

## National coastal susceptibility: Vulnerable areas and demographics

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## Executive summary

The delineation of coastal elevation zone shapefiles from the enhanced-merged Landcare/SKM national DEM, at a substantially improved accuracy than using previous national DEMs, provides a reasonable national overview of the demographic composition within areas potentially susceptible to coastal inundation hazards in New Zealand.

Shapefiles were developed for successively higher coastal elevation zones of 0–3 m, 3–5 m and 5–10 m above MHW. Land area and demographic distributions within these zones have been enumerated within GIS from overlays with the topography and the 2006 Census meshblocks. The lowest elevation zone (0–3 m) is a reasonable surrogate for the exposure of coastal areas to both present-day coastal hazards, such as storm tides and wave run-up plus infrequent tsunami and credible sea-level rises of 0.7 to 1 m likely within the next 100 years.

The proportion of low-lying coastal land area in New Zealand is low, with only 2.1% of the total land area below 10 m above MHW and directly connected to the coast, due in part to the relatively young geology of our country. Consequently, the proportion of land area within these coastal elevation zones is a poor surrogate by itself as a national measure of coastal inundation hazard susceptibility – it needs to include demographic information and eventually the enumeration of the built environment asset base within these coastal margins to assess socio-economic susceptibility.

For all ages, most of the people resident in the 0–3 m coastal zone in New Zealand lived in either Canterbury (41%), Hawke's Bay (17%) or Auckland (13%), with these three regions accounting for 71% of all people who were resident in this zone in the 2006 Census.

This same general distribution was reflected in the percentage of 65+ year old people within those three regions accounting for 67% of all the 65+ year olds who were resident in the 0–3 m coastal zone in the 2006 Census.

As a proportion of the 65+ year population to all ages in each of the three coastal elevation zone, nationally this was consistently at an average across New Zealand of around 14.5%. Regionally, the highest proportions of the 65+ year population to the total number of residents were as follows:

- 0–3 m zone: Waikato (20%), Otago (19.5%) and Tasman (18.5%).
- 3–5 m zone: Otago (19.8%), Tasman (19.7%) and Southland (19.3%).
- 5–10 m zone: Otago (19.7%), Tasman (18.3%) and Marlborough (18.2%).

An important caveat with this broad demographic overview is that the populations in each meshblock are based on people present on census night (a Tuesday in March), so is likely to be a significant underestimate of people who would be temporarily resident in coastal settlements and cities in say January. Future work assessing the number of dwellings in these coastal elevation zones will assist to further address the demographic susceptibility to coastal inundation hazards (both present-day and future sea-level rise), with many buildings only occupied for part of the year (typically summer).

# 1 Introduction

The Centre for Research Evaluation and Social Assessment (CRESA) has 2-year contestable funding from the Ministry of Business, Innovation & Employment (MBIE) in the Health & Society portfolio to undertake a research project entitled *Community Resilience and Good Ageing: Doing Better in Bad Times*.

CRESA sub-contracted NIWA to undertake research in Sequence 1.1.3 under Research Aim 1.1 (*Older People and Community resilience in Adverse Events*), which involved developing an evidence base for vulnerability at two different spatial scales:

- 1) a susceptibility index or GIS-layer related to the vulnerability of older people nationally to river flood and coastal inundation, alongside a
- 2) finer-grain analysis of risk at the local-scale using RiskScape to support local case studies in the areas where the elderly are vulnerable to flooding and inundation hazards.

This present report covers the national coastal inundation hazard susceptibility overview, focused around determining coastal areas in New Zealand below 3 m above mean high water (MHW), which in lieu of having accurate storm-induced and sea-level rise inundation maps nationally, is a reasonable surrogate for areas potentially vulnerable to coastal hazards (including tsunamis) and climate change. The elevation threshold is also limited by the accuracy of the best-available digital elevation model (DEM) at the national scale.

The national river flood-plain susceptibility work has been previously reported by Henderson & Sykes (2013) and the local-scale RiskScape investigations by Paulik & Sturman (2014).

## 2 Background to a national coastal susceptibility

Coastal inundation hazard susceptibility on coastal plains is a function of the drivers of coastal processes (storms, waves, tides, tsunami and sea-level rise) which cause elevated water levels at the shoreline, and subsequent exposure of inhabitants and their associated built environment, which is primarily a function of overland flowpaths. These flowpaths are related to the topography of the coastal plains relative to mean high water (MHW). Hence, the accuracy of any determination of susceptibility to coastal inundation hazards and sea-level rise will in large part be related to the accuracy and consistency of the digital elevation model available at the different spatial scales being considered.

### 2.1 NZ digital elevation models

Some developed countries, such as the USA and parts of Europe, have available accurate DEMs for their coastal areas. These accurate DEMs have facilitated the publication of regional/local maps highlighting coastal hazard zones and the extent of future sea-level rise impacts, along with enumerating associated socio-economic exposure. An example are the coastal planning and elevation maps for the east coast of USA such as those at: <http://plan.risingsea.net/Florida.html>.

The situation in New Zealand is we are unable to resolve our coastal topography down to the required sub-metre accuracy at a national level. The exceptions are specific areas which have been flown by local or regional government agencies using Light Detection And Ranging (LiDAR), which can achieve accuracies down to 0.15 m in vertical elevation. While these provide useful DEMs to work with at the local/regional scale in some parts of New Zealand, there is no consistent LiDAR-enhanced national DEM available.

At the national level, previously the first DEM was based on the Land Information NZ (LINZ) 1:50,000 map series elevation contours, which were only available at 10 m contour intervals.

An improvement was the release around 2005 of the global terrain dataset from the NASA Shuttle Topography Radar Mission (STRM) originally flown in February 2000. The STRM DEM was publically available at 90 m horizontal resolution and a vertical elevation accuracy of around 5–8 m. In 2008, NIWA used the STRM DEM to produce a national-scale map of two sets of coastal areas where the topography was less than 5 m and 10 m above mean high water (MHW), with these elevation increments aligned with the vertical accuracy. This map was included as Figure 3.1 in the Ministry for the Environment's national guidance on Coastal Hazards and Climate Change (MfE, 2008).

More recently, Landcare produced an enhanced New Zealand DEM at a 15 m horizontal resolution, which was subsequently improved by SKM (now Jacobs) consultants by merging the Landcare DEM with a 30-m resolution STRM DEM product<sup>1</sup> as part of the collective NZ government agency KiwImage project to obtain high-resolution imagery for NZ. This merged-enhanced Landcare/SKM DEM was used for this project application, with an unknown but improved vertical accuracy than the original 90-m resolution STRM DEM.

Initially, GIS shapefiles were formed at 0–5 m and 5–10 m coastal elevation intervals as extracted previously, but a qualitative comparison with a LiDAR DEM in Auckland indicated the accuracy was sufficient to justify bringing the lowest elevation band down to 0–3 m above

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<sup>1</sup> previously only available for defence purposes



MHW. Further increments of 3–5 m and 5–10 m above MHW were also extracted from the merged-enhanced Landcare/SKM DEM.

These GIS shapefiles for low-lying coastal areas (especially 0-3 m above MHW) therefore provide a surrogate at a broad national scale of coastal areas that could at some point be susceptible to coastal inundation impacts including ongoing sea-level rise.

The coastal elevation shapefiles were then mapped onto coastal census mesh-blocks to enumerate the demographics within each coastal elevation zone.

## **2.2 Coastal geomorphology and hazards**

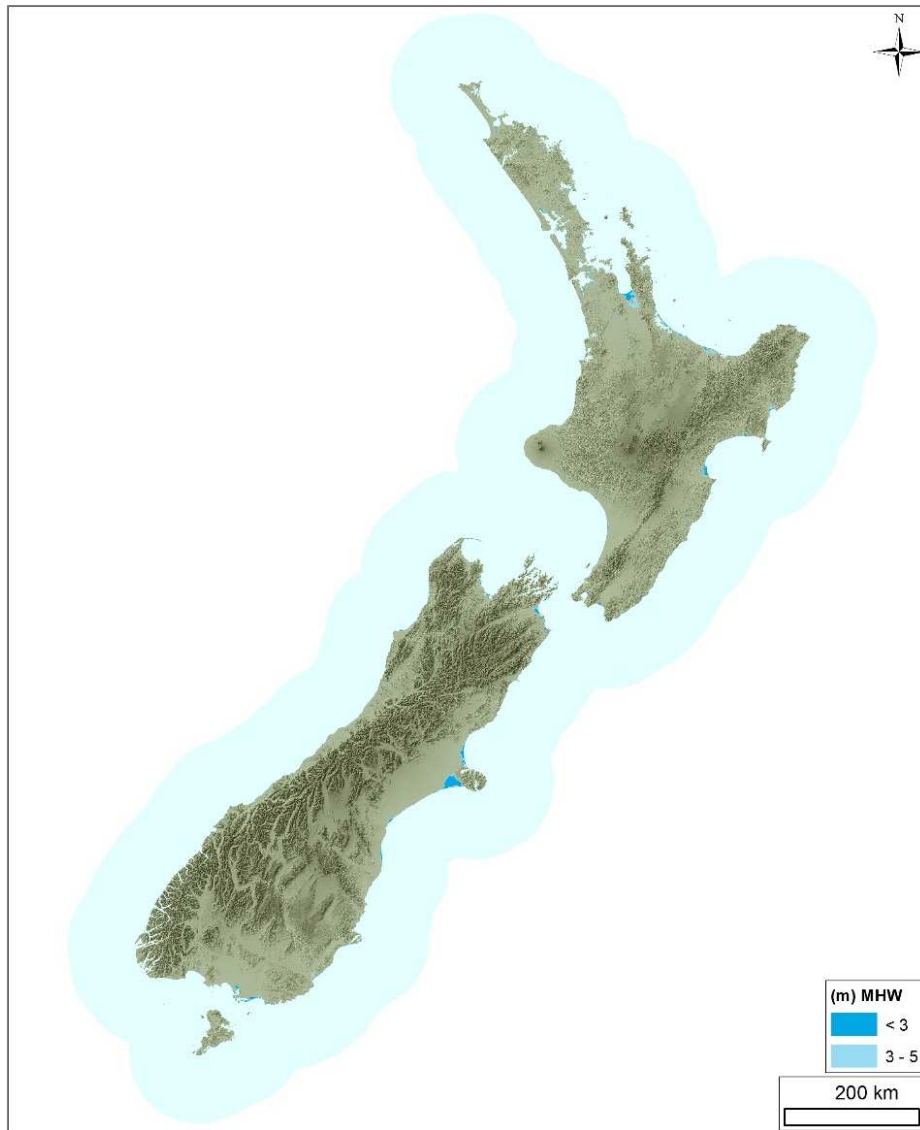
### **2.2.1 Physical setting**

New Zealand is geologically young, so doesn't have extensive low-lying coastal plains nor does it have large river delta systems (e.g., the Mississippi deltaic region around New Orleans). There are however, pockets of low-lying coastal areas that have arisen through geomorphological processes. Some of the larger low-lying areas are the Hauraki Plains (old flood-plain of the Waikato River), Christchurch City (former river swamp and branch of the Waimakariri River) and the Hastings/Napier area (natural reclaimed area from uplift during the Napier/Hastings earthquake of 1931).

