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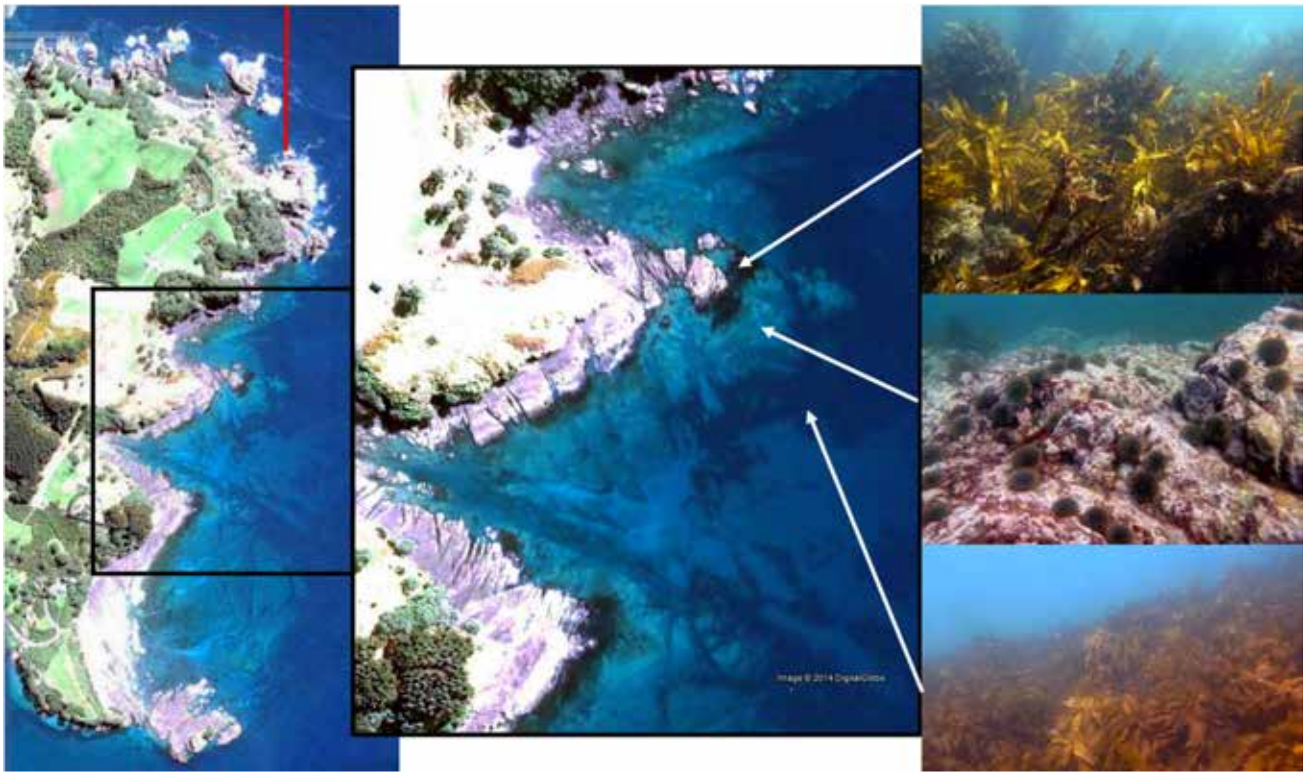
Vince Kerr and Roger Grace,
October 2017



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**Cover Photo:** An example of the urchin barren condition taken just south of the Cape Rodney to Okakari Point (Leigh) Marine Reserve at Cape Rodney, showing the greyish bare rock appearance of the urchin barren contrasted with the dark appearance in the aerial view of the algal forests. These photos also demonstrate the typical zonation of macroalgal forests and urchin barrens found in fished areas in northern New Zealand. Photo credit: Nick Shears

**Keywords: urchin barrens,** marine habitat mapping, habitat classification, algal forest health, algal forest restoration, wave exposure, marine reserves, partially protected areas, Northland

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## Executive summary

Overfishing of sea urchin predators on shallow reefs can lead to the loss of kelp forests and transition to 'urchin barrens'. In this study we estimate the extent of urchin barren habitat along New Zealand's Northland coast. The study area was the entire exposed east coast running from Ahipara in the Far North to Tawharanui at the entrance of the Hauraki Gulf. Two large scale habitat maps covering the entire study area were used to compute the total area of rocky reef. Six fine scale maps spread along the coast from Doubtless Bay to Tawharanui where urchin barrens were mapped were used to compute extent of urchin barrens. In the study area there was an estimated total of 32,515 hectares of rocky reef (≤30 m depth). The projected estimate of urchin barren extent (based on the six mapped areas) for the entire study area came to a total of 5,528 hectares, representing 17% of the available rocky reef system. It is important to note that most of the urchin barrens in the region occur at depths <10 m meaning that urchin barrens occupy a considerably higher proportion of shallow reefs. Mapping data also allowed us to compare inside the two marine reserves with fished areas outside the marine reserves and the partially protected Marine Park at Mimiwhangata. Inside the two marine reserves, where sea urchin predators are abundant, urchin barrens covered 1 % of the available reef. In contrast in the partially protected Marine Park, where recreational fishing is still allowed, the extent of urchin barrens was 21.23%. These results are consistent with previous research that have demonstrated that the recovery of crayfish and reef fish (mainly snapper) can lead to a recovery of kelp forests in no-take marine reserves. Region-wide mapping demonstrates that urchin barrens are a prominent feature of the entire Northland coast and indicates that shallow kelp forests are vulnerable to intensive fishing at large-spatial scales. The results suggest greater understanding and recognition of the key biodiversity status and productivity of kelp forests is needed to better understand the ecosystem-level consequences of fishing on rocky reefs. Future management of coastal ecosystems must use a range of available tools to address these ecological challenges. We discuss various factors affecting the estimation of urchin barren extent and provide a set of initial thresholds for kelp forest monitoring which could be used to inform management decisions.

## Client brief

Kerr & Associates has been requested by the Motiti Rohe Moana Trust to provide a summary of 'lessons learned' from research on algal forests in northeast New Zealand and in particular Northland's east coast shallow reefs. Below is a list of the specifics of what the Motiti Rohe Moana Trust has asked to investigate:

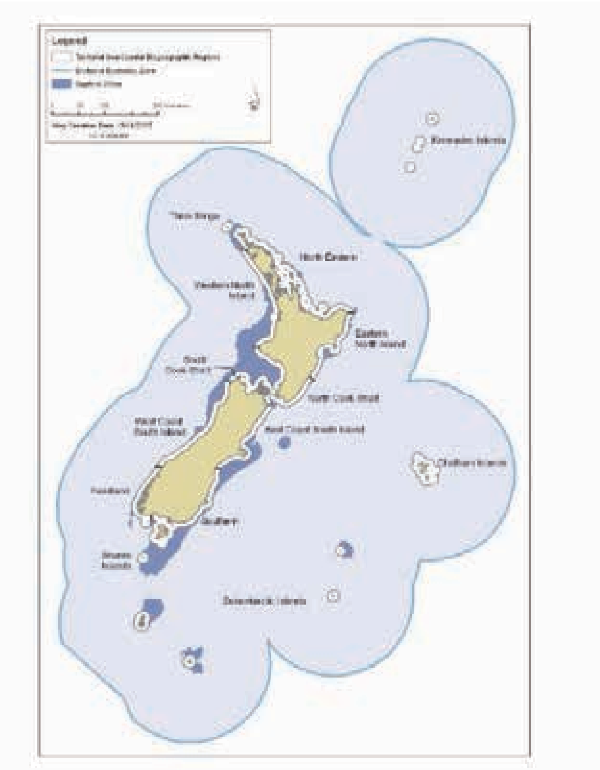
1. Describe what is known about the threat and extent of the urchin barren decline condition in shallow algal forests in Northland
2. Examine the relevance or similarity of shallow reef ecology and urchin barren studies to shallow rocky reefs in Bay of Plenty
3. What are the ecological implications of the decline in algal reef health as seen in Northland studies?
4. What have we learned in Northland and elsewhere from various locally applied management actions involving localised controls on fishing?
5. Would the extent and persistence of urchin barrens be a suitable SOE indicator, and could this be measured and monitored in an ongoing system that was efficient?

## Background

The Northland region is unique in several aspects relating to marine habitat mapping. First, Northland has an extensive coastline and a very large area of shallow rocky reefs. Many of the Northland reef systems have an ecological sequence with large areas of offshore 'deep reefs' (rocky reef structures occurring at depths greater than 30m). Secondly, Northland has had more marine habitat mapping projects completed than any other region. In this study we have brought all this information together in a GIS based project to question the state of health of shallow rocky reefs, particularly the extent of the habitat type known as 'urchin barrens', large numbers of sea urchins have removed kelp forests. This study area also has a rich body of ecological information about shallow rocky reefs based on decades of studies in the two long term no-take marine reserves located at Cape Rodney to Okakari Point (Leigh) and Tawharanui where habitat mapping, observations, experiments and monitoring date back to the 1960's. Tawharanui was set up as a Marine Park in the 1980's, but was effectively a marine reserve with a full 'no-take' rule in place. It has recently obtained full marine reserve status. A third site of interest in the study area is the partially protected Mimiwhangata Marine Park.

## A Bioregional view of similarities between Northland's east coast and Bay of Plenty

In our view the results and implications of the extensive work done on shallow reefs in Northland is largely applicable to the Bay of Plenty region. This view is supported by extensive work supporting the creation of a regional classification system for coastal New Zealand. This classification system appears in its most updated form in the Government's Marine Protected Areas Policy and Implementation Plan (DOC & MPI, 2008) (please refer to Map 1 below). Northland's east coast shares the same regional classification, 'Northeast Bioregion', with Hauraki Gulf, Coromandel, and Bay of Plenty. Underpinning this bioregional level classification is a large body of data that shows that these three regions share similar currents, water temperatures and flora and fauna groups. Detailed studies testing the validity of the bioregional classification and specifically similarities between the shallow reefs across the bioregion have been carried out and also support the concept and application of the current classification (Shears et al. 2008; Shears & Babcock, 2007), Shears & Babcock, 2004).




