Waikato Regional Council Technical Report 2017/37

Ecosystem service maps of Coromandel estuaries

www.waikatoregion.govt.nz
ISSN 2230-4355 (Print)
ISSN 2230-4363 (Online)

Prepared by: M Townsend
National Institute of Water & Atmospheric Research Ltd

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

November 2017

Document #: 11464200

Peer reviewed by:
Hannah Jones Date November 2017

Approved for release by:
Dominique Noiton Date January 2018

Ecosystem Service Maps of Coromandel Estuaries

Prepared for Waikato Regional Council

June 2017

Prepared by:
M. Townsend

For any information regarding this report please contact:
Michael Townsend

Marine Ecology Group
+64-7-856 1789
Michael.townsend@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

NIWA CLIENT REPORT No: 2017131HN
Report date: October 2016
NIWA Project: EVW17201

Quality Assurance Statement		
Drew Lohrer	Reviewed by:	
Alison Bartley	Formatting checked by:	
Judi Hewitt	Approved for release by:	

Contents

Tables

Figures

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 services[1]' 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.

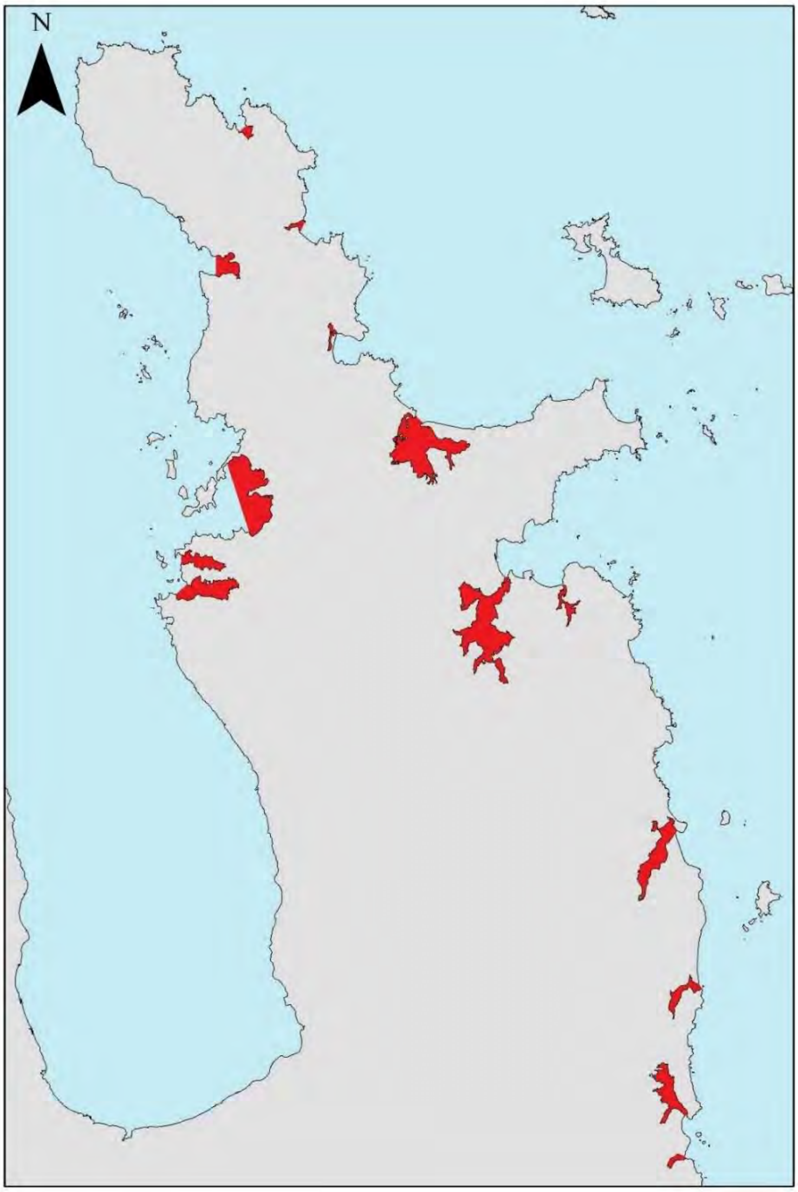
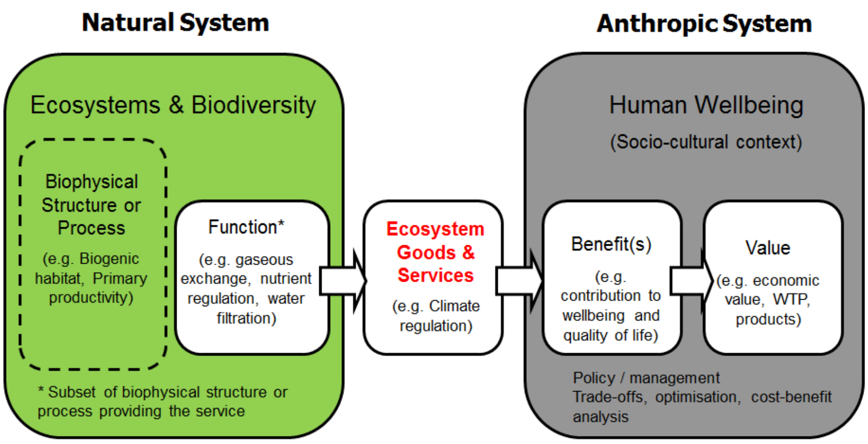


Figure 1: Map showing the estuaries (red) assessed. Starting bottom-right and working in an anticlockwise direction around the Coromandel Peninsula, the locations of intertidal habitat mapping were: Otahu estuary, Whangamata Harbour, Wharekawa Harbour, Tairua Harbour, Purangi estuary, Whitianga Harbour, 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
Flora	
Seagrass	Primary production, habitat structure, sediment stability & retention.
Mangroves	Primary production, carbon sequestration, gas and climate regulation, disturbance prevention, sediment stability & retention, habitat structure and coastal defence.
Pneumatophores	Nutrient cycling, sediment stability.
Fauna	
Tube worm mats	Sediment stability.
Cockle or Pipi beds	Secondary productivity, cultural harvesting, waste treatment, processing and storage, carbon sequestration.
Amphibola (mudflat snail / Titiko)	Cultural harvesting.
Oysters	Biogenic habitat provision, cultural harvesting, waste treatment, sediment stability & retention.
Macomona (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.
Macomona	≥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.
Amphibola	≥10 ind. 0.25m^{-2} were present in 3 or more random quadrats with a spatial extent of ≥10 m in any one direction.
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 m^2 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 *Macomona*	1	3	NA	3	1	1	1	1
Mounds & Pits (Mixed)	1	1	1	1	1	1	1	1
High density *Amphibola*	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
(red)	High contribution	3 NZ focused, peer-reviewed literature.
(orange)	Moderate contribution	2 NZ focused, reports, grey literature, overseas literature.
(yellow)	Low contribution	1 Expert opinion.
(white)	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 benefits[2]; 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).

of contaminants through burial or binding in tissue, or altering them so that their toxicity is reduced (Beaumont et al. 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).

Provisioning services:

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

2.3 Confidence

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.

2.4 Spatial adaptation

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).

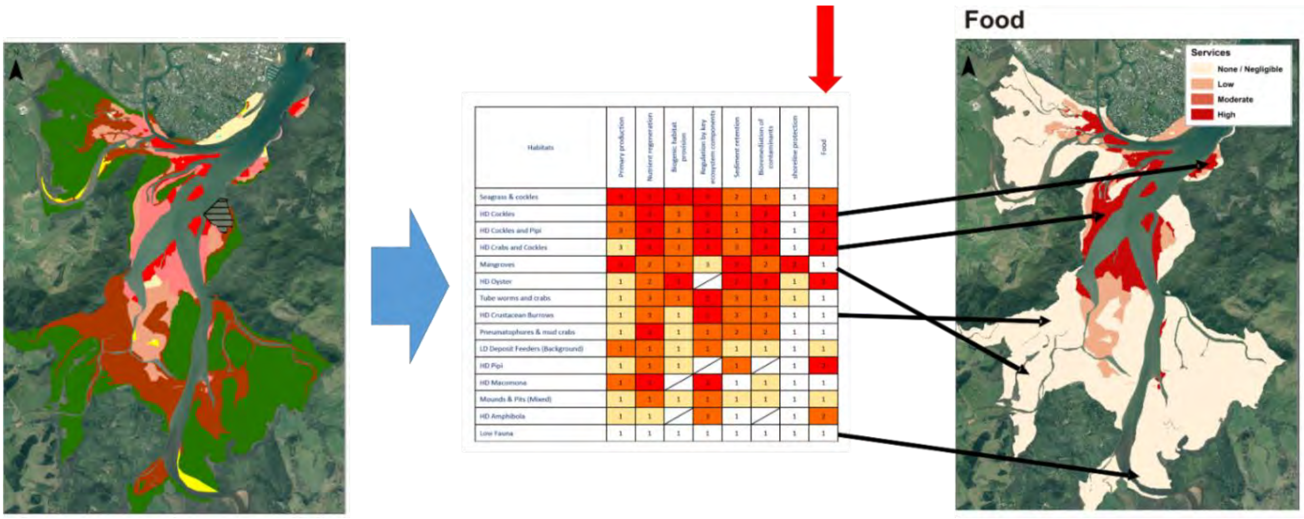


Figure 2: Schematic of converting habitat maps into simple ecosystem service maps using the matrix.

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.

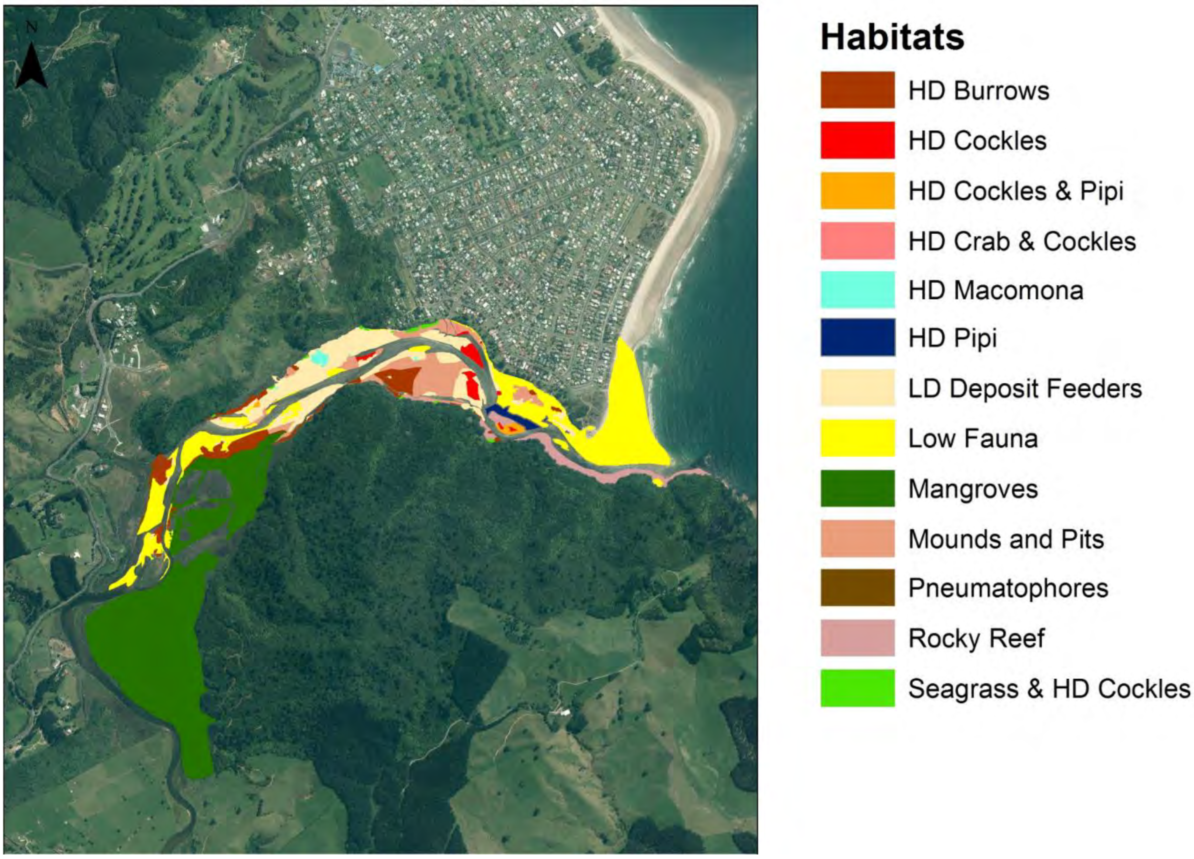


Figure 3: Habitat map of Otahu estuary.

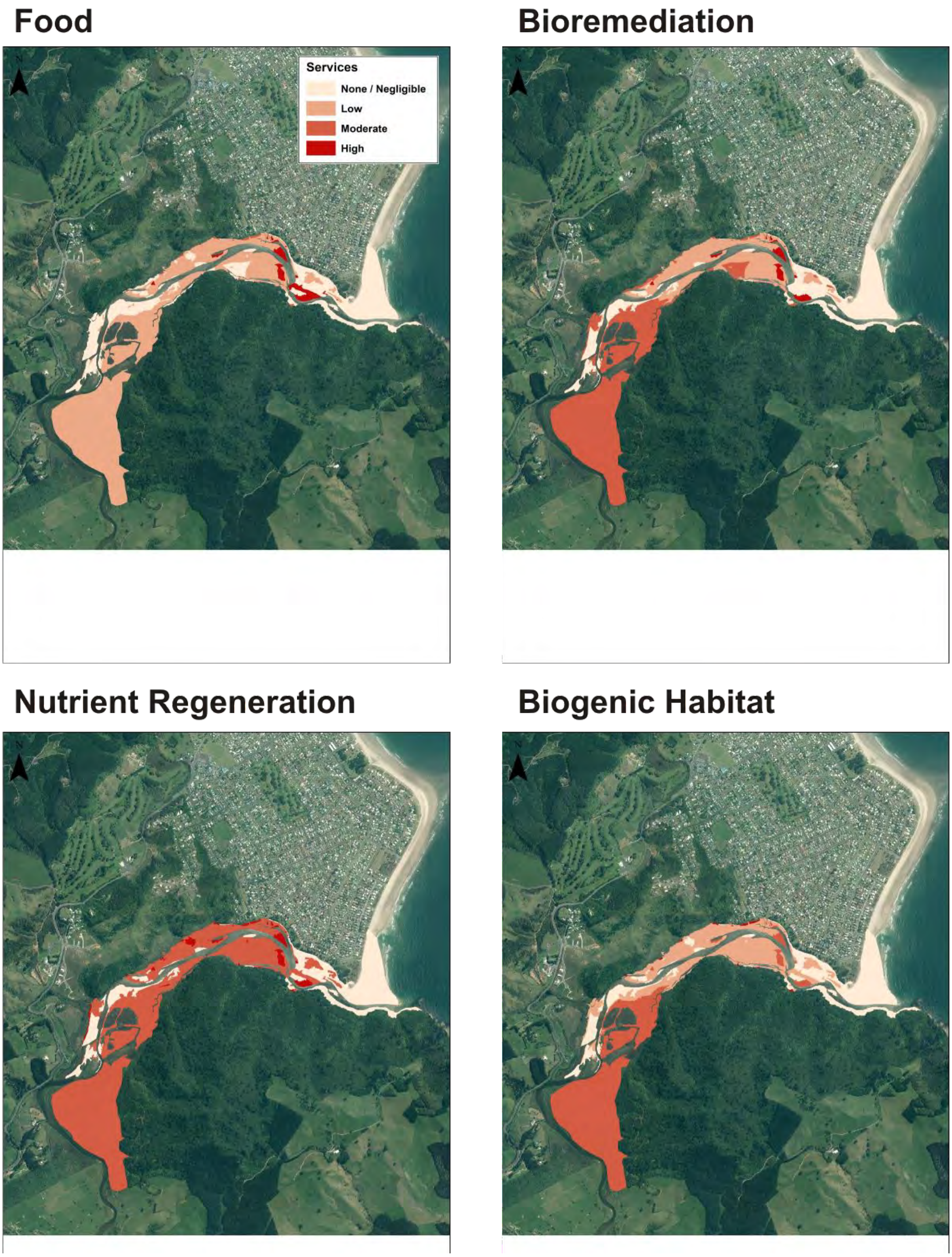


Figure 4: **Ecosystem service maps of Otahu estuary.**

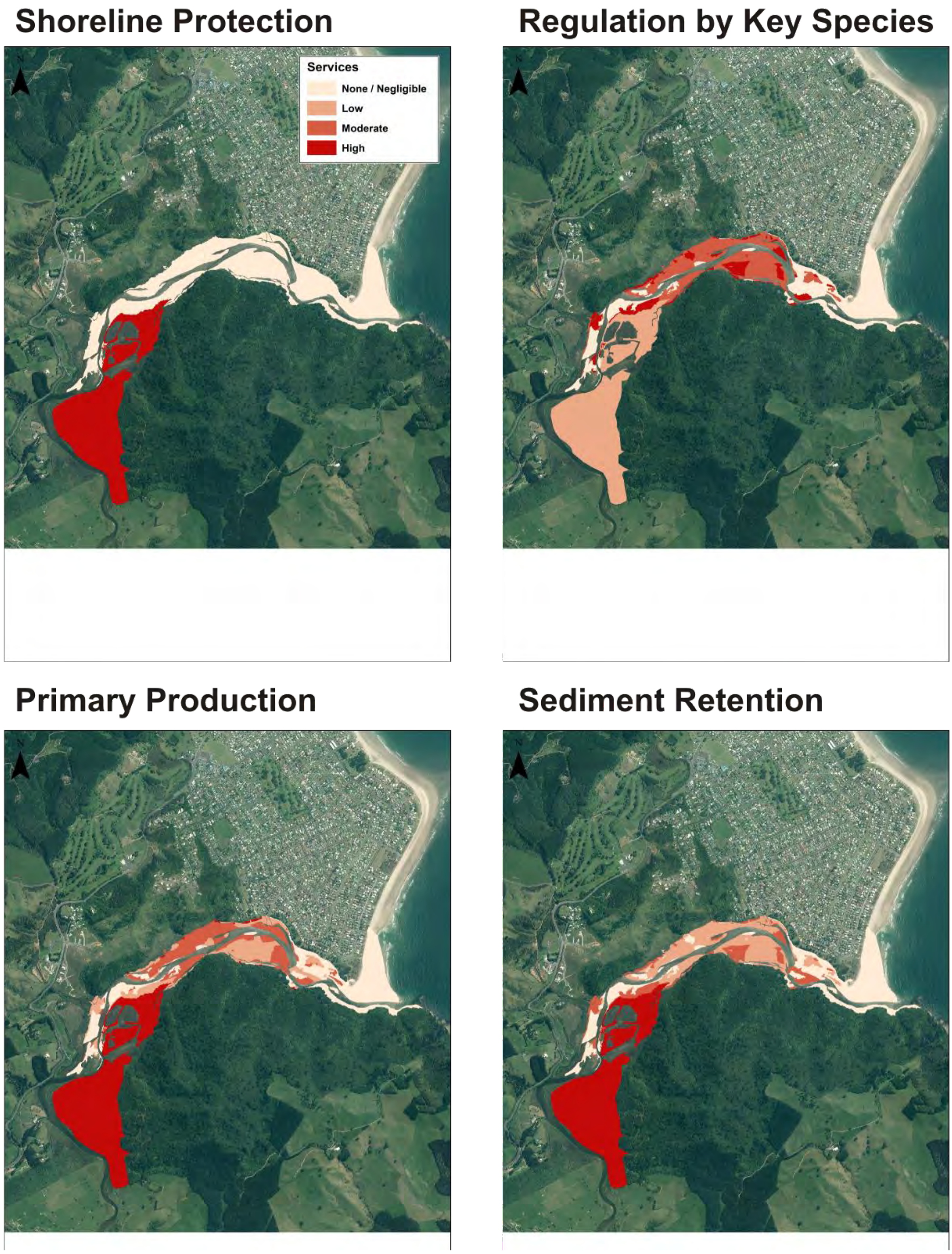


Figure 4 Continued: Ecosystem service maps of Otahu estuary.

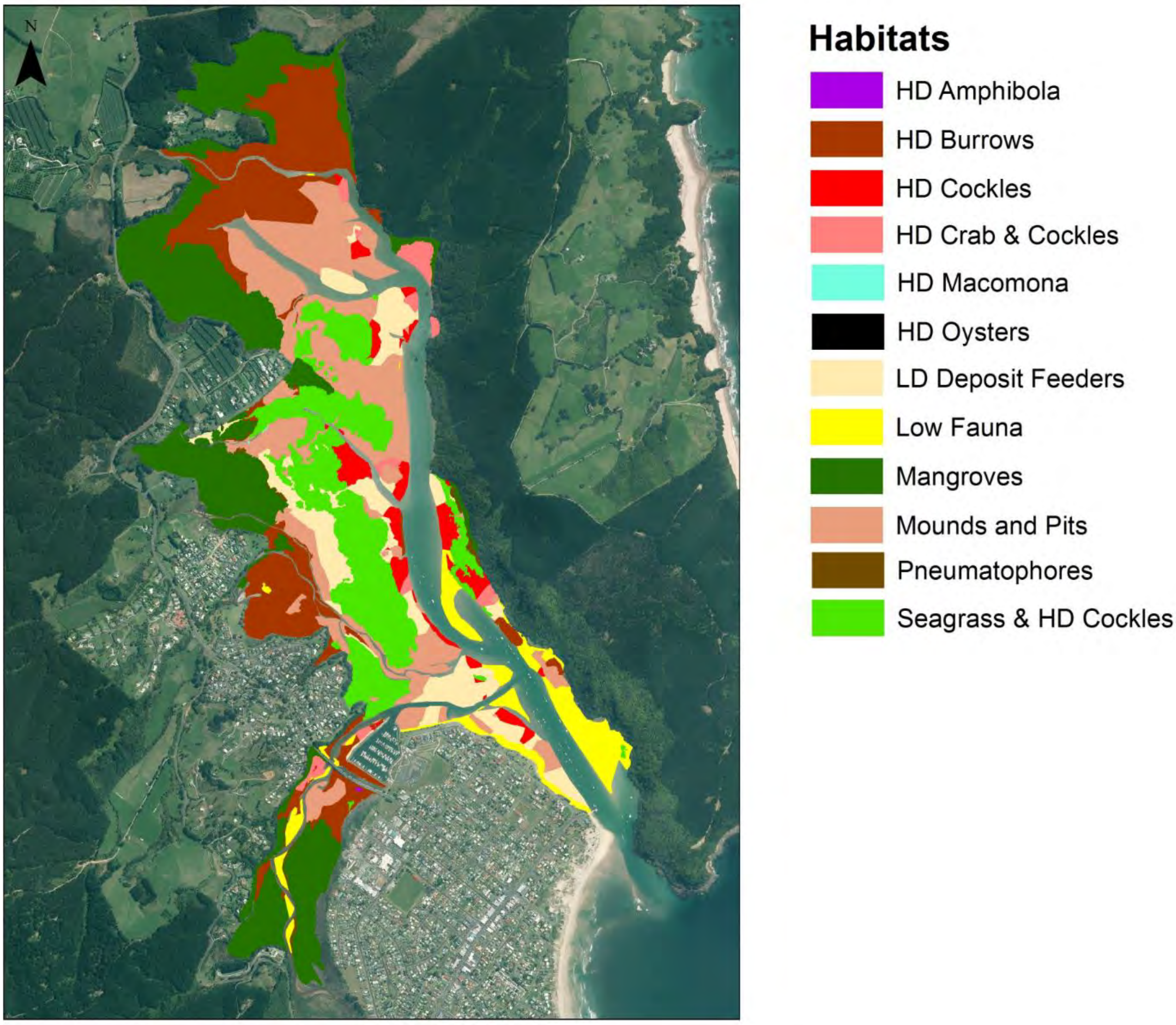


Figure 5: Habitat map of Whangamata Harbour.

