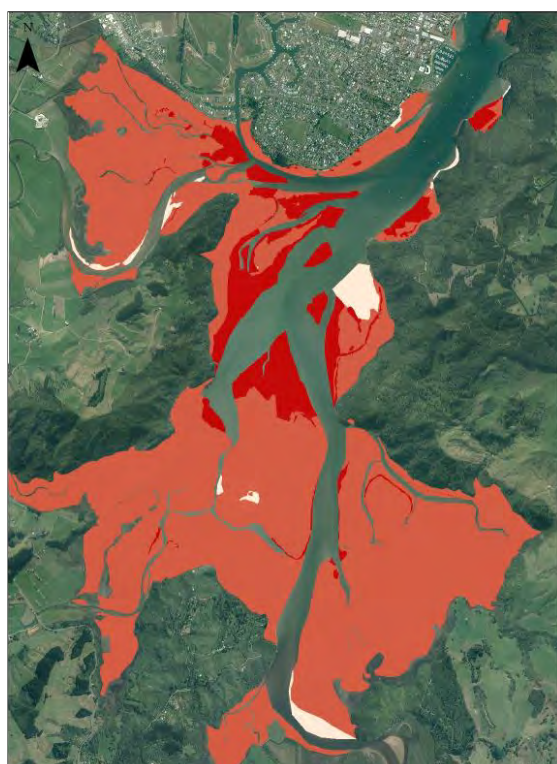
Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat

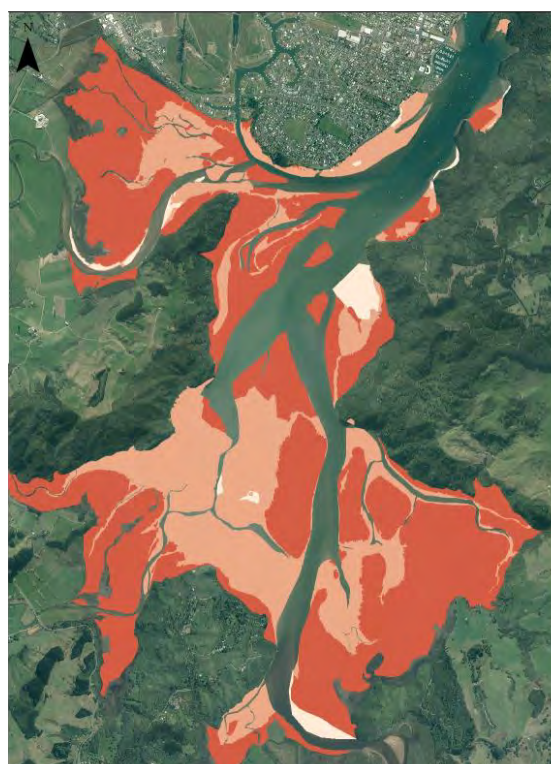
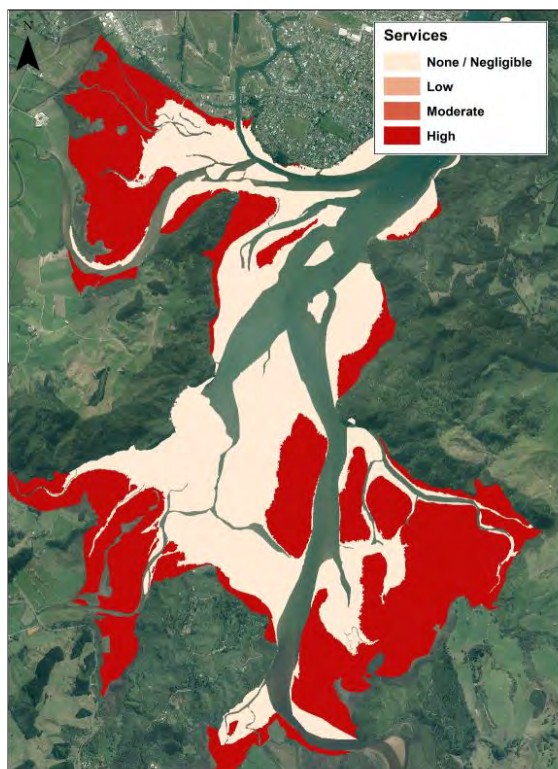
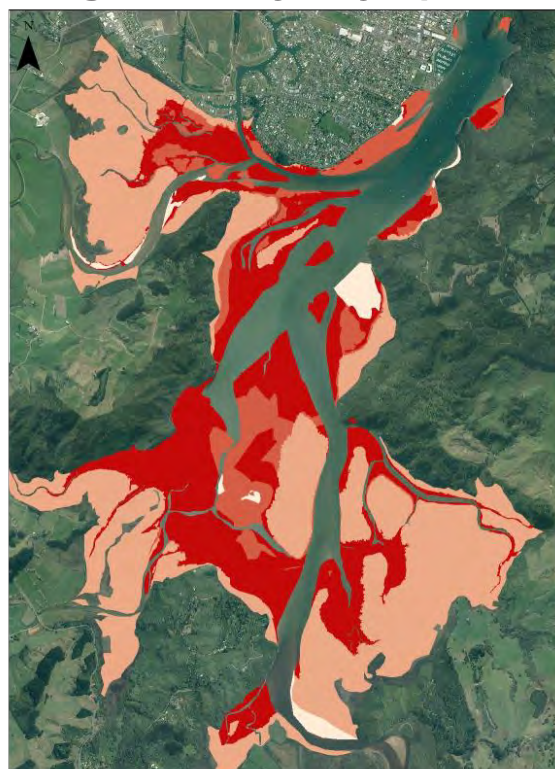


Figure 14: Ecosystem service maps of Whitianga Harbour.

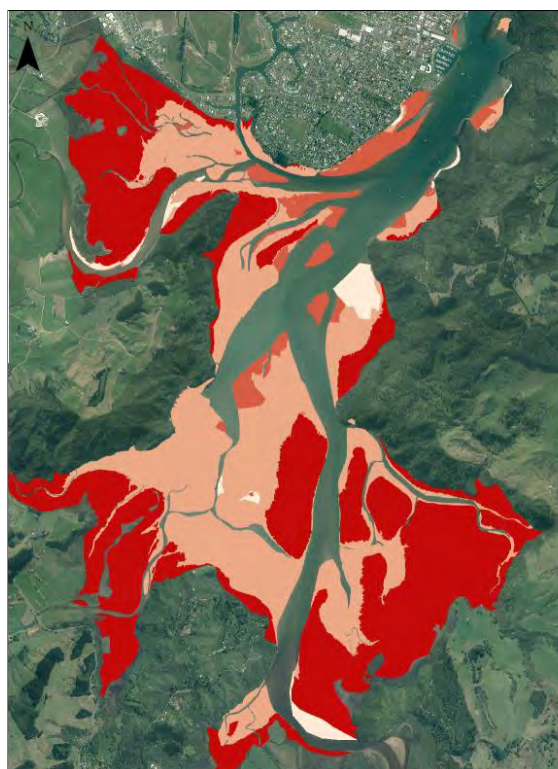
Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention

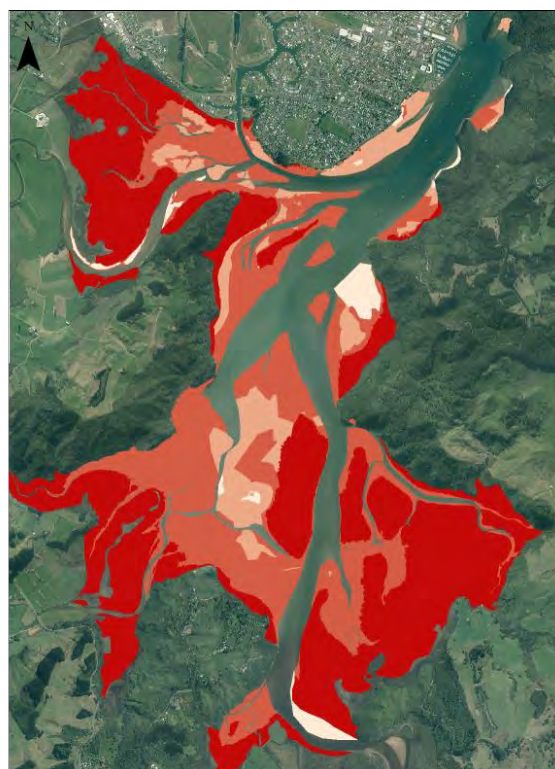


Figure 14 continued: Ecosystem service maps of Whitianga Harbour.