Map 1 Currently adopted bioregional boundaries for coastal New Zealand.

## Ecological significance of shallow rocky reefs and the urchin barren dynamic

Shallow rocky reef systems in ecological terms are generally accepted to be one of the most significant habitats of the exposed coast marine environment, however there is no current regime of monitoring that looks specifically at the health of algal forests which are the foundation of productivity and structure for this habitat. Most of the information we do have on the health of rocky reefs comes from habitat mapping projects which have been arranged to support marine protected area planning. The shallow rocky reef ecosystem is very rich in biodiversity of flora and fauna. Unravelling the details of such a complex habitat is a big job. A big picture review of the ecology of Northland's reefs and coastal environments was completed by NIWA (Morrison, 2005). This review highlights the fact that many commercially important fish species spend part of their life cycle on the shallow rocky reefs. Also highlighted in the NIWA report is the high diversity levels of invertebrates and algal species in this habitat. In Northland and Bay of Plenty our coasts are regularly swept with warm subtropical currents which bring with them an extra dimension of larvae from subtropical origins. As a result the northeast bioregion has by far the New Zealand's highest fish diversity associated with its shallow reefs. This was documented in a comprehensive Northland rocky reef fish diversity study (Brook, 2002). Some of the most diverse sites in Northland like the Poor Knights Islands can have in excess of one hundred species resident on the reefs. At the fine scale under the kelp canopy there are also fascinating studies of the diversity occurring associated with kelp plants and their holdfast structures (the base holding the plant to the reef surface) (Smith et al. 1996) (Anderson et al. 2005). In these micro habitats small invertebrates are largely hidden from sight however they are a significant part of the overall diversity and food sources for reef dwelling fish and large invertebrates like crayfish. Up to one hundred species of invertebrates have been counted living in a single kelp holdfast.

The sea urchin, *Evechinus chloroticus,* known as kina in New Zealand, is widespread in the Northeast Bioregion. In addition to being a traditional food species, it plays a key role as a primary grazer of kelp. Early studies in north east New Zealand documented kina's role as a habitat creator through grazing of kelp (Choat, 1982), (Grace 1983), however at that time it was thought that barren areas on the reef caused by urchin grazing was a 'natural' characteristic of our reefs.

In subsequent decades, the dynamics between kelp forests, sea urchins and exploitation of sea urchin predators (mainly snapper and crayfish) has been investigated in New Zealand (Shears et al. 2004; Shears and Babcock, 2002). The Mimiwhangata habitat mapping report (Kerr & Grace 2005) illustrated dramatic decline of the kelp forests over wide areas, starting sometime in the 1960s or 1970s. During the Mimiwhangata habitat mapping exercise, local kaumatua were interviewed and stated with confidence that the current condition of extensive urchin barren areas was not known prior to about 1960-1970 or mentioned in their tribal knowledge handed down from elders.

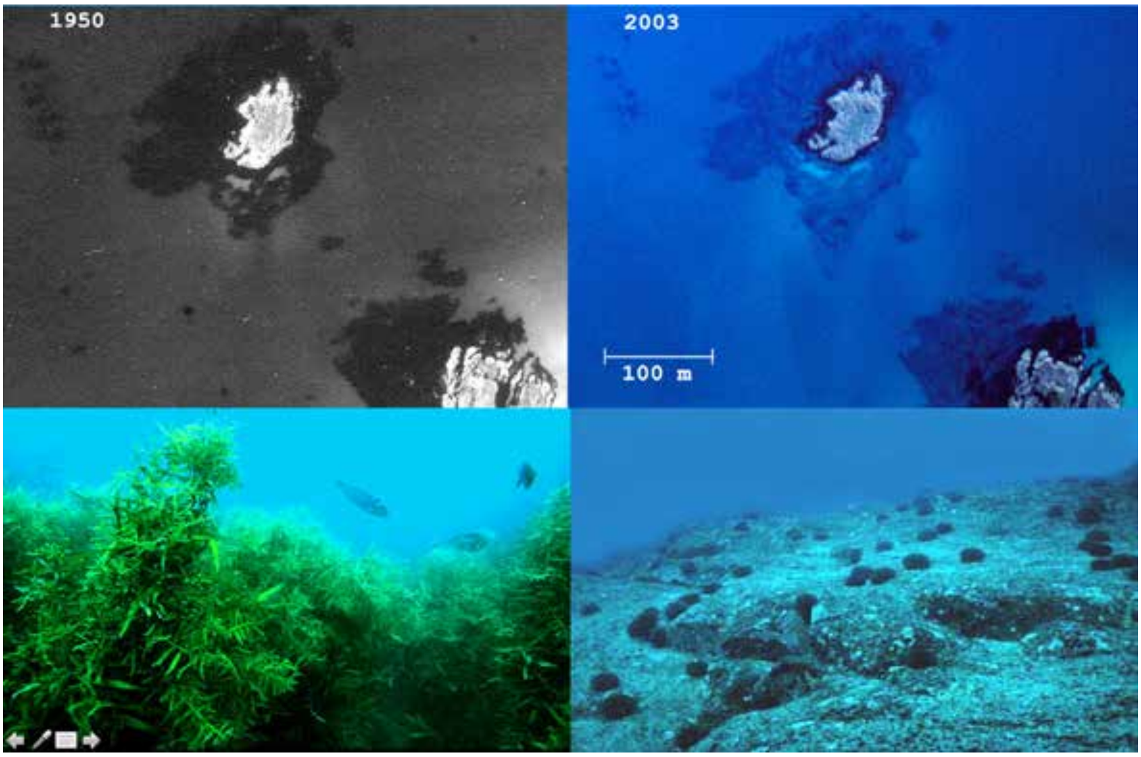



**Figure 1** An illustration of the progression of urchin barrens at Pa Point, Mimiwhangata showing dense algal forest seen as dark in the aerial photo (1950) top left and the advanced state urchin barrens seen in the 2003 photo. Bottom photos taken on scuba depict the algal forest once typical at this location and a typical urchin barren.

In northern New Zealand it was found that large snapper and crayfish are the main predators of urchins (Shears & Babcock, 2002). In their absence, population density of urchins can rise to ten fold of normal densities resulting in the urchins removing large areas of the kelp forest. These areas often become a stable state of drastically reduced productivity and diversity. Much of this research was based around the Leigh marine reserve where after thirty years of full protection the urchin barren areas which were extensive in the 1970's reverted to kelp forests, in parallel with the predator species re-establishing in the marine reserve. Overseas, a similar dynamic has been reported in virtually every other country with extensive temperate shallow rocky reef and kelp forest habitats (Ling, 2015). In New South Wales and Tasmania, the impact of intense fishing and establishment of urchin barrens has been extensively documented including significant adverse ecological impacts and impacts to commercial reef dwelling species like paua (Andrew, 1998) (Andrew, 2000) (Ling et al. 2009) (Ling, 2008). In the temperate areas of Australia there is now significant concern over biodiversity loss due to the increase of urchin barren areas and concern that this phase shift (as it is referred to) appears to be difficult to reverse in circumstances where current fishing pressures are maintained. Such diversity loss gives rise to further concerns around reefs' reduced ability to fulfil their natural role of fixing carbon and thus reduce greenhouse gas and potentially serious reduction in the reef systems' resilience to rapidly changing environmental conditions brought on by global warming.

Recognition of the importance of shallow rocky reefs and the threat of diversity and productivity loss due to overfishing and urchin barren establishment in New Zealand has unfortunately not yet lead to a point where it features in any monitoring programs regionally. Northland as a region however has begun a process to recognise the importance of the shallow reef habitats. Northland Regional Council as part of its revision of the Regional Coastal Plan for Northland has mapped all reef areas and an adjacent transition or edge habitats where the reefs join a soft sediment habitat (Kerr, 2016 a,b,c,d). In the current Proposed Regional Coastal Plan these areas are classified as ‘significant ecological areas’, providing a way for the Council to consider their biodiversity values when evaluating an application for use of the marine environment. Rules can also be made for the protection of these values.

In Figure 2 below you can see a glaring example from the Bay of Islands of the extent of urchin barrens in an area badly affected. There would naturally be continuous heavy kelp forest covering this entire reef (seen as dark brown). What we see is a thin edge of specialised shallow water seaweeds, species of *Carpophyllum* less palatable to urchins, and a remnant of the *Ecklonia radiata* (large brown kelp), seen here below about 10m depth only covering a small area of the bottom of the reef near where it drops off on to an edge with a sandy bottom habitat. This barren condition represents a major loss of productivity, habitat and diversity. The overall situation of kelp forest decline in the Bay of Islands is a major concern especially in low exposure areas. Research efforts of the marine conservation group Fish Forever have now documented this threat in three research reports (Kerr & Grace, 2015), (Booth, 2015) and (Booth, 2017).


**Figure 21** An Oceans 20/20 aerial photo of the east shore of Motukiekie Island, eastern Bay of Islands displayed at the 1:1,500 mapping scale. Pale greyish areas are urchin barrens.