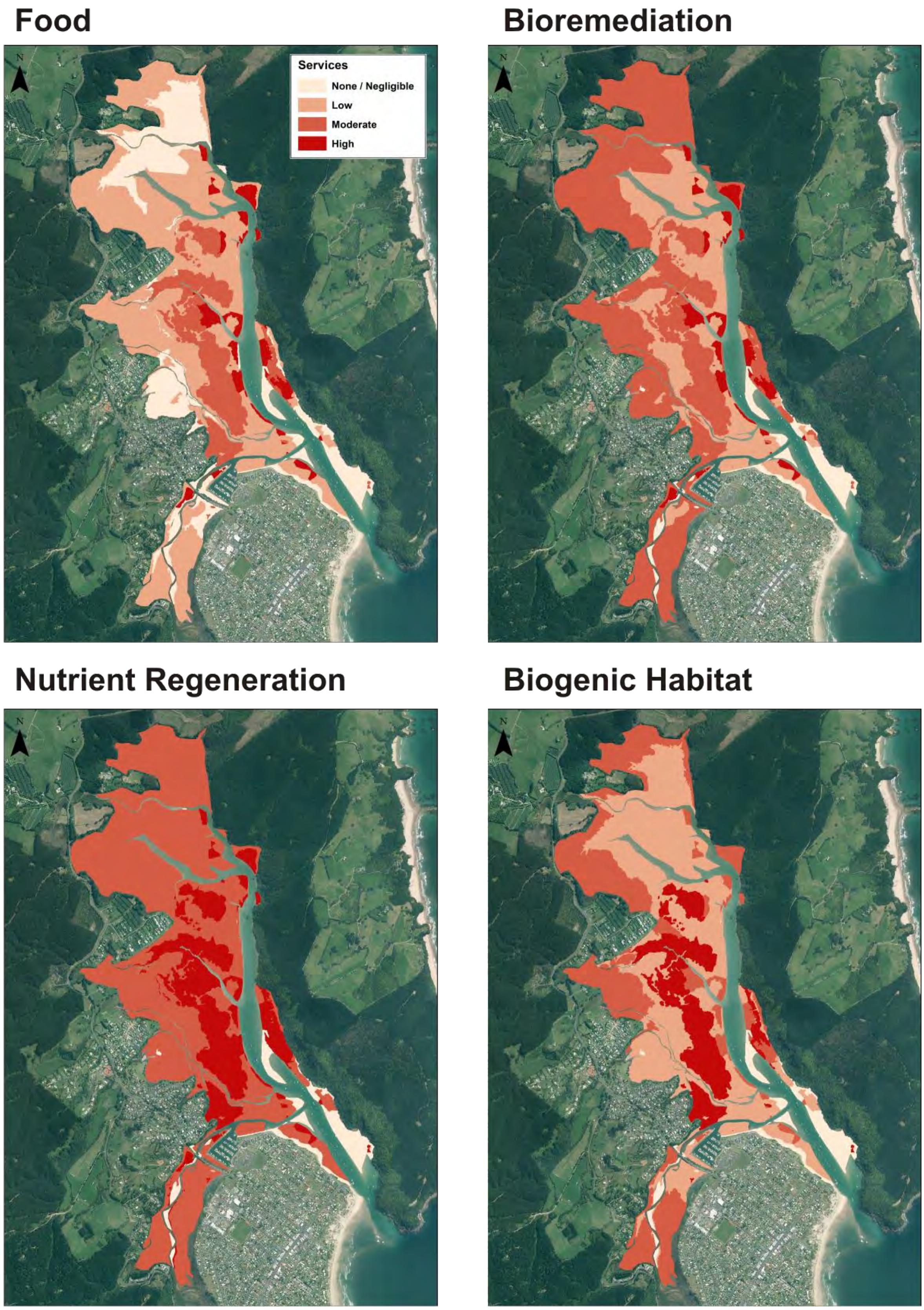


Figure 6: **Ecosystem service maps of Whangamata Harbour.**

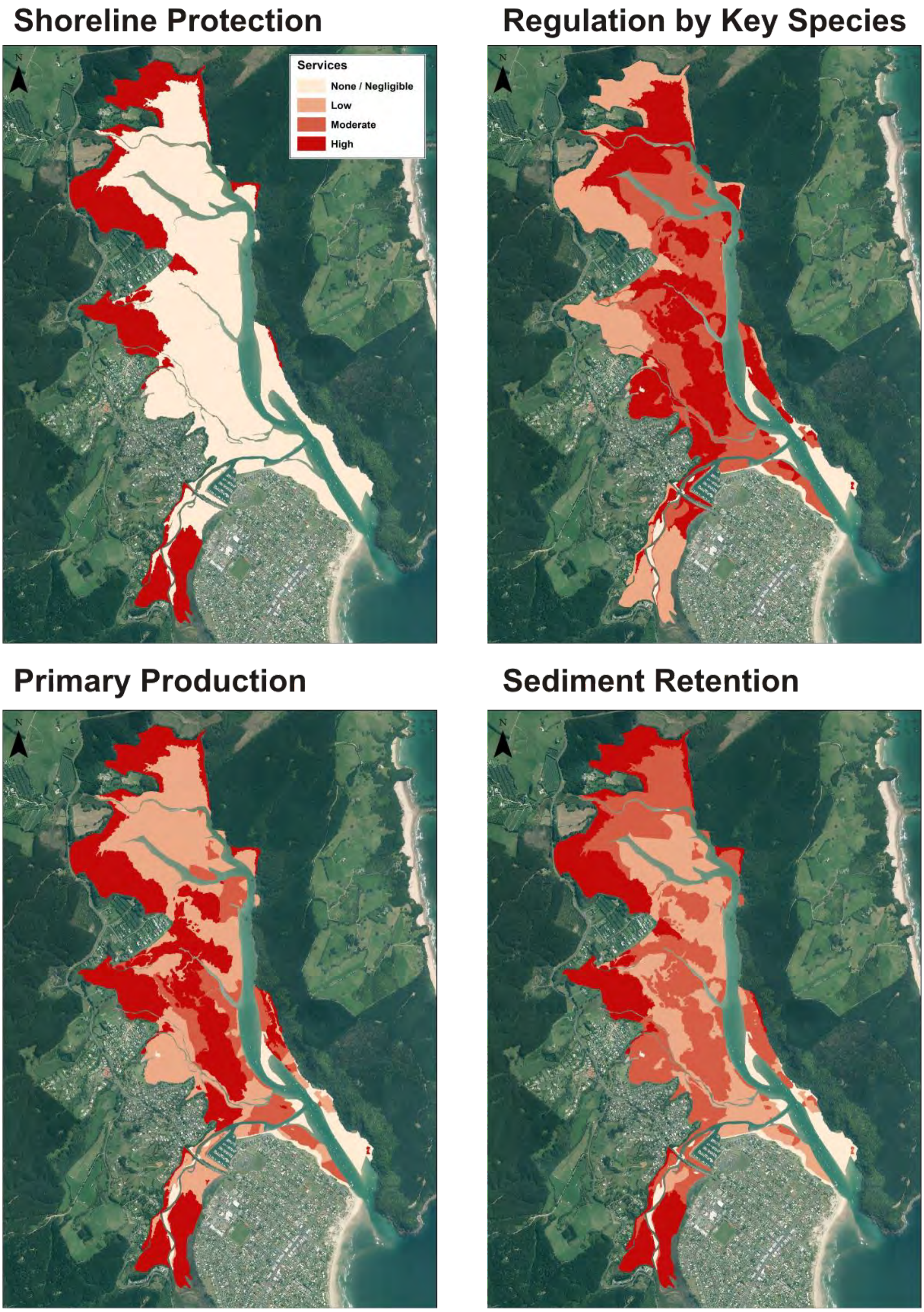


Figure 6 Continued: Ecosystem service maps of Whangamata Harbour.

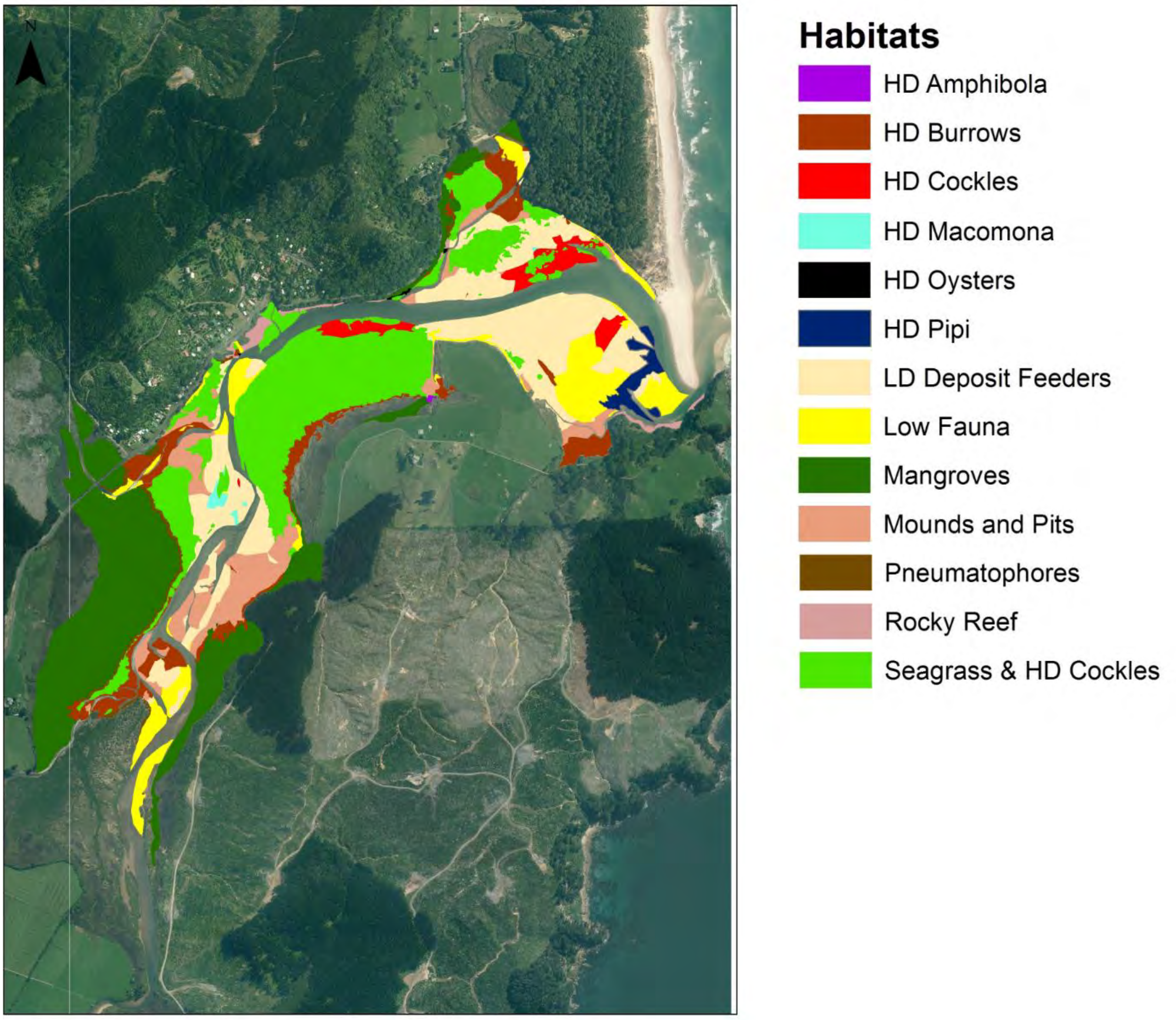


Figure 7: Habitat map of Wharekawa Harbour.

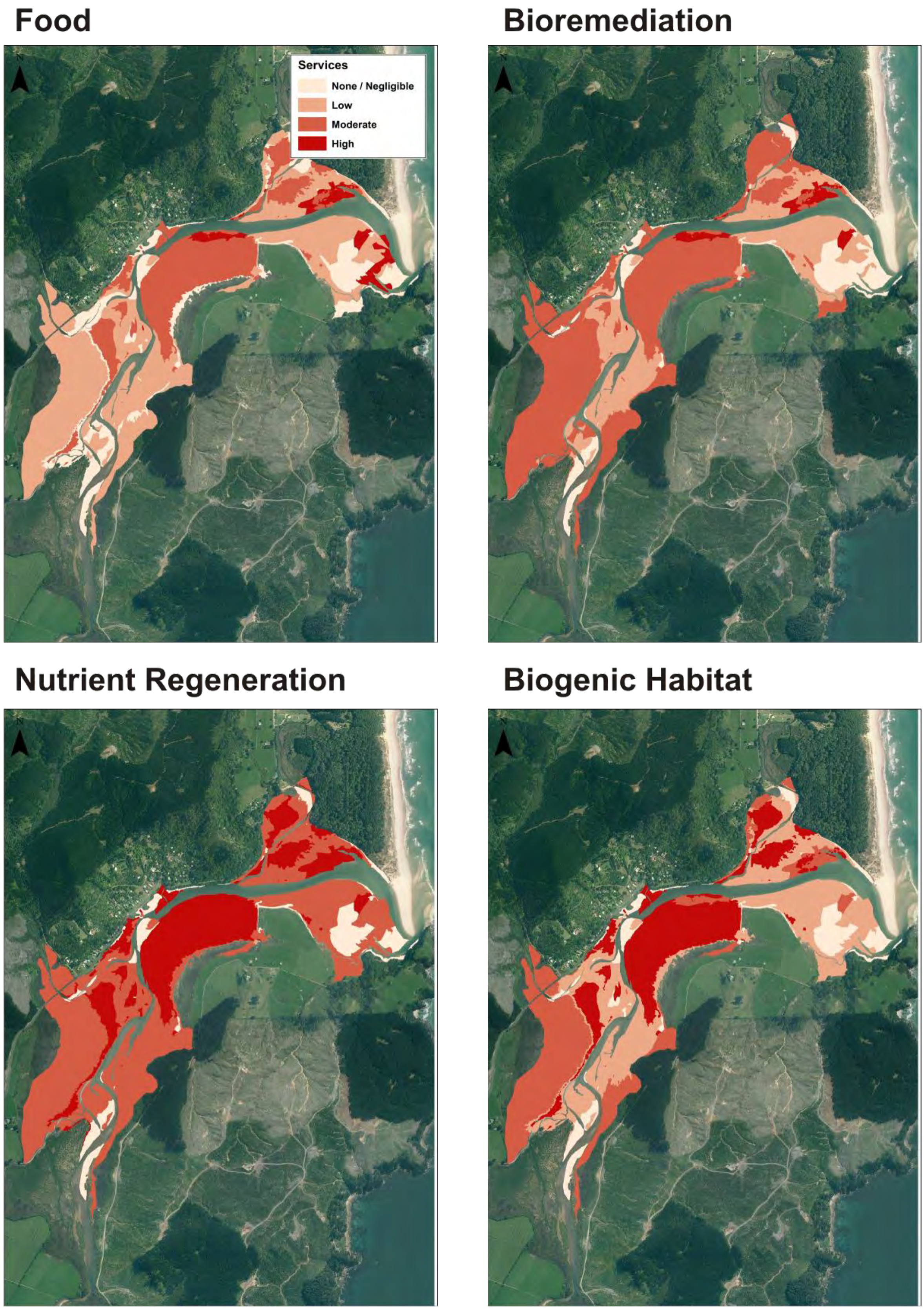


Figure 8: **Ecosystem service maps of Wharekawa Harbour.**

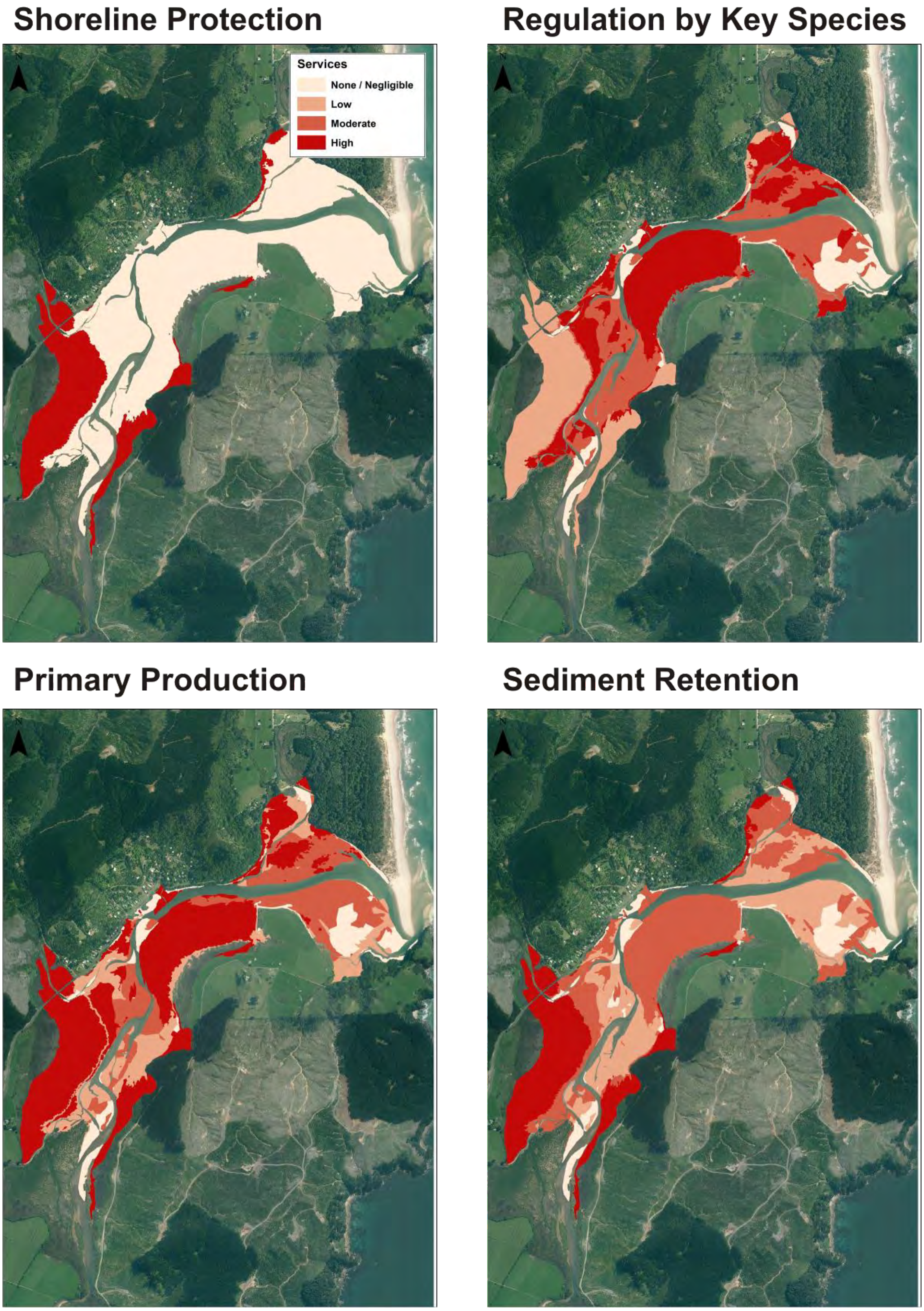


Figure 8 continued: Ecosystem service maps of Wharekawa Harbour.

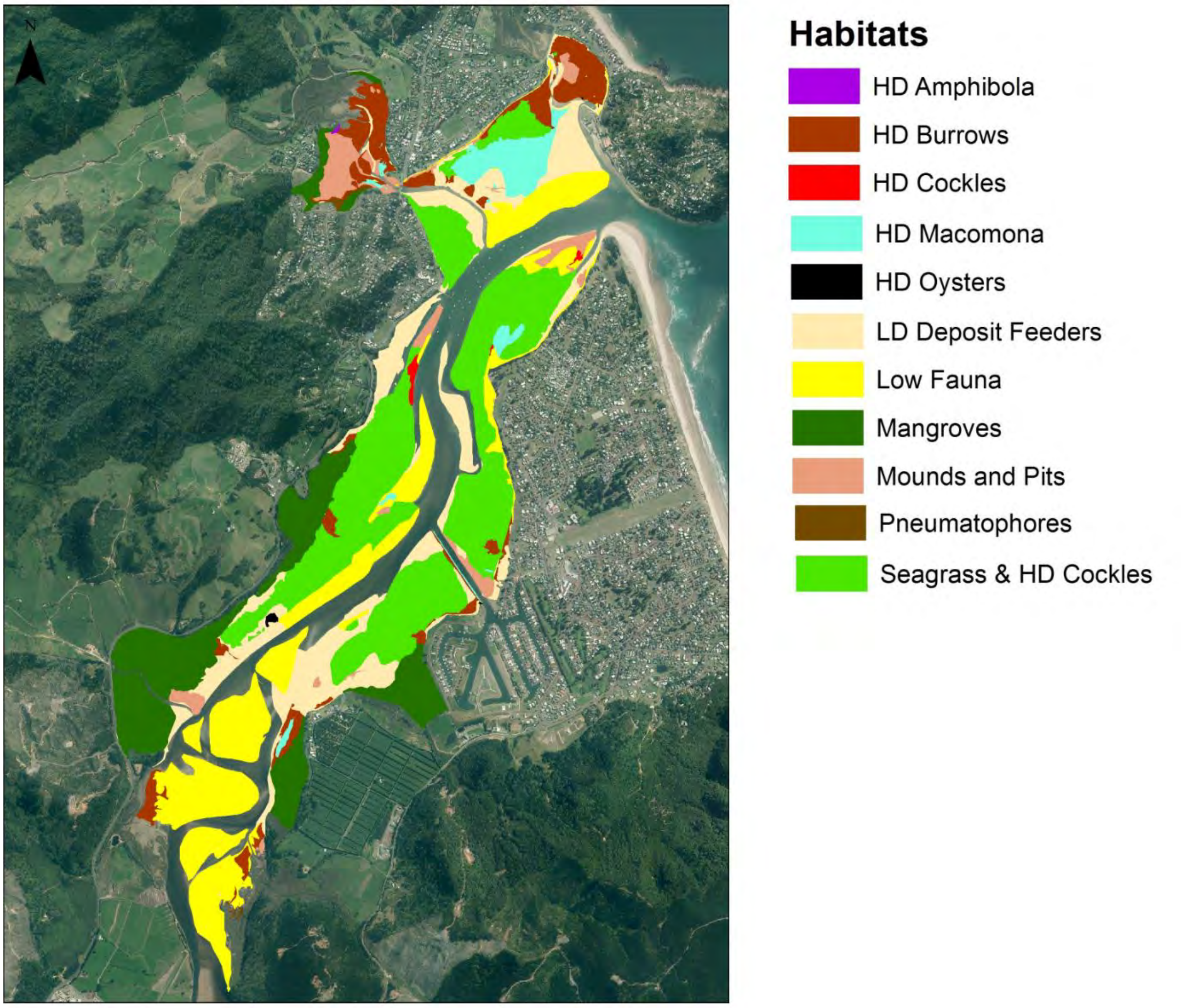


Figure 9: Habitat map of Tairua Harbour.