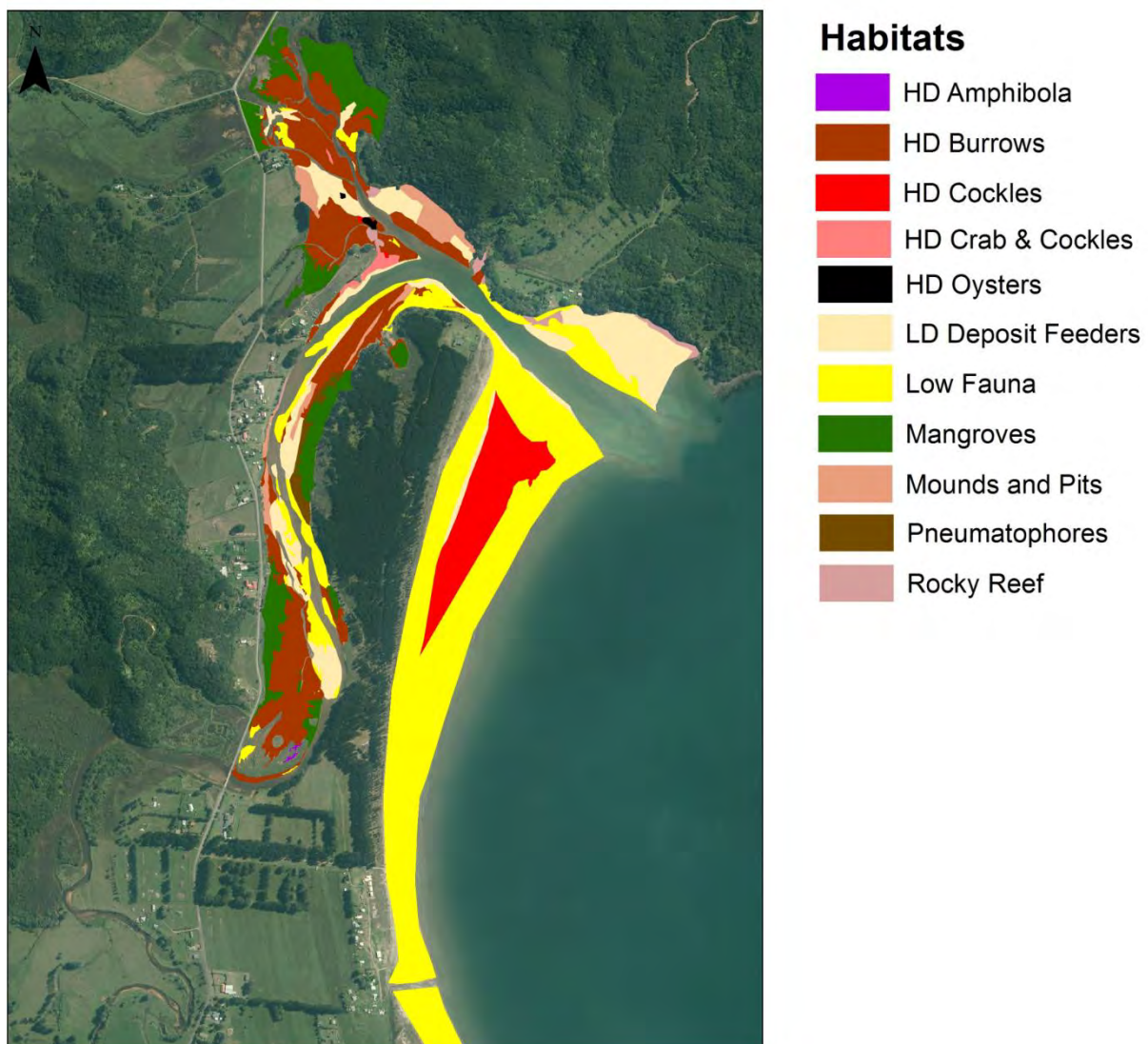


Figure 15: Habitat map of Kennedy Bay.

Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat



Figure 16: Ecosystem service maps of Kennedy Bay.

Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention



Figure 16 Continued: Ecosystem service maps of Kennedy Bay.

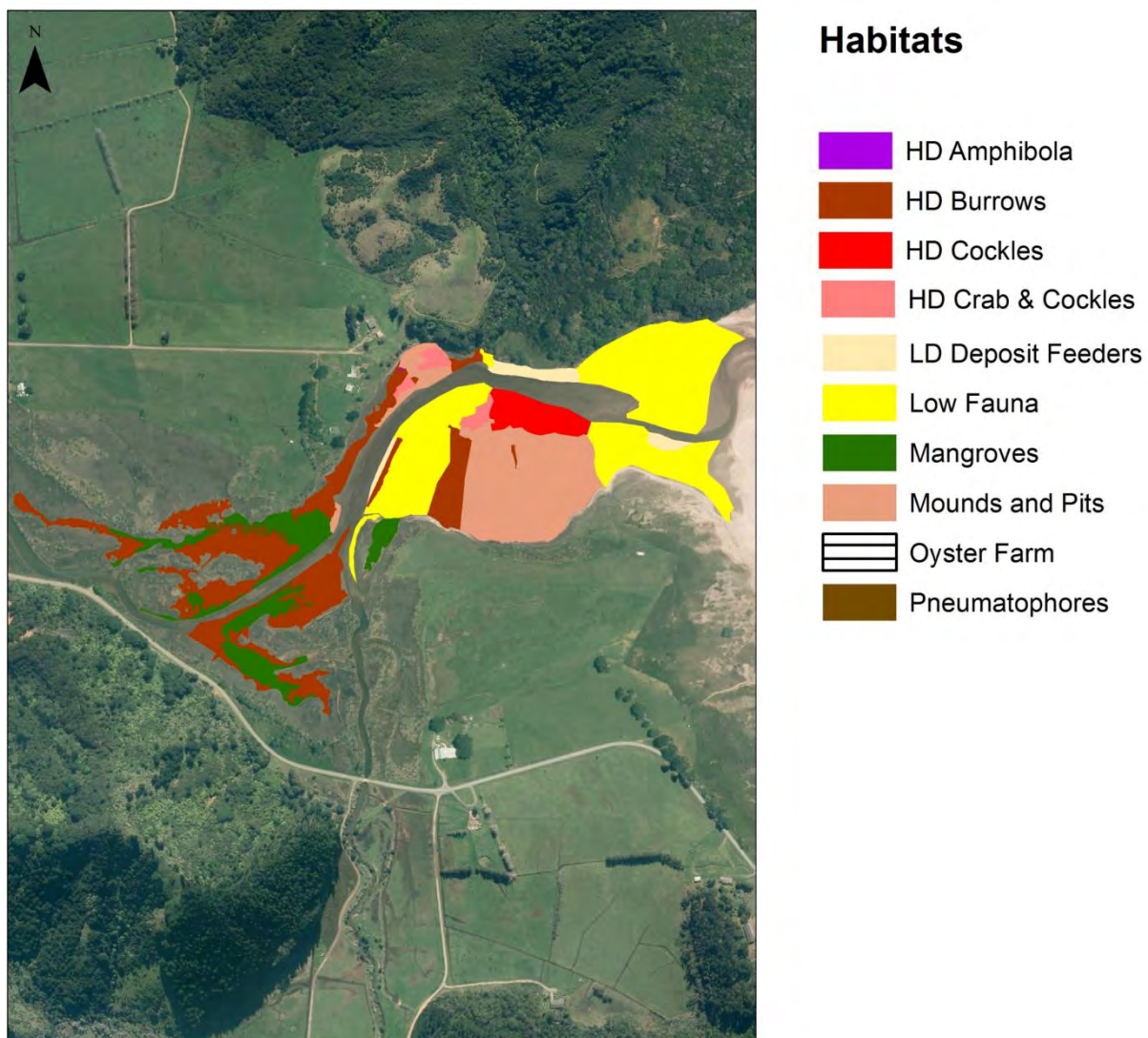
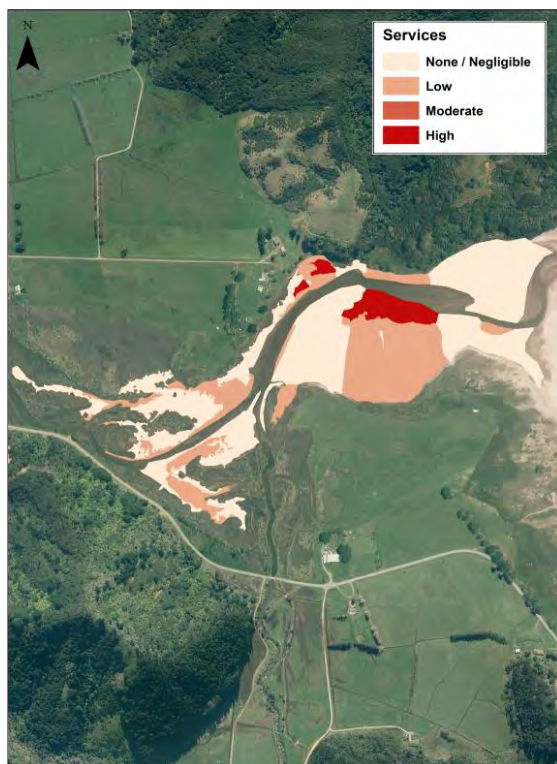


Figure 17: Habitat map of Waikawau estuary.

Food



Bioremediation



Nutrient Regeneration

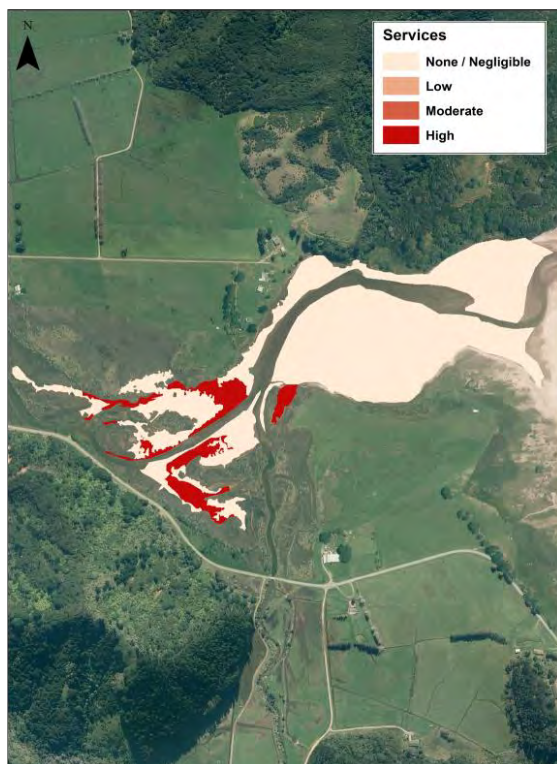


Biogenic Habitat



Figure 18: Ecosystem service maps of Waikawau estuary.

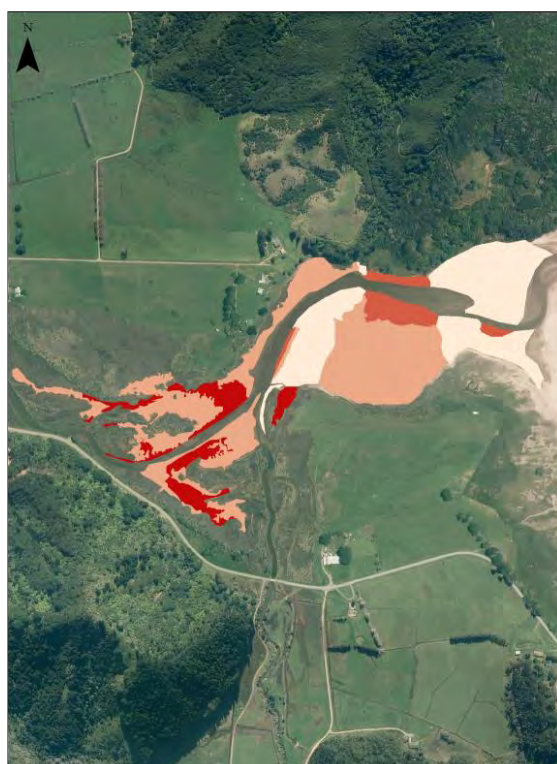
Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention



Figure 18 Continued: Ecosystem service maps of Waikawau estuary.