## Methods

### Habitat surveys

To estimate the extent of urchin barrens on Northland reefs (≤30 m depth), habitat maps were brought together in a GIS project which covered the area from Tawharanui to Ahipara. The maps have all been prepared with similar methodologies but not drawn to the exactly same scale. Ground truthing of the mapping effort, as well as precision, varied in approach across the maps. The maps used are described in groups below corresponding to how the data were used for calculations of the shallow kelp forest in this study. There were four groups of habitat maps: areas where urchin barrens were mapped, areas in or out of marine reserves, and areas where urchin barren were not mapped with shallow rocky reefs mapped as an undifferentiated reef habitat. These four groups are described below:

**Group 1 Areas where urchin barren were not mapped (large scale base maps)**

- Northland Habitat Map Ahipara to Mangawhai ver. 1 (Kerr, 2010)
- Hauraki Gulf Marine Habitat Map (DOC, 2014)

**Group 2 Areas where urchin barrens were mapped inside marine reserves**

- Leigh Marine Reserve Habitat Map (Leleu and Remy-Zephir, 2012)
- Tawharanui Marine Reserve Habitat Map (Grace, unpublished work completed for DOC 2006)

**Group 3 Areas where urchin barrens were mapped outside and adjacent to a marine reserve boundary**

- Leigh Marine Reserve Habitat Map (Leleu and Remy-Zephir, 2012)
- Tawharanui Marine Reserve Habitat Map (Grace, unpublished work completed for DOC 2006)

**Group 4 Areas where urchin barrens were mapped in open fishing areas**

- Doubtless Bay Marine Habitat Map (Grace & Kerr, 2005)
- Marine Habitats of the proposed Waewaetorea Island Marine Reserve (Kerr & Grace 2015)
- Marine Habitats of Cape Brett and Maunganui Bay (Kerr, 2016)
- Mimiwhangata Marine Habitat Map (Grace & Kerr, 2005)

A set of seven maps taken from this study can be viewed in Appendix 1.

## Mapping methodologies

All of the maps used, except two, have publications or technical reports including details of methodology, scale, information sources, habitat descriptions, ground truthing approach and reliability estimates.. The two exceptions are the Tawharanui map and DOC’s Hauraki Gulf habitat map. The Tawharanui map was drawn by Dr Roger Grace and used very good quality aerial photos for the entire coastline mapped and side scan surveys to delineate the reef/soft bottom edges. Dr Grace has also done many research dives throughout this area and has permanent transects established on each of the major reef areas which he mapped at fine scale (less than 5m error) for all his transects. It is reasonable to assume that the Tawharanui habitat is at least as accurate as the other maps used in this study. The DOC Hauraki Gulf map was produced by a number of DOC staff and contractors and drew information layers from many sources and approaches to mapping. For this reason, and the lack of a technical report to support this layer, it is beyond the scope of this report to comment on precision, however in the context of this study only a relatively small stretch of the coastal fringing shallow reef is used in the calculations, so even if there are sizeable errors in establishing the reef edge in this map it will not overly affect the results of this study.

If the reader wishes to further explore the classifications used, mapping methodology and precision or reliability considerations we advise study of the reports for the Northland map, (Kerr, 2010), the Mimiwhangata map (Kerr & Grace, 2005) and the Bay of Islands Waewaetorea Island map (Kerr & Grace 2015). In each case the various mapping approaches are detailed and are roughly common across all the maps used in this study. The Mimiwhangata map details an approach to mapping urchin barrens and also introduces a study of a time series of aerial photos tracking progression of the urchin barren over several decades. The Waewaetorea Island map also used similar methodology to that used at Mimiwhangata for the mapping of urchin barrens and is our best example of a 'low exposure coast'.

## GIS process

A GIS project was created containing all the data acquired for the study which was all of the shallow rocky reef polygons from all the maps of the study extending from Tawharanui in the south to Ahipara in the north. The GIS environment allows for a range of display and spatial analysis approaches to be used. A common attribute field was created listing all of the main classifications used to describe shallow reef habitats across all the maps. The two larger scale base maps (Northland and Hauraki Gulf) were cut for the areas where the smaller scale maps were located resulting in one continuous layer of shallow rocky reef for the entire shallow rocky reef defined as extending to the 30m depth contour. The Northland map included shallow rocky reef areas of offshore islands like Poor Knights and the Hen and Chicks Islands. A line was drawn across the entrance to all Northland estuaries and these estuarine shallow reefs were excluded in this study. This is not to say that the urchin grazing and barrens do not exist on shallow reefs within the entrances, however in our extensive estuaries there are a number of environmental factors operating on the urchins, the urchin predator species and the algal forests themselves that are substantially different from our exposed coastal environments. For this reason for this first study we excluded this complication by removing the estuarine shallow reefs.

A second attribute field was created that identified all polygons in terms of the four groups. This was done to allow calculations of the area of urchin barrens across these four groups.

### The four basic analysis groups

1. urchin barren were not mapped (larger scale base maps with shallow rocky reefs mapped)
2. urchin barrens were mapped inside marine reserves
3. urchin barrens were mapped outside and adjacent to a marine reserve boundary
4. urchin barrens were mapped in open fishing areas and Mimiwhangata (partial protection)

### Determination of exposure

Exposure to wind, wave energy and currents is known to influence the development of biological communities. Observations to date by the authors in the various mapping efforts in Northland have indicated that there is considerable variation in extent of urchin barrens which parallel to an unknown degree exposure and the impacts of wave energy on the reef system. For this reason we decided to carry out a simple exercise of producing a 3-way exposure layer. For consistency with the Marine Protected Areas Guidelines (DOC, 2008), we adapted the approach in that document which is outlined below.

The Marine Protected Areas Guidelines identify exposure as important in defining marine habitats for the purpose of its classification system. The guidelines define three exposure categories: low, medium, and high.

- High – areas of high wind/wave energy along open coasts facing prevailing winds and oceanic swell (fetch > 500 km e.g. ocean swell environments or currents > 3 knots).
- Medium – areas of medium wind/wave energy along open coasts facing away from prevailing winds and without a long fetch (fetch 50-500 km e.g. open bays and straits).
- Low – areas where local wind/wave energy is low (fetch <50 km e.g. sheltered areas; small bays and estuaries; current <3 knots).

This definition was applied by drawing a series of lines along the coast in our GIS project outward from the coastline within the survey area to approximately indicate the degree of exposure and fetch at each significant turn or 'point' along the coastline. In each of these locations fetch and fetch angle was interrogated according to the above guidelines and then a polygon for the coastal waters for that corresponding stretch of coast was drawn. Each polygon has an exposure classification of low, medium or high. This layer was then merged with the entire shallow reef layer which effectively split the shallow reefs into three exposure classifications and allowed the urchin barren calculations to be interpreted by exposure.

## Results

In Appendix 1 seven maps are presented which show the study area, the exposure classification map and the extracted shallow reef habitats for the study area. The boundaries of the areas which were mapped for urchin barrens are also illustrated.

### Urchin barren extent

Tables 1-5 below detail the various calculations made to:

- assess the spatial extent of kina barrens in all areas where they were mapped;
- asses a percentage value of urchin barrens where mapped which reflects how much of the shallow rocky reef is in the urchin barren condition;
- asses a value for spatial extent of all habitats by exposure class;
- extrapolate the mapped percentage value of urchin barren extent to the entire shallow reef study area; and
- compare directly urchin barren extent between urchin barren mapped areas across the entire study area.

Table 1 shows the respective areas of shallow reef involved in this study for the coastline stretching from Tawharanui in the south to Ahipara in the north. The area of shallow reefs that were mapped for urchin barrens is 4,362 hectares representing 13.41% of the total study area shallow reef area of 32,515 hectares.

| **Mapped Areas Totals** | | |
|---|---|---|
| **Mapping description** | **Hectares** | **Percentage of total study area** |
| Northland total area of shallow reefs with urchin barrens mapped | 4,362 | 13.41% |
| Northland total area of shallow reefs without urchin barrens mapped | 28,153 | 86.59% |
| | | |
| Total shallow reef area study area | 32,515 | 100% |

**Table 1** Total calculated areas of urchin barren mapped shallow reefs and shallow reefs where urchin barrens were not mapped.

Table 2 provides a summary of the areas of shallow reefs classified in the three exposure classes low, medium and high. Note that there is a relatively small area that was assessed as low exposure. A large part of this low exposure area was located in the sheltered side of islands of the Bay of Islands.

| Northland exposure classes | Hectares |
|---|---|
| High | 27,809.21 |
| Medium | 4,551.04 |
| Low | 154.41 |
| | |
| Total Northland shallow reefs area | 32,514.67 |

**Table 2** Shallow reef area totals calculated for each of three exposure classes.

Table 3 gives the calculated values of each shallow reef habitat by exposure class. The third column presents a percentage of spatial extent of each habitat on shallow reef by exposure class for all the areas where urchin barrens were mapped. The fourth column lists the value in hectares of each of these habitats by exposure class extrapolated to the entire study area. The fifth column then calculates a percentage value of spatial extent for each habitat and exposure class from the extrapolated areas calculated in column four. The column five percentage values reflect the predicted make-up for the entire shallow reef system of the study area.

Note that the low exposure urchin barren result represents a very small area within the entire study area but it has a very high spatial extent of urchin barrens (33%). For a more detailed discussion of this data see the Waewaetorea Island habitat report (Kerr & Grace, 2015).

| Exposure | Habitat type | % of reef area based on habitat maps (non-reserve) | Estimated area for Northland (hectares) | Estimated % of total reef area in Northland |
|---|---|---|---|---|
| High | *Ecklonia* forest | 73.60% | 20,466.47 | 62.95% |
| Medium | *Ecklonia* forest | 91.23% | 4,152.06 | 12.77% |
| Low | *Ecklonia* forest | 27.06% | 41.78 | 0.13% |
| High | Shallow mixed weed | 6.92% | 1,925.39 | 5.92% |
| Medium | Shallow mixed weed | 4.40% | 200.10 | 0.62% |
| Low | Shallow mixed weed | 38.58% | 59.57 | 0.18% |
| High | Urchin barren | **19.02%** | **5,288.95** | **16.27%** |
| Medium | Urchin barren | **4.11%** | **186.97** | **0.58%** |
| Low | Urchin barren | **33.83%** | **52.24** | **0.16%** |
| High | *Carpophyllum flexuosum* forest | 0.40% | 111.78 | 0.34% |
| Medium | *Carpophyllum flexuosum* forest | 0.26% | 11.92 | 0.04% |
| Low | *Carpophyllum flexuosum* forest | 0.53% | 0.82 | 0.00% |
| High | Algal turfs | 0.06% | 16.62 | 0.05% |
| Medium | Algal turfs | 0.00% | 0.00 | 0.00% |
| Low | Algal turfs | 0.00% | 0.00 | 0.00% |

**Table 3** Calculated values of habitats by exposure classes and extrapolated areas and percentage extent for the entire study area based on the values measured in areas where urchin barrens were mapped.