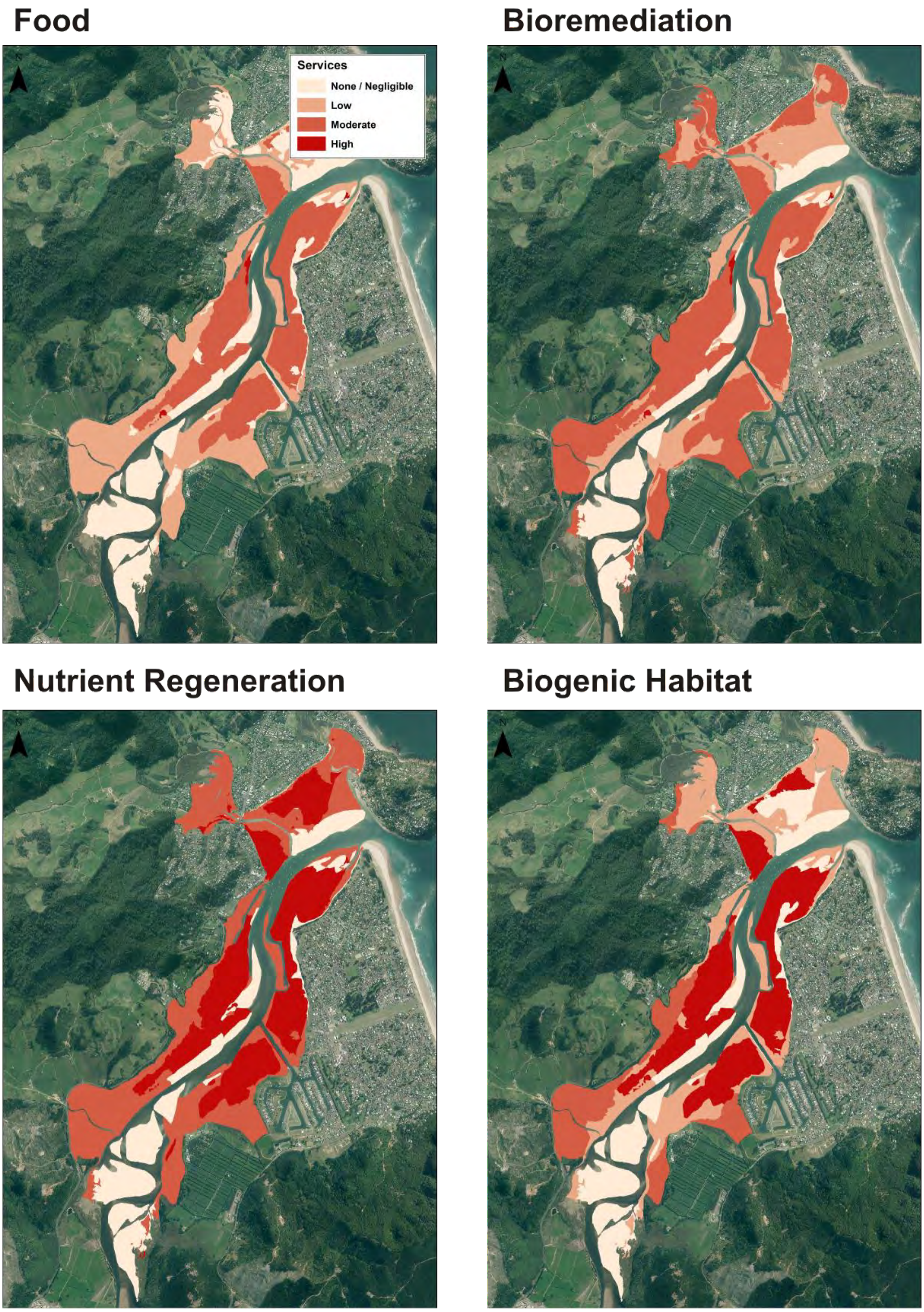


Figure 10: **Ecosystem service maps of Tairua Harbour.**

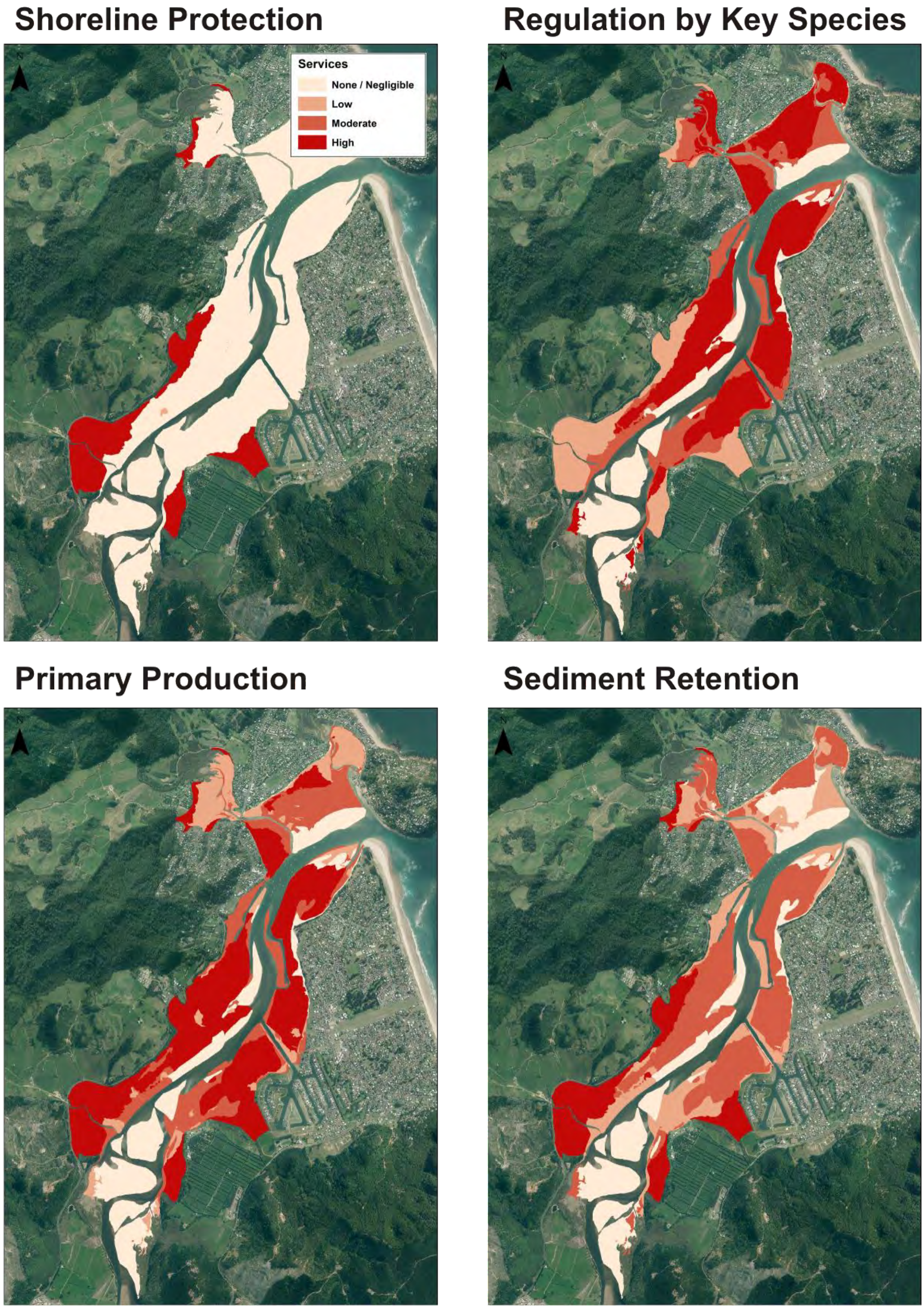


Figure 10 continued: Ecosystem service maps of Tairua Harbour.

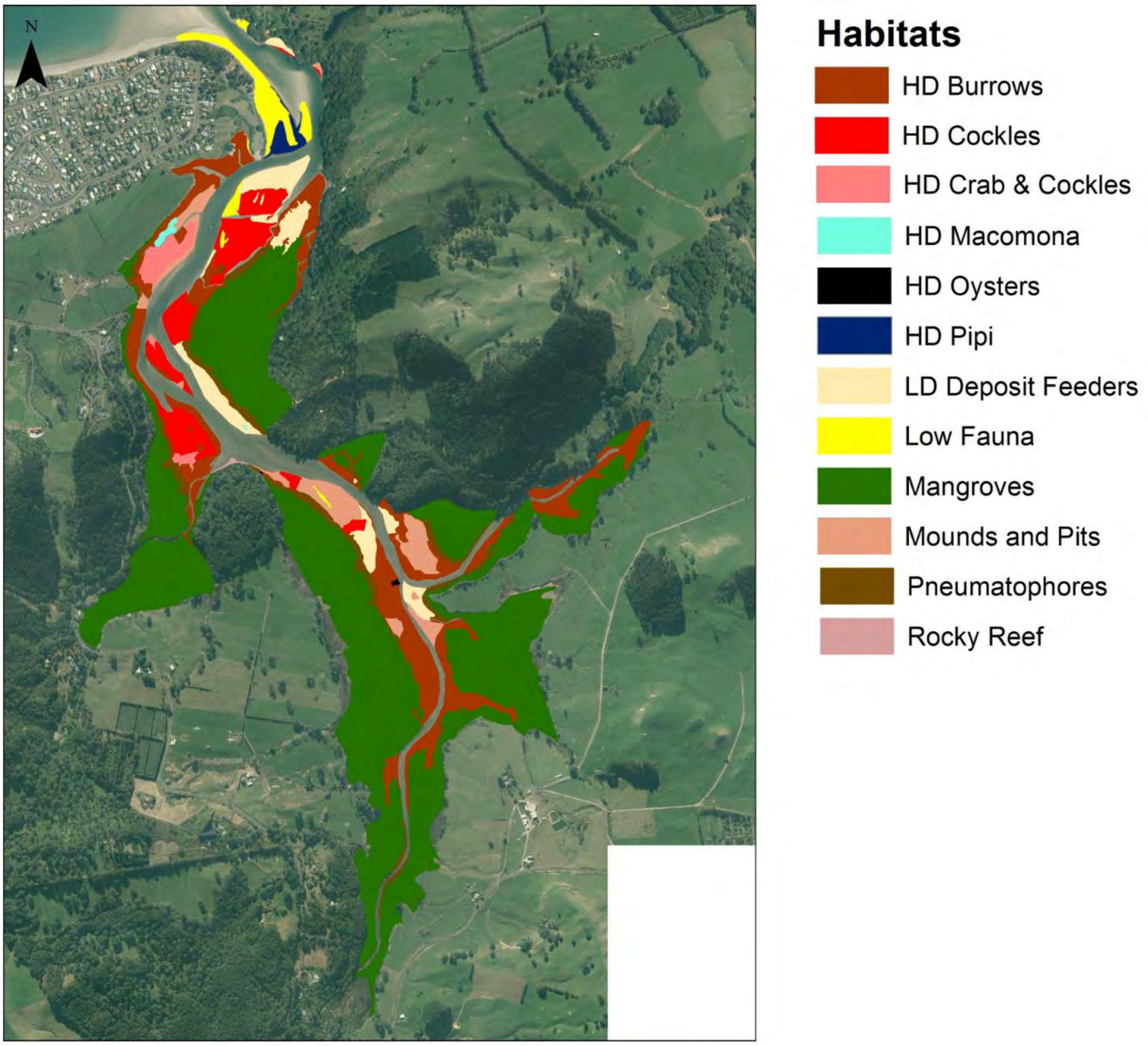


Figure 11: Habitat map of Purangi estuary.

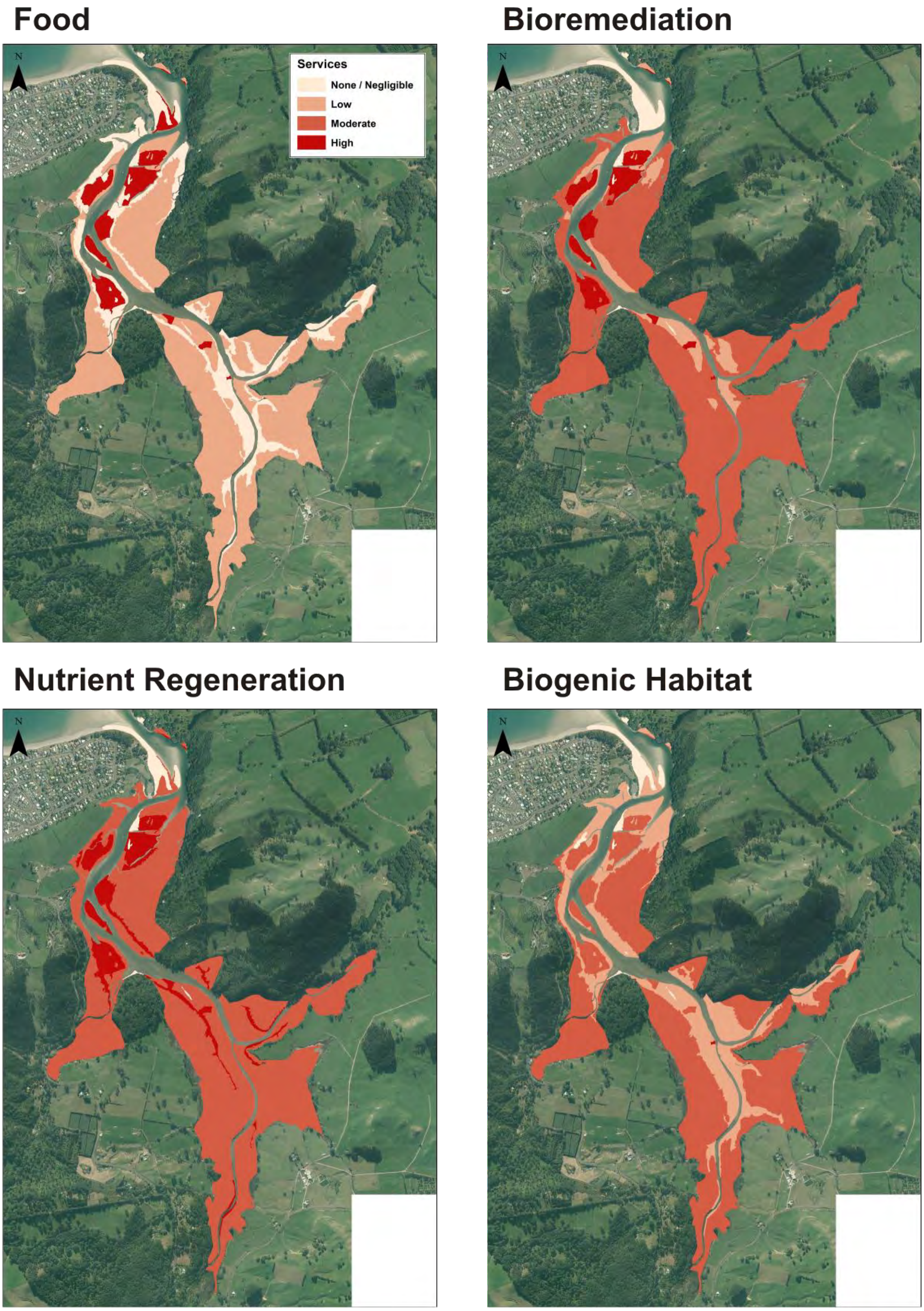


Figure 12: Ecosystem service maps of Purangi estuary.

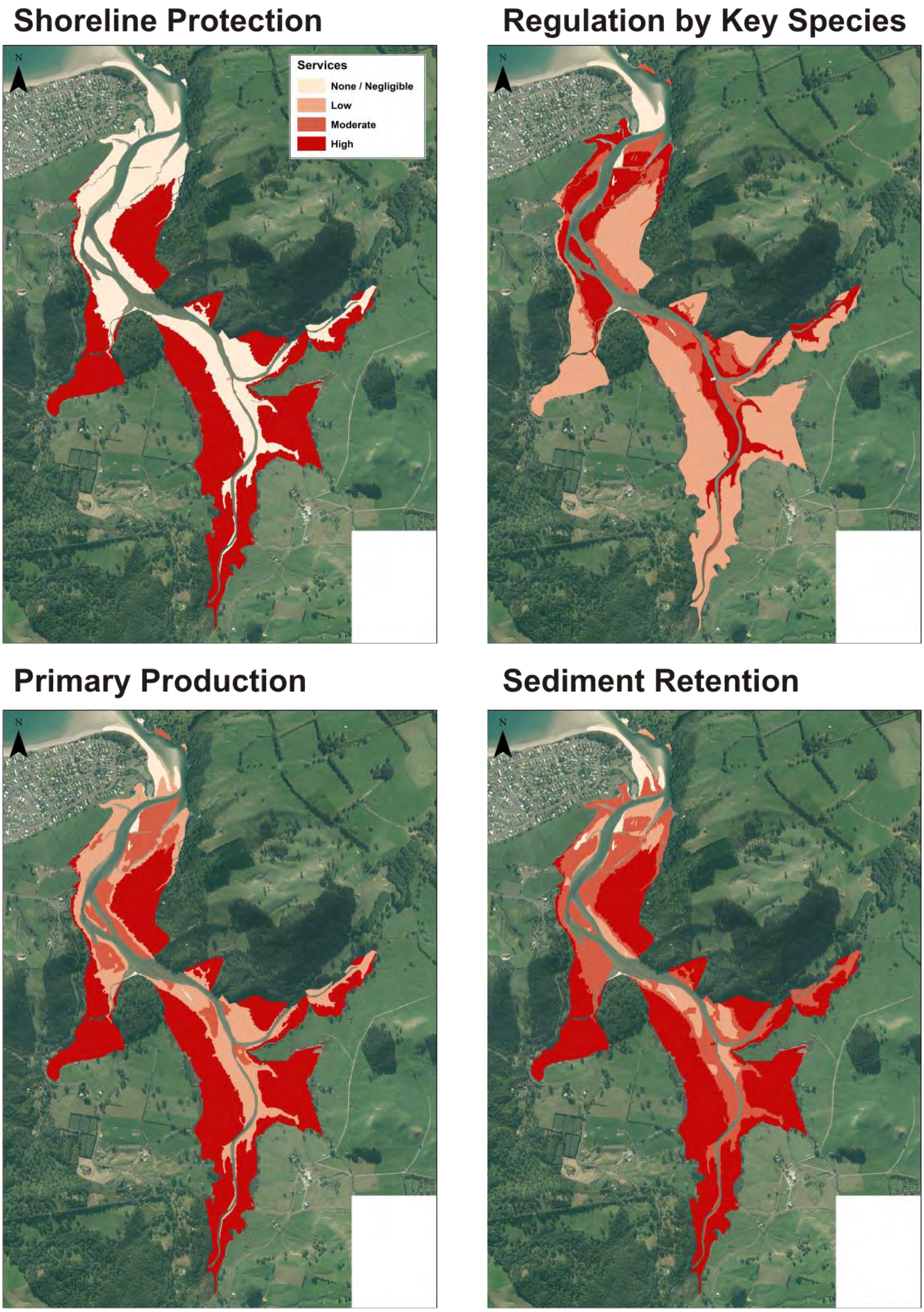


Figure 12 continued: Ecosystem service maps of Purangi estuary.