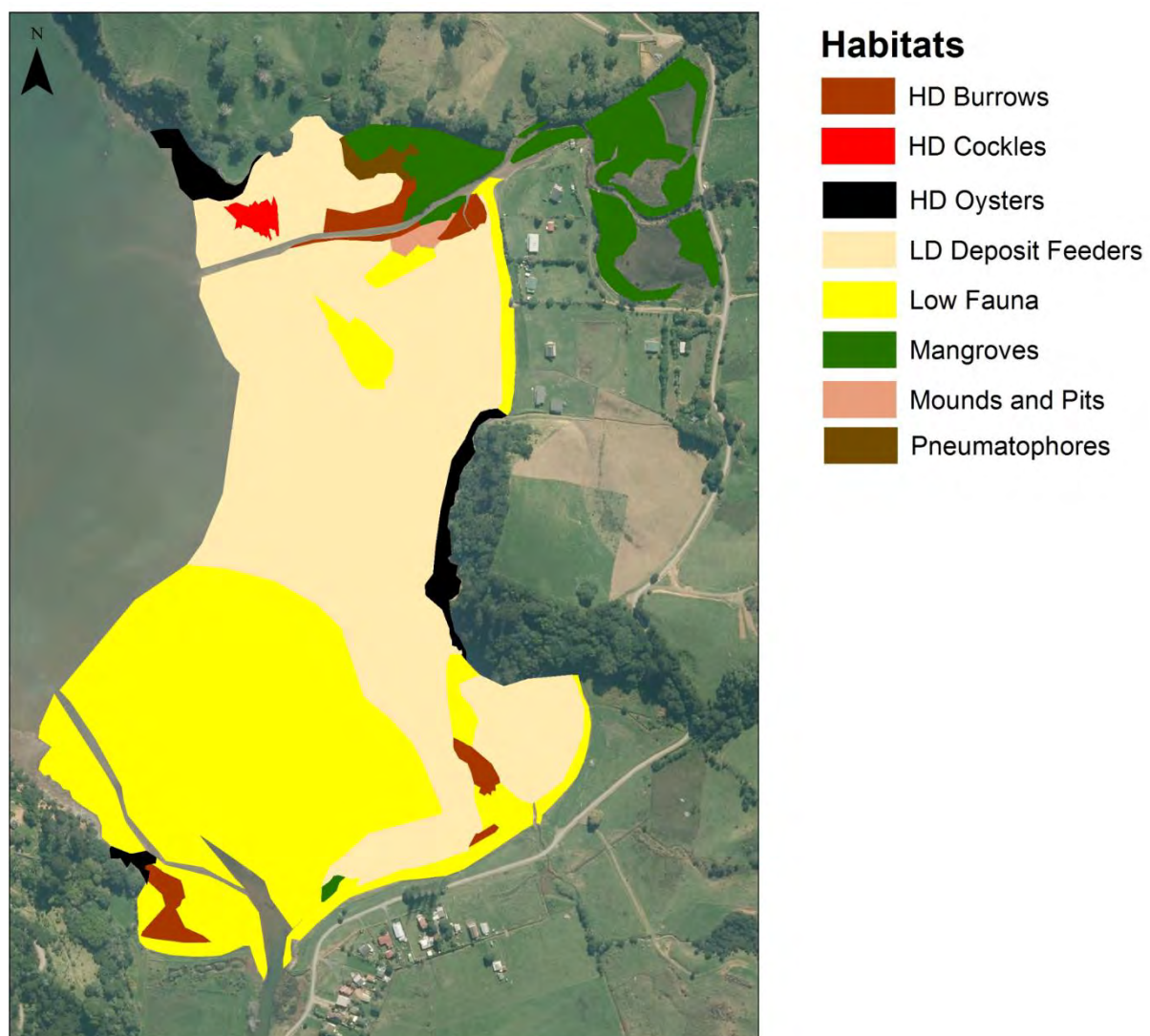
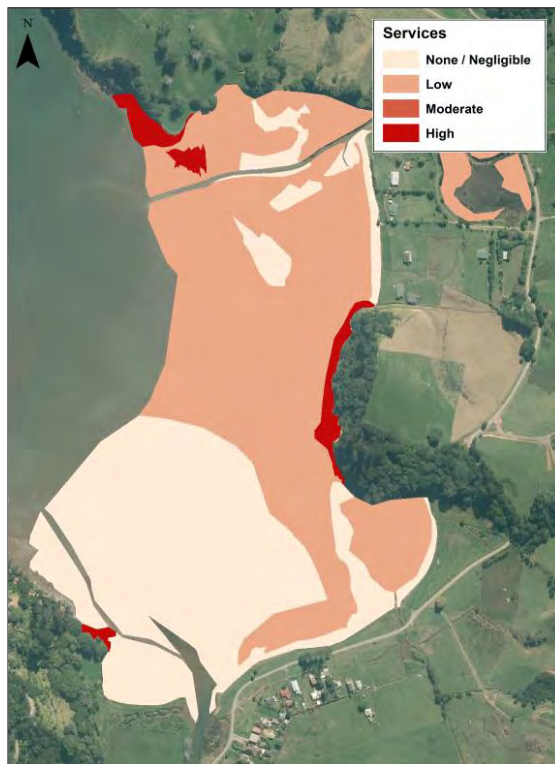


Figure 19: Habitat map of Port Charles.

Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat



Figure 20: Ecosystem service maps of Port Charles.

Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention



Figure 20 Continued: Ecosystem service maps of Port Charles.

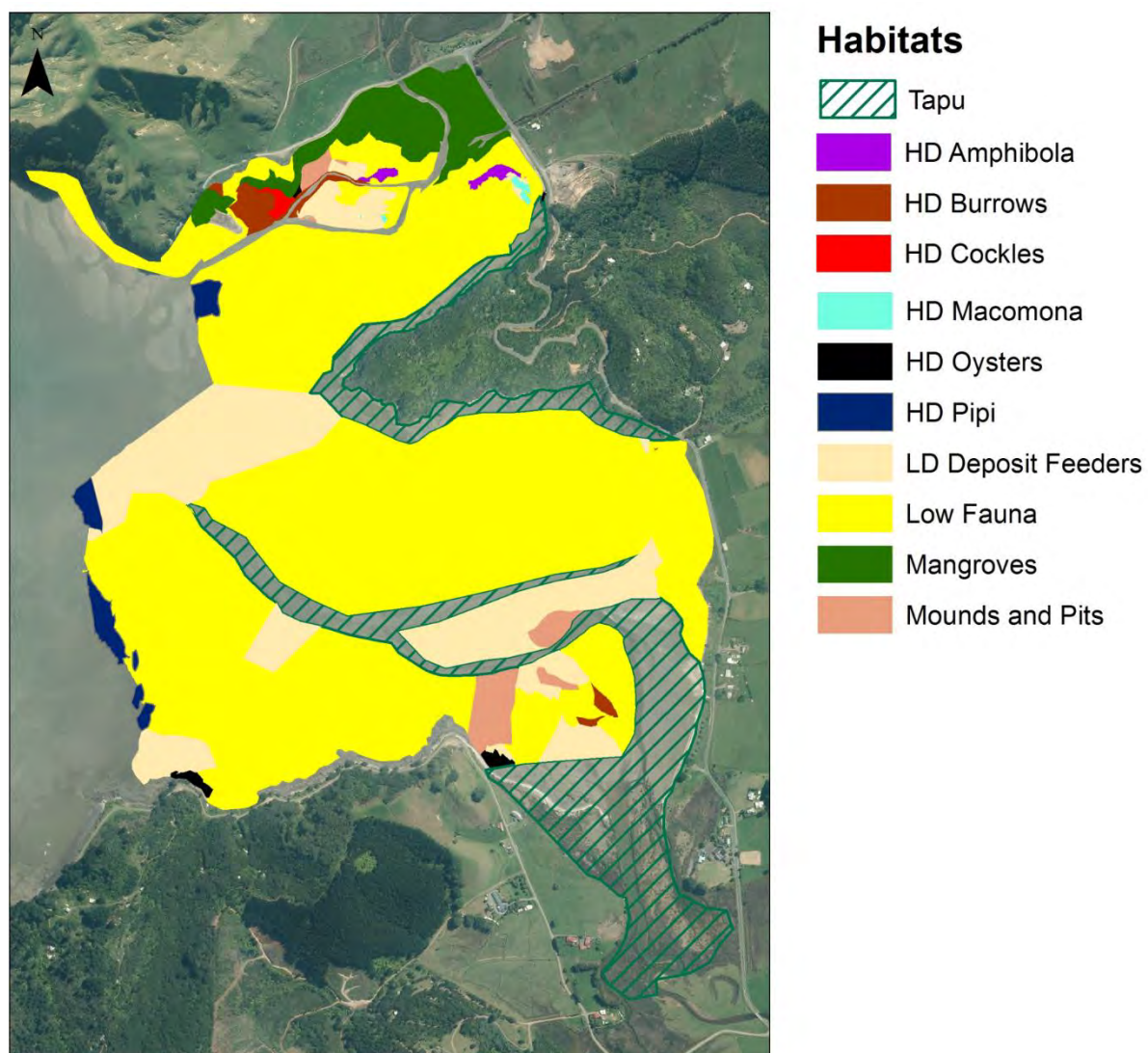
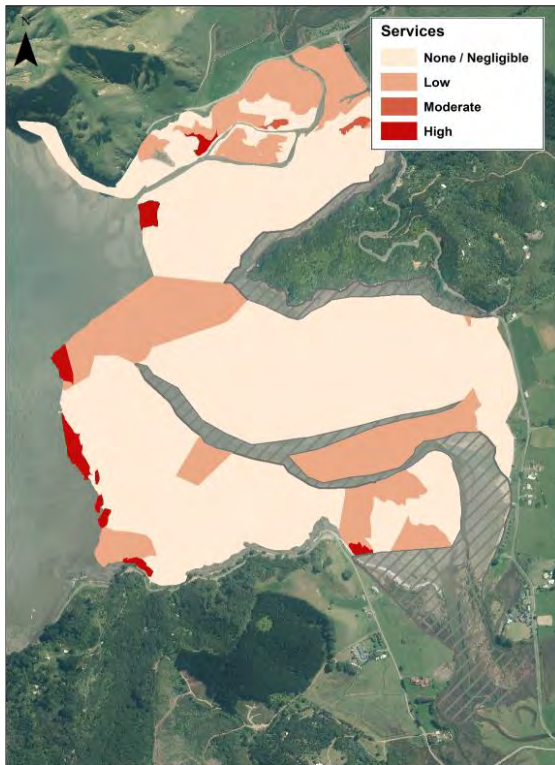


Figure 21: Habitat map of Colville Bay.

Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat



Figure 22: Ecosystem service maps of Colville Bay.

Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention



Figure 22 Continued: Ecosystem service maps of Colville Bay.