A considerable proportion of New Zealand's coastline comprises elevated sedimentary rock cliffs or marine terraces with narrow coastal plains, which are not significantly impacted by coastal inundation hazards. However, most of the coastal population centres or coastal settlements are built around the periphery of estuaries, harbours or embayments, which are generally associated with low-lying margins. Hence, at the national scale, coastal inundation hazard susceptibility appears at first to be quite confined, as shown in Figure 2-1, with only less than 1% of New Zealand's land area below 5 m above MHW (see Table 3-1).

Zooming in at regional scales shows a different picture, with a sample of regions or areas presented in Appendix A.





**Figure 2-1: National view of coastal elevation zones that are below 5 m MHW.** [Based on the enhanced-merged Landcare/SKM DEM].

### 2.2.2 Coastal inundation hazards in relation to the 0–3 m coastal zone

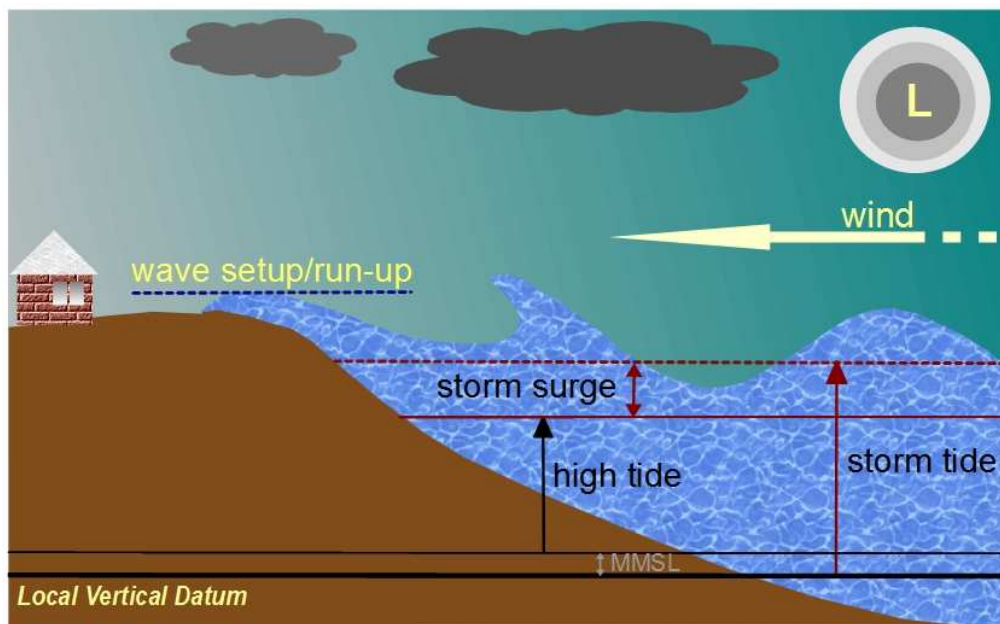
New Zealand is subject to coastal inundation hazards generated by either storms or tsunamis generated by geological disturbances (seabed-rupture during an earthquake, submarine volcanic eruption or a submarine landslide).

#### Storm-generated inundation

Storm systems can cause inundation of low-lying coastal areas through the combination of the following processes:

- High spring tides– which are predictable for years to come (due to sun and moon). Highest tides are on the west coast and lowest around mid-eastern New Zealand. Note: the DEM used is assumed to be corrected to the regional mean high water.

- Monthly mean sea level (MMSL)— sea level varies by up to  $\pm 0.25$  m around New Zealand primarily from the El Niño and La Niña climate cycle.
- Storm surge— due to a relaxation of the sea surface when low regional barometric pressure drops below the average pressure combined with a set-up in water level against the coast by winds (see Figure 2-2). The maximum recorded storm surge (over and above the tide level) was 0.88 m at Mount Maunganui during ex-tropical cyclone *Giselle* (aka *Wahine Storm*) in 1968. The maximum probable storm surge in New Zealand is around 1 m (Bell et al. 2000).
- Wave run-up— generated by the waves setting up inside the breaker zone and carried by momentum up the beach face or overtopping the shoreline (Figure 2-2). Wave run-up can add 0.5 to 1 m to storm-tide levels (tide+ MMSL+storm surge).



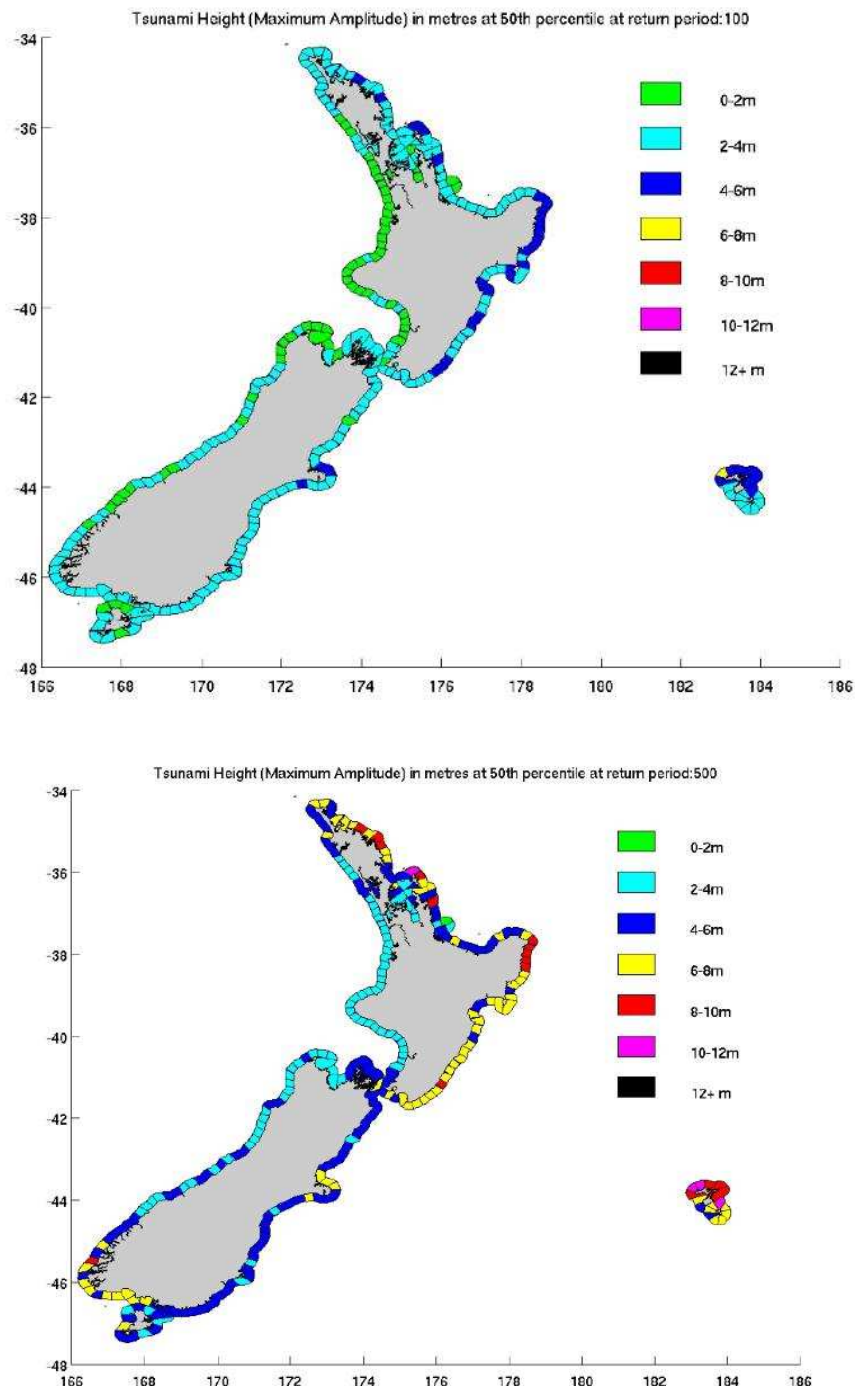
**Figure 2-2: Components leading to storm inundation at the coast.**

Consequently, storm inundation at the coast can exceed 2 m above MHW for a 50 to 100-yr average recurrence interval event, when wave run-up and overtopping is included. This will expose some of with the 0–3 m coastal elevation zone, although because such extreme levels would only occur for a short period of 1-2 hours around a peak high tide, the ability for extensive inland inundation is limited by time and volume of water.

### Tsunami

Unlike storm-generated inundation, tsunami waves have the potential to inundate large areas of low-lying coastal plains in New Zealand, due to both the wave height (could be up to or above 10 m for large magnitude earthquakes) and the long period of the waves (5–20 minute period for tsunami surges over land). Figure 2-3 shows the predicted tsunami wave heights for the New Zealand coastline at 100-year and 500-year average recurrence intervals that were determined in a recent revision of the tsunami hazard exposure for New Zealand

(Power et al. 2013). Such wave heights could be above MHW if the peak waves coincided with high tide. Large tsunami events are therefore likely to inundate most of the 0–3 m coastal elevation zone and beyond into the 3–5 m elevation zone or even the 5–10 m elevation zone in places.



**Figure 2-3: Tsunami wave heights (m) around NZ for average recurrence intervals of: (top) 100 years, (bottom) 500 years. Note: these are the median estimates [Source: Power et al. (2013).]**

### Sea-level rise

Sea levels have risen by around 0.17 m in the past 100 years in New Zealand (Hannah & Bell, 2012), but the Intergovernmental Panel on Climate Change (IPCC) is projecting sea level to rise by between 0.5 and 1.0 m by 2100 for the higher more-likely greenhouse gas emission pathways (IPCC, 2013).

Both storm-inundation levels and tsunami wave heights will be lifted higher as mean sea level rises. In particular, storm-tide and wave inundation will become much more frequent as sea level rises e.g., a present-day 100-year storm-tide events will become an annual occurrence on average with only a 0.4 m sea-level rise (based on an analysis for Auckland and Nelson).

### Surrogate for coastal hazards and coastal climate change

Based on the above magnitudes of coastal hazards, that will be compounded by rising sea-levels (or occur more frequently), the 0–3 m elevation zone is a reasonable surrogate for delineating the area most susceptible to coastal hazards, even if they occur infrequently (such as tsunami). Some of the hinterland parts of the 0–3 m zone may not be impacted to the same extent or frequency as those located closer to the shoreline, nevertheless, the 0–3 m zone does provide a best-available measure of coastal hazard susceptibility until such time the national DEM can be improved or local/regional LiDAR DEMs spliced in.

Results derived from using the 0–3 m coastal elevation zone, should only be taken in the context of a national overview, and should never replace the need for a thorough local or regional investigation to determine more precisely the hazard exposure for a community, area or region.

## **2.3 Demographic analysis**

Census meshblocks tend to vary in their orientation at the coast e.g., some blocks align along the coastal margin while others extend well back into the hinterland, with only a small coastal frontage. An assumption was made that the population in each meshblock would be a pro rata value of the ratio of area of the mesh-block overlapped by the coastal elevation shape-file divided by the total meshblock area. On average across New Zealand, this will be a reasonable assumption, but locally there will be differences arising depending on the shape and orientation of each meshblock.

Census population data by meshblock are not yet available for the 2013 Census, so the demographic analysis was undertaken using the previous 2006 Census dataset based on meshblocks used for that census.