For the shallow rocky reef systems of the study area, 17% of the area is estimated to be in the urchin barren condition. This corresponds to a total of 5,528 hectares. To put this in some sort of perspective, the total shallow reef habitat area of the study area is 32,515 hectares this is approximately 30% larger than all of Doubtless Bay which is 15 km across. This is more than thirty times larger than the entire area of the Leigh Marine Reserve. The estimated urchin barren extent for the study area at 5,528 hectares is five times larger than the Leigh marine reserve and roughly a quarter of the size of Doubtless Bay.

## Marine reserves vs fished areas

Table 5 offers a comparative view of the spatial extent of areas where urchin barrens were mapped, listing values for in and outside of the marine reserves mapped for urchin barren habitats in the study. Essentially the result shows a picture where outside the marine reserve the extent of urchin barren is large and is a significant part of the make-up of the shallow reef ranging from 33.83% (low exposure), 19.02% (high exposure), 4.11% (medium exposure) outside the marine reserves, to around 1% or less urchin barren extent in the marine reserves (Leigh .87% & Tawharanui 1.69%). This result of virtually complete recovery of kelp forests in the two marine reserves Leigh and Tawharanui is well documented and represents a long observation period (30 plus years) over which this restoration took place (Leleu & Remy-Zephir, 2012). Examination of aerial photos clearly shows the transition near the boundaries at these reserves from extensive urchin barrens outside the marine reserves to virtually no visible urchin barrens in the reserves. In these boundary areas this dramatic difference or transition can be seen over a distance of only a few hundred meters (see Figure 2 below).

| Exposure | Habitat Type | Percentage of shallow reefs by exposure class and habitats for non-reserve areas where urchin barrens were mapped | Percentage of shallow reefs by exposure class and habitats for marine reserves where urchin barrens were mapped |
|---|---|---|---|
| High | *Ecklonia* forest | 73.60% | 64.99% |
| Medium | *Ecklonia* forest | 91.23% | 12.23% |
| Low | *Ecklonia* forest | 27.06% | 0.00% |
| High | Shallow mixed weed | 6.92% | 19.51% |
| Medium | Shallow mixed weed | 4.40% | 30.46% |
| Low | Shallow mixed weed | 38.58% | 0.00% |
| High | Urchin barren | 19.02% | 1.15% |
| Medium | Urchin barren | 4.11% | 0.00% |
| Low | Urchin barren | 33.83% | 0.00% |
| High | *Carpophyllum flexuosum* forest | 0.40% | 6.23% |
| Medium | *Carpophyllum flexuosum* forest | 0.26% | 22.25% |
| Low | *Carpophyllum flexuosum* forest | 0.53% | 0.00% |
| High | Algal turfs | 0.06% | 8.12% |
| Medium | Algal turfs | 0.00% | 35.06% |
| Low | Algal turfs | 0.00% | 0.00% |

**Table 5** Comparison of percentage of spatial habitat areas by exposure class for areas mapped for urchin barrens inside versus outside marine reserves.

The differences between values in Table 5 above for the *Carpophyllum flexuosum* and algal turfs are mainly reflective of localised habitat differences and different mapping conventions and interpretations used to describe the shallow mixed weed habitat zone for the Leigh and Tawharanui habitat maps.

### Partial protection

This study also provided an opportunity to look at urchin barren extent in a key partially protected area that has a good history of monitoring and research. Mimiwhangata Marine Park located on the Whangarei coast has been a partially protected area since the 1980's. In establishing the park, fisheries regulations were created that banned commercial fishing and restricted recreational fishing to non weighted line fishing. Long term monitoring studies for reef fish and crayfish have enabled researchers to track the effectiveness of this partial protection management approach over several decades. Results are conclusive and dramatic for both reef fish (Denny & Babcock, 2004) and crayfish (Shears et al., 2006). The conclusion drawn from this body of monitoring data is that there has been no recovery of key predators over the history of the partially protected marine park. The calculated urchin barren extent at Mimiwhangata from our study is 21.23% of the shallow reef area in urchin barrens. This result seems to be consistent with trends found in the long term reef fish and crayfish studies. This poor result is also higher than the 17% figure estimated for the entire coast where no special restrictions on fishing apply and contrast markedly with the results from established fully protected marine reserves where algal forests recover fully over the same time period Mimiwhangata has been under a partial protection management regime.

## Discussion

### The canary in the mine

For over five decades researchers both here (northern New Zealand) and overseas have witnessed a decline in temperate shallow reef algal forests. It has become apparent that this decadal trend parallels intensive fishing on a broad commercial scale. This decline trend is likely exacerbated by a spatially disproportionate recreational fishing effort focused on 'accessible' shallow reefs. Fisheries research carried out by NIWA (Harthill et al., 2013) indicates that the recreational catch of snapper in northern New Zealand is significant compared to the commercial catch, but is spatially concentrated on shallow coastal reef areas. At a more localised level, John Booth (2017) prepared a report for the Bay of Islands Fish Forever group which uses the MPI recreational fishing data to compare and comment on localised recreational fishing and its now serious impacts on shallow rocky reefs at the local scale.

Results of this study clearly show that sea urchin barrens are prevalent along the Northland coast of New Zealand. Research in New Zealand and overseas has demonstrated that shifts in tropic state from kelp forests to urchin barrens are occurring in association with overfishing predators of sea urchins (Shears and Babcock 2002, Babcock et al 2010, Ling et al. 2009). Establishment and persistence of urchin barrens also appear to be context dependent and as a result variable (Shears et al., 2008), suggesting that environmental factors can also limit urchin grazing and formation of urchin barrens. The ecological impact of fishing has not been a consideration in fisheries management decisions or 'models' to date. Despite the significance of the rocky reef habitat to many fish species and the coastal environment, the loss of shallow algal forests and greater ecological consequences have not been monitored in any comprehensive manner. We suggest that this story of significant impact of persistent heavy fishing is a canary in the mine scenario. The extensive areas of decline on our reefs should now trigger a response of asking a multitude of questions. How serious is our situation? What other ecological imbalances are playing out that we haven't looked for or are not seeing? What is the best way to address this threat on a regional scale? There is a long and important list of questions to address.

There are clear pointers to how we can address these challenges. Directly contrasting with this story of decline is the story of recovery of kelp forests documented at the marine reserves at Goat Island and Tawharanui (Babcock et al 1999, Shears and Babcock 2002, Leleu et al., 2012) where full protection has allowed predators of urchins to restore natural control of their grazing. The fieldwork for the Leleu study work was completed in 2006. In this study the historic habitat map done at the Leigh Marine Reserve in 1981 (Ayling) was compared to a new survey and map. The result showed that the large areas of urchin barren (44 ha) in 1981 had virtually completely restored to healthy *Ecklonia* forest, with only 4.5 ha of urchin barren documented in 2012. The Leleu survey also found that the boundary areas immediately outside the reserve continued to have large urchin barren zones. A similar result of kelp restoration resulting from long-term full protection from fishing has been observed by the authors at Tawharanui.

## Strengths and weaknesses of the GIS approach and mapping sources

A large scale mapping exercise like this by definition is completely reliant on the methods, precision and accuracy of all the component parts making up the study. Also it must be appreciated that in the mapping methodologies scale really matters. In this case mapping scale of the various layers does vary, which we will comment on. A primary objective of all these mapping efforts is to create a map with full spatial coverage of the area of interest. Fulfilling this objective allows for the map to be useful for any form of spatial analysis and planning. As a result of this, mapping projects are compelled to produce the best possible map at the best precision with the resources they can bring together. What this means is that data layers vary in precision and quality. The end result is then the best precision that can be achieved with the time, technology and resources at hand. In this set of Northland maps most of the maps have detailed reports supporting them and descriptions of methodology and reliability. All the mapping projects were completed by a small team of Northland researchers and in one case graduate students working with this Northland team.

We will now comment globally on the reliability of overall estimate of urchin barren extent. First, there is the overall figure of shallow reef area. The best way to evaluate this figure is to look at the large scale Northland habitat map (Kerr, 2010). Since shallow reefs were drawn from a series of data sources there is no one value for error. Shore boundaries and shallow water boundaries were drawn with very accurate (<5m error) aerial photography resulting in a mapping error of well under 10m in virtually all areas. The seaward boundaries were largely bathymetry based as most Northland reefs extend seaward beyond 30m depth and transition to 'deep reef' habitats. The actual error of the bathymetry data set used is not known but in areas where it was ground truthed or matched with more accurate multibeam data, accuracy was good and typically did not exceed 20m or so in regard GPS positioning. There are also areas where the seaward boundary is determined by varying sonar methods, these errors could range from less than 5m for the best multi-beam data sets to areas with sparse single beam sonar coverage where mapping error could range between 5m to as high as 100m in a worst case scenario. To summarise the base shallow reef data set from the Northland map in our opinion would be within a 10-15% margin of error overall for the total area calculated. For the finer scale habitat maps where urchin barren habitats were mapped, the mapping scale was much finer often in shallow areas down to 1:500 and working with state of the art aerial photos with accuracy of <2m. Typically the seaward boundaries were drawn at finer scales with higher resolution data too. As a result we would argue that the shallow reef component for these maps would be within 10 % accuracy for the areas calculated. This brings us to the mapping of urchin barrens themselves. Essentially in all the studies this mapping was primarily done with high resolution aerial photography with high spatial accuracy. The only significant sources of error are interpretation by the mapper or variable water clarity conditions. In all these maps the mappers had years of experience with the interpretation and all studies had ground truthing efforts documented in reports. The quality of photos is however a significant variable and factor which we strongly suspect results in an underestimate of urchin barrens in many locations. The areas where the method has the most difficulty is in steeply sloping coastlines. A recent diver transect based study of one of these 'difficult to map' areas at Cape Brett indicated that these areas do indeed have urchin barrens. Urchin barren patches were sometimes missed by our commonly used methods (Kerr, 2016). Putting all these error sources together in a rough estimate, we would suggest that the overall shallow reef habitat mapping error would be in the range of ±10-15% of the total reef area mapped. The mapping of urchin barren extent would be well under ± 10% of the area mapped as it was done at finer scales and using much finer scale data. All areas mapped for urchin barren extent in this study had good quality aerial photography.