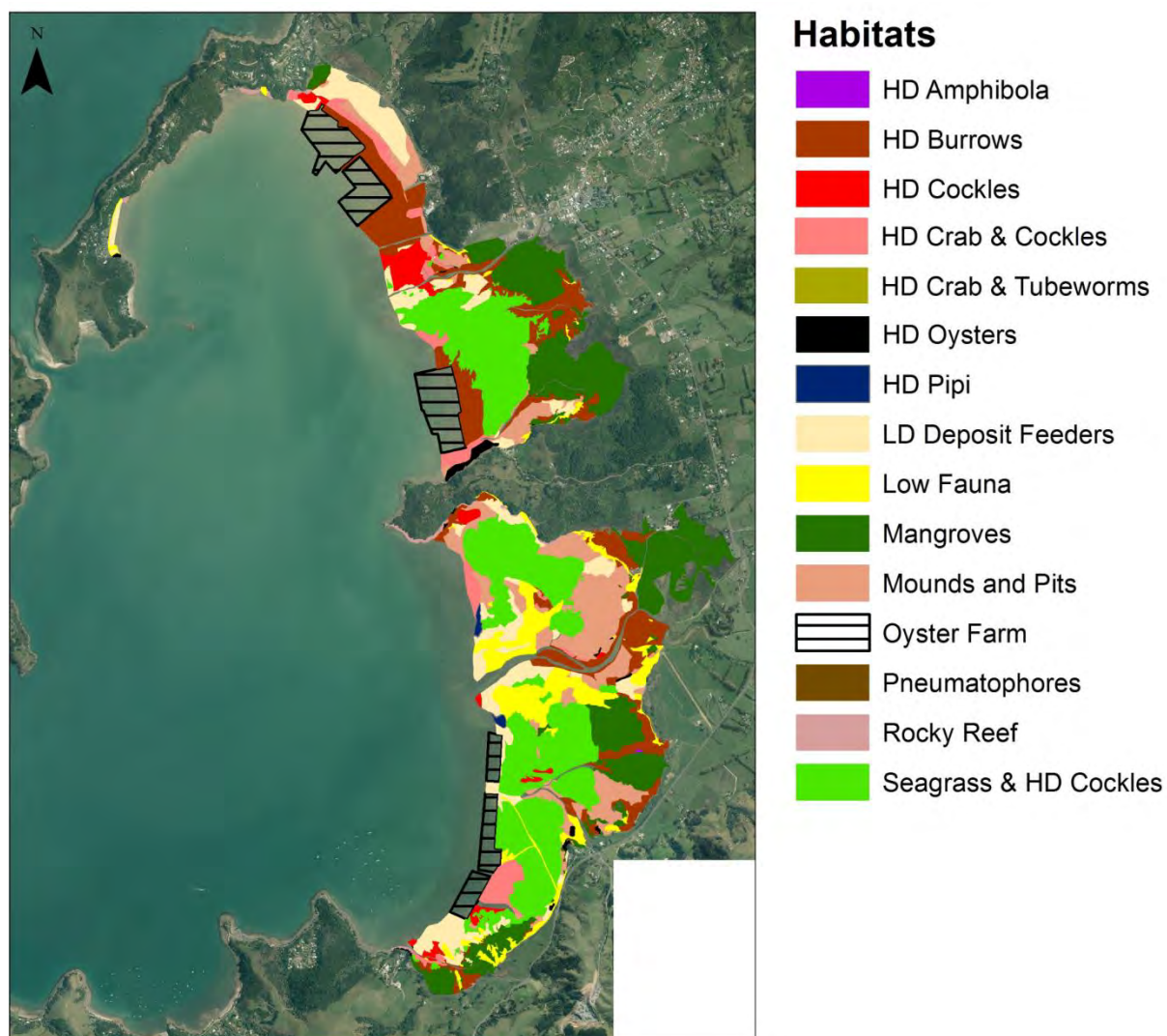
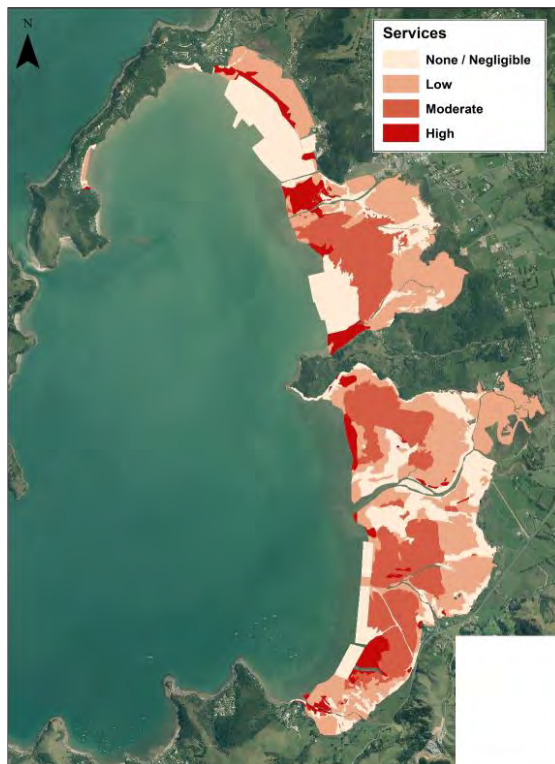
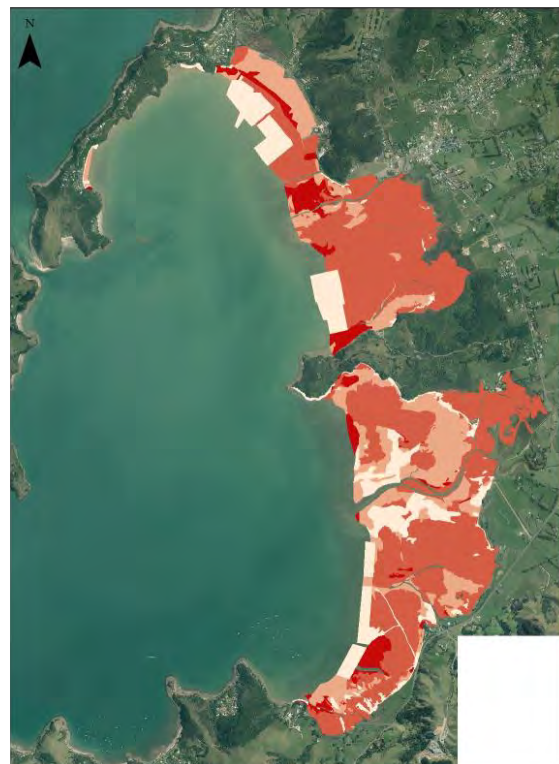


Figure 23: Habitat map of Coromandel Harbour.

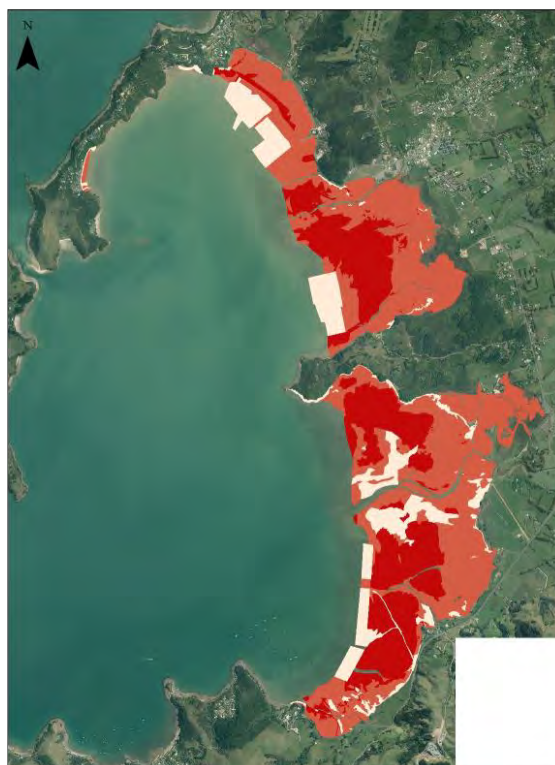
Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat

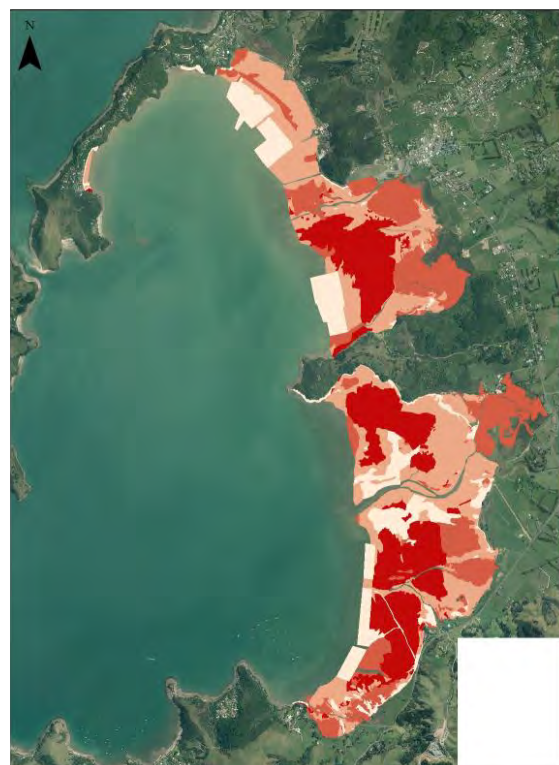
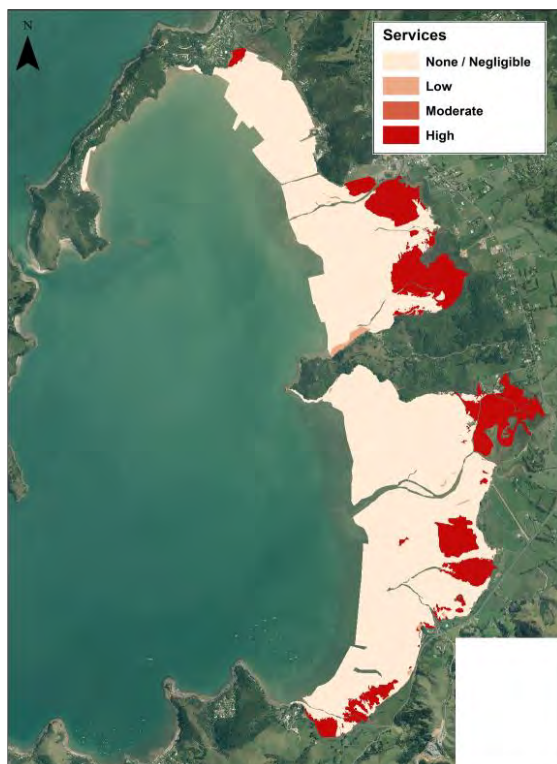
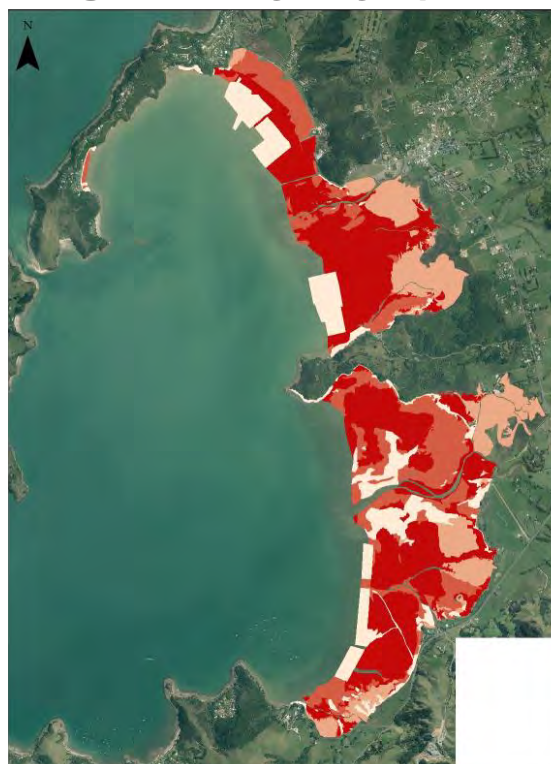


Figure 24: Ecosystem service maps of Coromandel Harbour.