## 3 Results from the national susceptibility overview

### 3.1 Key outputs

The key outputs from the national overview of coastal-inundation hazard susceptibility include:

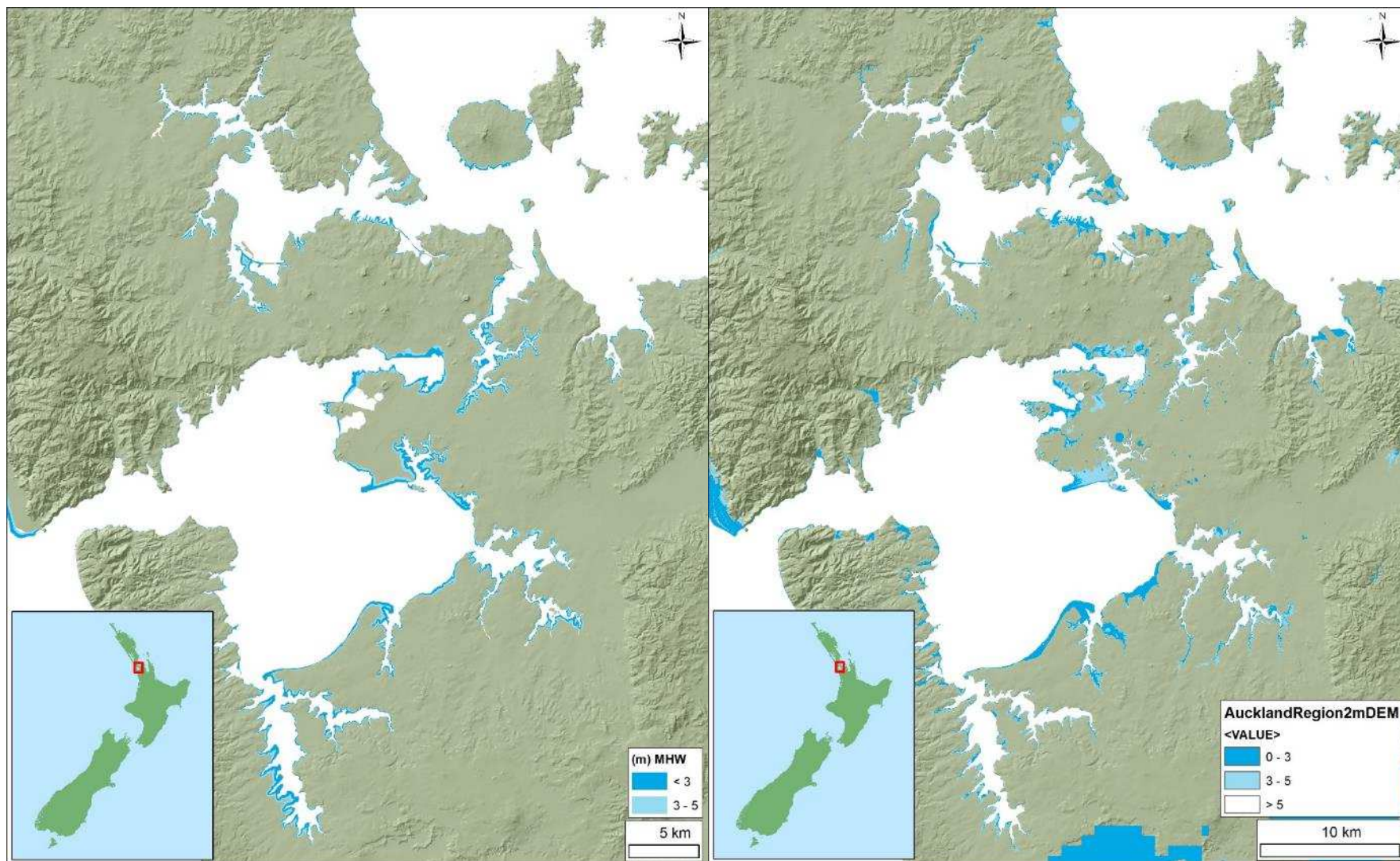
- Shapefiles determined, by intersecting the relevant lower and upper elevation in metres above MHW with the merged-enhanced Landcare/SKM DEM. Areas with topography within those limits that did not have a direct link to the coastline (for the 0–3 m zone) or the 3 m elevation line (for the 3–5 zone) i.e., were isolated areas, were removed from the shapefiles and not included in any further analysis. The rationale for this is that areas are only susceptible to coastal inundation if there is a clear and direct overland flowpath inland from the coastline.
- Regional maps of the 0–3 m and 3–5 m areas overlying a background NZ topographic layer.
- A demographic analysis of people present in the overlapping area of 0–3 m, 3–5 m and 5–10 m coastal polygons with each meshblock, applying a pro-rata reduction based on the relative area of overlap. The 2006 census data was stratified into people 65 years and older (65+) as well as the total population (all ages) in each meshblock. The results were also aggregated up into regional and national totals for each coastal elevation zone.

### 3.2 Comparison with LiDAR

To qualitatively assess the relative accuracy of the merged-enhanced Landcare/SKM DEM, an area of Auckland was compared with a 2-m horizontal resolution LiDAR DEM from Auckland Council over the same area. The LiDAR DEM has a 0.25 m vertical accuracy in the urban areas and 0.5 m accuracy in rural areas. The Auckland comparison between the two DEMs is shown in Figure 3-1.

Overall, it appears the merged-enhanced Landcare/SKM national DEM slightly underestimates the land area for a given elevation band, although in some areas it overestimates. A definitive comparison would require a more detailed analysis tied into checks on the relative datum's and how the MHW datum has been defined and applied around New Zealand. However, overall the merged-enhanced Landcare/SKM national DEM compares reasonably well with the more accurate LiDAR, and appears to have a much better vertical accuracy than the 5–8 m quoted for the 90-m resolution STRM DEM originally used for the previous national susceptibility mapping for the MfE guidance manual (MfE, 2008).





**Figure 3-1: Comparison of the 0–3 m and 3–5 m coastal elevation zones derived from the national enhanced DEM (left) and the adjusted Auckland Council 2 m LiDAR DEM (right).** Note: offsets of 1 m (east coast) and 1.4 m (west coast) were applied to the Auckland LiDAR DEM to adjust from Auckland Vertical Datum-1946 to MHW.

### 3.3 Regional coastal elevation zone maps: land area

Regional maps of the 0–3 m and 3–5 m coastal elevation zones are shown in Appendix A.

Table 3-1 lists land areas in km<sup>2</sup> within coastal elevation zone for each region and aggregated up to the national totals. The combined land area totals encompassed by the three elevation zones is shown in Figure 3-2.

The largest areas within a 0–3 m coastal elevation zone are in Canterbury, Waikato (mainly Hauraki Plains), Southland and Northland. Overall in New Zealand, the areal extent of the 0–3 m elevation zone is quite small at 0.5% of the total land area – however, it is these low-lying areas which are more likely to be populated and be built up. The Nelson region is such an example where the area of low-lying coastal land is small (Figure 3-2) but it is where much of the seaward part of the Nelson City CBD and adjoining suburbs are located.

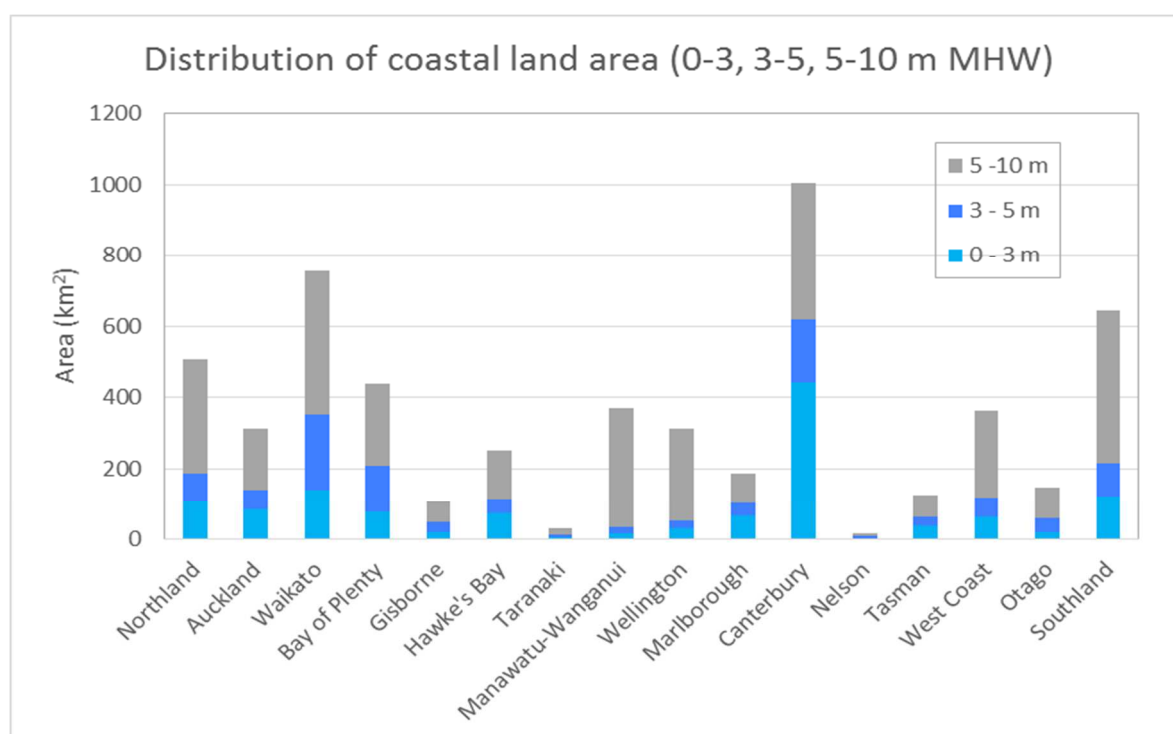
New Zealand's land area below 10 m above MHW and directly connected to the coast, only amounts to 2.1% of the total land area. This emphasises that the proportion of land area within these coastal elevation zones is a poor surrogate by itself as a national measure of the susceptibility – it needs to include demographic information and eventually the enumeration of built environment assets within these coastal areas to identify the socio-economic composition of areas potentially susceptible to coastal inundation hazards.

**Table 3-1: Areas of the various coastal elevation zones above MHW for each region in km<sup>2</sup>.**

Note: based on regional/unitary council boundaries. NZ totals of % area based on NZ land area of 268,021 km<sup>2</sup>.

| Region            | 0–3 m zone area<br>(km <sup>2</sup> ) | 3–5 m zone area<br>(km <sup>2</sup> ) | 5–10 m zone area<br>(km <sup>2</sup> ) |
|-------------------|---------------------------------------|---------------------------------------|--|
| Northland         | 108.4                                 | 78.0                                  | 321.8                                  |
| Auckland          | 84.4                                  | 55.8                                  | 172.2                                  |
| Waikato           | 141.1                                 | 212.6                                 | 401.4                                  |
| Bay of Plenty     | 79.5                                  | 129.6                                 | 229.0                                  |
| Gisborne          | 19.2                                  | 29.3                                  | 57.2                                   |
| Hawke's Bay       | 75.4                                  | 38.8                                  | 137.8                                  |
| Taranaki          | 7.5                                   | 5.2                                   | 17.0                                   |
| Manawatu-Wanganui | 16.0                                  | 19.0                                  | 336.8                                  |
| Wellington        | 31.7                                  | 19.8                                  | 259.3                                  |
| Marlborough       | 66.6                                  | 35.6                                  | 84.5                                   |
| Canterbury        | 442.7                                 | 177.4                                 | 383.4                                  |
| Nelson            | 3.9                                   | 3.9                                   | 8.1                                    |
| Tasman            | 39.8                                  | 24.0                                  | 60.5                                   |
| West Coast        | 63.7                                  | 54.8                                  | 244.1                                  |
| Otago             | 20.5                                  | 39.2                                  | 85.4                                   |
| Southland         | 120.3                                 | 95.0                                  | 429.9                                  |
| NZ total          | 1,320.7 (0.5%)                        | 1,017.8 (0.4%)                        | 3,228.3 (1.2%)                         |





**Figure 3-2: Composite bar chart showing land areas in each of the coastal elevation zones for each region.** Based on data shown in Table 3.1.