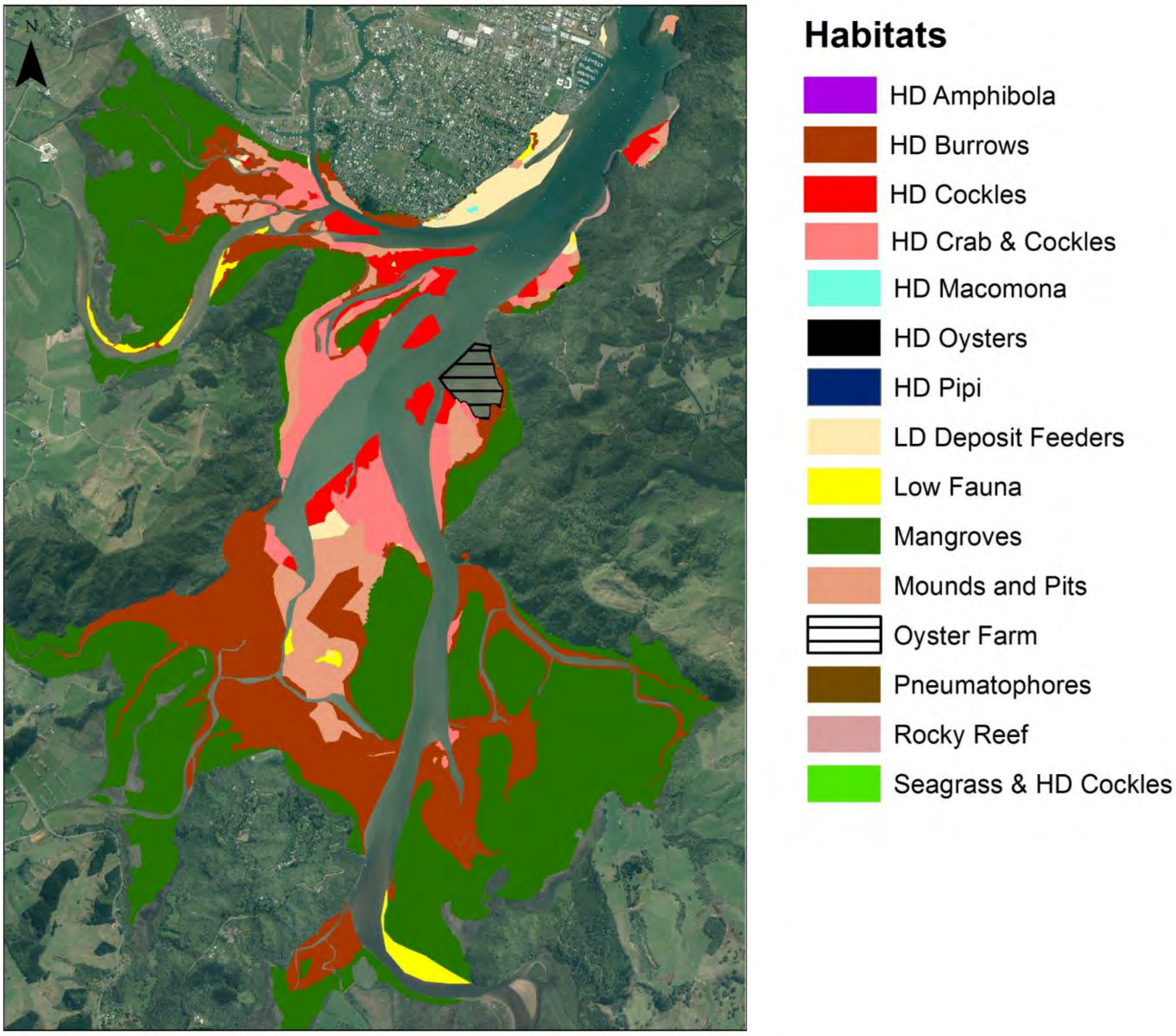


Figure 13: Habitat map of Whitianga Harbour.

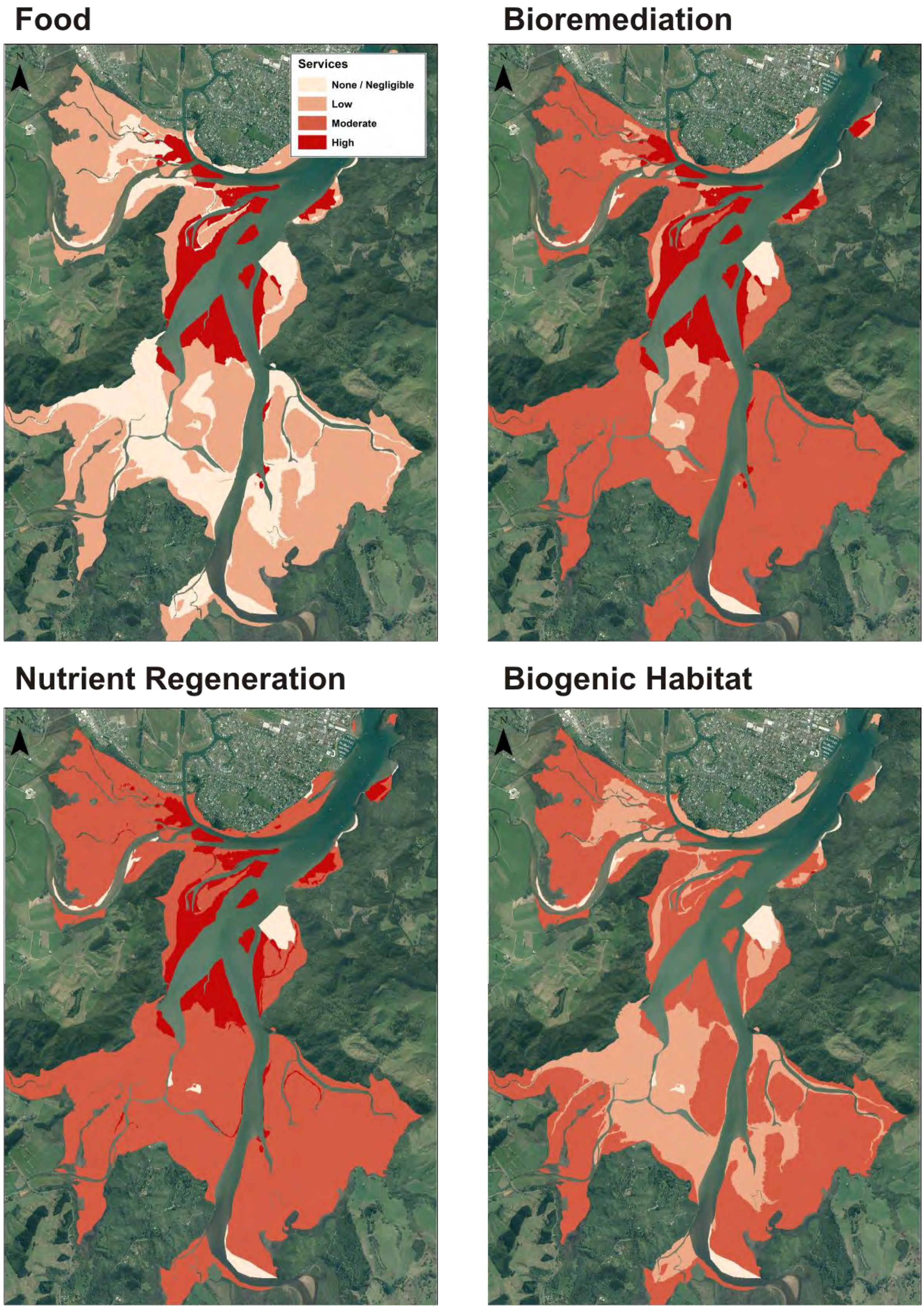


Figure 14: Ecosystem service maps of Whitianga Harbour.

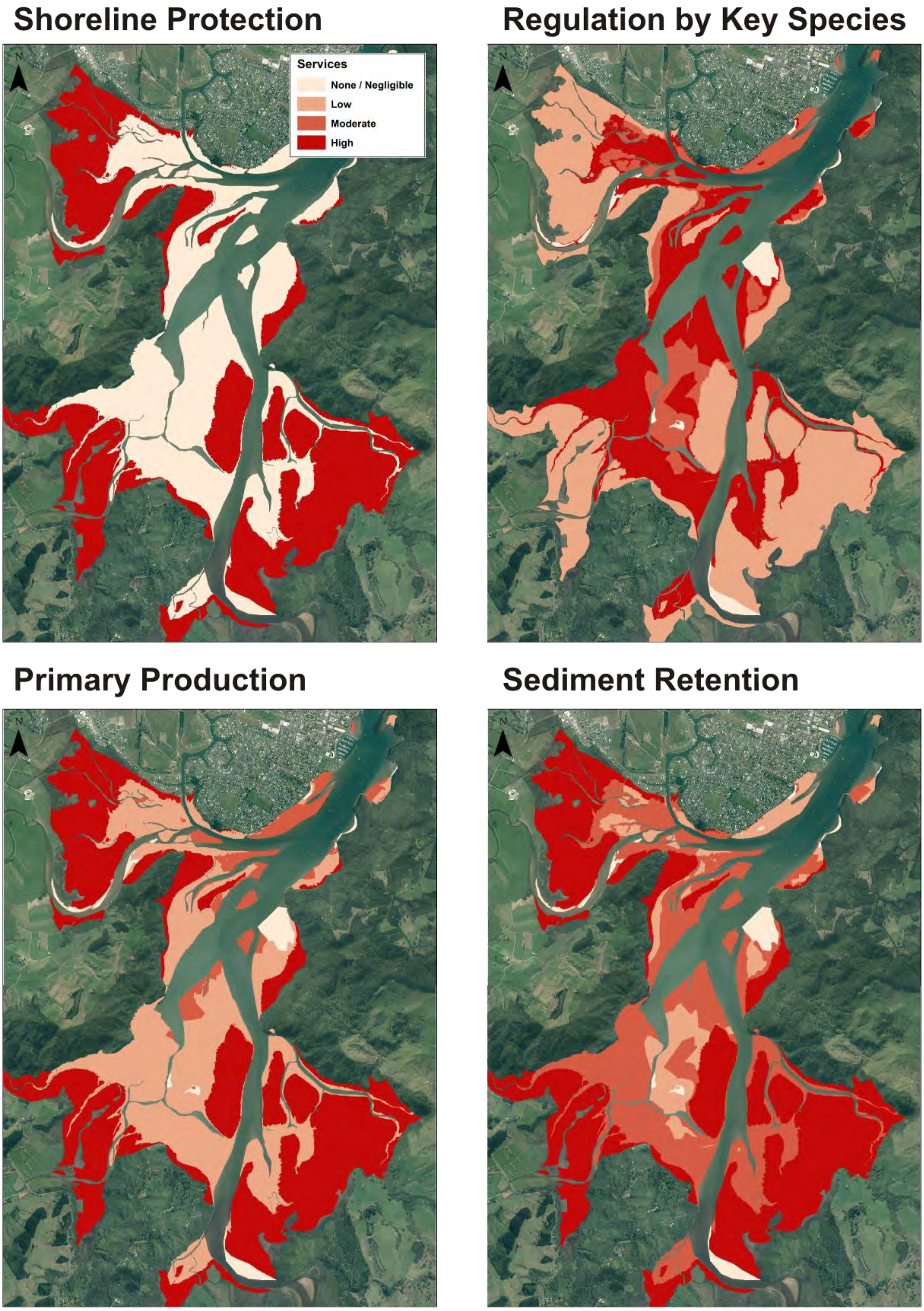


Figure 14 continued: Ecosystem service maps of Whitianga Harbour.

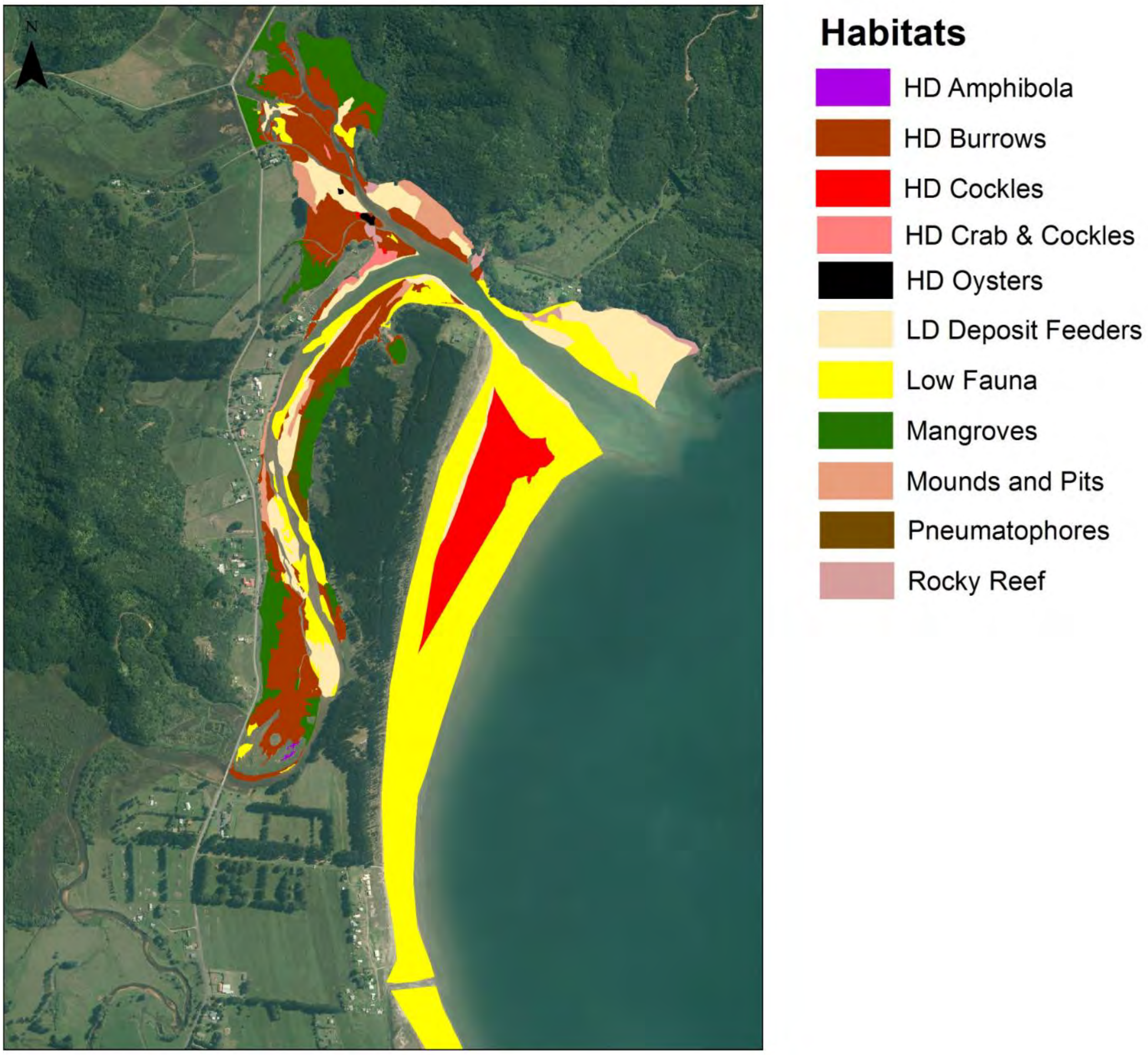


Figure 15: Habitat map of Kennedy Bay.

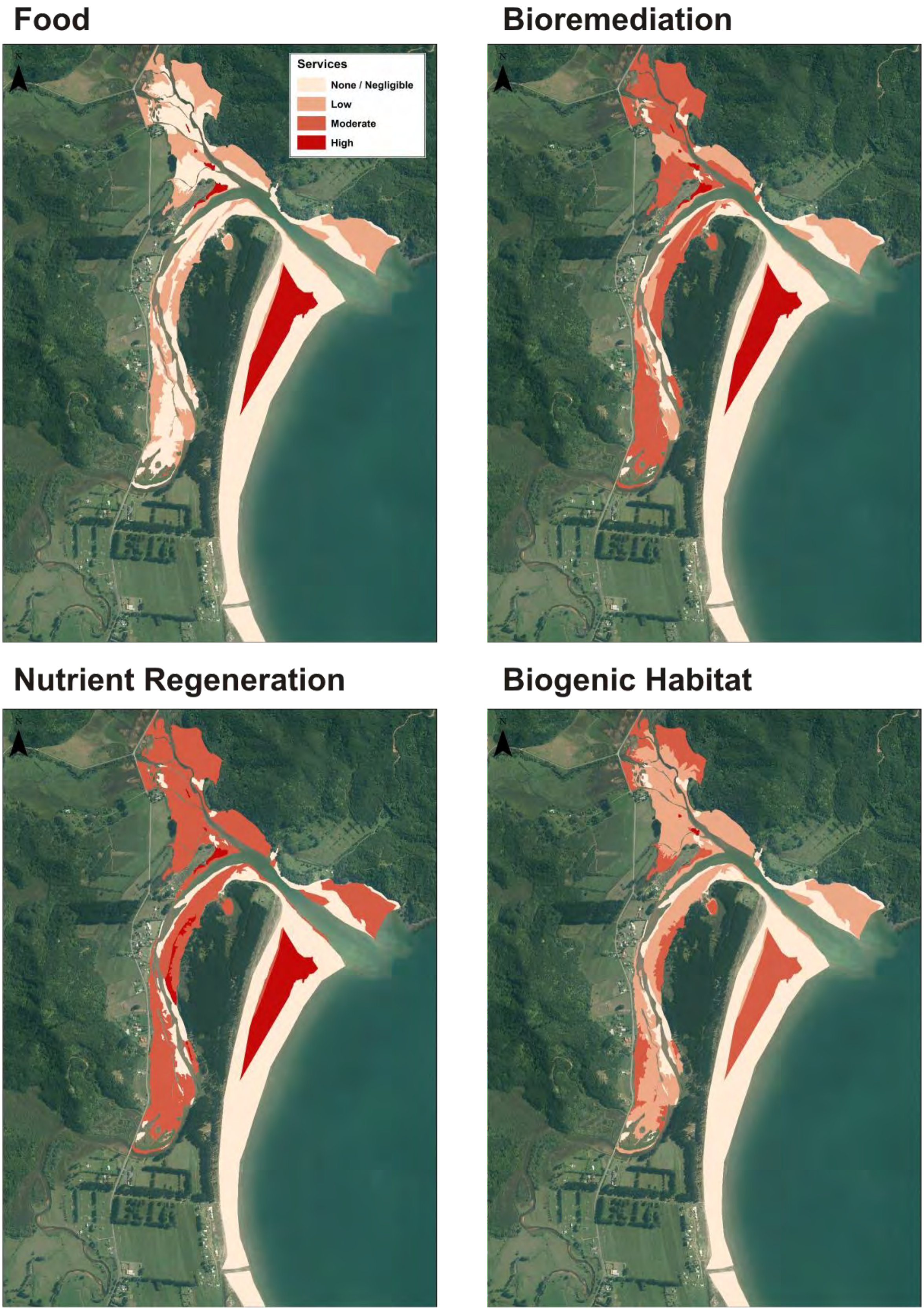


Figure 16: **Ecosystem service maps of Kennedy Bay.**

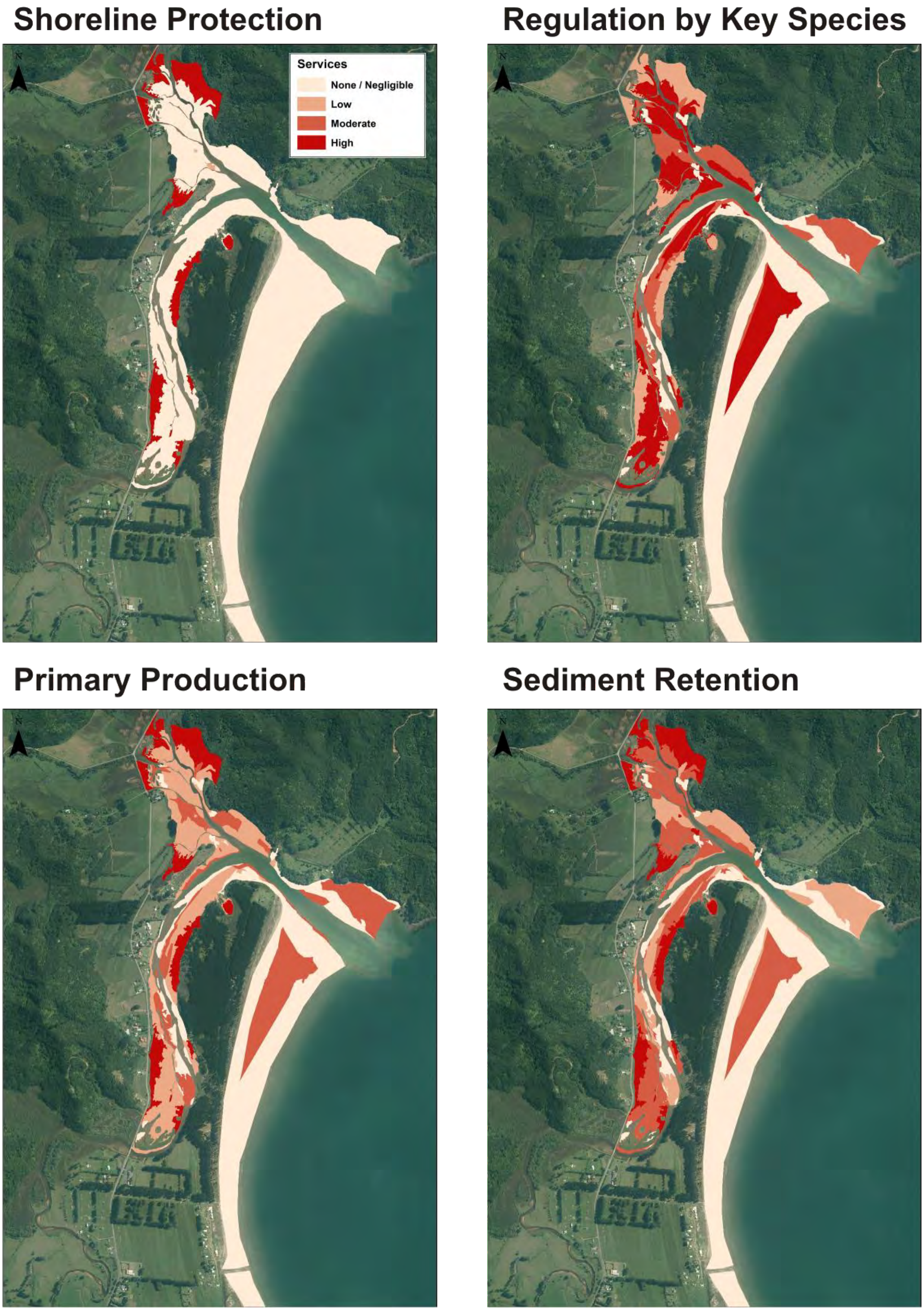


Figure 16 Continued: Ecosystem service maps of Kennedy Bay.