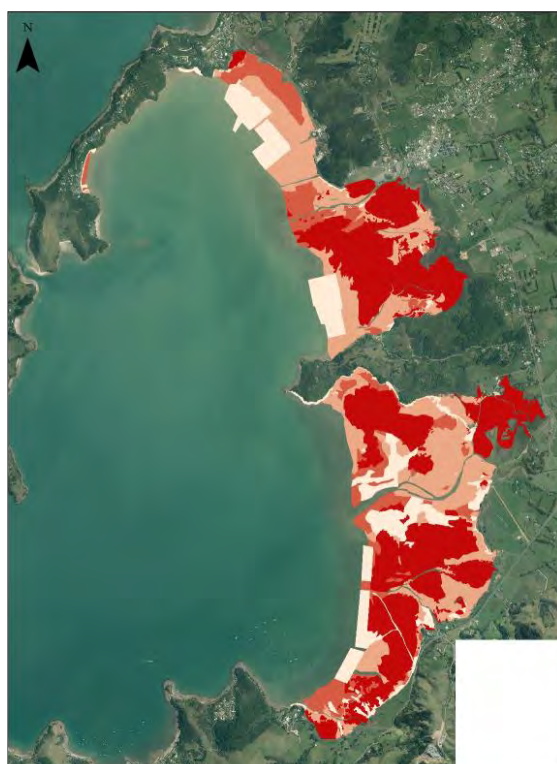
Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention

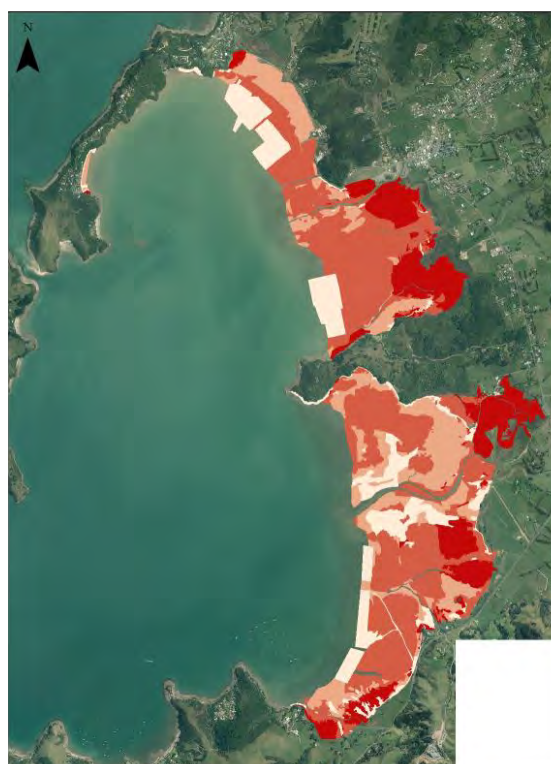


Figure 24 Continued: Ecosystem service maps of Coromandel Harbour.

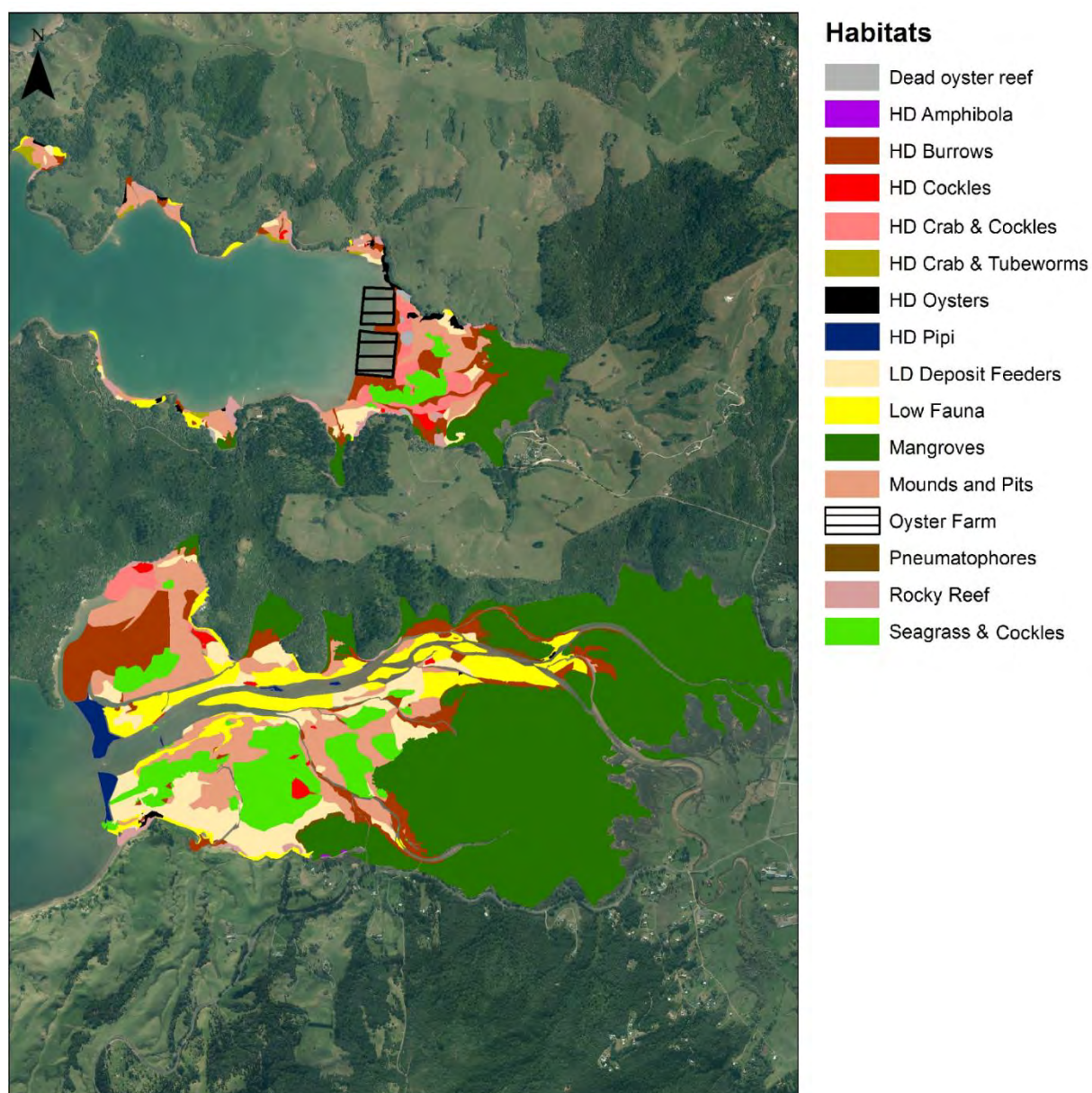
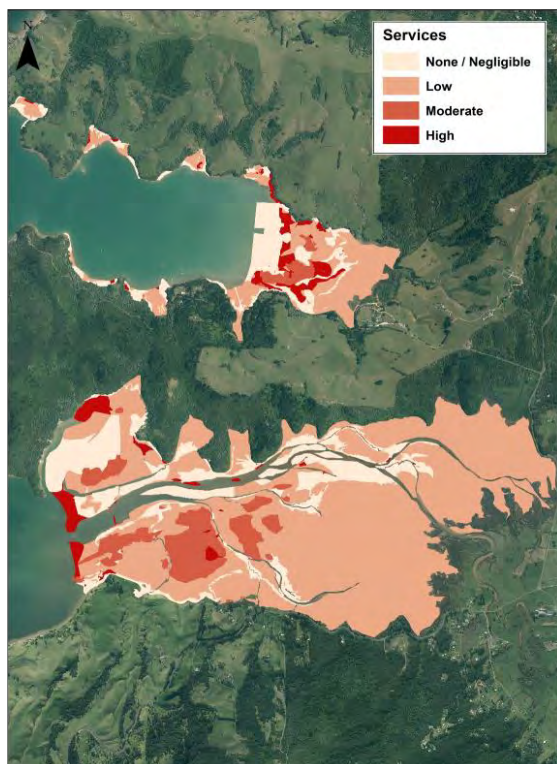
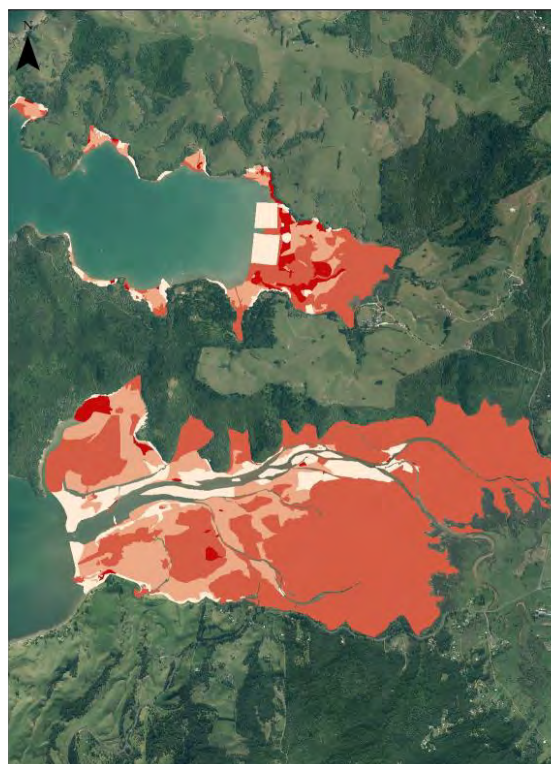


Figure 25: Habitat maps of Te Kouma and Manaia Harbours.