### 3.4 Regional coastal maps: demographic analysis

The results from enumerating people of all ages and those 65+ years old within the 2006 Census meshblocks overlapping the coastal elevation zones are provided in Table 3-2 (for the 0–3 m MHW zone), Table 3-3 (for the 3–5 m MHW zone), and Table 3-4 (for the 5–10 m MHW zone).

The results have been aggregated up to the regional level and each table ends with a national summary.

The regional population counts have also been aggregated up over the three coastal elevation zones and shown as bar graphs for all ages (Figure 3-3) and for the 65+ year age range (Figure 3-4).

For all ages, most of the people resident in the 0–3 m coastal elevation zone in New Zealand lived in either Canterbury (41%), Hawke’s Bay (17%) or Auckland (13%), with these three regions accounting for 71% of all people who were resident in this zone in the 2006 Census.

This same general distribution was reflected in the percentage of 65+ year old people within those three regions accounting for 67% of all the 65+ year olds who were resident in the 0–3 m coastal zone in the 2006 Census.

As a proportion of the 65+ year population to all ages in each of the three coastal elevation zone, nationally this was consistently at an average across New Zealand of around 14.5%. Regionally, the highest proportions of the 65+ year population to the total number of residents were as follows:

- 0–3 m zone: Waikato (20%), Otago (19.5%) and Tasman (18.5%).
- 3–5 m zone: Otago (19.8%), Tasman (19.7%) and Southland (19.3%).
- 5–10 m zone: Otago (19.7%), Tasman (18.3%) and Marlborough (18.2%).

An important caveat with this demographic overview is that the populations in each meshblock are based on people present on census night (a Tuesday in March), so is likely to be a significant underestimate of people who would be temporarily resident in coastal settlements and cities in say January. Future work assessing the number of dwellings in these coastal elevation zones will assist to further address coastal-inundation hazard susceptibility of coastal areas, with many buildings only occupied for part of the year (typically summer).

**Table 3-2: Population enumerated for the 0–3 m coastal elevation zone for each region, percentage of national total for that zone and proportion that were 65+ years old in each zone.** [Based on 2006 Census].

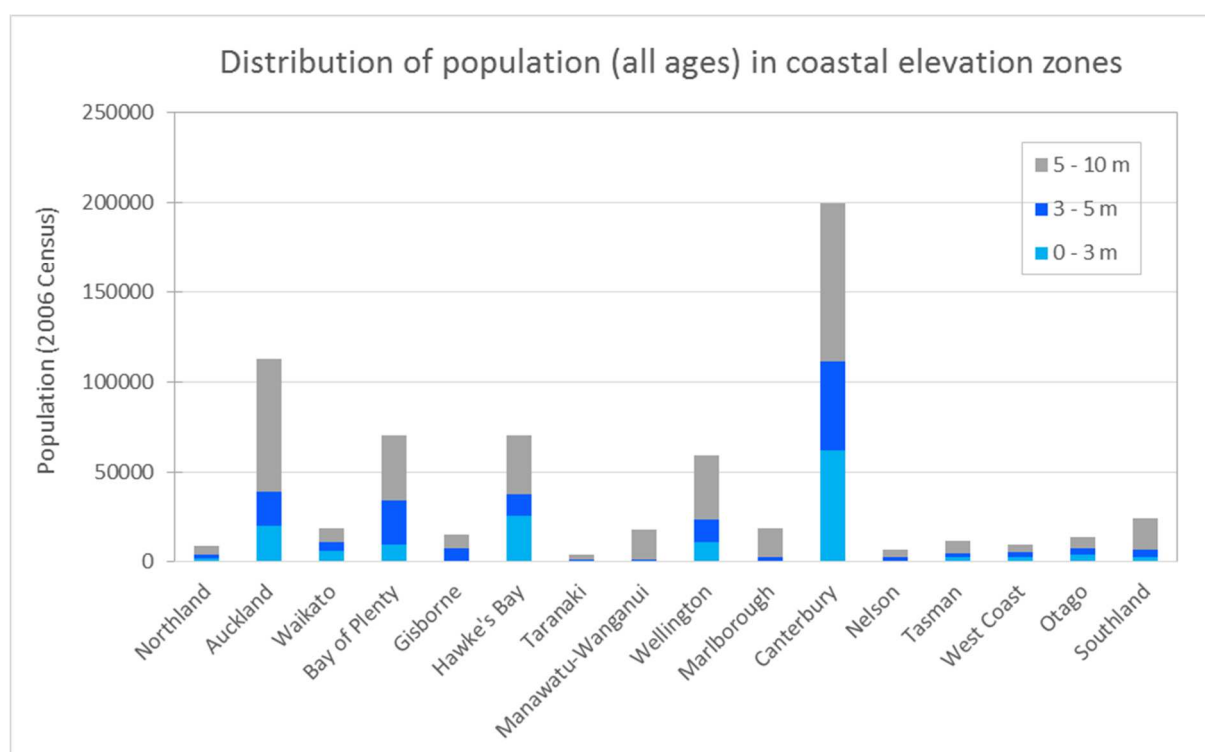
| Region                | Resident pop.<br>(all ages) | % of national<br>total in zone | Resident pop.<br>(65+ years) | % of national<br>total in zone | Proportion of<br>65+ years |
|-----------------------|-----------------------------|--------------------------------|------------------------------|--------------------------------|----------------------------|
| Northland             | 2,168                       | 1.4                            | 346                          | 1.6                            | 16.0                       |
| Auckland              | 19,993                      | 13.2                           | 2,915                        | 13.3                           | 14.6                       |
| Waikato               | 5,946                       | 3.9                            | 1,194                        | 5.4                            | 20.1                       |
| Bay of Plenty         | 9,895                       | 6.5                            | 1,649                        | 7.5                            | 16.7                       |
| Gisborne              | 951                         | 0.6                            | 120                          | 0.5                            | 12.6                       |
| Hawke's Bay           | 25,762                      | 17.0                           | 3,203                        | 14.6                           | 12.4                       |
| Taranaki              | 569                         | 0.4                            | 96                           | 0.4                            | 16.9                       |
| Manawatu-<br>Wanganui | 323                         | 0.2                            | 35                           | 0.2                            | 10.8                       |
| Wellington            | 11,220                      | 7.4                            | 1,676                        | 7.6                            | 14.9                       |
| Marlborough           | 643                         | 0.4                            | 78                           | 0.4                            | 12.1                       |
| Canterbury            | 62,148                      | 41.0                           | 8,605                        | 39.2                           | 13.8                       |
| Nelson                | 800                         | 0.5                            | 123                          | 0.6                            | 15.4                       |
| Tasman                | 2,606                       | 1.7                            | 481                          | 2.2                            | 18.5                       |
| West Coast            | 2,454                       | 1.6                            | 421                          | 1.9                            | 17.2                       |
| Otago                 | 3,914                       | 2.6                            | 765                          | 3.5                            | 19.5                       |
| Southland             | 2,362                       | 1.6                            | 261                          | 1.2                            | 11.0                       |
| NZ total              | 151,754                     | 100                            | 21,968                       | 100                            | 14.5                       |

**Table 3-3: Population enumerated for the 3–5 m coastal elevation zone for each region, percentage of national total for that zone and proportion that were 65+ years old in each zone.**  
[Based on 2006 Census].

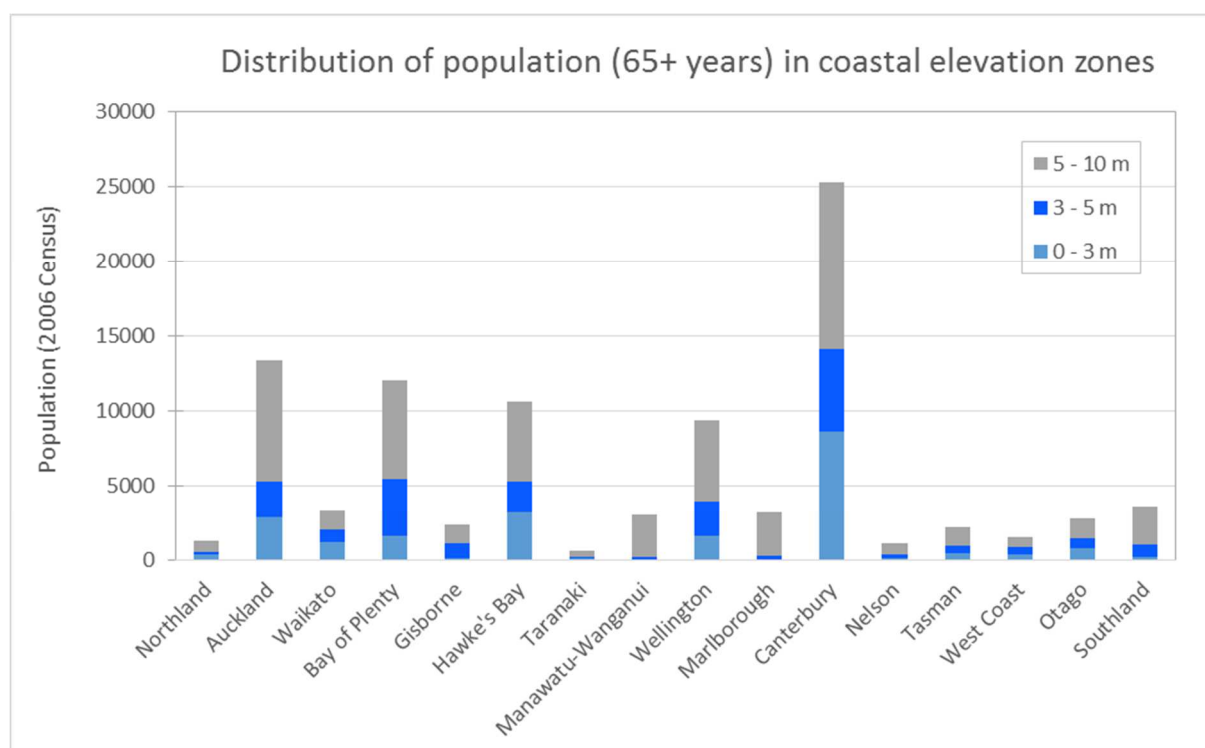
| Region                | Resident pop.<br>(all ages) | % of national<br>total in zone | Resident pop.<br>(65+ years) | % of national<br>total in zone | Proportion of<br>65+ years |
|-----------------------|-----------------------------|--------------------------------|------------------------------|--------------------------------|----------------------------|
| Northland             | 1,602                       | 1.1                            | 240                          | 1.1                            | 15.0                       |
| Auckland              | 19,160                      | 12.9                           | 2,379                        | 11.2                           | 12.4                       |
| Waikato               | 4,958                       | 3.3                            | 847                          | 4.0                            | 17.1                       |
| Bay of Plenty         | 24,626                      | 16.5                           | 3,853                        | 18.1                           | 15.6                       |
| Gisborne              | 6,811                       | 4.6                            | 998                          | 4.7                            | 14.7                       |
| Hawke's Bay           | 12,181                      | 8.2                            | 2,055                        | 9.6                            | 16.9                       |
| Taranaki              | 701                         | 0.5                            | 97                           | 0.5                            | 13.8                       |
| Manawatu-<br>Wanganui | 998                         | 0.7                            | 144                          | 0.7                            | 14.4                       |
| Wellington            | 12,039                      | 8.1                            | 2,258                        | 10.6                           | 18.8                       |
| Marlborough           | 1,755                       | 1.2                            | 189                          | 0.9                            | 10.8                       |
| Canterbury            | 49,215                      | 33.1                           | 5,494                        | 25.8                           | 11.2                       |
| Nelson                | 1,843                       | 1.2                            | 299                          | 1.4                            | 16.2                       |
| Tasman                | 2,281                       | 1.5                            | 449                          | 2.1                            | 19.7                       |
| West Coast            | 2,854                       | 1.9                            | 484                          | 2.3                            | 17.0                       |
| Otago                 | 3,700                       | 2.5                            | 734                          | 3.4                            | 19.8                       |
| Southland             | 4,165                       | 2.8                            | 804                          | 3.8                            | 19.3                       |
| NZ total              | 148,889                     | 100                            | 21,324                       | 100                            | 14.3                       |