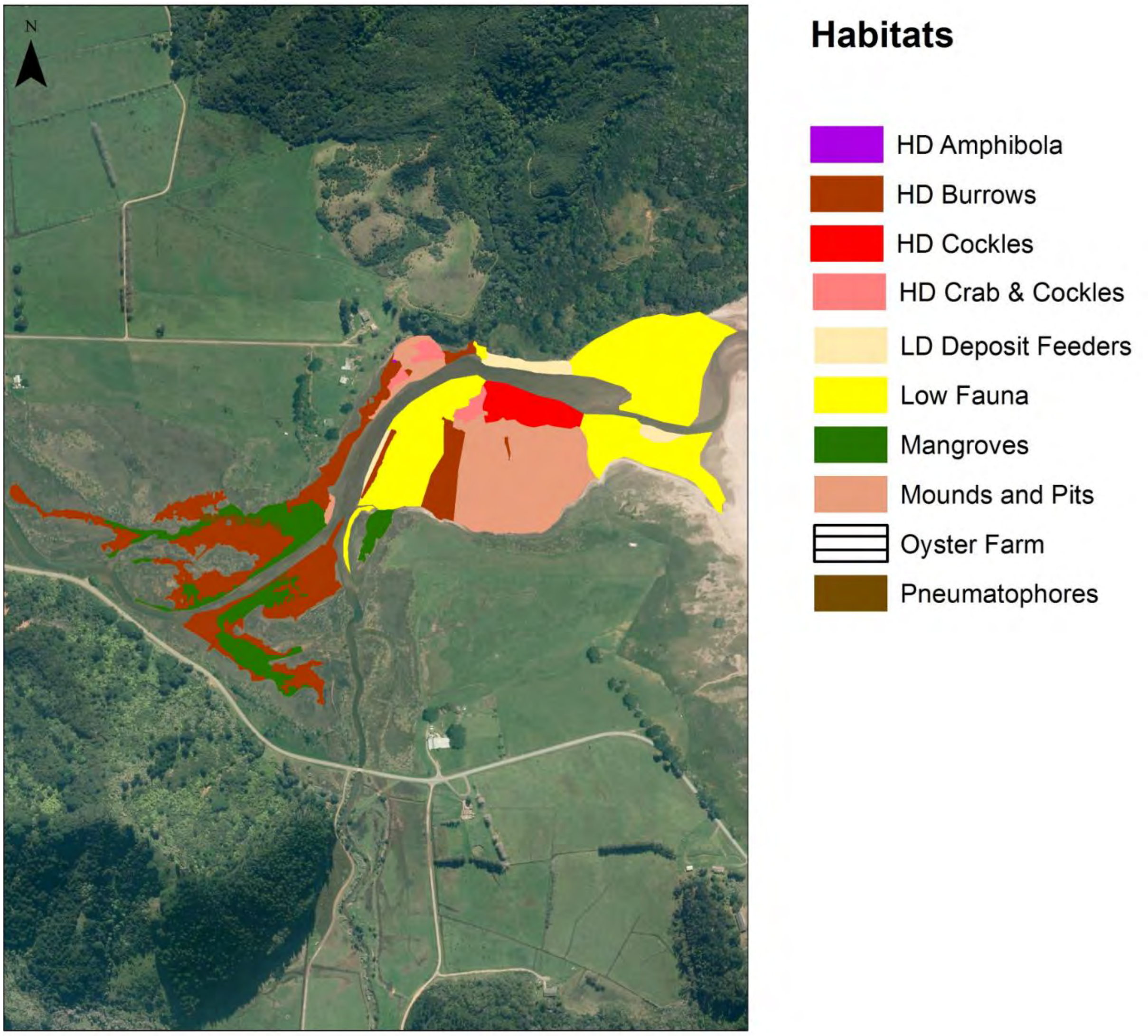


Figure 17: Habitat map of Waikawau estuary.

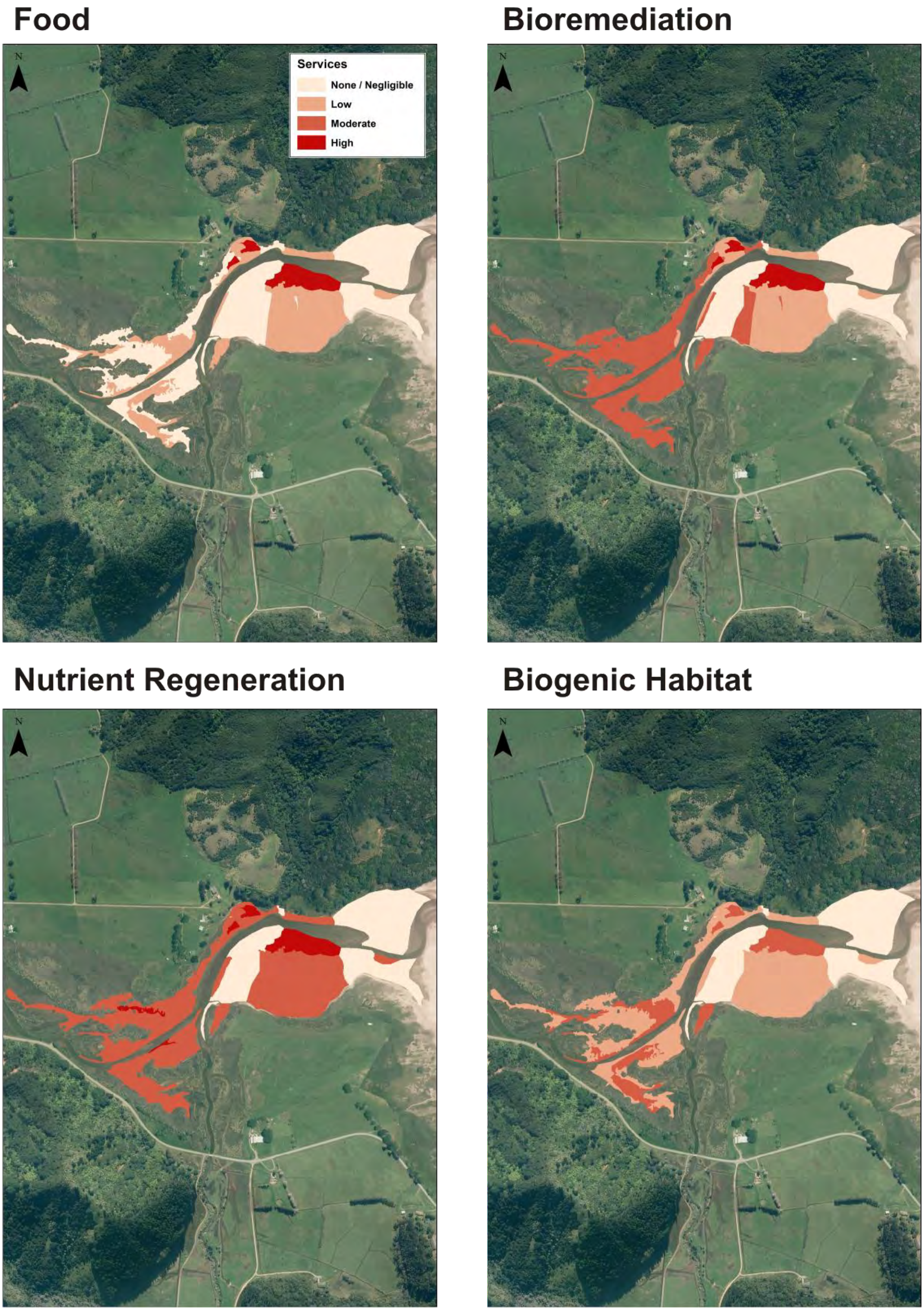


Figure 18: **Ecosystem service maps of Waikawau estuary.**

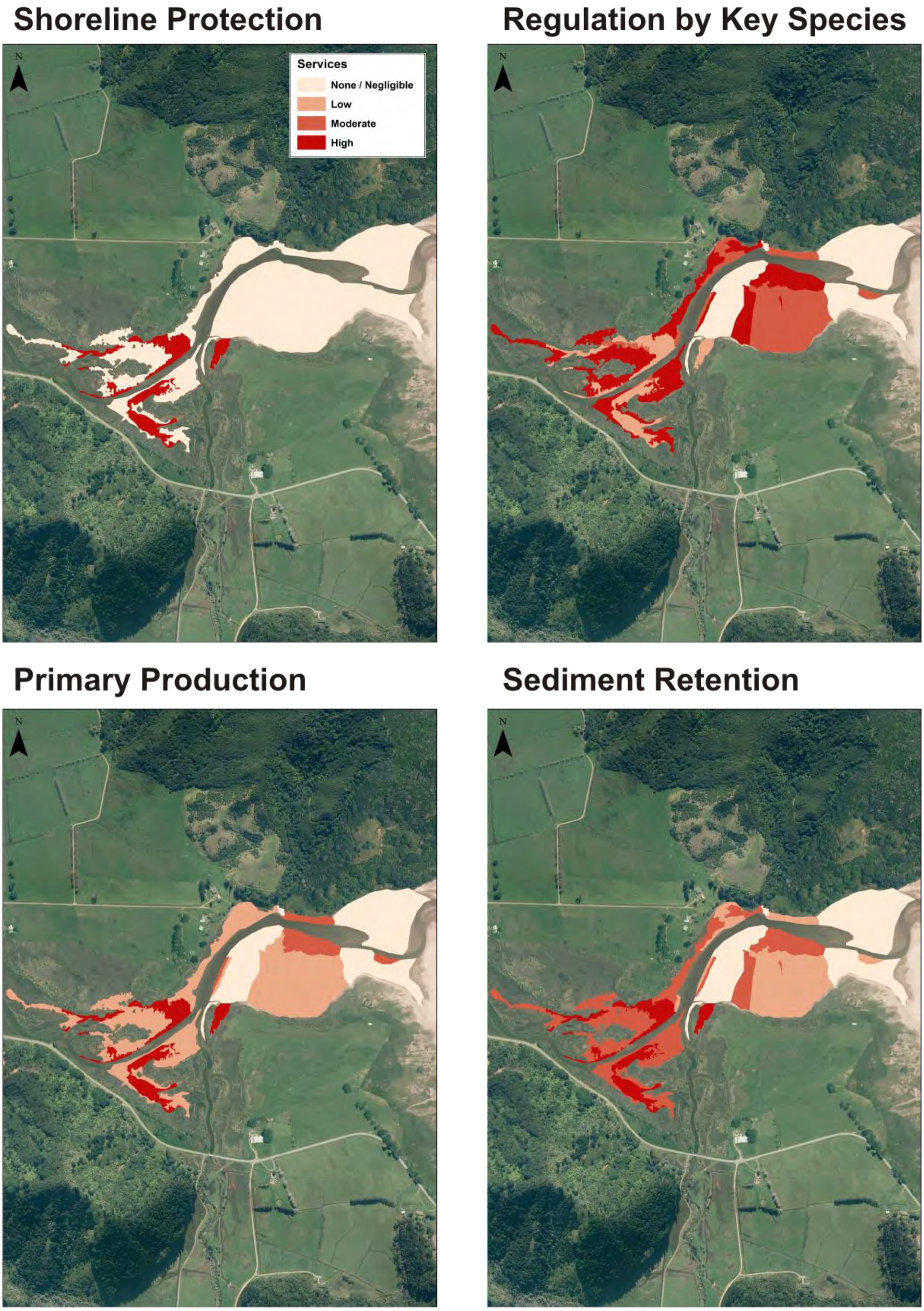


Figure 18 Continued: Ecosystem service maps of Waikawau estuary.

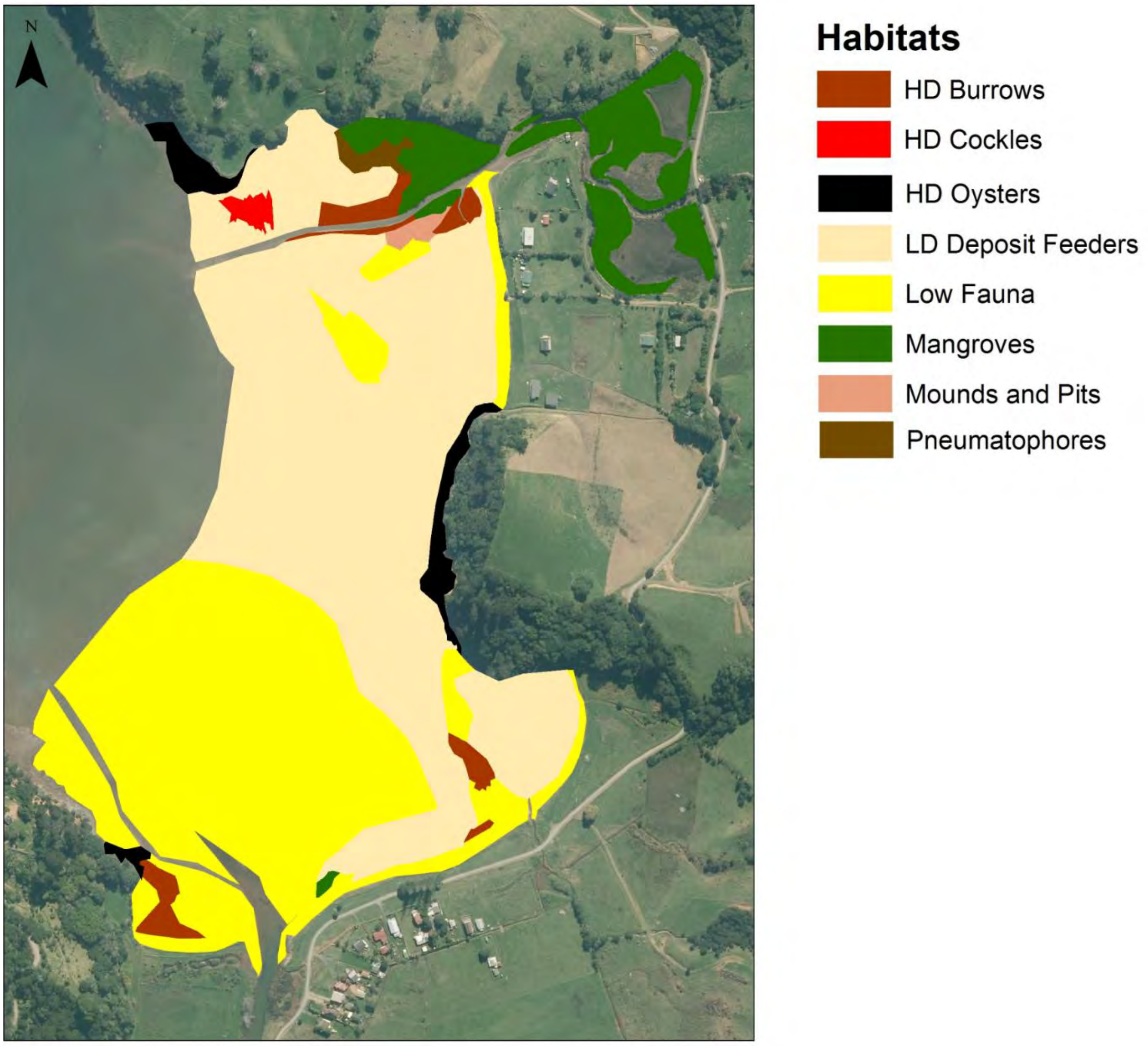


Figure 19: Habitat map of Port Charles.

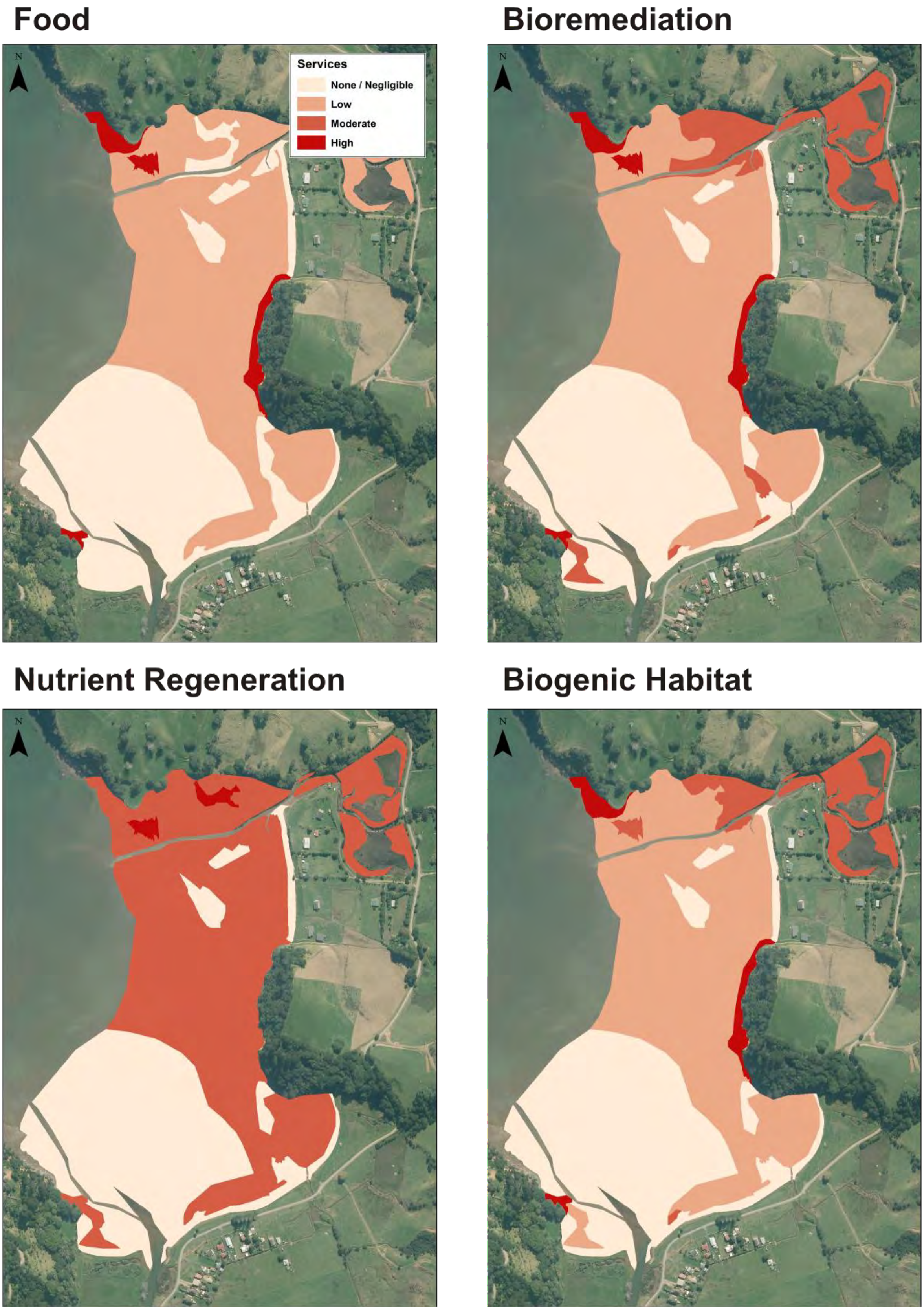


Figure 20: Ecosystem service maps of Port Charles.

Figure 20 Continued: Ecosystem service maps of Port Charles.

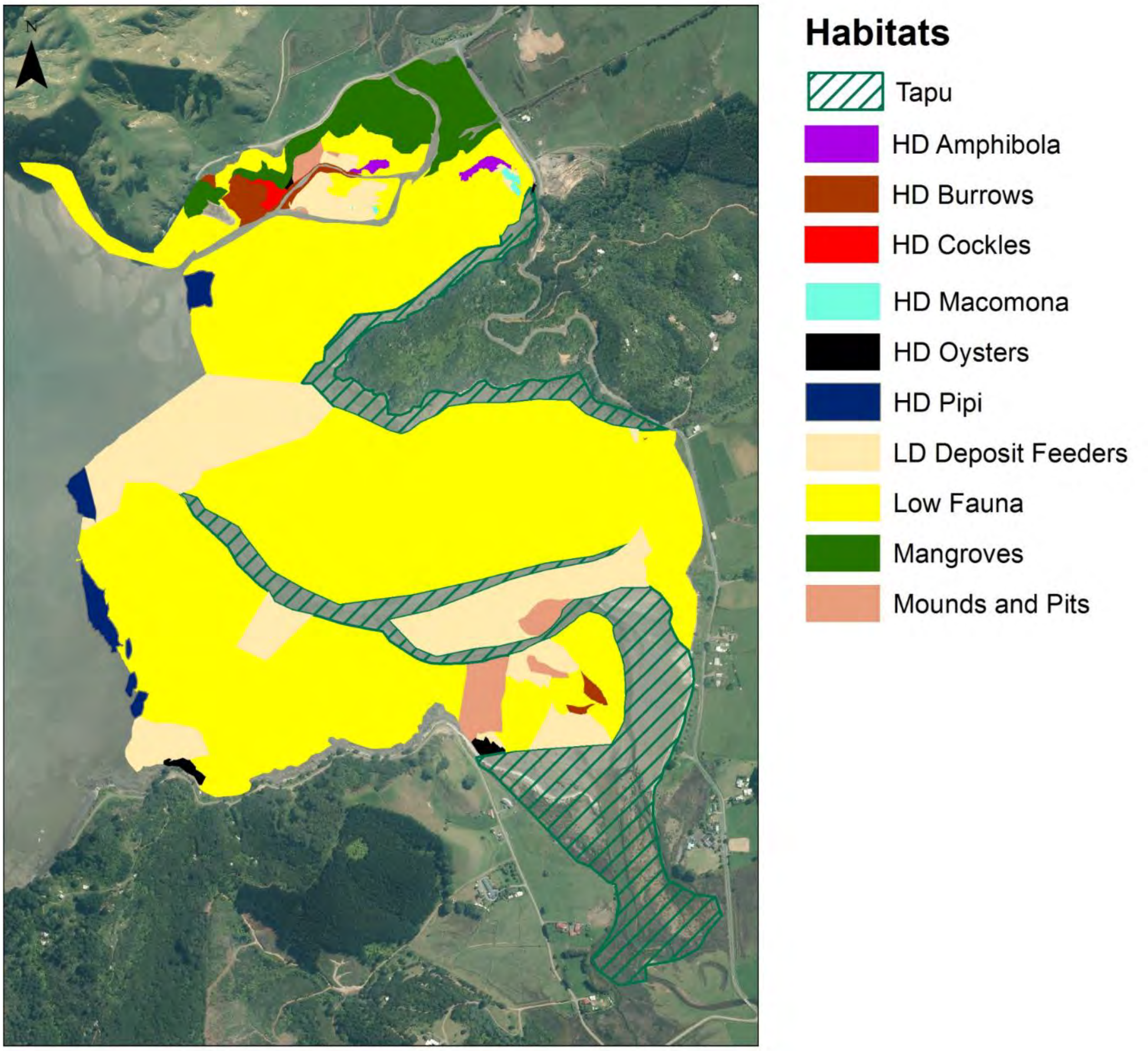


Figure 21: Habitat map of Colville Bay.