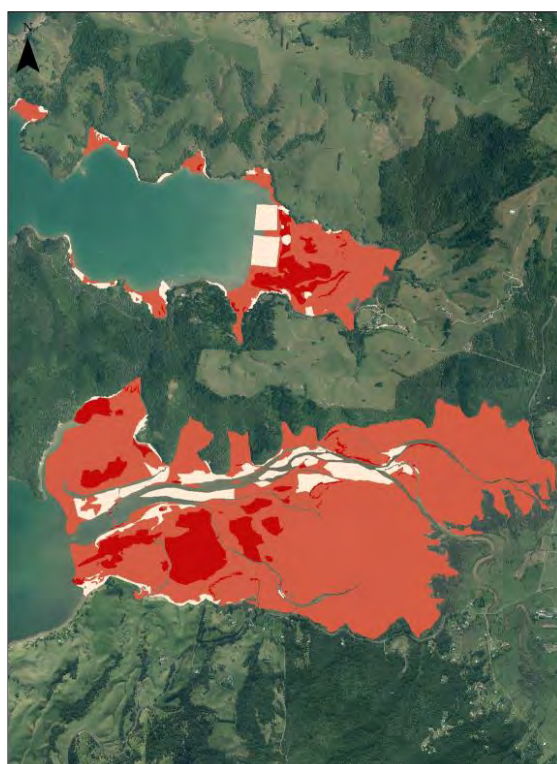
Food



Bioremediation



Nutrient Regeneration



Biogenic Habitat

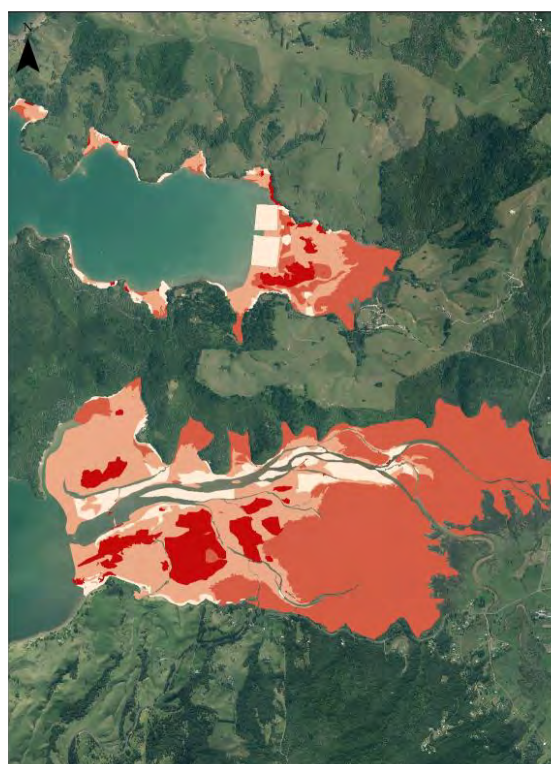
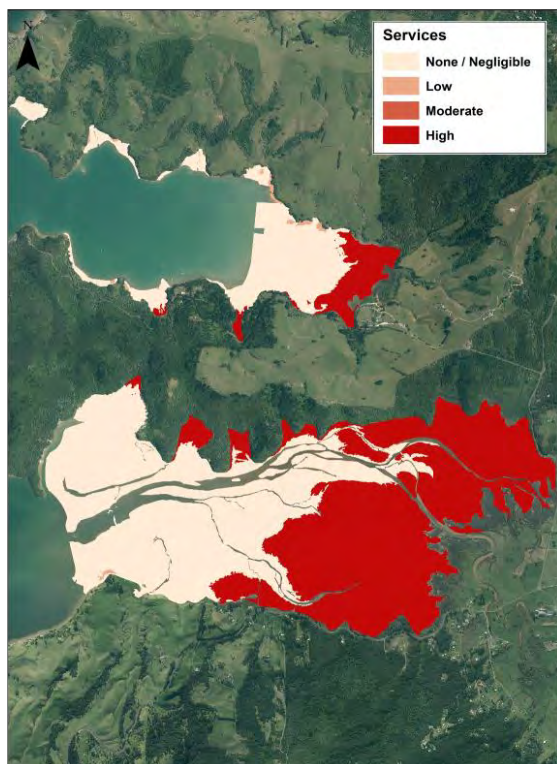
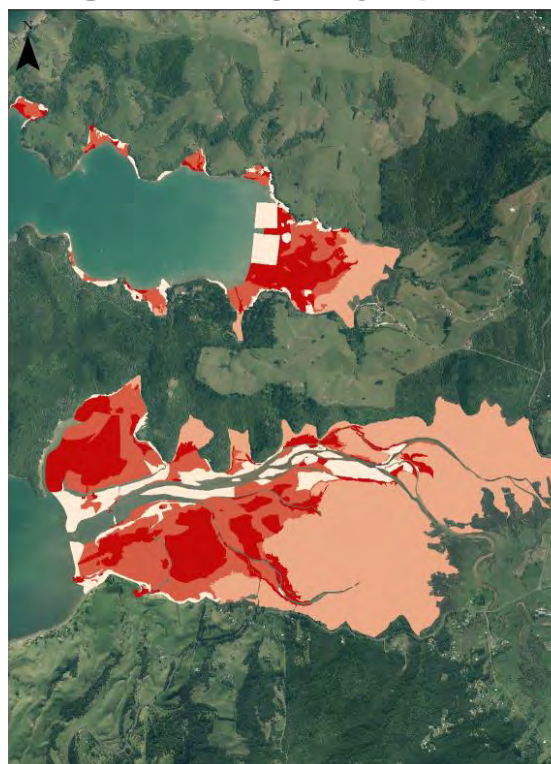


Figure 26: Ecosystem service maps of Te Kouma and Manaia Harbours.

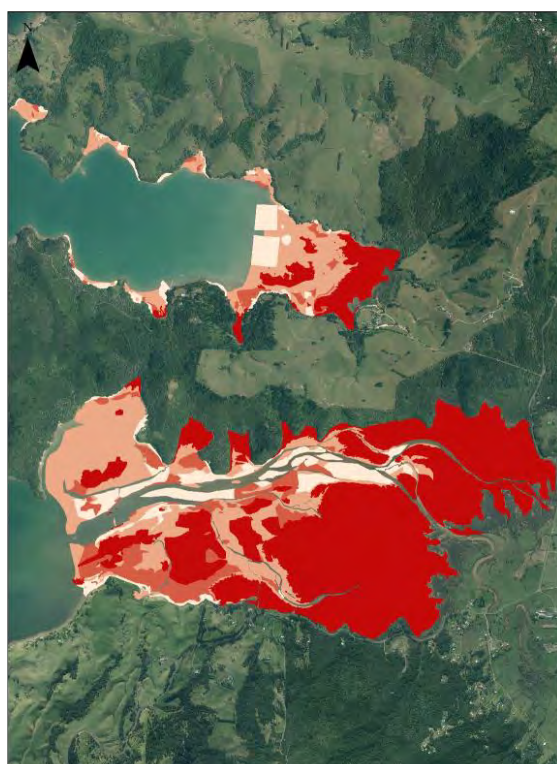
Shoreline Protection



Regulation by Key Species



Primary Production



Sediment Retention

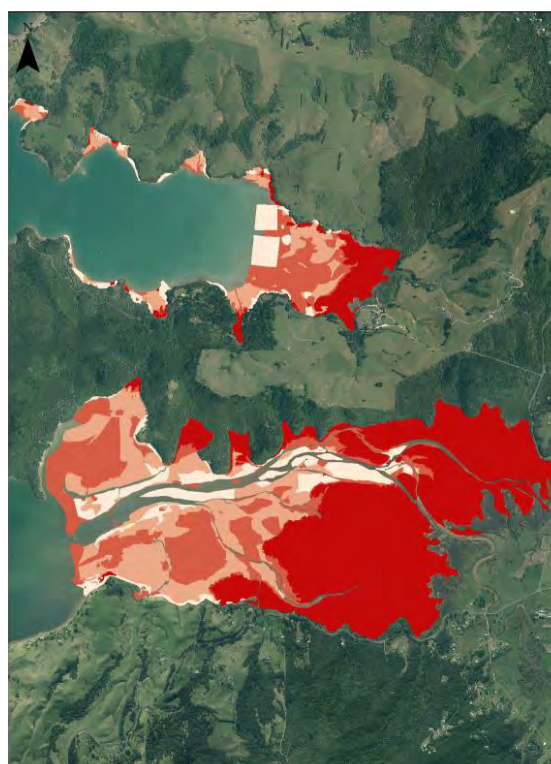


Figure 26 Continued: Ecosystem service maps of Te Kouma and Manaia Harbours.

4 Ecosystem service maps: recommendations for their use and future improvements

The process of combining habitat information with an ecosystem service matrix may be best described as demonstrating ecosystem service ‘potential’ rather than demonstrating *actual* ecosystem service delivery. For example, cockles are well known as an intertidal food source (see Figures 4-24), however, not all cockle beds in the Coromandel are necessarily utilised as food sources. Similarly, areas of uninhabited coast may have marine vegetation with the potential to protect the shoreline, though the benefit of this may not be fully realised until a time when property is built and in need of protection. Habitats are highlighted for their capacity to bioremediate anthropogenic contaminants e.g., heavy metals, but provision of this service requires that the environment is subjected to contamination. In this regard the maps do not explicitly show the use of ecosystem service per se, but they indicate which services are possible. The exception to this is supporting services, when it can be reasoned that the benefits are actuated as they maintain the estuaries themselves; through production, decomposition and recycling processes and by providing habitat space for organisms. All estuaries in the Coromandel are used in some capacity which is, in part, the result of supporting services.

The primary use of the service maps (Figures 4-24) should be as a simple visual tool and a way of communicating that estuaries offer an array of benefits that support human wellbeing. All estuarine habitats in the matrix (

Table 3) contributed highly or moderately to at least one service. Similarly, all services, except for shoreline protection, had more than six habitat types making either high or moderate contributions (

Table 3). These maps demonstrate that different parts of estuaries generate different types of service. This is important considering that estuaries and their upper sections are often perceived to be of low value (Batstone and Sinner 2010) relative to outer sandy locations. The ecosystem service maps should not be used in a planning capacity e.g., to guide the placement of activities with negative effects on the marine environment. In such situations, a greater knowledge base is required to understand the spatial extent of potential impacts, how sensitive specific species/habitats are to stress, and connectivity within an estuary. Although individual habitats can be isolated in maps, many habitats and ecosystem services are interconnected³. Thus there can be differences between where services are produced and where the benefits occur. In recognition of this, Costanza (2008) discusses the need to consider ecosystem services with respect to their spatial characteristics (See Table 4).