**Table 3-4: Population enumerated for the 5–10 m coastal elevation zone for each region, percentage of national total for that zone and proportion that were 65+ years old in each zone.**  
[Based on 2006 Census].

| Region                | Resident pop.<br>(all ages) | % of national<br>total in zone | Resident pop.<br>(65+ years) | % of national<br>total in zone | Proportion of<br>65+ years |
|-----------------------|-----------------------------|--------------------------------|------------------------------|--------------------------------|----------------------------|
| Northland             | 5,248                       | 1.4                            | 758                          | 1.4                            | 14.4                       |
| Auckland              | 74,063                      | 20.4                           | 8,038                        | 15.3                           | 10.9                       |
| Waikato               | 7,591                       | 2.1                            | 1,315                        | 2.5                            | 17.3                       |
| Bay of Plenty         | 36,127                      | 10.0                           | 6,545                        | 12.4                           | 18.1                       |
| Gisborne              | 7,617                       | 2.1                            | 1,240                        | 2.4                            | 16.3                       |
| Hawke's Bay           | 32,844                      | 9.1                            | 5,374                        | 10.2                           | 16.4                       |
| Taranaki              | 2,609                       | 0.7                            | 421                          | 0.8                            | 16.1                       |
| Manawatu-<br>Wanganui | 16,418                      | 4.5                            | 2,878                        | 5.5                            | 17.5                       |
| Wellington            | 36,263                      | 10.0                           | 5,404                        | 10.3                           | 14.9                       |
| Marlborough           | 16,039                      | 4.4                            | 2,923                        | 5.6                            | 18.2                       |
| Canterbury            | 88,693                      | 24.4                           | 11,220                       | 21.3                           | 12.7                       |
| Nelson                | 4,121                       | 1.1                            | 724                          | 1.4                            | 17.6                       |
| Tasman                | 6,846                       | 1.9                            | 1,256                        | 2.4                            | 18.3                       |
| West Coast            | 4,368                       | 1.2                            | 685                          | 1.3                            | 15.7                       |
| Otago                 | 6,426                       | 1.8                            | 1,263                        | 2.4                            | 19.7                       |
| Southland             | 17,538                      | 4.8                            | 2,604                        | 4.9                            | 14.8                       |
| NZ total              | 362,811                     | 100                            | 52,648                       | 100                            | 14.5                       |



**Figure 3-3: Populations for all ages in each region aggregated up over all three coastal elevation zones.** [Based on 2006 Census].



**Figure 3-4: Populations for 65+ year ages in each region aggregated up over all three coastal elevation zones.** [Based on 2006 census].

## 4 Conclusions

The delineation of coastal elevation shapefiles from the enhanced-merged Landcare/SKM national DEM, at a substantially improved accuracy than using previous national DEMs, provides a reasonable baseline for a national overview of the demographic composition within New Zealand's coastal areas, particularly the more susceptible 0–3 m elevation zone.

Shapefiles for coastal elevation zones have been developed for 0–3 m, 3–5 m and 5–10 m above MHW, and the land area and demographic distributions have been enumerated from overlays with the topography and the 2006 Census meshblocks. The lowest elevation zone (0–3 m) is a reasonable surrogate for the exposure of coastal areas to both present-day coastal hazards, such as storm tides and wave run-up plus infrequent tsunami and credible sea-level rises of 0.7 to 1 m likely within the next 100 years.

The proportion of low-lying coastal land area in New Zealand is low, with only 2.1% of the total land area below 10 m above MHW and directly connected to the coast, due in part to New Zealand's relatively young geology. Consequently, the proportion of land area within these coastal elevation zones is a poor surrogate by itself as a national measure of coastal inundation hazard susceptibility – it needs to include demographic information and eventually the enumeration of the built environment asset base within these coastal margins to assess socio-economic susceptibility.

For all ages, most of the people resident in the 0–3 m coastal zone in New Zealand lived in either Canterbury (41%), Hawke's Bay (17%) or Auckland (13%), with these three regions accounting for 71% of all people who were resident in this zone in the 2006 Census.

This same general distribution was reflected in the percentage of 65+ year old people within those three regions accounting for 67% of all the 65+ year olds who were resident in the 0–3 m coastal zone in the 2006 Census.

As a proportion of the 65+ year population to all ages in each of the three coastal elevation zone, nationally this was consistently at an average across New Zealand of around 14.5%. Regionally, the highest proportions of the 65+ year population to the total number of residents were as follows:

- 0–3 m zone: Waikato (20%), Otago (19.5%) and Tasman (18.5%).
- 3–5 m zone: Otago (19.8%), Tasman (19.7%) and Southland (19.3%).
- 5–10 m zone: Otago (19.7%), Tasman (18.3%) and Marlborough (18.2%).

An important caveat with this broad demographic overview is that the populations in each meshblock are based on people present on census night (a Tuesday in March), so is likely to be a significant underestimate of people who would be temporarily resident in coastal settlements and cities in say January. Future work assessing the number of dwellings in these coastal elevation zones will assist to further address coastal-inundation hazard susceptibility in coastal areas, with many buildings only occupied for part of the year (typically summer).

## 5 Acknowledgements

The authors acknowledge Auckland Council for the use of the 2-m LiDAR DEM for a comparison with the national DEM used. Stella Bellis (Landcare) provided a useful update on the status of the various national DEMs. Discussions with Kay Saville-Smith and Ruth Fraser (CRESA) have sharpened the final analysis.

## 6 Glossary of abbreviations and terms

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|                   |   |
|-------------------|---|
| <b>65+ years</b>  | Census population category that includes people 65 years and older on census night.   |
| <b>DEM</b>        | Digital Elevation Model of topography.  |
| <b>IPCC</b>       | Intergovernmental Panel on Climate Change.  |
| <b>LiDAR</b>      | Light Detection and Ranging laser scanning system for aerial surveying of topography. |
| <b>MHW</b>        | Mean High Water.  |
| <b>MMSL</b>       | Monthly Mean Sea Level.   |
| <b>Storm tide</b> | Combination of MMSL, predicted tide height and storm surge.                           |

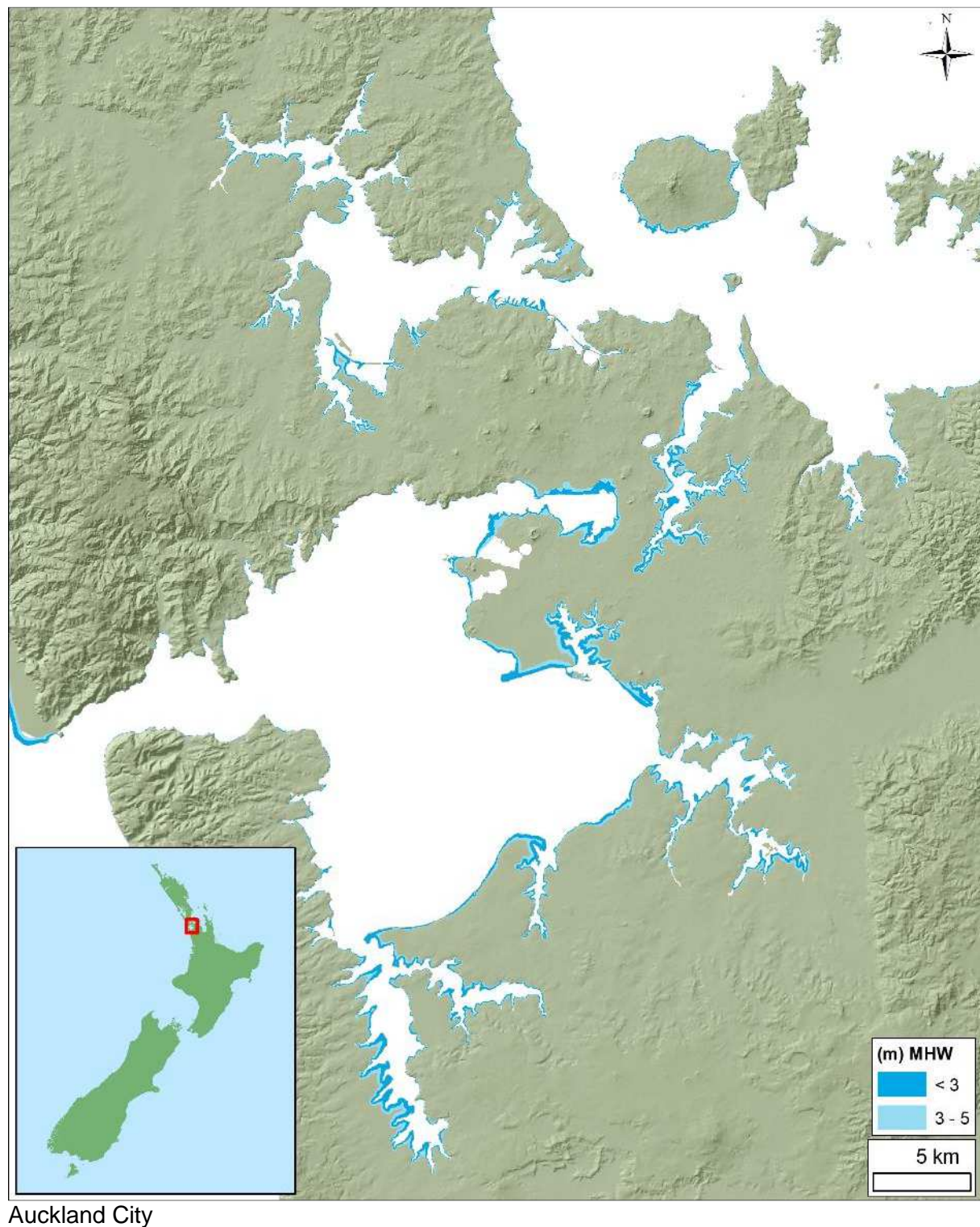
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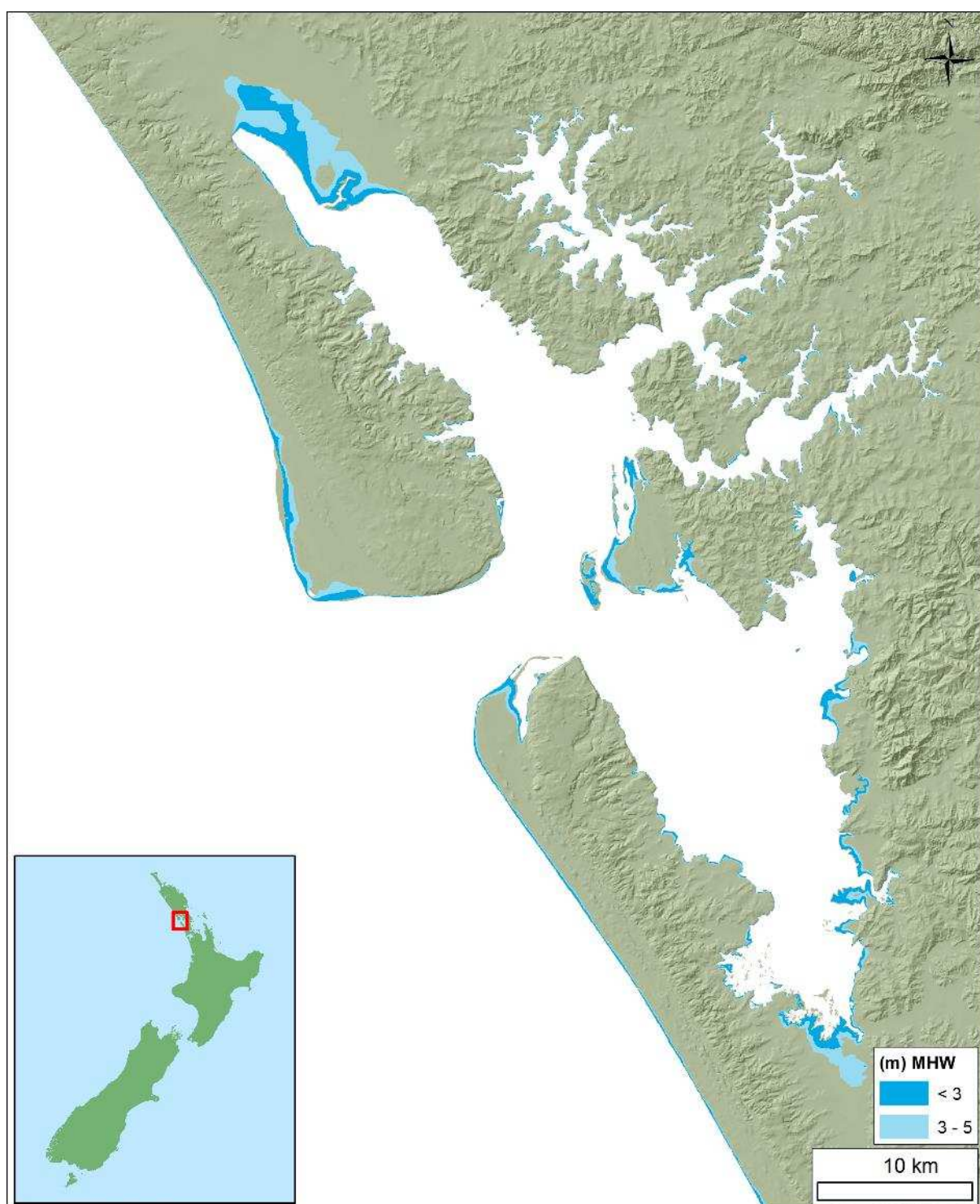