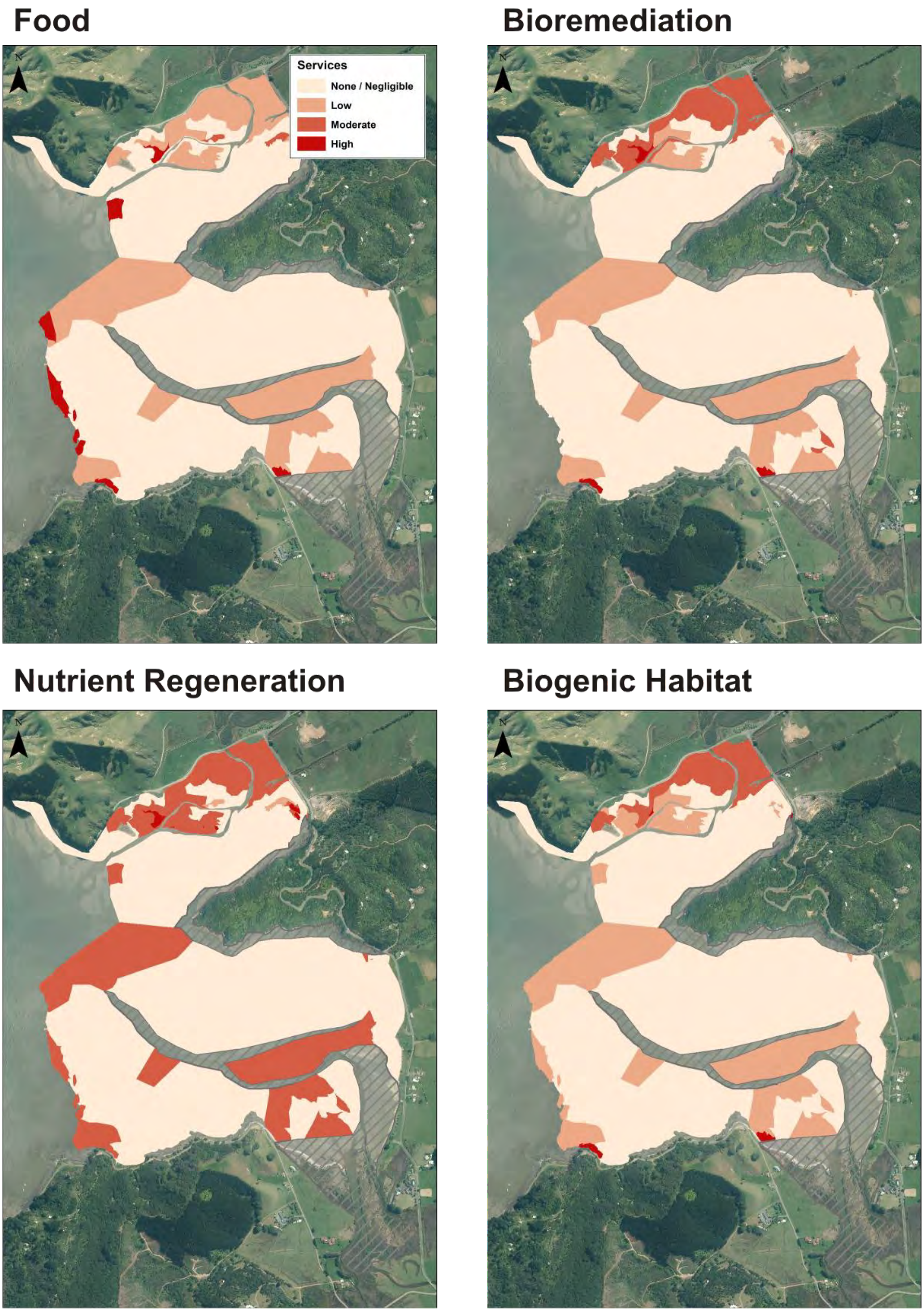


Figure 22: **Ecosystem service maps of Colville Bay.**

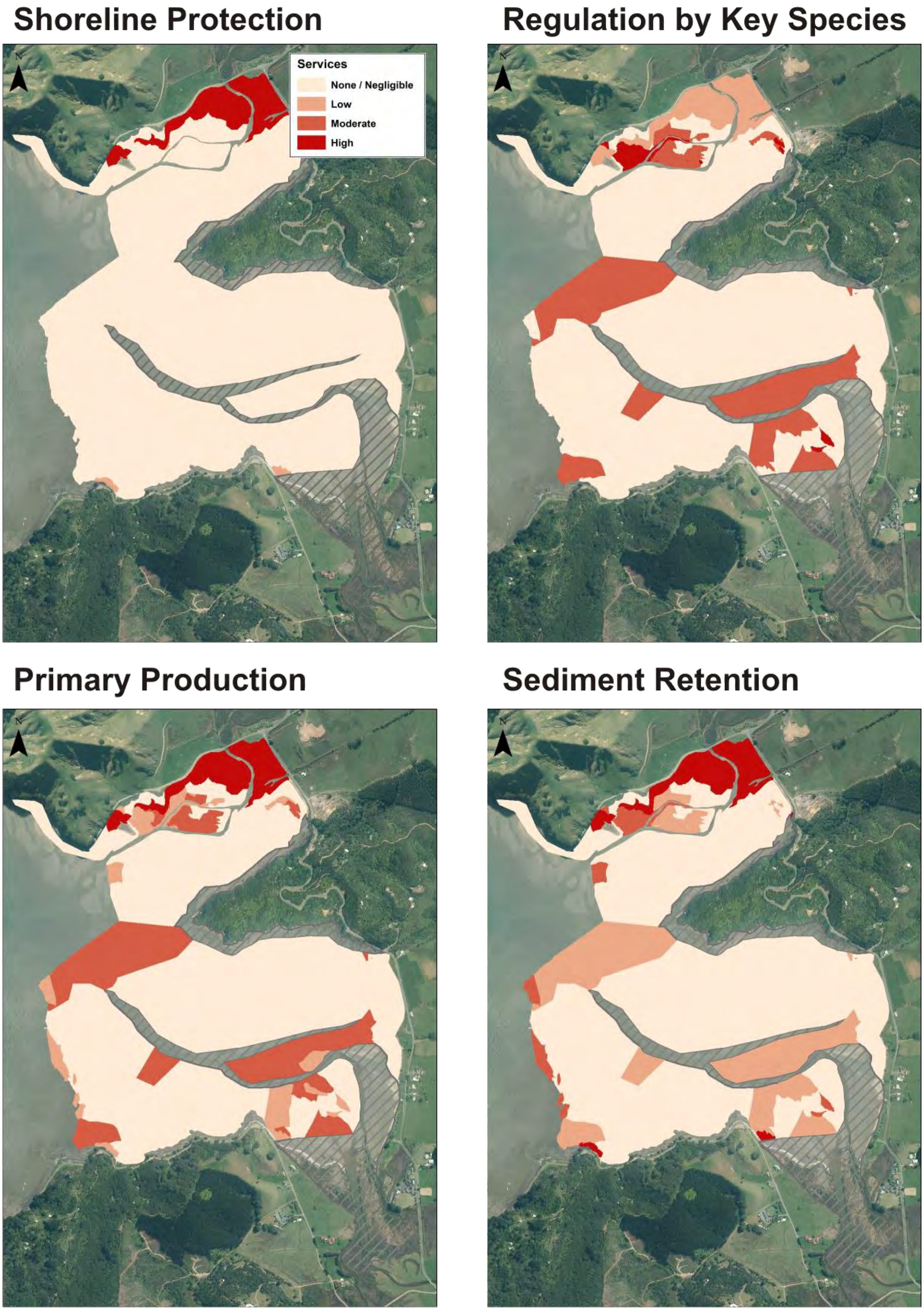


Figure 22 Continued: Ecosystem service maps of Colville Bay.

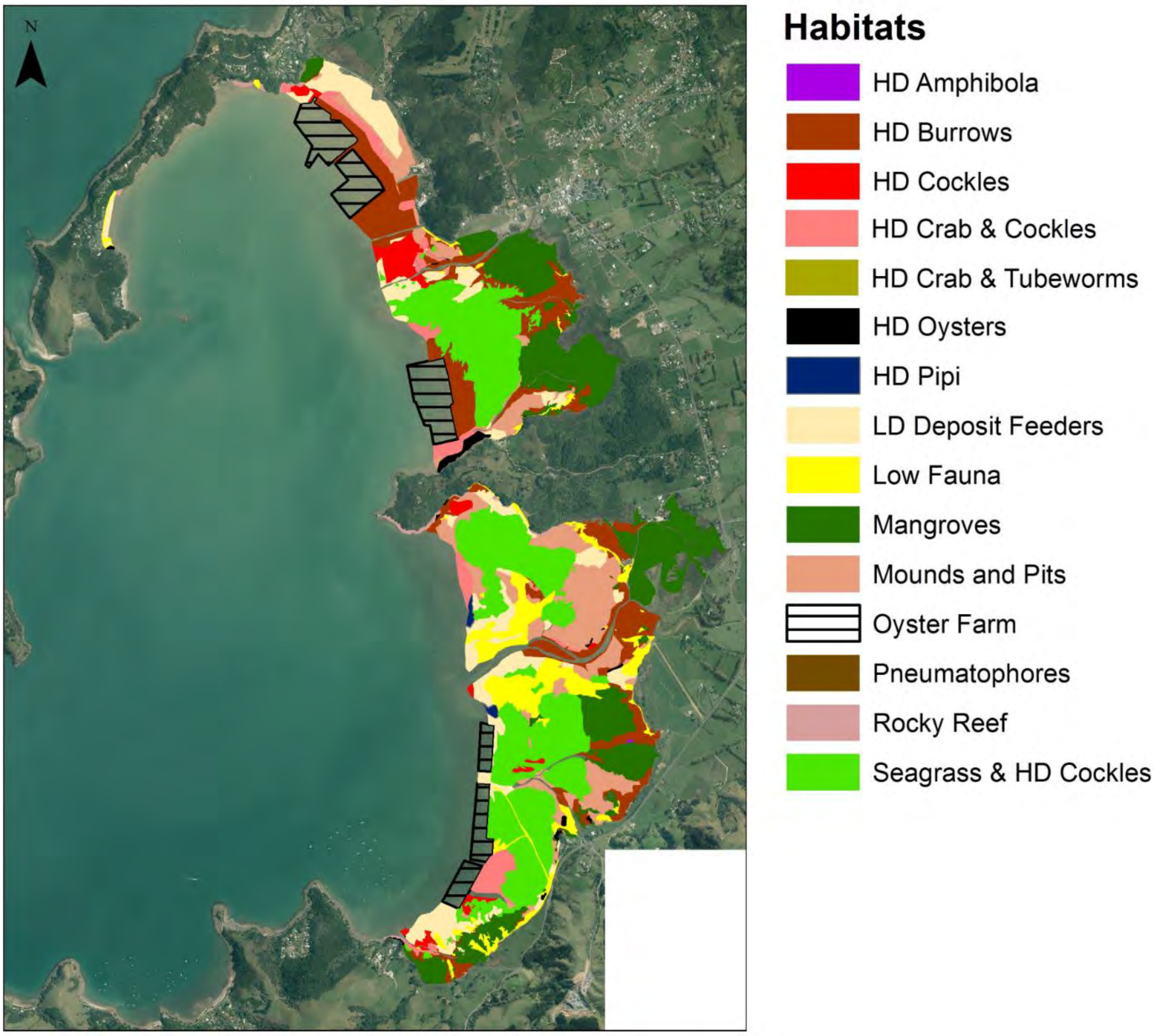


Figure 23: Habitat map of Coromandel Harbour.

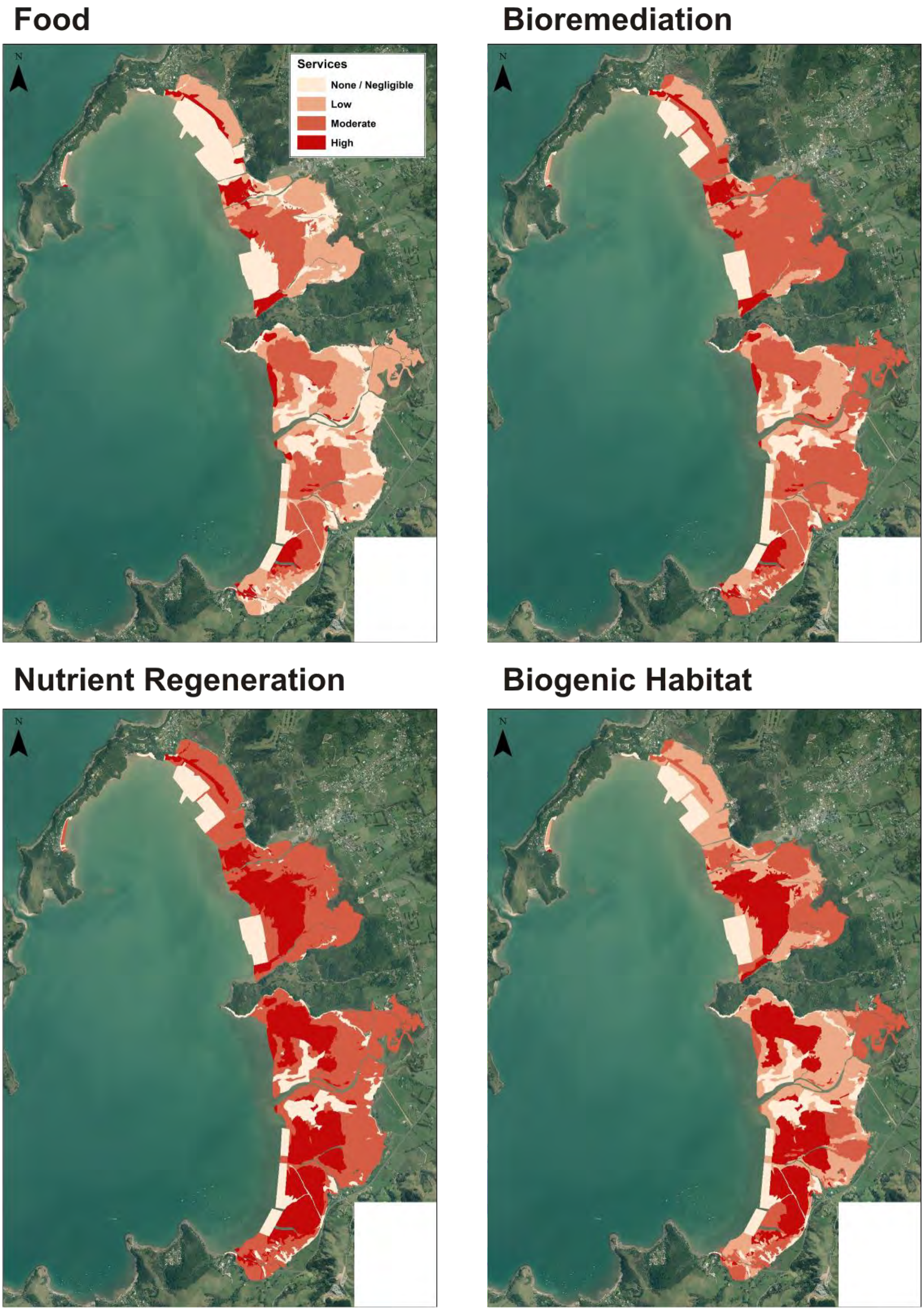


Figure 24: Ecosystem service maps of Coromandel Harbour.

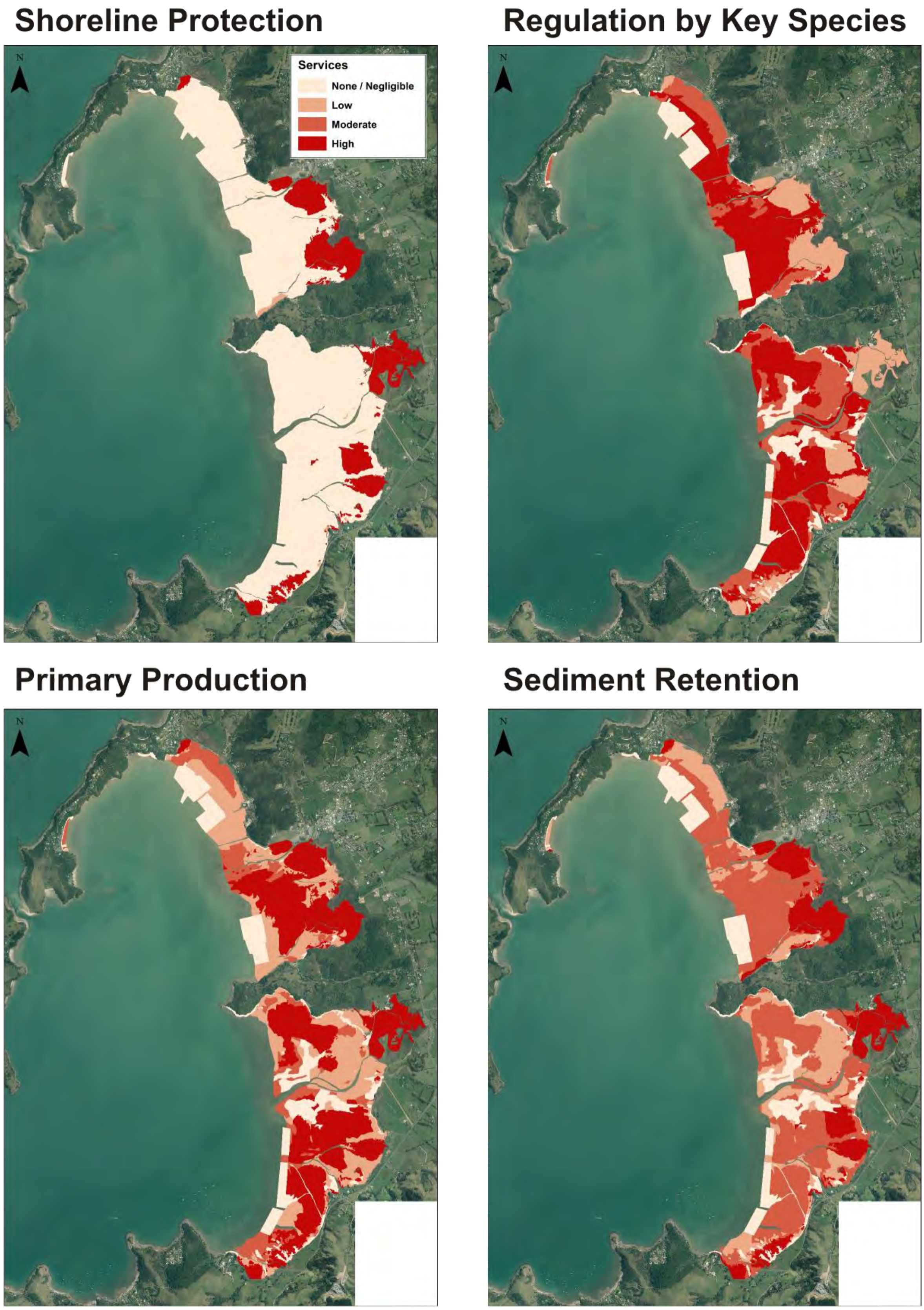


Figure 24 Continued: Ecosystem service maps of Coromandel Harbour.

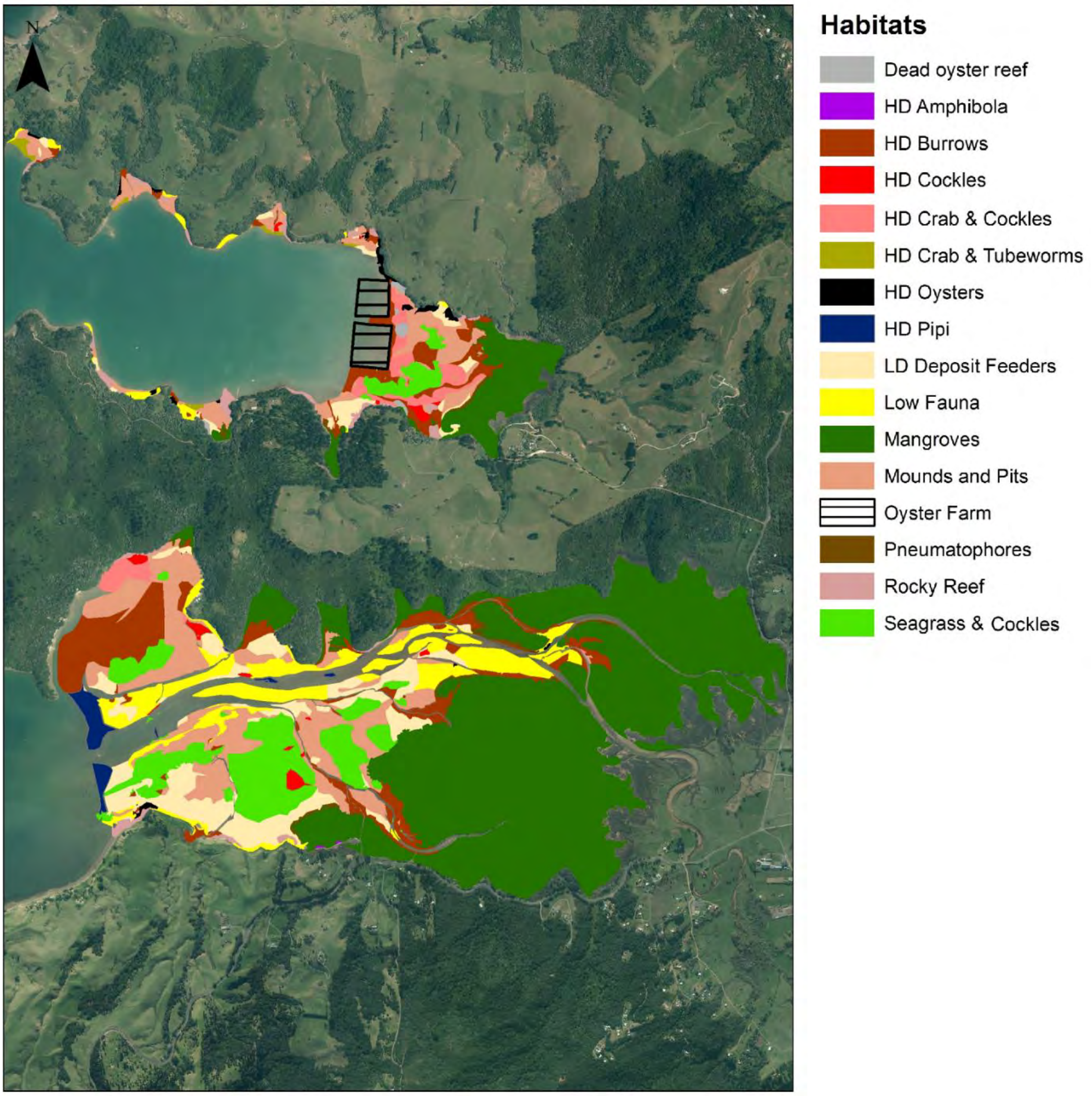


Figure 25: Habitat maps of Te Kouma and Manaia Harbours.