## Urchin barren dynamic and non-fishing factors

There are three further aspects of our 17% urchin barren estimate that we would like to comment on:

***Variations in reef habitat zonation with depth***

For this study we used the definition of seaward extent of the shallow rocky reef habitat as 30m depth. This figure represents what we have measured on Northland reefs as a good average value of the approximate depth where due to lack of light kelp forests thin out and make way entirely for the deep reef habitats dominated by filter feeding invertebrates. However as was first defined in a regional algal forest zonation report (Grace 1983), this value varies with location and water clarity. In the southern part of our study area the lower boundary of the algal forest zone would be more like 20m depth. However the reef area in the south is very small in comparison to the north of the study area. As a result our figure for the overall shallow reef area is overstated to a small degree. Within this variation of depth description for the zone of algal growth urchins have a shallower preferred habitat zone which could be described as 1 to 15m depth in the North and offshore islands to 1 to 10m depth at the entrance to the Hauraki Gulf (Grace 1983, Shears et al., 2004). If we recalculated the percentage figure for urchin barren extent based on the urchin barren preffered depth zone only the figure would be much higher, possibly as high as 25-40%. Urchin barren extent of this magnitude has been mapped in Bay of Islands, Mimiwhangata and recorded on transect studies for a number of locations around Northland occurring outside marine reserves (Shears et al., 2004). This calculation using only the shallow portion of the reef could be completed in a further study or applied locally in monitoring.

***Zonation and habitat preference of urchin species and algal forest productivity***

Density and productivity of large brown kelps decreases markedly in the lower third of the depth range (20-30m depth). This lower third of the habitat is normally not a preferred habitat of urchins, resulting in most urchin barrens occurring in the depth range of 1-15m.

The prevalence of urchin barrens in shallow water also has disproportionate effects on kelp forest productivity. Shallow water kelp forests (<10 m depth) are much more productive than those found in deeper water where sea urchins are rare (Rodgers et al 2016). Potentially a preferred sea urchin habitat zone could be identified and matched with data on algal forest productivity as a function of depth. This zone definition would vary to a degree along the coast.

### *Natural (non-fishing related) dynamics of urchin barrens*

While reduced predation of urchins is suggested as a primary cause of long-term urchin barren formation, there is a known list of other factors that also affect the dynamic relationship between the algal forest and urchins as its primary browser. These factors include:

1. wave exposure
2. reef slope and topology which may affect the impact of wave energy on urchins; the abundance of crevices and other refugia for urchins;
3. effects of sedimentation;
4. storm damage and recovery of kelp forest ;
5. urchin and kelp disease outbreaks.

All these factors have been observed to operate on urchins and can influence the dynamic between urchin population density, urchin grazing and the persistence of urchin barrens (Grace 1983, Shears and Babcock 2004, Shears et al 2008). In the case of factors 1 & 2 & 3 the result is a positive one for kelp forests in that there will be a tendency for the kelp forest to persist even in the face of removal of the local reef predators. In the case of factors 4 & 5 our observations to date are that these impacts are short term in nature and are not a major factor in urchin barren formation or persistence. Kelp forest have high reproductive potential and growth rates, full recovery from episodes with these natural impacts typically occur within 1-2 year time spans, leading to the conclusion that the large and persistent urchin barrens we have seen develop in the last five decades are not caused by these factors. This is also consistence with the long term observation of our marine reserves.

A further observation from long term observations and transect studies at places like Mimiwhangata and Tawharanui is that in the early phase of urchin barren formation there can be a number of years where the size of the barren fluctuates with apparently a balance between the urchin barren grazing and the kelp's recovery hanging in the balance. Typically over time this balance at some point shifts and the large urchin barrens are established. These larger urchin barren areas appear to be something like a stable state as they are rarely reversed in our experience. Our observation is consistent with studies carried out in Tasmania on the persistence of urchin barrens (Ling et al., 2015).

## Extent and persistence of urchin barrens as a state of the environment indicator

There are compelling reasons why urchin barren extent and persistence should be considered as a key ecological indicator summarised in the list below:

1. Shallow kelp forests and their adjacent soft bottom edge habitats are arguably one of the most valuable coastal habitats. In Northland they are clearly threatened by prolonged localised fishing.

2. A monitoring system focused on urchin barrens is essentially measuring primary production (kelp forest), the primary grazer population density and grazing impact, and indirectly the keystone predator presence or absence on the reef. These are the main drivers of all ecosystems and as such affect all other species associated with the reefs.
3. Our experience here and overseas is that the serious impacts of fishing resulting in urchin barrens can be reversed completely by long term cessation of fishing.
4. Experience here and overseas has demonstrated that urchin barrens can be effectively mapped and their extent quantified over time. A range of low cost methods have been employed to date to support mapping. There are new exciting technologies now on stream to further improve our ability to monitor kelp forest health. Combination of high resolution satellite imagery, conventional aerial photography, drone imagery, underwater photography, low cost sonar systems supported by software algorithms designed for mapping underwater vegetation and accurate 3D mapping systems are now all tools that can support efficient kelp forest mapping and monitoring efforts.

## Thresholds in urchin barren development that could be used to inform management arrangements

We anticipate a great deal of future interest in the move to ecosystem based monitoring and management approaches. Focus on key habitats especially those with high social economic and cultural values that can be monitored effectively will no doubt be subject to a great deal of research development and new adaptive management systems of the future. However the known threat of urchin barren development occurring today dictates that it is our responsibility to adapt management approaches based on current knowledge. In taking this action we can begin to reverse the current decline as well as inform future management. To this end we are offering here some initial guidelines for thresholds which could be measured in a low cost monitoring system. Results of this system could guide planning and decisions around local control of fishing to allow for recovery of the ecology of rocky reefs and associated biodiversity.

### *Working assumptions*

For a given management area, a basic marine habitat map is completed outlining the extent of rocky reefs

A system of representative monitoring sites are established where the reef’s biological zonation is mapped.

At each site a shallow reef depth zone is established representing preferred urchin habitat zone, (shown in white in figure 3 below). Typically this would range from 10-15m or the depth of the reef edge if it is less than this figure. Wave exposure would guide this determination.

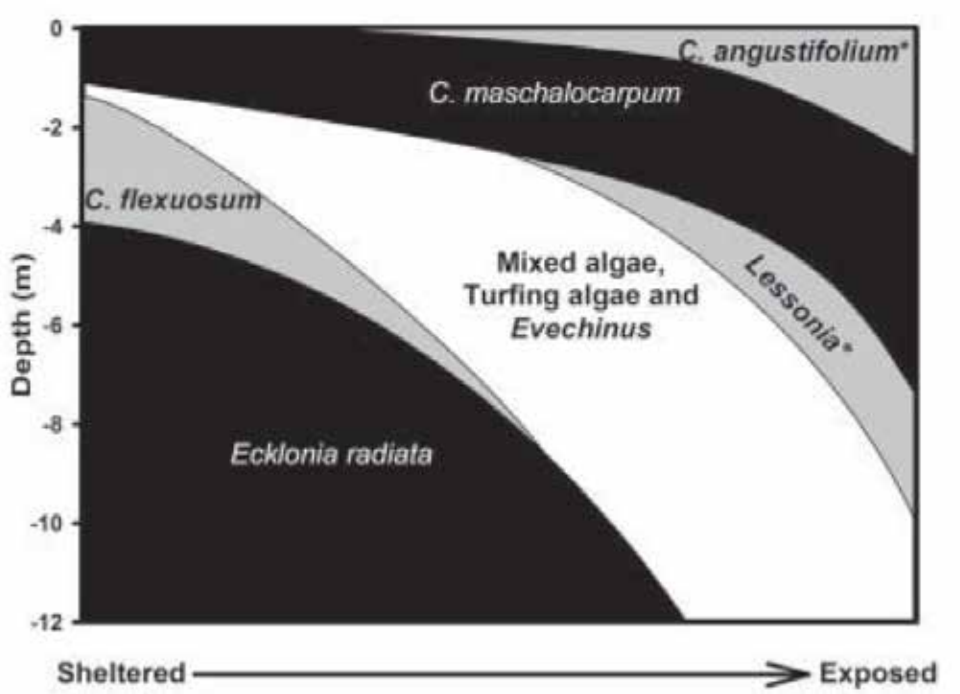



**Figure 3** A proposed model for rocky reef zonation as a function of depth and wave exposure, (taken from Shears et al. 2004).

***Thresholds used to inform management actions (restrictions on fishing)***

Based on the monitoring of the shallow portion of the reef classified as sea urchin preferred habitat, the following thresholds could be considered to trigger management arrangements:

**Level 1** 5-10% urchin barren extent signals concern that impacts of urchin barrens are becoming significant. If this level persists or expands and is supported by low reef fish diversity counts and low counts of large snapper and crayfish restrictions of fishing could be considered

**Level 2** >10% urchin barren extent which is persistent or expanding and supported by poor monitoring results for reef fish diversity, large snapper and crayfish counts. This level triggers consideration of long term no fishing protection to restore ecological balance and productivity of the reef. Decisions to remove the no-fishing restriction could be considered only after recovery of kelp forest had reached a level better than the Level 1 trigger and where sufficient representative areas in the management area remain as a network of fully protected areas to meet basic marine protection goals.