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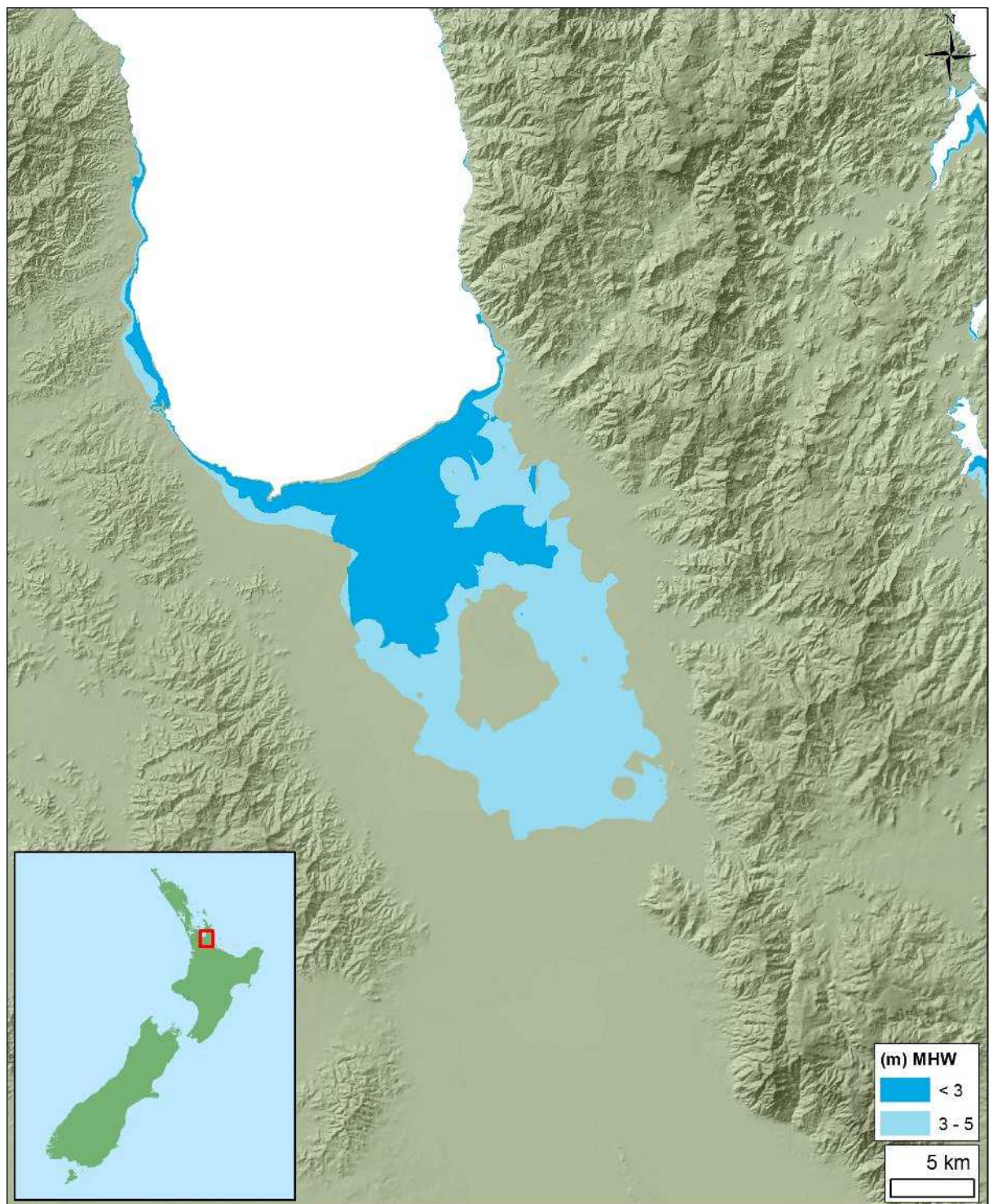
## Appendix A Regional coastal zone maps of 0–3 and 3–5 m elevation zones (some example from a national overview)