Limitations of the mapping approach are that simplistic linkages between habitats and services do not reflect the demand for ecosystem services and thus whether habitat patches are of sufficient size for sustainable use (e.g., whether rates of harvesting or nutrient/contaminant inputs exceed the assimilative capacity). Ultimately there is a need to move towards quantifying rates of ecosystem services and examining the associated demands. The maps do not include cultural considerations; except where Tapu areas have been identified and avoided. Maps do not identify culturally significant areas for food collection, they instead make simple assumptions about organism density (e.g., cockles) and the links between habitat type and the food service. The matrix assumes that habitats are in a good state of health, which is not always the case in Coromandel estuaries. With certain stressors (e.g., heavy metal contaminants), there can be a loss of functioning and a concomitant loss of ecosystem services, but this would not be evident in the maps unless stress causes a change in habitat type.

³ Sediment retention and nutrient recycling affect primary production (Sundbäck et al. 2003), primary production and biogenic habitat provision support food production.

Table 4: Ecosystem services classified by their spatial characteristics. Terminology following that of Costanza (2008). In situ, when the benefit is at the point of use. Directional flow related, where there is flow from the point of the service production to the point of use. Local – proximal, where the benefit occurs within the vicinity of service production.

Service	Spatial Characteristics
Primary production	<i>In situ</i>
Nutrient regeneration	Directional – flow related
Biogenic habitat provision	Local - proximal
Regulation by key species	Local - proximal
Sediment retention	Directional – flow related
Bioremediation of contaminants	Local - proximal
Storm protection	Directional – flow related
Food	<i>In situ</i>

4.1 Additional layers

4.1.1 Confidence

The ecosystem service matrix table used a numeric indicator to reflect the confidence in assigned scores (

Table 3) although this is not presented in the service maps. The rationale for exclusion was that including both ‘contribution’ and ‘confidence’ into a single layer produced 16 map categories. Visually presenting this number of categories becomes unwieldy and difficult to interpret, detracting from the purpose of producing simple, visually informative maps. Instead additional layers were produced in ARCGIS containing confidence scores to be super-imposed on top of service maps (Figure 27). Parallel lines were used to reflect confidence: where the lines were widely spaced, we had the greatest confidence; where we have lower confidence e.g., contributions based on expert opinion, the lines were much closer together. The superimposed confidence layers have an important role when interpreting the service maps. The use of multiple map layers together may be best suited to mapping software e.g., ARCGIS or use online, when individual layers can be switched on and off and users can alternate between different screen views.

4.1.2 Sum service value

Looking across the matrix table, it is evident some habitats contribute to multiple services (

Table 3). Cockles feature prominently, with high density cockles, seagrass and high density cockles, high density cockles and pipi and all making high contributions to four services and moderate contributions to another four services. High density crab and cockles habitat is similarly useful, making high contributions to four services and moderate contributions to another three. Mangroves and high density oysters also contribute to multiple services in both high and moderate capacities. There is merit in assessing habitats’ ability to contribute to multiple services (Figure 28); although this requires careful interpretation. For example, high density *Amphibola* may make a low contribution across services, but can be a culturally significant food source and, in areas of high density, can have an important regulatory role through grazing. A relatively narrow contribution across ecosystem services by a habitat should not necessarily be interpreted as being of low importance. Furthermore, as the list of services is expanded, habitats may contribute to a wider number of services. There were general patterns in the breadth of services that habitats contributed

to across the Coromandel estuaries: typically, central sections in estuaries, where seagrass and cockle beds were present, contributed to the broadest number of services. Upper estuarine locations were narrower, as these were typically muddier habitats with more limited contributions to services. Another generalisation was that, across services, there was greatest confidence in the habitats making high contributions (e.g. Figure 27). This was because these habitats tended to be well-studied and had the greatest body of supporting literature.

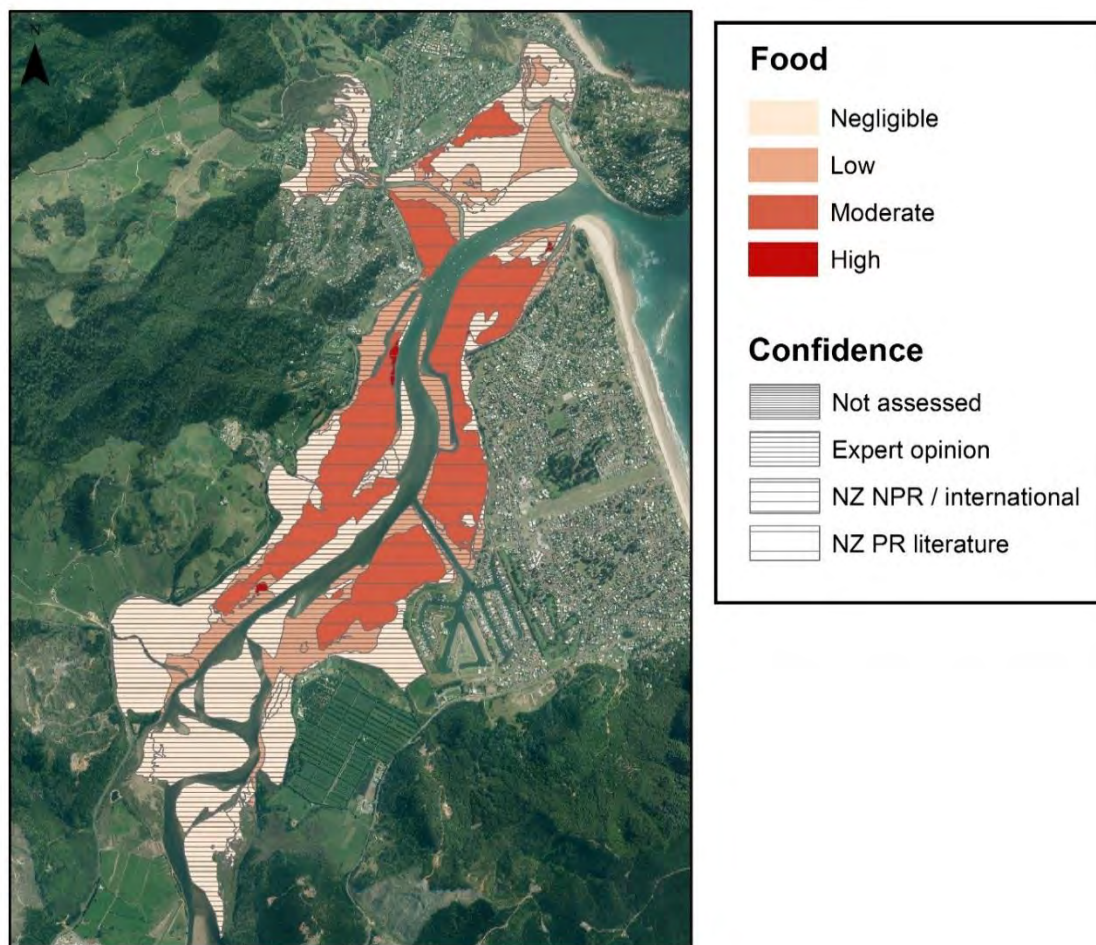


Figure 27: Ecosystem service maps of Tairua Harbour with Confidence layer superimposed. Confidence of 'NZ NPR / international' indicates the information source was either a non peer-reviewed report or was from peer-reviewed literature external to New Zealand; Confidence of 'NZ NPR literature' indicates the information source was a New Zealand focused, peer-reviewed scientific study.

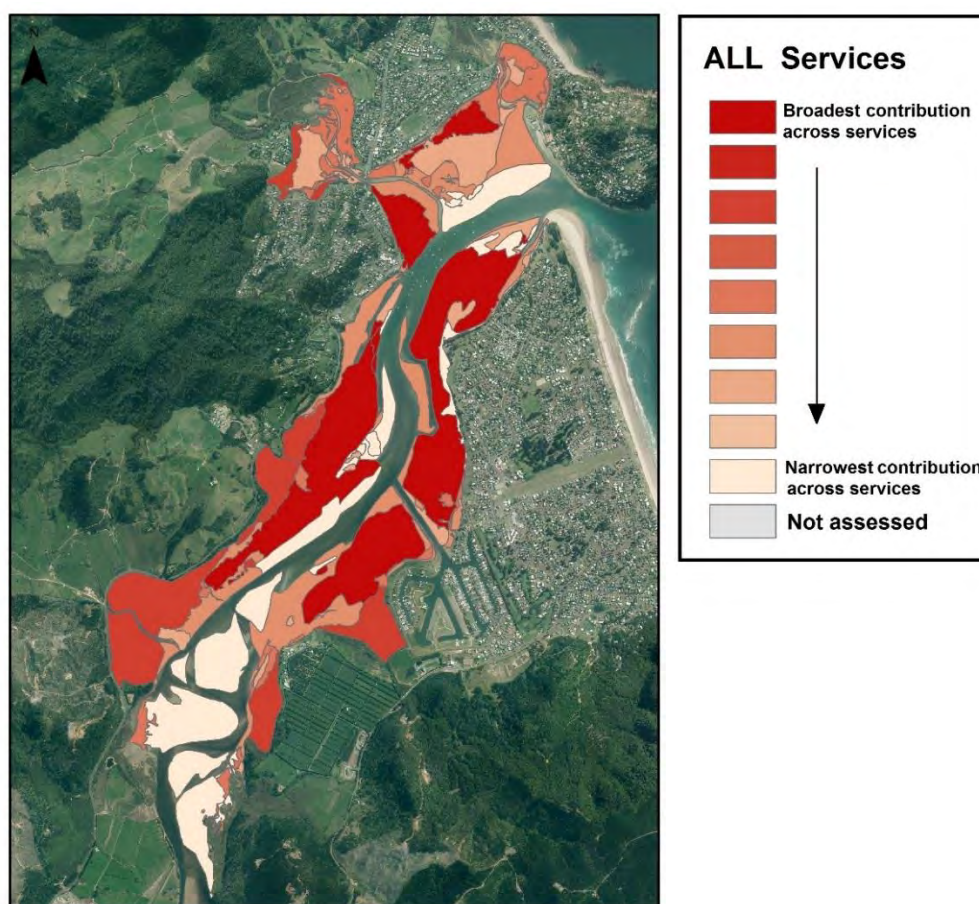


Figure 28: Summation of ecosystem service maps into a single layer to identify the breadth of habitat contributions for Tairua Harbour. Each service was scored depending on its contribution to a service (High = 3, moderate = 2, low = 1, negligible = 0) and summed across the eight services. Summed scores were ranked and coloured coded.