Fishing controls considered should include areas mapped as reef edge habitats of adjacent soft bottom habitats and extend offshore to a minimum distance of 2 km where possible. This design guideline is informed by studies of crayfish (Kelly, 2001 & MacDiarmid & Kelly, 2003) and snapper home range (Parsons et al. 2003) and use of reef edge soft bottom habitats (Langlois, 2005 & 2006).

## Recommendations

1) We have identified a specific biodiversity threat to shallow rocky reefs, which is not being taken into account by the current fisheries management framework. This leads us to a conclusion that there is a valid reason to adopt other means to support biodiversity conservation and restoration by pursuing localised management controls on areas where fishing is having serious adverse effects. This would support fisheries management overall.

2) Support further investigations into the special nature of habitats and biodiversity in the shallow coastal zone where localised heavy fishing pressure can have specific ecological impacts. Fish, algal communities, benthic invertebrate communities, and deep reef encrusting invertebrate communities are all good candidates for future investigations.

3) Establish a set of representative rocky reef study areas where long-term changes can be documented and understood.

4) Develop a research programme that reviews the spatial implications of various forms of fishing and specific impacts on shallow rocky reefs. The specific impacts of fishing intensity at the local or reef scale must be quantified for its ecological impact role to be understood.

5) Support ongoing study of the restoration of kelp forests in New Zealand marine reserves and other fully protected areas. Studies of marine reserves have demonstrated that marine reserves can reverse the urchin barren condition back to a restored kelp forest and offer an essential ‘control area’ to evaluate the impacts of fishing at a local scale.

6) Create a research project that examines the climate change implications of loss of kelp forests. In Tasmania loss of kelp forest is believed to significantly reduce carbon absorption and reduce resilience to unstable or fast changing environmental conditions associated with climate change (Ling, 2009).

7) Develop a model for documenting the ecological goods and services value of shallow rocky reefs and the ecological, economic and cultural losses associated with the loss of kelp forests verses the positive value of their restoration (Van den Belt & Cole 2014).

8) Develop local and regional goals or design objectives for the extent and arrangement of a network of fully protected areas that would insure against further decline of shallow reefs and support restoration of kelp forests at a regional scale.

## Acknowledgements

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It has been a pleasure and privilege to work with the team at the Motiti Rohe Moana Trust on this project. We look forward to the day when their hard work and vision will reap rewards for the marine environment and their community. We can do better in engaging our communities in local marine conservation and management work and we will profit from the coming together of matauranga maori and scientific approaches to caring for the sea.

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## Appendix 1 Map Book

**Map 1 Study area**

**Map 2 Exposure classification map**

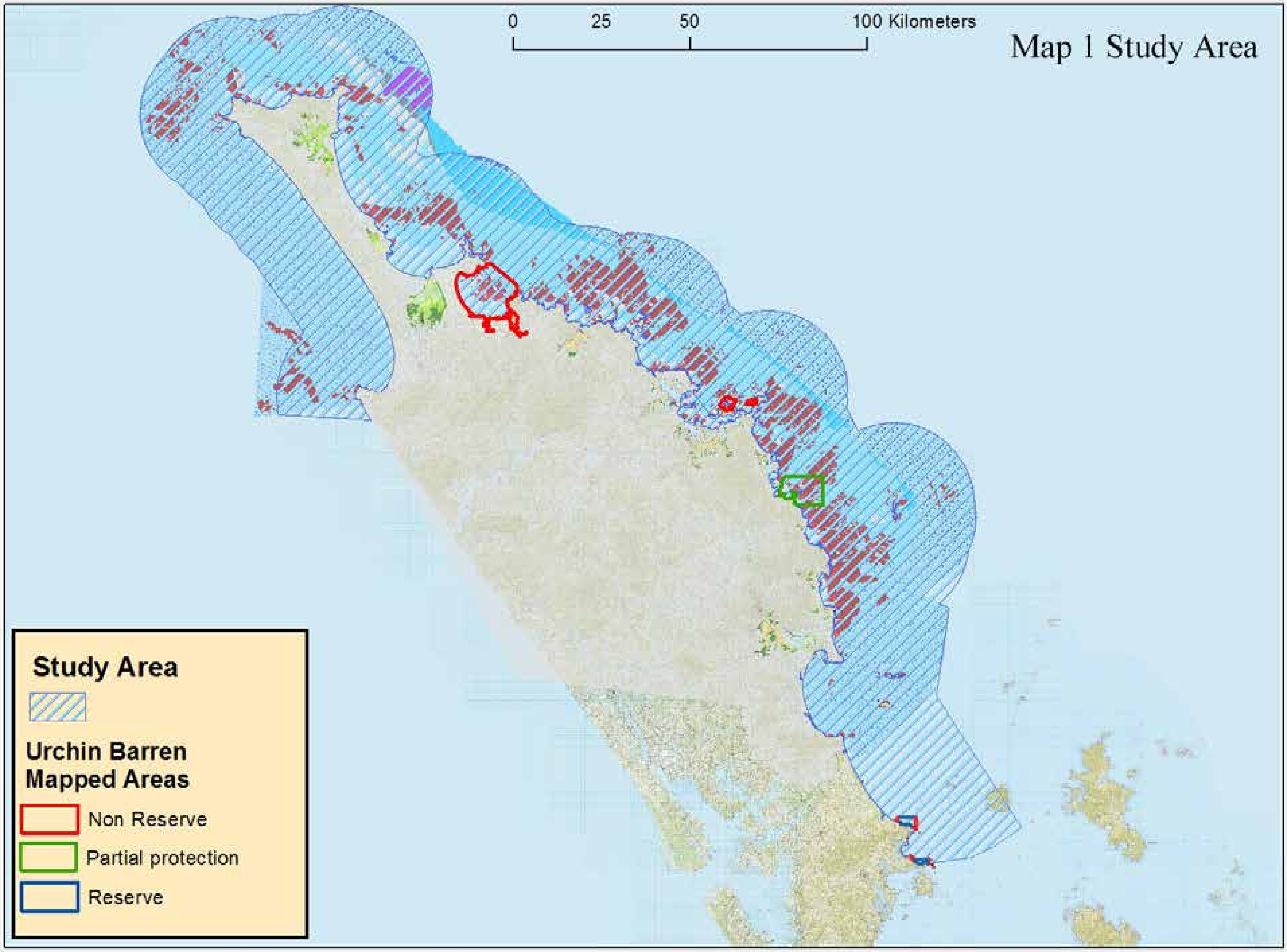
**Map 3 Doubtless Bay (urchin barren mapped area)**

**Map 4 Bay of Islands (urchin barren mapped areas)**

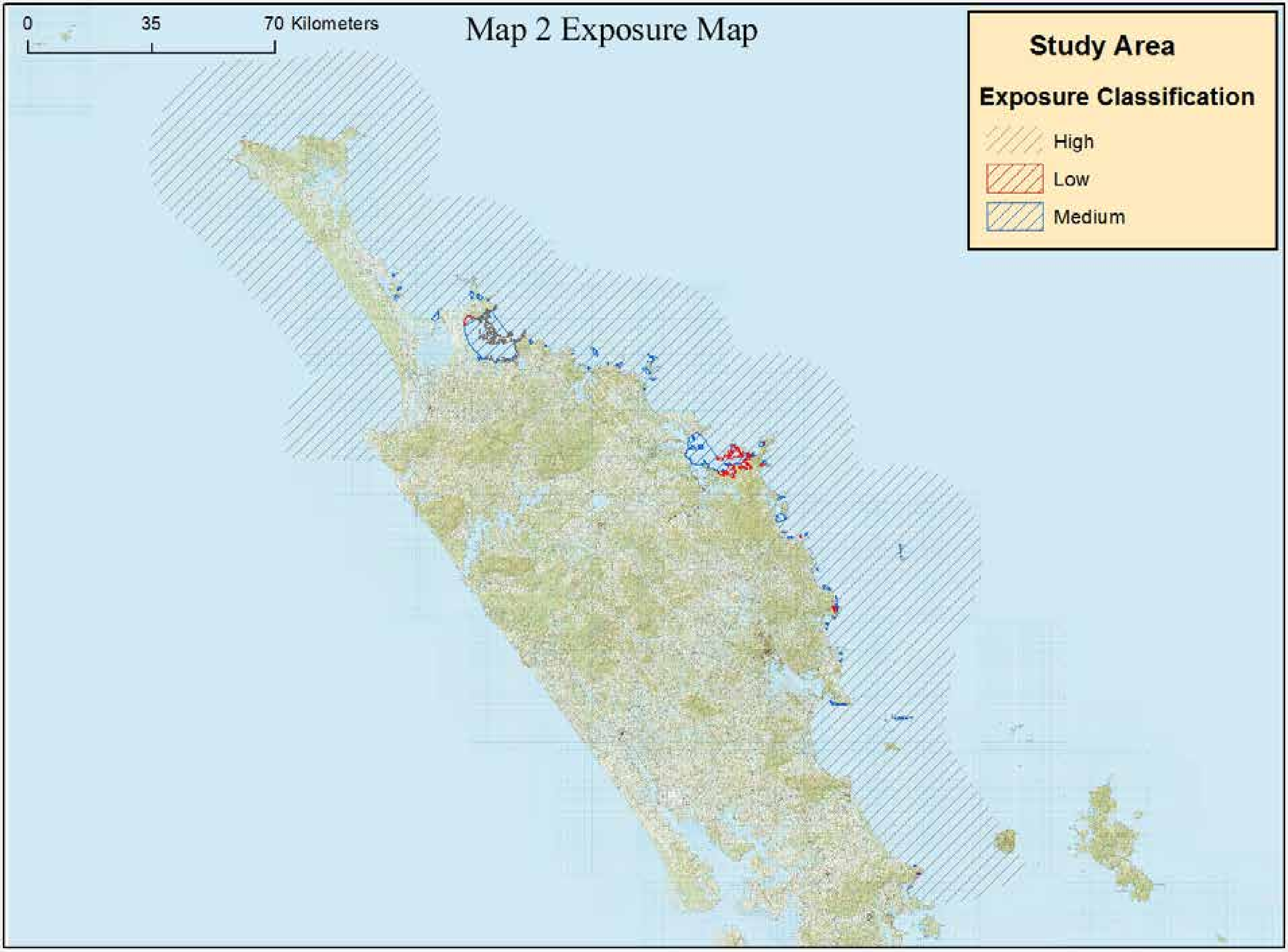
**Map 5 Mimiwhangata Marine Park (urchin barren mapped area)**