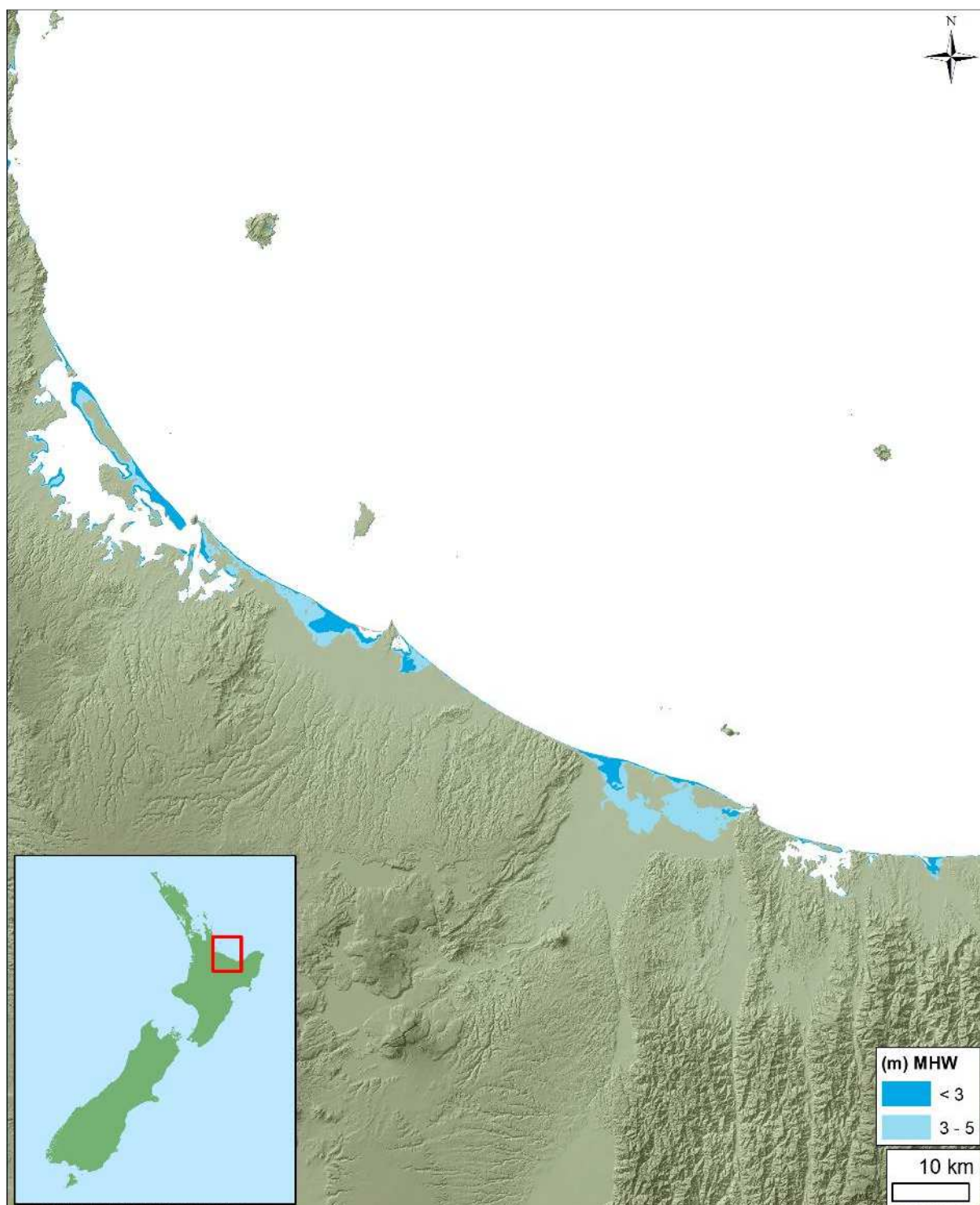


Kaipara Harbour area



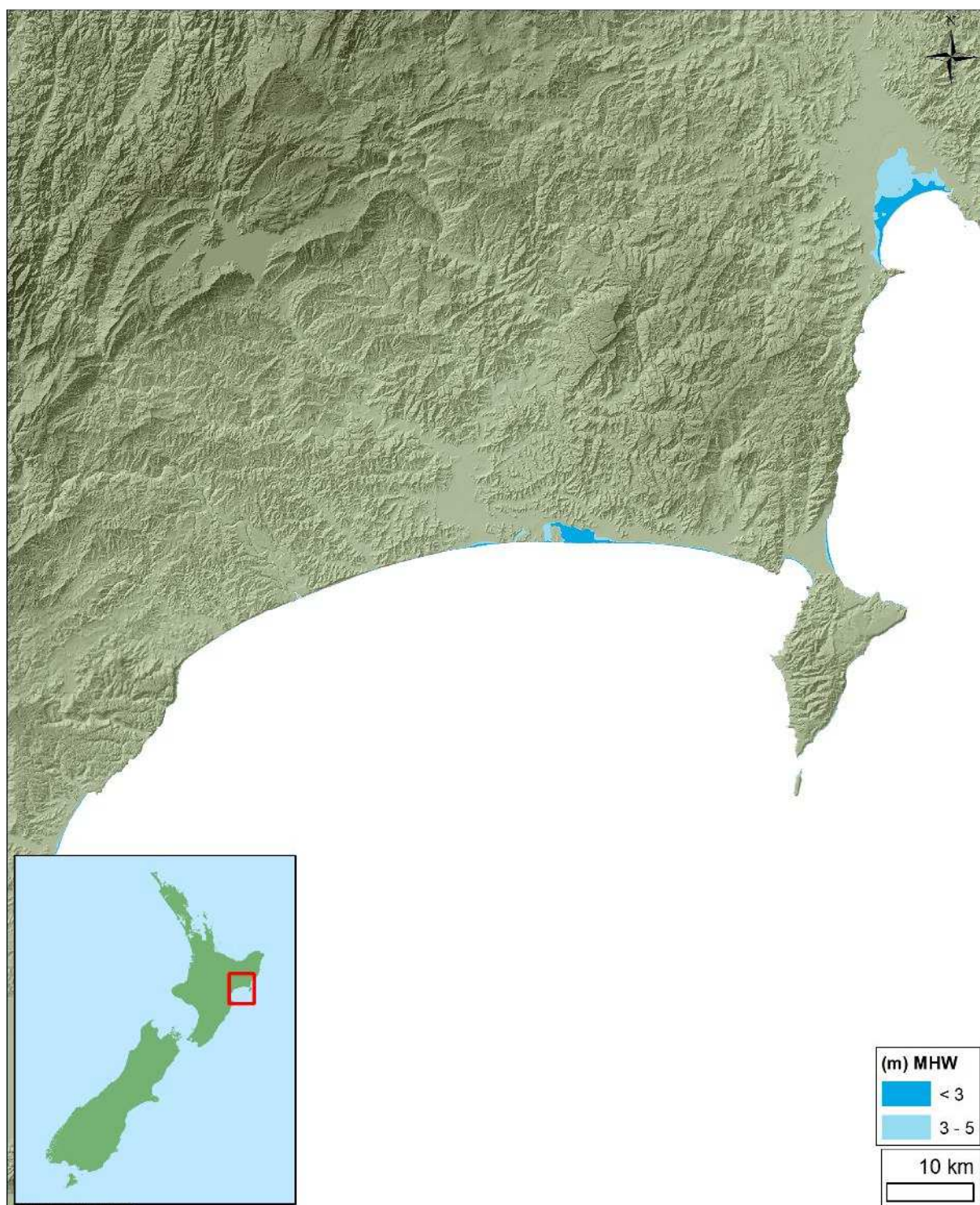


Hauraki Plains

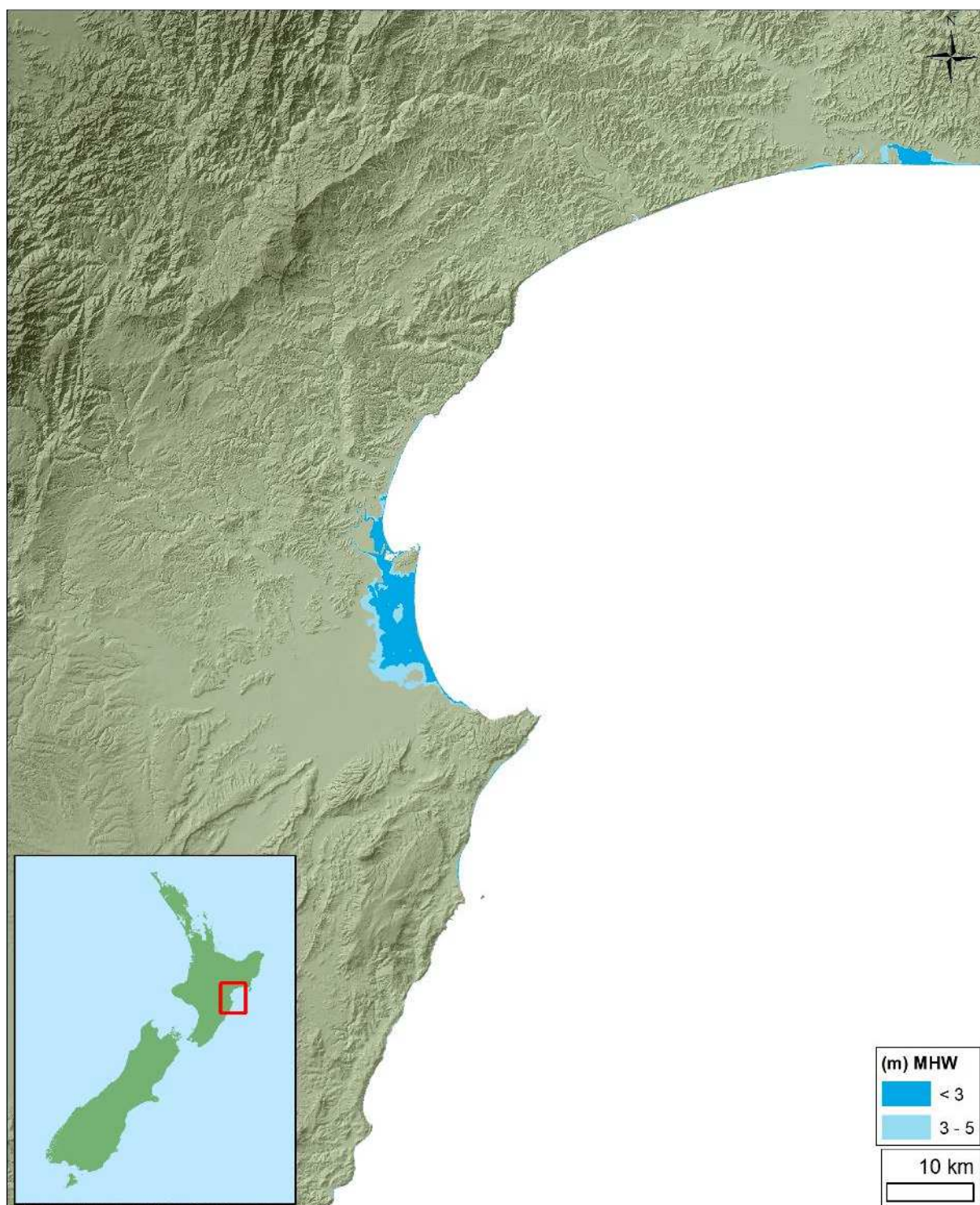


Bay of Plenty area



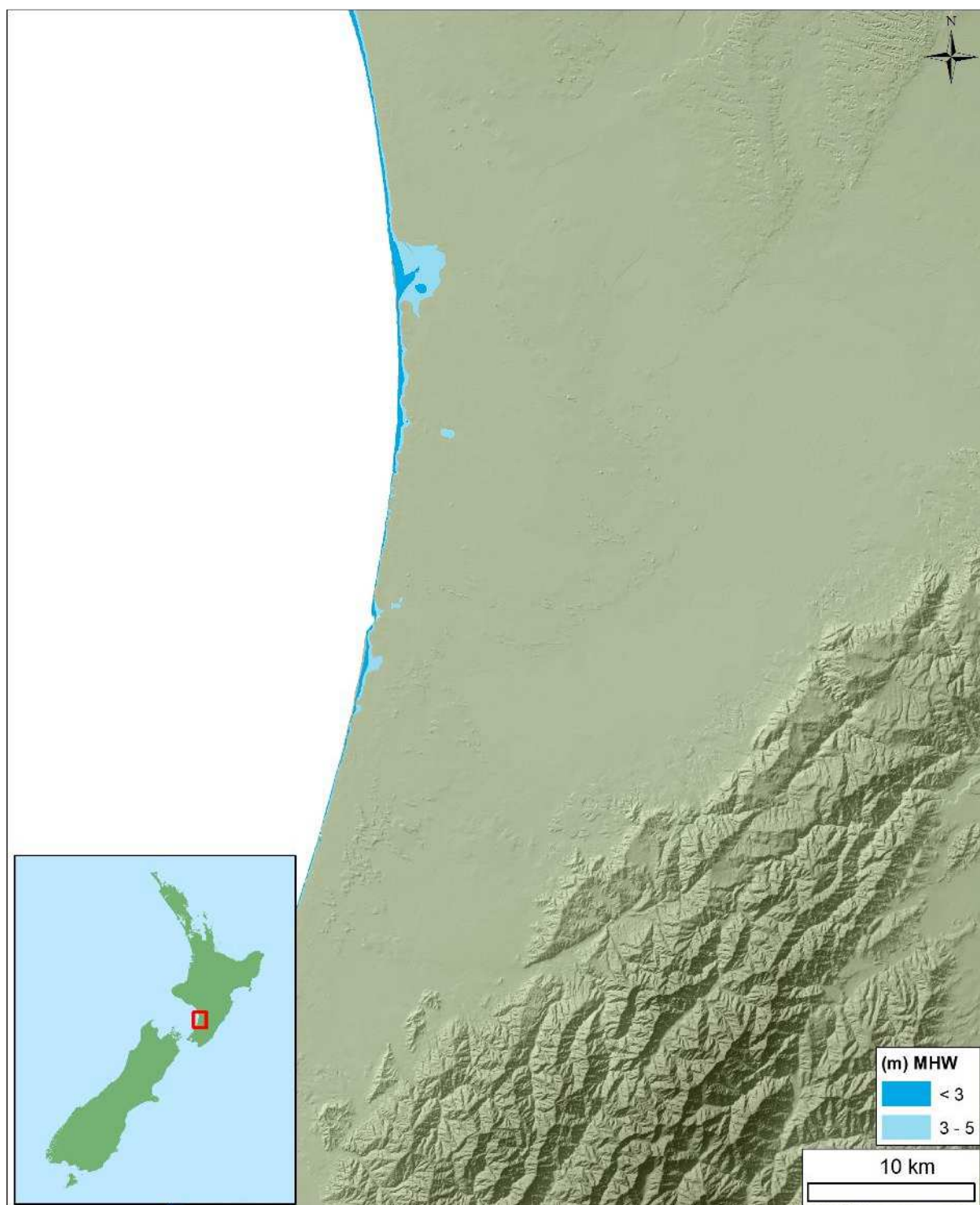