4.2 Future improvements

The integration of stressors into the approach would improve on current assumptions of habitats being in a good state of health. Building this into the maps would require knowledge of the distribution and concentration/severity of stressors in Waikato Estuaries. Needham et al. (2013b) presented a basic stress-matrix that assessed the susceptibility of the habitats to a variety of stressors including: sediments, nutrients, low oxygen, contaminants, overharvesting and effects of climate change. This could be improved by a review of literature and a refinement of rankings. Like the confidence layer (Section 4.1.1), estuarine stressors might be handled most effectively as a series of GIS layers that can be superimposed on top of habitat and service maps. In areas where stressors occur, the susceptibility of the encompassed habitats could be reviewed using the stress-matrix layers. From this, simple inferences about which ecosystem services might be impaired and where management intervention may be most appropriate. Beyond this simple expansion, more quantitative considerations of stress would likely be beyond the limit of a matrix-based approach. Instead, further effort is needed to develop metrics and quantify individual ecosystem services and build an understanding of how these change across environmental gradients.

Acknowledgements

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Glossary of abbreviations and terms

Ecosystem functions	Ecosystem function and processes are used synonymously, to refer to the physical, chemical and biological actions that link organisms and their environment.
Ecosystem goods and services	Are broadly defined as the benefits that mankind derives from natural or semi-natural habitats.
goods	These are the tangible resources that are extracted and utilised by humans, such as food and raw materials.
services	These are the abilities of ecological systems to provide favourable conditions by processing material or providing intrinsic benefits.
Ecosystem services	This is used in much of the literature to refers to both goods <i>and</i> services.
habitats	Habitats are comprised of both biological and environmental attributes that support particular species.
ecosystem component	The direct and emergent properties of the character defining species.
Species	The basic unit of biological classification. The largest group of organisms in which two individuals can produce fertile offspring, typically by sexual reproduction.
Provisioning services	Synonymous with ‘goods’. These are the array of products that can be extracted from marine ecosystems such as food, raw material or medicinal products (MEA 2005).
Cultural services	These are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (MEA 2005).
Regulating services	These are the benefits obtained from the regulation of ecosystem processes (MEA 2005).
Supporting services	These are the services that are necessary to produce all other ecosystem services (MEA 2005).
Ecosystem Services (ES) Matrix	This is a grid-like rectangular array that records the ability of habitats (rows) to contribute to ecosystem services (columns), with information recorded in cells at the intersections.

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Appendix A Ecosystem Service Matrix Tables

The relative importance of mobile species (habitat users, generally with high cultural value) in providing services. Shading of cells indicates the relative importance of each species in providing each service, and numeric indicators within each cell represent the confidence in the importance of the contribution (see key). The scoring assumes that the species is in a good state of health. The matrix can be read horizontally to observe the mix of services that a mobile species contributes to, or vertically to identify which particular species contribute to a specific service.

Components	Habitat & supporting services				Regulating services						Provisioning services			Cultural services	
	Primary production	Nutrient regeneration	Biogenic habitat provision	Formation of sediments	Regulation by key ecosystem components	Carbon sequestration & storage	Sediment retention	Gas balance	Bioremediation of contaminants	Storm protection	Food	Raw materials	Biochemical/medicinal resources	Leisure & eco-tourism	Spiritual & cultural wellbeing
Albatross	1	2-2		1		3	1	1	1	1	1	1		3	3
Baleen whales	1	2-2	1	1		3	1	1	1	1	1	1	1	3	3
Blue cod	1	1	1	1	1	1	1	1	1	1	3	1	1	3	3
Flat fish	1	1		1		3	1	1	1	1	2-1	1	1	2-1	2-1
Kahawai	1	1	1	1	1	1	1	1	1	1	2-1	1		2-1	2-1
Kingfish	1	1	1	1	1	1	1	1	1	1	2-1	1		2-1	2-1
Lamnidae sharks	1	1	1	1	2-1	1	1	1	2-2	1	2-1	3	3	3	3
Marlin	1	1	1	1	2-2	1	1	1	2-2	1	2-1			3	1
Mullet	1	1		1		3	1	1	1	1	2-1	1		2-1	2-1
Packhorse lobster	1	1		1		3	1	1	1	1	2-1			1	2-1
Paddle crabs	1	1			3	2-2	1			1	2-1			1	2-1
Pelagic fish	1	2-2	1	1	2-1	1	1	1	2-2	1	2-1	1	1	3	2-1
Penguins	1	2-2		1		3	1	1	1	1	1	1		2-1	3
Petrels/shearwaters	1	2-2		1		3	1	1	1	1	2-1	1	1	2-1	1
Pinnipeds	1	2-2	1	1	3	1	1	1	1	1	1		1	2-1	2-1
Rays	1	1	1	1	2-2	1	1	1	2-2	1	1	2-2	2-2	3	2-1

Continued:

Components	Habitat & supporting services				Regulating services						Provisioning services			Cultural services	
	Primary production	Nutrient regeneration	Biogenic habitat provision	Formation of sediments	Regulation by key ecosystem components	Carbon sequestration & storage	Sediment retention	Gas balance	Bioremediation of contaminants	Storm protection	Food	Raw materials	Biochemical/medicinal resources	Leisure & eco-tourism	Spiritual & cultural wellbeing
Rock lobster	1	1		1	3	3	1	1	1	1	2-1			1	2-1
Shags	1	2-2		1		3	1	1	1	1	1	1		1	1
Snapper	1	1			3	1	1	1	1	1	2-1	1		3	2-1
Toothed whales/dolphins	1	2-2	1	1	3	3	1	1	1	1	1	1	1	3	3
Wading birds	1	2-2		1	2-2	3	1			1	2-2	1	2-2	1	2-2
Scale of ES supplied by the ecosystem component High contribution Moderate contribution Low contribution No/negligible contribution							Confidence in evidence 3 NZ focused, peer-reviewed literature 2-1 NZ focused, grey literature 2-2 Overseas literature 1 Expert opinion / Not assessed								

The relative importance of biogenic ecosystem components (habitat formers) in providing services. Shading of cells indicates the relative importance of each biogenic ecosystem component in providing each service, and numeric indicators within each cell represent the confidence in the importance of the contribution (see key). The scoring assumes that the ecosystem component is in a good state of health. The matrix can be read horizontally to observe the mix of services that an ecosystem component contributes to, or vertically to identify which particular ecosystem component contribute to a specific service.

Components	Habitat & supporting services				Regulating services						Provisioning services			Cultural services	
	Primary production	Nutrient regeneration	Biogenic habitat provision	Formation of sediments	Regulation by key ecosystem components	Carbon sequestration & storage	Sediment retention	Gas balance	Bioremediation of contaminants	Storm protection	Food	Raw materials	Biochemical/medicinal resources	Leisure & eco-tourism	Spiritual & cultural wellbeing
Black coral garden	1	1	3	1	2-2	1	1	1		1	1	1	2-2	3	1
Brachiopod bed	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Bryozoan bed	1	1	3	1		3	1	1		1	1	1	2-2	1	1
Bull kelp (<i>Durvillaea</i>) forest	3	1	3	3		1	2-2	1	2-2	1	1	3	2-2	1	3
Cerianthid bed	1	1	2-2	1	1	1	1	1	2-2	1	1	1	2-2	1	1
Cockle bed	3	3	3	1	3	1	1	1	2-1	1	2-1	1		3	2-1
Coralline paint	2-2	1	3	3	2-1	2-1	1	1	1	1	1	1	2-2	1	1
Coralline turfing algae	2-2	1	3	3		3	1	1	1	1	1	1	2-1	1	1
Deep/cold coral garden	2-2	1	3	3		1	1	1	1	1	1	1	2-2	3	1
<i>Ecklonia</i> forest	2-1	1	2-2		2-2	2-2	1	2-2	3	1	2-1	1	3	1	
Erect soft sediment inverts	1	1	2-1	1		1	1	1		1	1	1	1		
Mangrove forest	3	2-2	3	3	3	3	3	3	2-2	2-1	1	1		1	1
Green algal forest	1	1	1	1	1	1	1	1	1	1	2-2	1	2-2	1	2-1
Heart urchin plain	3	3		1	3	2-2	1	3	2-2	1	1	1	1	1	1
Horse mussel bed	1	3	3	1	3	1	3	1		1	1		1	1	1
Kina plain	1	2-2	1	3	3	1	1	1	1	1	3	1	1	1	2-1
<i>Macrocystis</i> forest	3	1	2-2		2-2	2-1	1	2-2	3	1	3	2-2	3	1	
Mixed brown algae	1	1	3	1		1	1	1	3	1	3	3	3	1	1
Mixed suspension feeders	1	3	1	1		1	1	1	1	1	1	1		1	1

Continued:

	Habitat & supporting services				Regulating services						Provisioning services			Cultural services	
Components	Primary production	Nutrient regeneration	Biogenic habitat provision	Formation of sediments	Regulation by key ecosystem components	Carbon sequestration & storage	Sediment retention	Gas balance	Bioremediation of contaminants	Storm protection	Food	Raw materials	Biochemical/medicinal resources	Leisure & eco-tourism	Spiritual & cultural wellbeing
Mud crab bed	1	3	1		1	2-2	3		3	1	1			1	2-1
Mussel bed	1	1	2-1	1	3	1	1		1	1	3	3	3	1	2-2
Oyster reef	1	2-2	2-2	3		2-2	2-2	1	2-2	1	2-1	2-2	2-2	2-1	2-1
Paua bed	1	2-2	1	1	1	1	1	1	2-2	1	3	2-1	1	3	2-1
Red algae meadow	1	1	3	1		1	1	1	2-2	1	3	3	3	1	3
Red coral garden	1	1	1	3	1	1	1	1		1	1	1		1	1
Rhodolith bed	2-2	1	2-1	3		2-1	1	2-2	1	1	1	1	2-1	1	1
Saltmarsh	2-2	2-2	2-2	2-2		2-2	2-2	2-2	2-2	2-2	1	1		2-2	2-2
Scallop bed	1	1	1	1		2-2	1			1	3	1		3	2-1
Seagrass meadow	3	2-2	2-2		3	3	2-2	3	1	1	1				1
Seapen bed	1	1	1			2-2	1			1	1	1	2-2	1	1
Soft sediment whelks assoc.	1	1			3	3	1			1	2-1	2-1		1	2-1
Sponge garden	2-2	3	3	3		3	1	1	3	1	1	3	3	1	1
Surf clam bed	1	1	1	1		1	1			1	1			1	3
Tubeworm mat	1	1	1		2-2	1	2-2			1	1	1	1	1	1
Tubeworm reef	1	1	3	3		3	1	1	1	1	1	1	2-2	1	1
Wedge shell bed	1	3		1	3	1	1	1		1	1	1	1	1	1
Scale of ES supplied by the habitat component						Confidence in evidence									
High contribution Moderate contribution Low contribution No/negligible contribution						3 NZ focused, peer-reviewed literature 2-1 NZ focused, grey literature 2-2 Overseas literature 1 Expert opinion / Not assessed									

Appendix B Supporting Literature

Scoring based on expert opinion for Mounds & Pits (Mixed), LD Deposit Feeders (Background), Low Fauna.

Cockles

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Macomona

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Tube worms

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