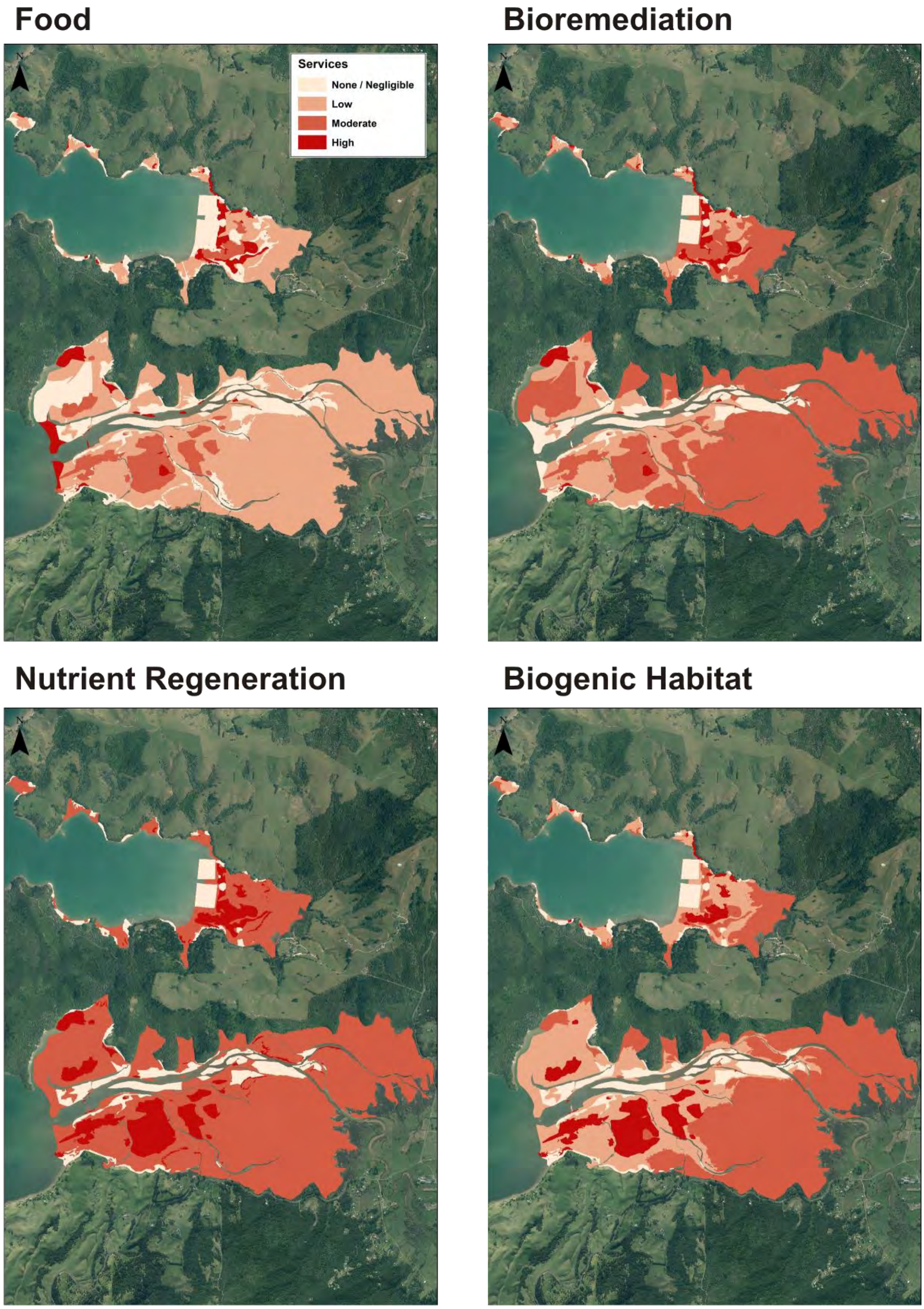


Figure 26: **Ecosystem service maps of Te Kouma and Manaia Harbours.**

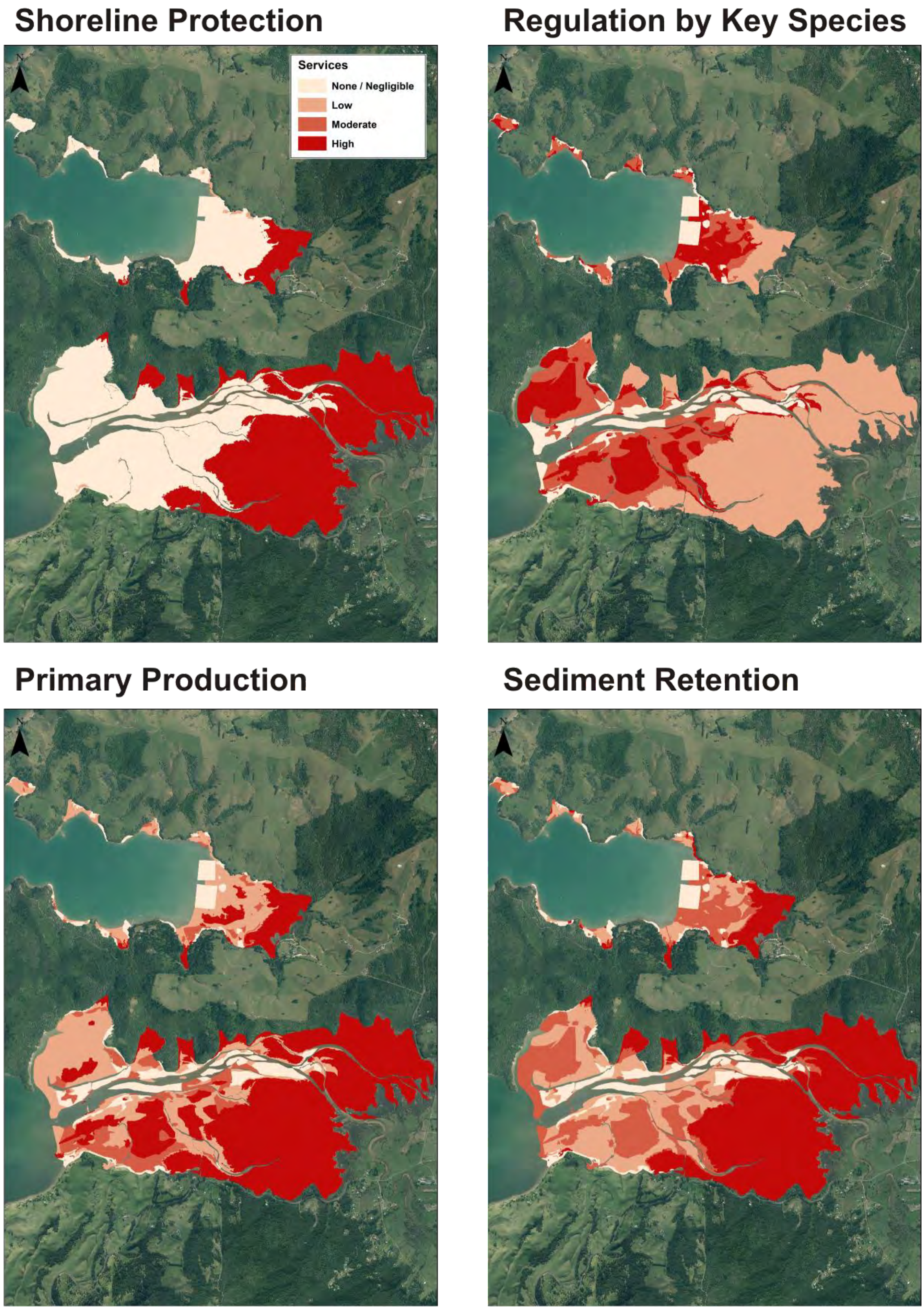


Figure 26 Continued: Ecosystem service maps of Te Kouma and Manaia Harbours.

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 interconnected[3]. 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	*In situ*
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	*In situ*

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.

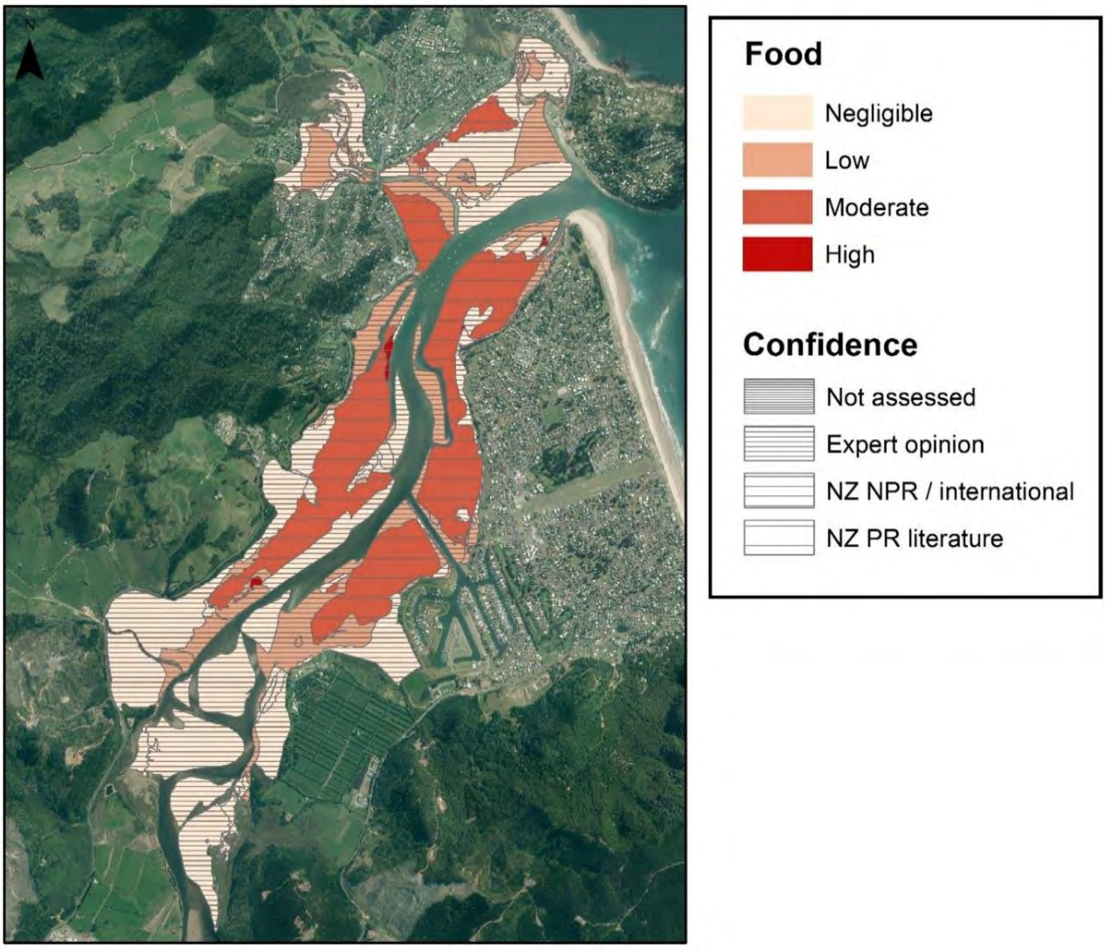


Figure 27: Ecosystem service maps of Tairua Harbour with Confidence layer superimposed. Confidence of 'NZ NPR / international' indicates the information source was either a non peer-reviewed report or was from peer-reviewed literature external to New Zealand; Confidence of 'NZ NPR literature' indicates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

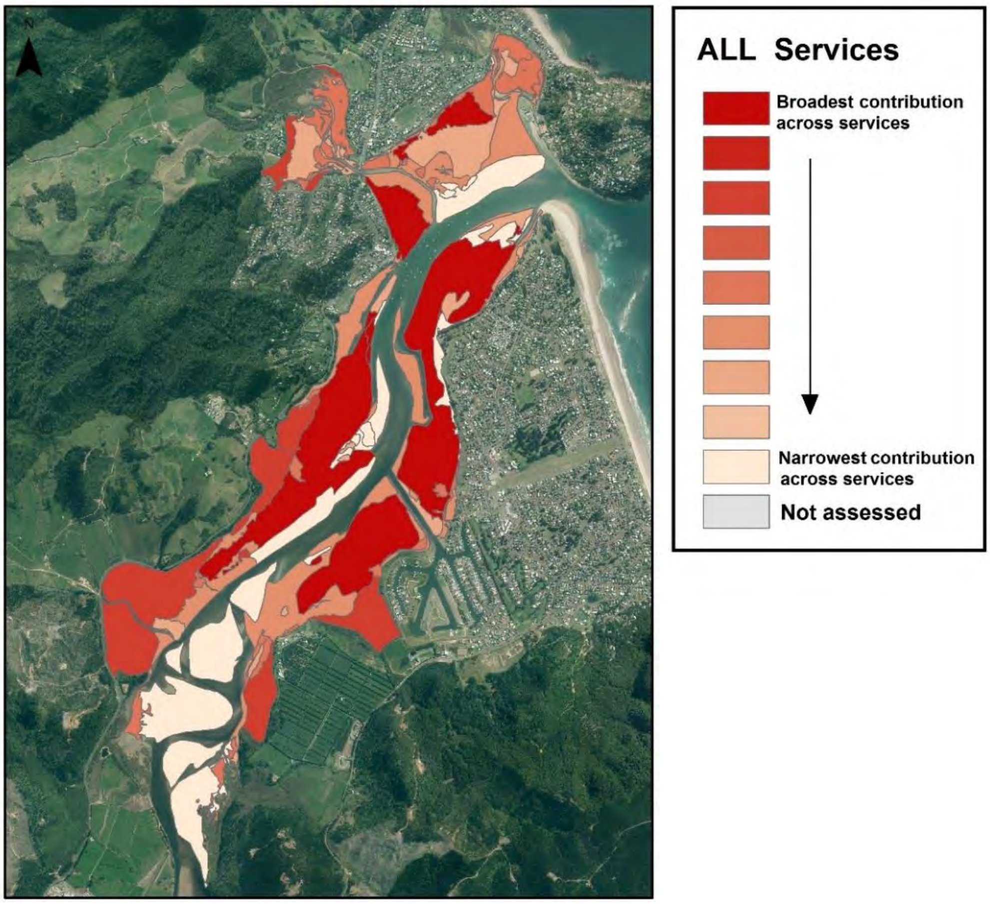


Figure 28: Summation of ecosystem service maps into a single layer to identify the breadth of habitat contributions for Tairua Harbour. Each service was scored depending on its contribution to a service (High = 3, moderate = 2, low = 1, negligible =0) and summed across the eight services. Summed scores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

We would like to thank the participants of an expert workshop for idea development: Malene Felsing, Shane Geange, Hilke Giles, Judi Hewitt, Steve Hunt, Hannah Jones, Russell O'Leary and Graeme Silver.

The original ecosystem service matrix was funded by the Department of Conservation (DOC) and developed by Drew Lohrer (NIWA), Dana Clark and Joanne Ellis (Cawthron Institute), Simon Thrush (University of Auckland) and Shane Geange (DOC). We also thank the 18 marine scientists who contributed to the matrix through an expert workshop and review process (May 12th 2014, Auckland).

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 *and* 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.

References

Batstone, C., Sinner, J. (2010) Techniques for evaluating community preferences for managing coastal ecosystems. Auckland region stormwater case study, discrete choice model estimation. Prepared by Cawthron Institute for Auckland Regional Council. *Auckland Regional Council Technical Report,* 2010/012.

Beaumont, N.J., Austen, M.C., Mangi, S.C., Townsend, M. (2008) Economic valuation for the conservation of marine biodiversity. *Mar. Pollut. Bull.,* 56: 386-396.

Boyd, J., Banzhaf, S. (2007) What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics*, 63(2-3): 616–626.

Burkhard, B., Kandziora, M., Hou, Y., Müller, F. (2014) Ecosystem service potentials, flows and demand–concepts for spatial localisation, indication and quantification. *Landsc Online.* 34:1–32.

Burkhard, B., Kroll, F., Müller, F., Windhorst, W. (2009) Landscapes' capacities to provide ecosystem services – a concept for land-cover based assessments. *Landsc Online.* 15:1–22.

Cahoon, L.B. (1999) The role of benthic microalgae in neritic ecosystems. *Oceanography and Marine Biology: Annual Review, 37*: 47-86.

Costanza, R. (2008) Ecosystem services: Multiple classification systems are needed. *Biological Conservation,* 141: 350-352.

Costanza, R. et al. (1997) The value of the world's ecosystem services and natural capital. *Nature,* 387: 253–260.

Daily, G.C. (1997) Introduction: What are ecosystem services? Pp. 1-10 in G. Daily, editor. *Nature's Services: Societal Dependence on Natural Ecosystems.* Island Press, Washington, D.C. (1997).

Daily, G.C., Söderqvist, T. et al. (2000) The Value of Nature and the Nature of Value. *Science*, 289(5478): 395–396.

Danielsen, F., Sorensen, M.K. et al. (2005) The Asian Tsunami: A protective role for coastal vegetation. *Science,* 310(5748): 643-643.

DeGroot, R.S. (1992) *Functions of nature: Evaluation of nature in environmental planning, management and decision making.* Wolters-Noordhoff, Groningen.

DeGroot, R.S., Wilson, M.A., Bounmans, R.M.J. (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics,* 41(3): 393-408.

Fenchel, T., Bernard, C. (1996) Behavioural responses in oxygen gradients of ciliates from microbial mats. *European Journal of Protistology,* 32(1): 55-63.

Fonseca, M.S., Cahallan, J.A. (1992) A preliminary evaluation of wave attenuation by four species of seagrass. *Estuarine, Coastal and Shelf Science,* 35: 565-576.

Haines-Young, R., Potschin, M. (2010) The links between biodiversity, ecosystem services and human well-being. In: Raffaelli, D.G & C.L.J. Frid (eds.): *Ecosystem Ecology: A New Synthesis.* Cambridge University Press, British Ecological Society: 110-139 (2010).

Hebel, M. (1999) World-view as the emergent property of human value system. *Systems Research and Behavioral Science,* 16: 253-261.

Hofstede, G. (1991) *Cultures and organisations: software of the mind*. McGraw-Hill International (UK) Limited, London: 279.

Holt, T.J., Rees, E.I., Hawkins, S.J., Seed. R. (1998) Biogenic Reefs (volume IX). *An overview of dynamic and sensitivity characteristics for conservation management of marine SACs*. Scottish Association for Marine Science (UK Marine SACs Project): 170 Jacobs et al. 2014

Jones, H.F.E., Pilditch, C.A., Bruesewitz, D.A., Lohrer, A.M. (2011) Sedimentary environment influences the effect of an infaunal suspension feeding bivalve on estuarine ecosystem function. *PLoS One 6:* e27065.

Lelieveld, S.D., Pilditch, C.A., Green, M.O. (2004) Effects of deposit-feeding bivalve (*Macomona liliana*) density on intertidal sediment stability. *New Zealand Journal of Marine and Freshwater Research,* 38 (1): 115-128.

Millennium Ecosystem Assessment (2003) *Ecosystems and human well-being: A framework for assessment.* Island Press, Washington, DC: 222.

Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Synthesis.* Island Press, Washington, DC. (2005).

Needham, H., Townsend, M., Hewitt, J. Hailes, S (2013a) Intertidal habitat mapping for ecosystem goods and services: Tairua Estuary. *Waikato Regional Council Report*, TR2014/39.

Needham, H., Townsend, M., Hewitt, J., Hailes, S. (2013b) Intertidal habitat mapping for ecosystem goods and services: Waikato Estuaries. *Waikato Regional Council Report*, TR2013/52.

Oviatt, C.A., Keller, A.A. et al. (1986) Patterns of productivity during eutrophication: a mesocosm experiment. *Marine Ecology Progress Series,* 28: 69-80.

Oviatt, C.A., Lane, P. et al. (1993) Phytoplankton species and abundance in response to eutrophication in coastal marine mesocosms. *Journal of Plankton Research,* 11(6): 1223-1244.

Potts, T., Burdon, D., Jackson, J., Atkins, J., Hastings, E., Langmead, O. (2014) Do marine protected areas deliver flows of ecosystem services to support human welfare? *Marine Policy*, 44: 139-148.

Sandwell, D.R., Pilditch, C.A., Lohrer, A.M. (2009) Density dependent effects of an infaunal suspension-feeding bivalve (*Austrovenus stutchburyi*) on sandflat nutrient fluxes and microphytobenthic productivity. *Journal of Experimental Marine Biology and Ecology,* 373: 16-25.

Sundbäck, K., Miles, A. et al. (2003) Importance of benthic nutrient regeneration during initiation of macroalgal blooms in shallow bays. *Marine Ecology Progress Series,* 246: 115-126.

Tait, R.V., Dipper, F.A. (1998) *Elements of Marine Ecology*. Oxford, Butterworth-Heinemann.

Thrush, S.F., Whitlatch, R.B. et al. (1996) Scale-dependent recolonization: the role of sediment stability in a dynamic sandflat habitat. *Ecology,* 77(8): 2472-2487.

Townsend, M., Clark, D., Lohrer, D., Ellis, J., Lundquist, C., Hewitt, J., Thrush, S. (2014) An Ecosystem Services Matrix for New Zealand's coastal marine environment. *Report prepared by NIWA for the Department of Conservation.*

UK NEA (2011) The UK National Ecosystem Services Assessment: Synthesis of the Key Findings, UNEP-WCMC, Cambridge. See also http://uknea.unep-wcmc.org/

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.

	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
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.

	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
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 (*Durvillaea*) 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
Ecklonia 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
Macrocystis 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:

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
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

- 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

Appendix B Supporting Literature

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

Cockles

Irwin, C.R. (2003) Maori and harvesting of the New Zealand littleneck clam (Austrovenus stutchburyi). *Proceedings of the 13th Biennial Coastal Zone Conference*, Baltimore, MD, July 13–17.

de Juan, S., Hewitt, J. (2011) Relative importance of local biotic and environmental factors versus regional factors in driving macrobenthic species richness in intertidal areas. *Marine Ecology Progress Series*, 423.

De Luca-Abbott, S. (2001) Biomarkers of Sublethal Stress in the Soft-Sediment Bivalve *Austrovenus stutchburyi* Exposed In-Situ to Contaminated Sediment in an Urban New Zealand Harbour. *Mar. Pollut. Bull*., 42(10): 817-825.

Gadd, J., Coco, G. et al. (2010) Interactions between heavy metals, sedimentation and cockle feeding and movement Part 3. Prepared for Auckland Regional Council.

Hewitt, J.E., Cummings, V.J. (2013) Context-dependent success of restoration of a key species, biodiversity and community composition. *Marine Ecology Progress Series*, 479.

Jones, H.F.E., Pilditch, C.A., Bruesewitz, D.A., Lohrer, A.M. (2011) Sedimentary Environment Influences the Effect of an Infaunal Suspension Feeding Bivalve on Estuarine Ecosystem Function. *PLoS ONE,* 6(10): e27065. doi:10.1371/journal.pone.0027065.

Ministry for Primary Industries (2013) Fisheries Assessment Plenary, May 2013: stock assessments and yield estimates. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington.

Sandwell, D.R., Pilditch, C.A., Lohrer, A.M. (2009) Density dependent effects of an infaunal suspension-feeding bivalve (Austrovenus stutchburyi) on sandflat nutrient fluxes and microphytobenthic productivity. *Journal of Experimental Marine Biology and Ecology,* 373(2009): 16–25.

Thrush, S., Hewitt, J.E., Gibbs, M., Lundquist, C., Norkko, A. (2006) Functional Role of Large Organisms in Intertidal Communities. *Community Effects and Ecosystem Function Ecosystems,* 9: 1029–1040.