**Map 6 Cape Rodney to Okakari Point Marine Reserve (urchin barren mapped area)**

**Map 7 Tawharanui (urchin barren mapped area)**



Map 1 Study Area
0
25
50
100 Kilometers
Study Area
Urchin Barren
Mapped Areas
Non Reserve
Partial protection
Reserve


Map 2 Exposure Map
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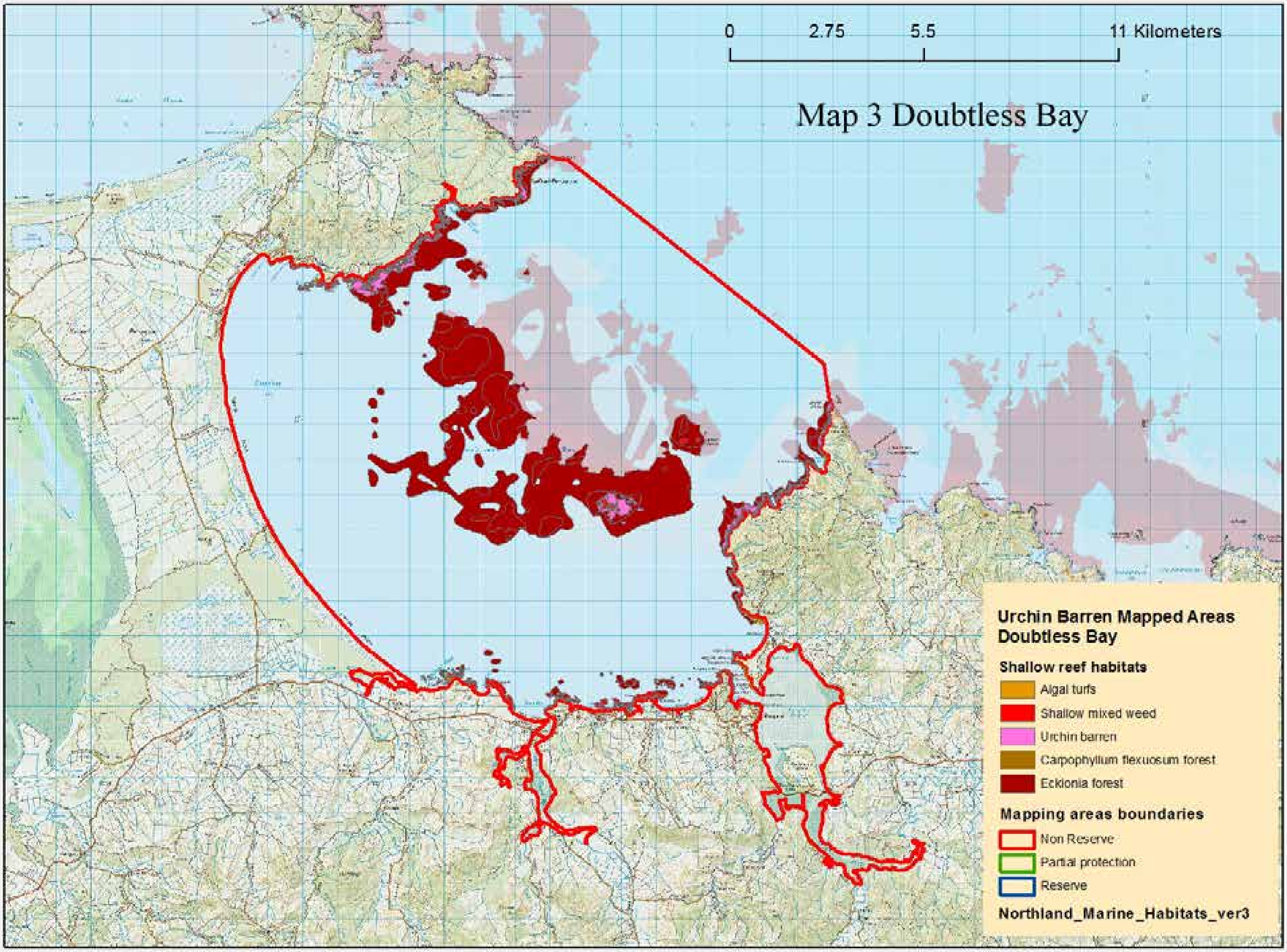
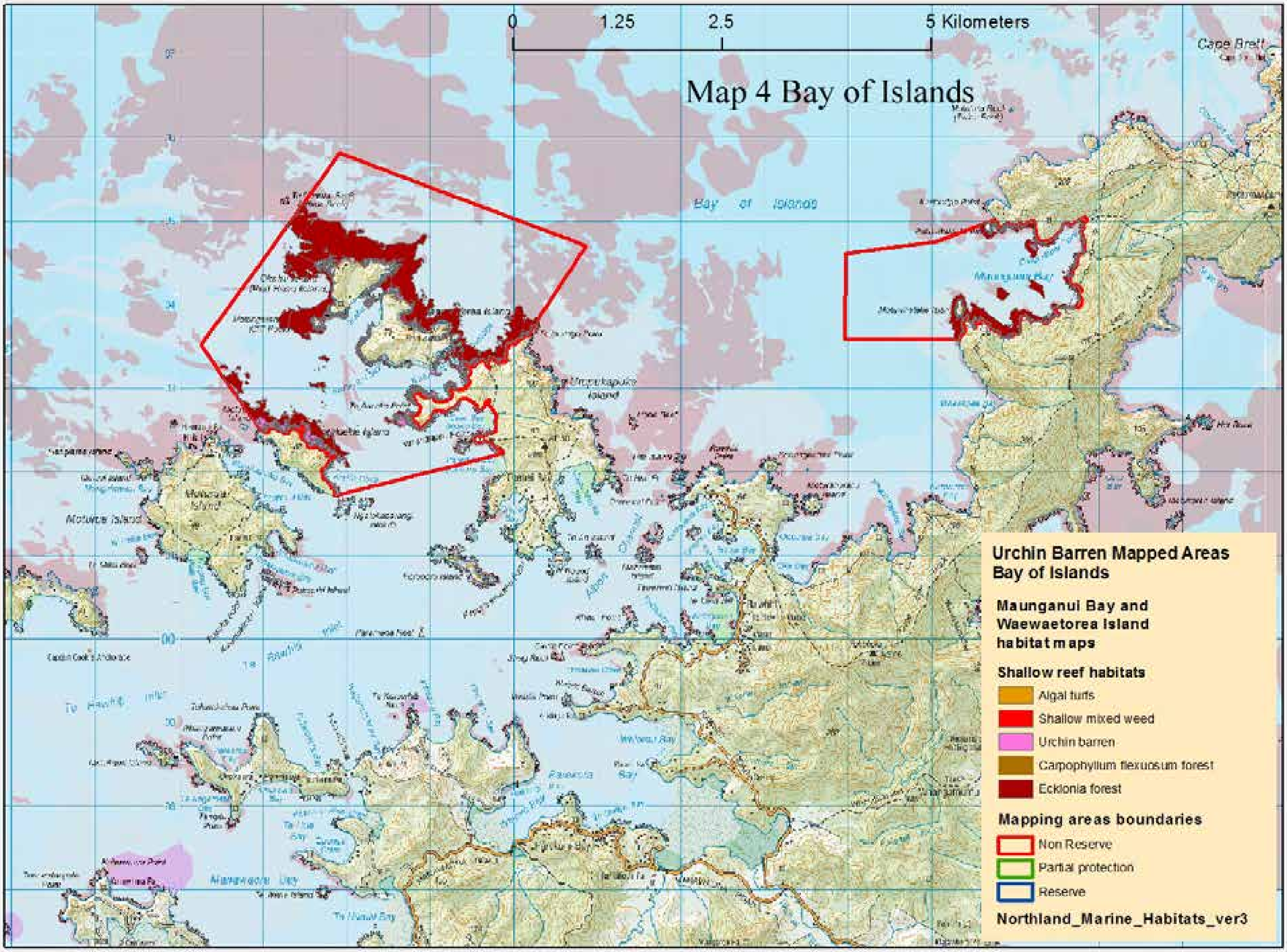
35
70 Kilometers
Study Area
Exposure Classification
High
Low
Medium


0
2.75
5.5
11 Kilometers
Map 3 Doubtless Bay
Urchin Barren Mapped Areas
Doubtless Bay
Shallow reef habitats
Algal turfs
Shallow mixed weed
Urchin barren
Carpophyllum flexuosum forest
Ecklonia forest
Mapping areas boundaries
Non Reserve
Partial protection
Reserve
Northland_Marine_Habitats_ver3


0
1.25
2.5
5 Kilometers
Map 4 Bay of Islands
Cape Brett
Bay of Islands
Urchin Barren Mapped Areas
Bay of Islands
Maunganui Bay and
Waewaetorea Island
habitat maps
Shallow reef habitats
Algal turfs
Shallow mixed weed
Urchin barren
Carpophyllum flexuosum forest
Ecklonia forest
Mapping areas boundaries
Non Reserve
Partial protection
Reserve
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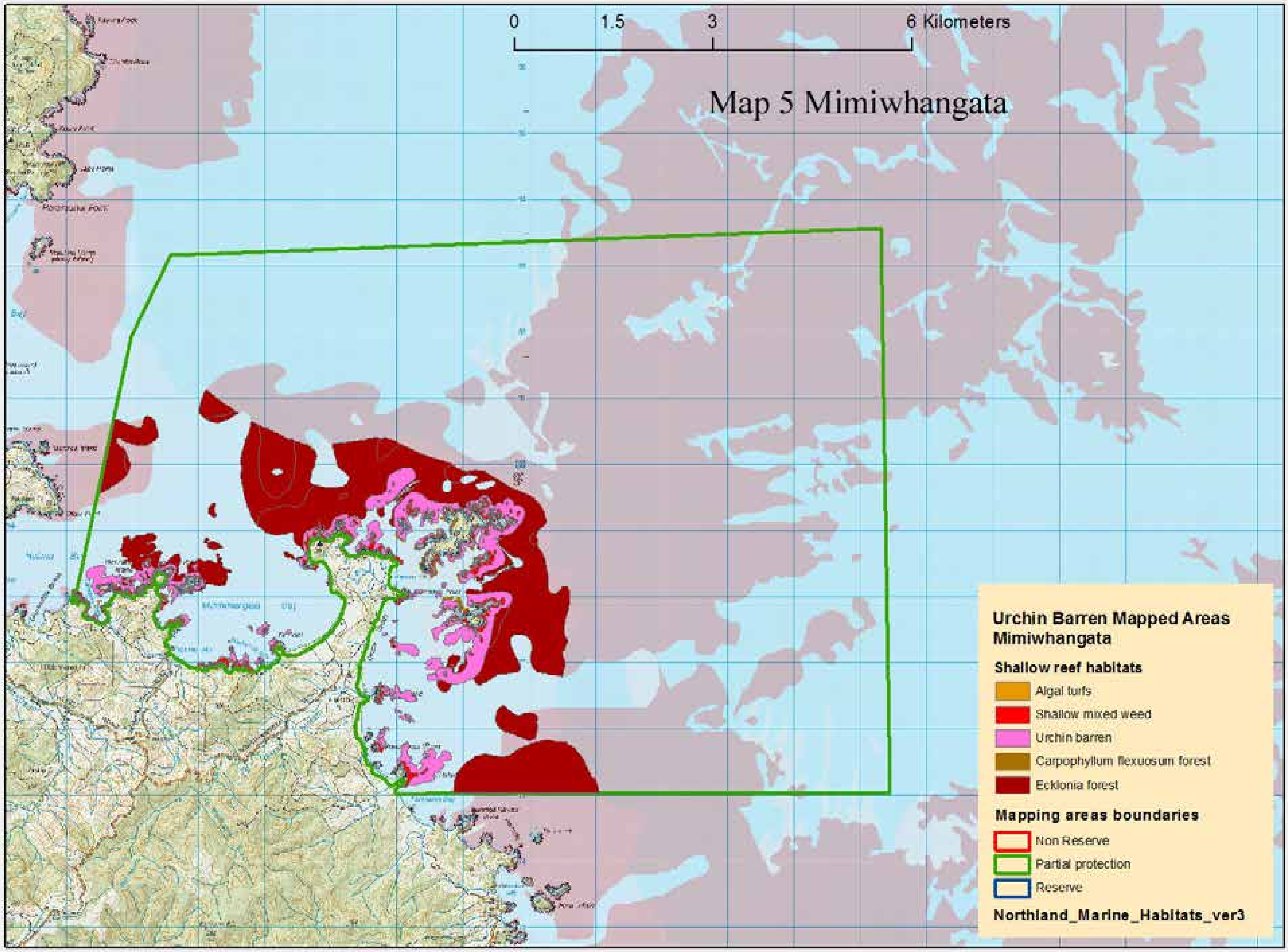
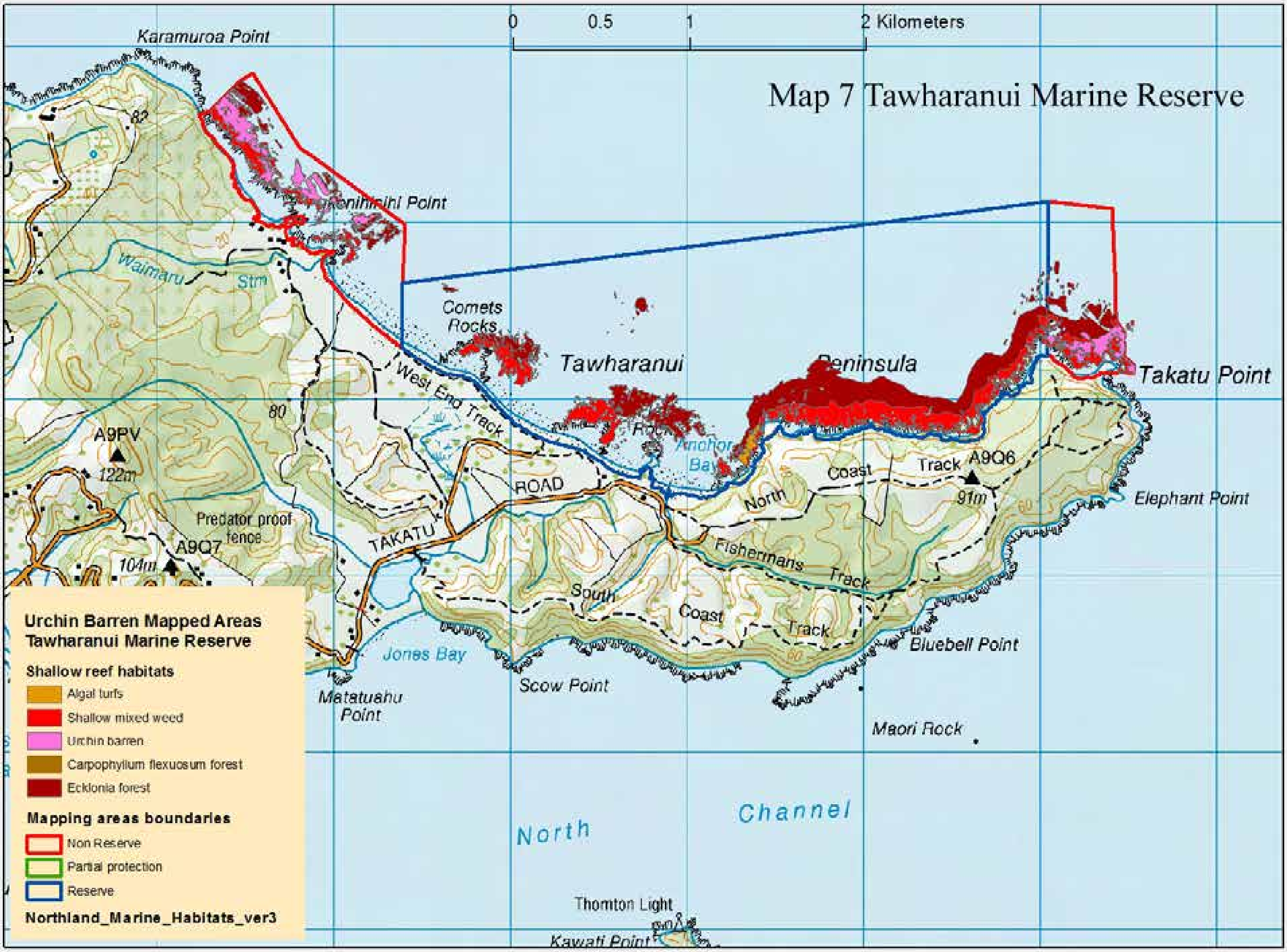

0
1.5
3
6 Kilometers
Map 5 Mimiwhangata
Urchin Barren Mapped Areas Mimiwhangata
Shallow reef habitats
Algal turfs
Shallow mixed weed
Urchin barren
Carpophyllum flexuosum forest
Ecklonia forest
Mapping areas boundaries
Non Reserve
Partial protection
Reserve
Northland_Marine_Habitats_ver3

Map 6 Leigh Marine Reserve
0
0.5
1
2 Kilometers
Point
Island
Te Re
Cape Rodney
ROAD
RD
SEAVIEW
J GREENWOOD RD
295
279
94
GOAT ISLAND RD
A9PH
116m
CAPE
RODNEY
ROAD
PAKIRI
ROAD
TENETAHI RD
MT PLEASANT
DRIVE
135
58
Panetiki Island
(The Outpost)
Omaha Cove
Kohuroa Stream
Airstrip
FROST RD
Leigh
20
60
62
63
64
174°50'
Urchin Barren Mapped Areas
Leigh Marine Reserve
Shallow reef habitats
Algal turfs
Shallow mixed weed
Urchin barren
Carpophyllum flexuosum forest
Ecklonia forest
Mapping areas boundaries
Non Reserve
Partial protection
Reserve
Northland_Marine_Habitats_ver3


Map 7 Tawharanui Marine Reserve
0
0.5
1
2 Kilometers
Karamuroa Point
Comets Rocks
Tawharanui
Peninsula
Takatu Point
Elephant Point
West End Track
Anchor Bay
A9PV
122m
A9Q7
104m
Predator proof fence
TAKATU
ROAD
North
Coast
Track
A9Q6
91m
Fishermans
Track
South
Coast
Track
Bluebell Point
Jones Bay
Scow Point
Matatuahu Point
Maori Rock
North
Channel
Thornton Light
Kawau Point
80
Urchin Barren Mapped Areas
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