Townsend, M., Phillips, N., Hewitt, J.E., Coco, G. (2009) Interactions between heavy metals, sedimentation and cockle feeding and movement. *Auckland Regional Council Report.*

Macomona

de Juan, S., Hewitt, J. (2011) Relative importance of local biotic and environmental factors versus regional factors in driving macrobenthic species richness in intertidal areas. *Marine Ecology Progress Series*, 423.

Lelieveld, S.D., Pilditch, C.A., Green, M.O. (2004) Effects of deposit-feeding bivalve (Macomona liliana) density on intertidal sediment stability. *New Zealand Journal of Marine and Freshwater Research*, 38(1).

Thrush, S.F., Hewitt, J.E., Pridmore, R.D., Cummings, V.J. (1996) Adult/ juvenile interactions of infaunal bivalves: contrasting outcomes in different habitats. Mar*. Ecol. Prog. Ser.* 132: 83–92.

Thrush, S.F., Pridmore, R.D., Hewitt, J.E., Cummings, V.J. (1992) Adult infauna as facilitators of colonization on intertidal sandflats*. J. Exp. Mar. Biol. Ecol.* 159: 253–265.

Woodin, S.A., Wethey, D.S., Hewitt, J.E., Thrush, S.F. (2012) Small scale terrestrial clay deposits on intertidal sandflats: Behavioral changes and productivity reduction*. Journal of Experimental Marine Biology and Ecology,* 413(2012): 184–191.

Tube worms

de Juan, S., Hewitt, J. (2011) Relative importance of local biotic and environmental factors versus regional factors in driving macrobenthic species richness in intertidal areas. *Marine Ecology Progress Series*, 423.

Friedrichs, M. et al. (2000) Skimming flow induced over a simulated polychaete tube lawn at low population densities. *Marine Ecology Progress Series,* 192: 219-228.

Larson, A.A., Stachowicz, J.J., Hentschel, B.T. (2009) The effect of a tube-building phoronid on associated infaunal species diversity, composition and community structure. *Journal of Experimental Marine Biology and Ecology,* 381(2009): 126–135.

Seagrass

Duarte, C.M., Cebrian, J. (1996) The fate of autotrophic production in the sea. *Limnol. Oceanogra.* 41: 1758–1766.

Duffy, J.E. (2006) Biodiversity and the functioning of seagrass ecosystems*. Mar. Ecol-Prog. Ser.* 311: 233–250.

Fonseca, M.S., Cahalanb, J.A. (1992) A preliminary evaluation of wave attenuation by four species of seagrass. *Estuarine, Coastal and Shelf Science*, Volume 35, Issue 6, December 1992: 565–576.

Fonseca, M.S., Fisher, J.S. (1986) A comparison of canopy friction and sediment movement between four species of seagrass with reference to the ecology and restoration. *Mar. Ecol-Prog. Ser.* 29: 15–22.

Fourqurean, J.W. et al. (2012) Seagrass ecosystems as a globally significant carbon stock. *Nat. Geosci.* 5: 505–509. doi:http://www.nature.com/ngeo/journal/v5/n7/abs/ngeo1477.html#supplementary-information.

http://www.niwa.co.nz/news/baby-snapper-all-grew-one-big-nursery

Kendrick, A.J., Hyndes, G.A. (2003) Patterns in the abundance and size-distribution of cynognathid fishes among habitats in a seagrass-dominated marine environment. *Estuarine, Coastal and Shelf Science*, 57(2003): 631–640.

Leduc, D. et al. (2006) Macroinvertebrate diet in intertidal seagrass and sandflat communities: a study using C, N, and S stable isotopes. *New Zealand Journal of Marine and Freshwater Research*, 40(4): 615-629.

Luisetti T., Jackson, E.L., Turner, R.K. (2013) Valuing the European 'coastal blue carbon' storage benefit. *Marine Pollution Bulletin*, 71(2013): 101–106.

Matheson, F.E., Schwarz, A.-M. (2007) Growth responses of *Zostera capricorni* to estuarine sediment conditions. *Aquatic Botany*, 87: 299–306.

Parsons, D.M. et al. (2013) The influence of habitat structure on juvenile fish in a New Zealand estuary. *Marine Ecology-an Evolutionary Perspective,* 34(4): 492-500.

Taylor, H.A., Rasheed, M.A. (2011) Impacts of a fuel oil spill on seagrass meadows in a subtropical port, Gladstone, Australia – The value of long-term marine habitat monitoring in high risk areas. *Marine Pollution Bulletin,* 63: 431–437.

Turner, S.J. (2007) Growth and productivity of intertidal *Zostera capricorni* in New Zealand estuaries. *New Zealand Journal of Marine and Freshwater Research*, Vol. 41: 77-90.

Turner, S.J., Schwarz, A.M. (2006) Biomass development and photosynthetic potential of intertidal Zostera capricorni in New Zealand estuaries. *Aquatic Botany,* 85: 53–64.

van Houte-Howes, S.S., Turner, S.J., Pilditch, C.A. (2004). Spatial differences in macroinvertebrate communities in intertidal seagrass habitats and unvegetated sediment in three New Zealand estuaries. *Estuaries,* 27: 945e957.

Watson, R.A., Coles, R.G., Lee Long, W.J. (1993) Simulation estimates of annual yield and landed value for commercial penaeid prawns from a tropical seagrass habitat, northern Queensland. *Aust. J. Mar. Fresh. Res*. 44: 211–220.

Mangroves & Pneumatophores

Alongi, D.M. (2008) Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. *Estuar. Coast Shelf Sci*: 76: 1–13.

Brinkman, R.M., Massel, S.R., Ridd, P.V., Furukawa, K. (1997) Surface wave attenuation in mangrove forests. Centre for Advanced Engineering, University of Canterbury, Christchurch.

Alongi, D.M., Tirendi, F., Clough, B.F. (2000) Below-ground decomposition of organic matter in forests of the mangroves *Rhizophora stylosa* and *Avicennia marina* along the arid coast of Western Australia. *Aquatic Botany*, 68(2000): 97–122.

Alongi, D.M. (2011) Carbon payments for mangrove conservation: ecosystem constraints and uncertainties of sequestration potential. *Environmental Science and Policy,* 14: 462 –470.

Gladstone-Gallagher, R.V. (2012) Production and decay of mangrove (Avicennia marina subsp. australasica) detritus and its effects on coastal benthic communities. *(Thesis, Master of Science (MSc)).* University of Waikato, Hamilton, New Zealand. Retrieved from http://hdl.handle.net/10289/7036.

McAlpine, K.G., Wotton, D.M. Conservation and the delivery of ecosystem services. A literature review. *Science for Conservation,* 295.

Morrisey, D., Beard, C., Morrison, M., Craggs, R., Lowe, M. (2007) The New Zealand mangrove: review of the current state of knowledge. Report prepared for Auckland Regional Council by National Institute of Water & Atmospheric Research Ltd (NIWA). *NIWA Client Report*: HAM2007-052.

Morrisey, D. et al. (2010) The Ecology and Management of Temperate Mangroves. *Oceanography and Marine Biology: An Annual Review*, 48: 43-160.

Phuoc, V.L.H., Massel, S.R. (2006) Experiments on wave motion and suspended sediment concentration at Nang Hai, CanGio mangrove forest, southern Vietnam. *Oceanologia,* 48: 23–40.

Yang, et al. (2013) Vegetation and sediment characteristics in an expanding mangrove forest in New Zealand Under the protection of seaward fringe mangroves, mangrove-derived carbon is retained and stored in the interior sediment. *Estuarine, Coastal and Shelf Science*, 134: 11e18.

Crabs

Needham, H.R., Pilditch, C.A., Lohrer, A.M., Thrush, S.F. (2010) Habitat dependence in the functional traits of *Austrohelice crassa*, a key bioturbating species. *MEPS*, 414: 179-193.

Needham, H.R., Pilditch, C.A., Lohrer, A.M., Thrush, S.F. (2010) The role of functional plasticity of a key bioturbator in the regulation of nutrient cycling. In *45th European Marine Biology Symposium*. Conference held at Heriot-Watt University, Edinburgh.

Needham, H.R., Pilditch, C.A., Lohrer, A.M., Thrush, S.F. (2013) Density and habitat dependent effects of crab burrows on sediment erodibility. *Journal of Sea Research*, 76: 94–104.

Needham, H.R., Pilditch, C., Lohrer, D., Thrush, S. (2011) Context-Specific Bioturbation Mediates Changes to Ecosystem Functioning. *Ecosystems,* November 2011, Volume 14, Issue 7: 1096-1109.

Williamson, B.R., Wilcock, W.I., Wise, B.E., Pickmere, S. (1999) Effect of burrowing by the crab helice crassa on chemistry of intertidal muddy sediments. *Environmental Toxicology and Chemistry*, Vol. 18, No. 9: 2078–2086.

Pipi

Akroyd, J.A.M. et al. (2002) Abundance, distribution, and size structure of toheroa (Paphies ventricosa) at Ripiro Beach, Dargaville, Northland, New Zealand. *New Zealand Journal of Marine and Freshwater Research,* 2002, Vol. 36: 547-553.

Ansell, A.D. (2001) Dynamics of Aggregations of a Gastropod Predator/Scavenger on a New Zealand Harbour Beach. *J. Moll. Stud.*, 67: 329–341.

Cummings, V.J., Thrush, S.F. (2004) Behavioural response of juvenile bivalves to terrestrial sediment deposits: implications for post-disturbance recolonisation. *Marine Ecology Progress Series*, 278: 179-191.

Davidson, J.M. (1967) Midden analysis and the economic approach in New Zealand archaeology. *Record of the Auckland Institute Museum,* 6: 203-208.

Fisheries Assessment Plenary. May 2013: stock assessments and yield estimates. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington.

Hooker, S.H. (1995) Preliminary evidence for post-settlement movement of juvenile and adult pipi, *Paphies australis* (Gmelin, 1790) (Bivalvia: Mesodesmatidae*). Marine and Freshwater Behaviour and Physiology*, 27(1): 37-47.

Hooker, S.H., Creese, R.G. (1995) The reproductive biology of the pipi, *Paphies australis* (Gmelin,1790) (Bivalvia: Mesodesmatidae). I. Temporal patterns of the reproductive cycle. *Journal of Shellfish Research,* 14(1): 7-15.

http://www.panoramio.com/photo/7057884

Hull, P.J., Cole, R.G., Creese, R.G., Healy, T.R. (1998) An experimental investigation of the furrowing behaviour of *Paphies australis* (Bivalvia : Mesodesmatidae). *Marine and Freshwater Behaviour and Phyisology*, 31(3): 167-183.

Norkko, J., Hewitt, J.E., Thrush, S.F. (2006) Effects of increased sedimentation on the physiology of two estuarine soft-sediment bivalves, *Austrovenus stutchburyi* and *Paphies australis*. *Journal of Experimental Marine Biology and Ecology*, 333(1): 12-26.

Oysters

Achour, A., Lachgar, A., Astgen, A., Chams, V., Bizzini, B., Tapiero, H., Zagury, D. (1997) Potentialization of IL-2 effects on immune cells by oyster extract (JCOE) in normal and HIV-infected individuals. *Biomedicine & Pharmacotherapy*, 51(10): 427-429.

Airoldi, L., Balata, D., Beck, M.W. (2008) The Gray Zone: Relationships between habitat loss and marine diversity and their applications in conservation*. Journal of Experimental Marine Biology and Ecology*, 366(1-2): 8-15.

Anderson, R.S., Beaven, A.E. (2001) Antibacterial activities of oyster (*Crassostrea virginica*) and mussel (*Mytilus edulis* and *Geukensia demissa*) plasma. *Aquatic Living Resources,* 14(6): 343-349.

Aquaculture New Zealand (2011) Pacific Oysters. http://aquaculture.org.nz/industry/pacific-oysters/ [accessed 05/05/14]

Breitburg, D.L., Coen, L.D., Luckenbach, M.W., Posey, M.H., Wesson, J.A. (2000) Oyster reef restoration: convergence of harvest and conservation strategies. *Journal of Shellfish Research*, 19(1): 371-377.

Cerco, C., Noel, M. (2007) Can oyster restoration reverse cultural eutrophication in Chesapeake Bay? *Estuaries and Coasts,* 30(2): 331-343.

Coen, L.D., Brumbaugh, R.D., Bushek, D., Grizzle, R., Luckenbach, M.W., Posey, M.H., Powers, S.P., Tolley, S.G. (2007) Ecosystem services related to oyster restoration. *Marine Ecology Progress Series,* 341: 303-307.

Coen, L.D., Luckenbach, M.W., Breitburg, D.L. (1999) The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. In Fish habitat: essential fish habitat and rehabilitation. Benaka LR, ed*. American Fisheries Society, Symposium*, 22, Bethesda, MD: 438-454.

Dame, R.F., Zingmark, R.G., Haskin, E. (1984) Oyster reefs as processors of estuarine materials. *Journal of Experimental Marine Biology and Ecology,* 83: 239-247.

zu Ermgassen, P.S.E., Gray, M.W., Langdon, C.J., Spalding, M.D., Brumbaugh, R.D. (2013) Quantifying the historic contribution of Olympia oysters to filtration in Pacific Coast (USA) estuaries and the implications for restoration objectives. *Estuaries and Coasts* Published online 24 February 2013.

zu Ermgassen, P.S.E., Spalding, M.D., Grizzle, R.E., Brumbaugh, R.D. (2013) Quantifying the Loss of a Marine Ecosystem Service: Filtration by the Eastern Oyster in US Estuaries. *Estuaries and Coasts,* 36: 36-43.

Freeman, A.M., III (1995) The Benefits of Water Quality Improvements for Marine Recreation: A Review of the Empirical Evidence. *Marine Resource Economics*, 10(4): 385-406.

Fujita, T., Fukase, M., Miyamoto, H., Matsumoto, T., Ohue, T. (1990) Increase of bone mineral density by calcium supplement with oyster shell electrolysate. *Bone and Mineral,* 11(1): 85-91.

Gifford, S., Dunstan, R.H., O'Connor, W., Roberts, T., Toia, R. (2004) Pearl aquaculture - profitable environmental remediation? *Science of the Total Environment*, 319(1-3): 27-37.

Gifford, S., Dunstan, H., O'Connor, W., MacFarlane, G.R. (2005) Quantification of in situ nutrient and heavy metal remediation by a small pearl oyster (*Pinctada imbricata*) farm at Port Stephens, Australia. *Marine Pollution Bulletin,* 50(4): 417-422.

Gifford, S., Dunstan, R.H., O'Connor, W., Koller, C.E., MacFarlane, G.R. (2007) Aquatic zooremediation: deploying animals to remediate contaminated aquatic environments. *Trends in Biotechnology,* 25(2): 60-65.

Gili, J.M., Coma, R. (1998) Benthic suspension feeders: their paramount role in littoral marine food webs. *Trends in Ecology & Evolution*, 13(8): 316-321.

Grabowski, J.H., Peterson, C.H. (2007) Restoring oyster reefs to recover ecosystem services. In: Cuddington, K., Byers, J.E., Wilson, W.G., Hastings, A. ed. *Ecosystem engineers: concepts, theory and applications.* Elsevier-Academic Press, Amsterdam: 281-298.

Grabowski, J.H., Brumbaugh, R.D., Conrad, R.F., Keeler, A.G., OJ, J., Peterson, C.H., Piehler, M.F., Powers, S.P., Smyth, A.R. (2012) Economic Valuation of Ecosystem Services Provided by Oyster Reefs. *Bioscience*, 62(10): 900-909.

Grizzle, R.E., Greene, J.K., Coen, L.D. (2008) Seston Removal by Natural and Constructed Intertidal Eastern Oyster (*Crassostrea virginica*) Reefs: A Comparison with Previous Laboratory Studies, and the Value of in situ Methods. *Estuaries and Coasts*, 31(6): 1208-1220.

James, N.P., Reid, C.M., Bone, Y., Levings, A., Malcolm, I. (2013) The macroalgal carbonate factory at a cool-to-warm temperate marine transition, Southern Australia*. Sedimentary Geology*, 291: 1-26.

Jones, A.B., Dennison, W.C., Preston, N.P. (2001) Integrated treatment of shrimp effluent by sedimentation, oyster filtration and macroalgal absorption: a laboratory scale study. *Aquaculture*, 193(1-2): 155-178.

Kwon, H.B., Lee, C.W., Jun, B.S., Yun, J.D., Weon, S.Y., Koopman, B. (2004) Recycling waste oyster shells for eutrophication control. *Resources Conservation and Recycling,* 41(1): 75-82.

La Peyre, M.K., Humphries, A.T., Casas, S.M., La Peyre, J.F. (2014) Temporal variation in development of ecosystem services from oyster reef restoration. *Ecological Engineering,* 63(0): 34-44.

Lee, C.H., Lee, D.K., Ali, M.A., Kim, P.J. (2008) Effects of oyster shell on soil chemical and biological properties and cabbage productivity as a liming materials. *Waste Management*,28 (12): 2702-2708.

Lenihan, H.S., Peterson, C.H. (1998) How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. *Ecological Applications*, 8(1): 128-140.

Meyer, D.L., Townsend, E.C., Thayer, G.W. (1997) Stabilization and erosion control value of oyster cultch for intertidal marsh. *Restoration Ecology*, 5(1): 93-99.

MFish (2010) Dredge oysters (OYS7) - Nelson/Marlborough. Ministry of Fisheries.

Nelson, C.S. (1978) Temperate shelf carbonate sediments in the Cenozoic of New Zealand. *Sedimentology*, 25(6): 737-771.

Nelson, C.S., Keane, S.L., Head, P.S. (1988) Non-tropical carbonate deposits on the modern New Zealand shelf. *Sedimentary Geology*, 60: 71-94.

Neori, A., Chopin, T., Troell, M., Buschmann, A.H., Kraemer, G.P., Halling, C., Shpigel, M., Yarish, C. (2004) Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modem mariculture. *Aquaculture,* 231(1-4): 361-391.

Newell, R.I.E., Koch, E.W. (2004) Modeling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. Estuar*ies*, 27: 793-806.

Newell, R.I.E. (2004) Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: A review. *Journal of Shellfish Research*, 23(1): 51-61.

Newell, R.I.E., Cornwell, J.C., Owens, M.S. (2002) Influence of simulated bivalve biodeposition and microphytobenthos on sediment nitrogen dynamics*. Limnology and Oceanography*, 47: 1367-1379.

Newell, R.I.E., Fisher, T.R., Holyoke, R.R., Cornwell, J.C. (2005) Influence of eastern oysters on nitrogen and phosphorus regeneration in Chesapeake Bay, USA. In: Dame, R.F., Olenin, S. ed. *The comparative roles of suspension feeders in ecosystems*. Springer, Netherlands.

Peterson, C.H., Grabowski, J.H., Powers, S.P. (2003) Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative valuation*. Marine Ecology Progress Series*, 264: 249-264.

Piazza, B.P., Banks, P.D., La Peyre, M.K. (2005) The potential for created oyster shell reefs as a sustainable shoreline protection strategy in Louisiana. *Restoration Ecology*, 13(3): 499-506.

Posey, M.H., Alphin, T.D., Powell, C.M. (1999) Use of oyster reefs as habitat for epibenthic fish and decapods. In: Luckenbach, M.W., Mann, R., Wesson, J.A. ed*. Oyster Reef Habitat Restoration: a synopsis and synthesis of approaches.* Virginia Institute of Marine Science, Williamsburg, VA: 299-237.

Prins, T.C., Smaal, A.C., Dame, R.F. (1997) A review of the feedbacks between bivalve grazing and ecosystem processes. *Aquatic Ecology*, 31(4): 349-359.

Scyphers, S.B., Powers, S.P., Heck, K.L., Byron, D. (2011) Oyster reefs as natural breakwaters mitigate shoreline loss and facilitate fisheries. *PLoS ONE,* 6(8): e22396.

Shiozaki, K., Shiozaki, M., Masuda, J., Yamauchi, A., Ohwada, S., Nakano, T., Yamaguchi, T., Saito, T., Muramoto, K., Sato, M. (2010) Identification of oyster-derived hypotensive peptide acting as angiotensin-I-converting enzyme inhibitor. *Fisheries Science*, 76(5): 865-872.

Shpigel, M., Gasith, A., Kimmel, E. (1997) A biomechanical filter for treating fish-pond effluents. *Aquaculture,* 152(1-4): 103-117.

Southland New Zealand Iconic South. http://www.southlandnz.com/Visit/Land-and-people/Icons-of-the-South [accessed 05/05/14]

Wang, Q.K., Li, W., He, Y.H., Ren, D.D., Kow, F., Song, L.L., Yu, X.J. (2014) Novel antioxidative peptides from the protein hydrolysate of oysters (*Crassostrea talienwhanensis*). *Food Chemistry,* 145: 991-996.

Yoon, G.L., Kim, B.T., Kim, B.O., Han, S.H. (2003) Chemical-mechanical characteristics of crushed oyster-shell. *Waste Management,* 23(9): 825-834.

Yoon, H., Park, S., Lee, K., Park, J. (2004) Oyster shell as substitute for aggregate in mortar. *Waste Management & Research*, 22(3): 158-170.

zu Ermgassen, P.S.E., Spalding, M.D., Grizzle, R.E., Brumbaugh, R.D. (2013) Quantifying the Loss of a Marine Ecosystem Service: Filtration by the Eastern Oyster in US Estuaries. *Estuaries and Coasts,* 36: 36-43.

Amphibola

Bennington, S.L. (1979) Some Aspects of the Biology and Distribution of Amphibola crenata (Gastropoda: Pulmonata) With Special Reference to Possible Effects of Pollution from Sewage Outfalls. *A thesis submitted for the Degree of Doctor of Philosophy in Zoology in the University of Canterbury.*

Juniper, S.K. (1987) Deposit feeding ecology of Amphibola crenata I. Long-term effects of deposit feeding on sediment micro-organisms. *New Zealand Journal of Marine and Freshwater Research*, 21:2: 235-246.

Juniper, S.K. (1987) Deposit feeding ecology of Amphibola crenata II. Contribution of microbial carbon to Amphibola's carbon requirements. *New Zealand Journal of Marine and Freshwater Research,* 21:2: 247-251.

Pilkington, M.C., Pilkincton, J.B. (1984) Settlement in the New Zealand mud snail, Amphibola crenata. *Journal of the Royal Society of New Zealand,* 14:2: 145-149.

Shumway, S.E. (1981) Factors Affecting Oxygen Consumption in the Marine Pulmonate Amphibola Crenata (Gmelin, 1791). *Biol. Bull.,* 160: 332-347.

Watters, P.A. (1964) Distribution of Amphibola crenata (Pulmonata) in the Dunedin Area, with Notes on the Probable Origin of the Species. *Transaction of the Royal Society of New Zealand,* 4(4).