Gisborne/Wairoa area

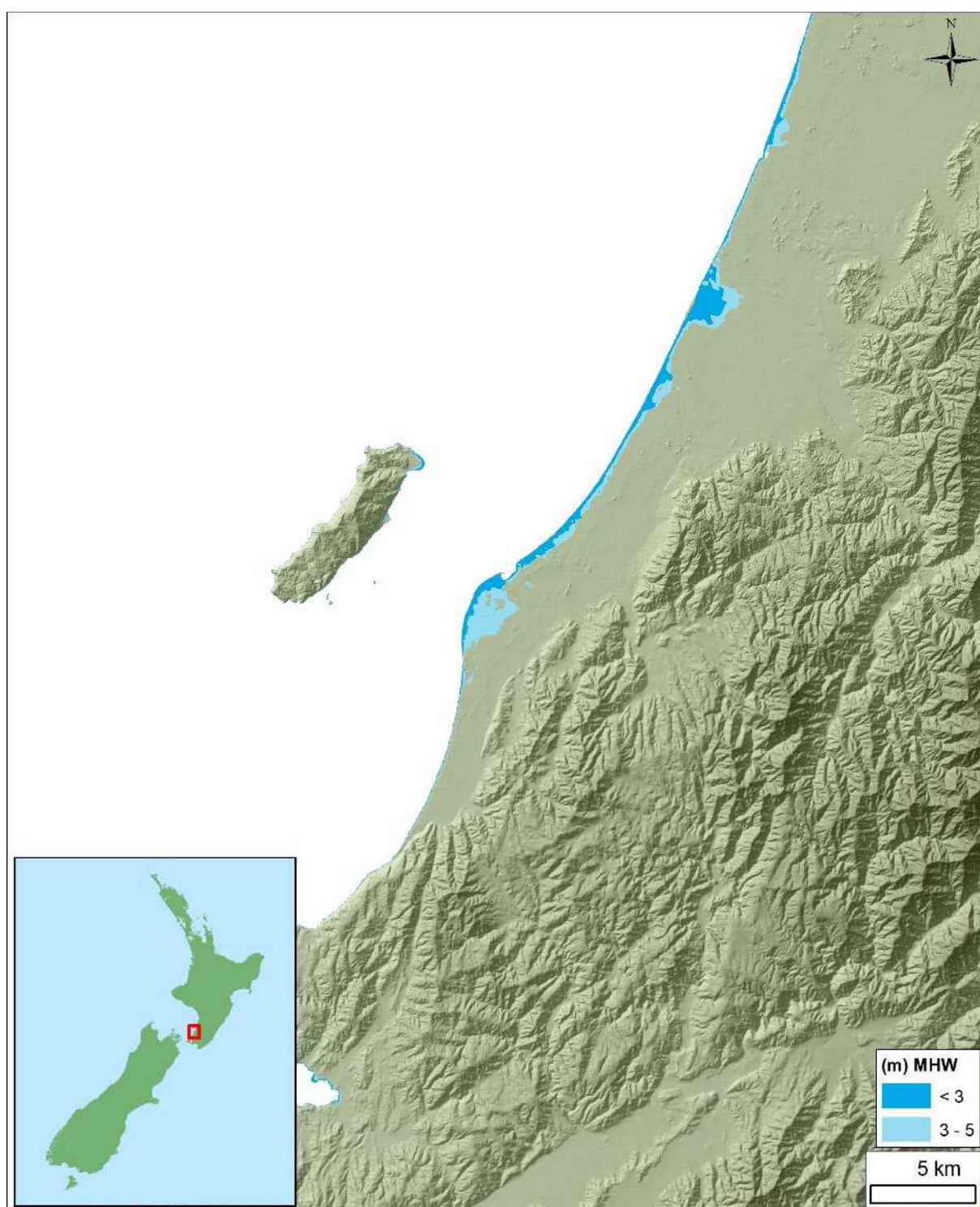


Hawke's Bay area



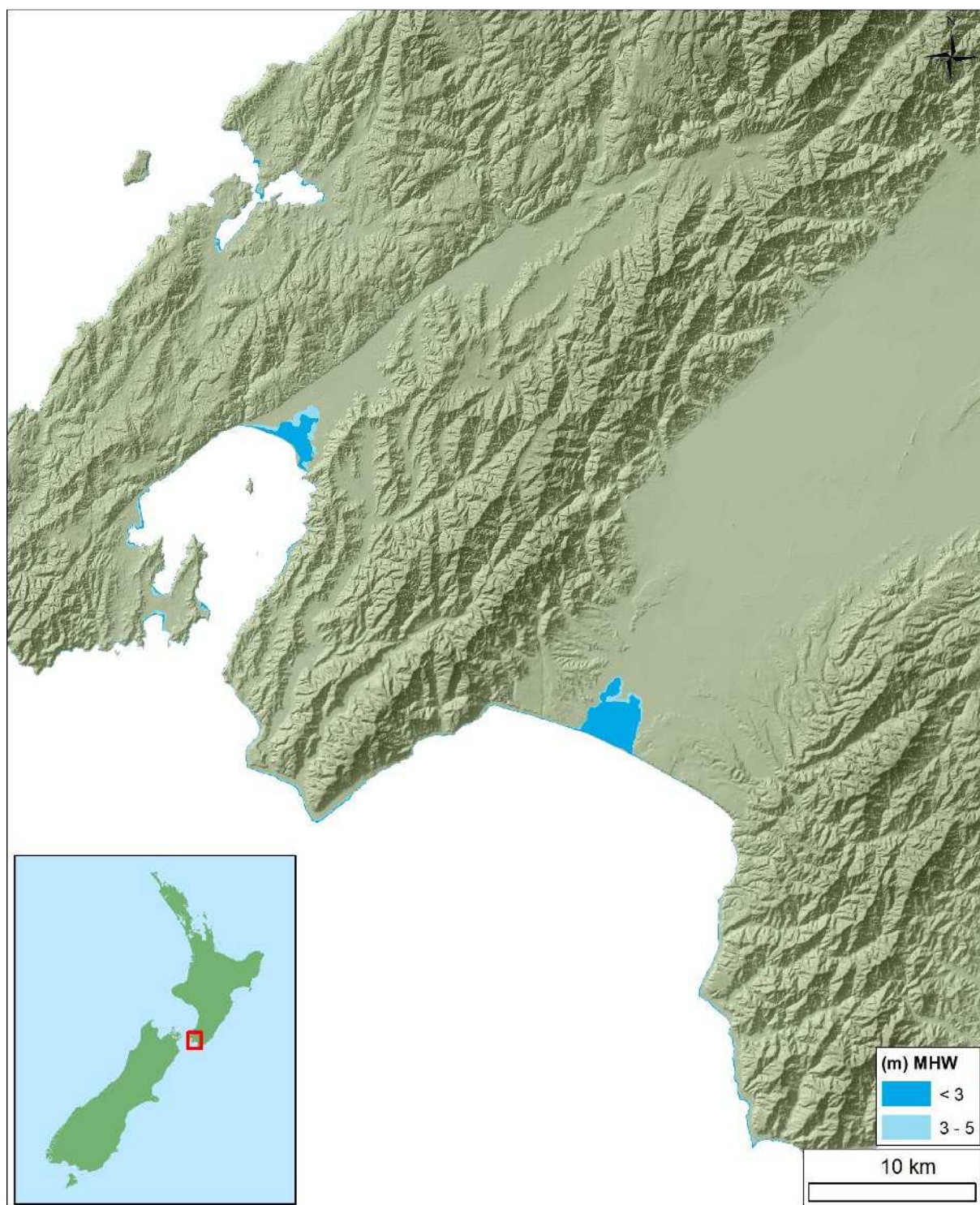


Manawatu area

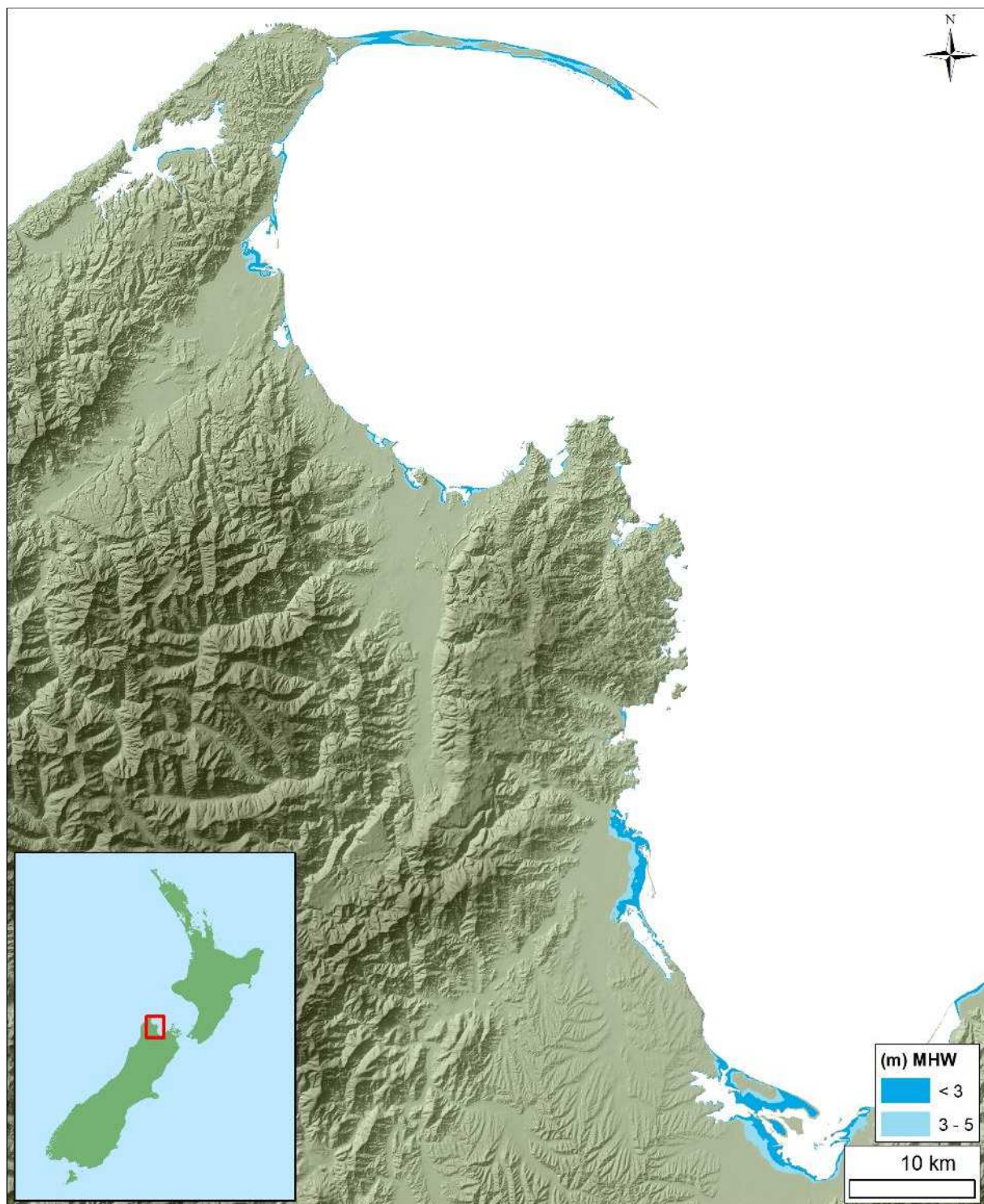


Kāpiti Coast area



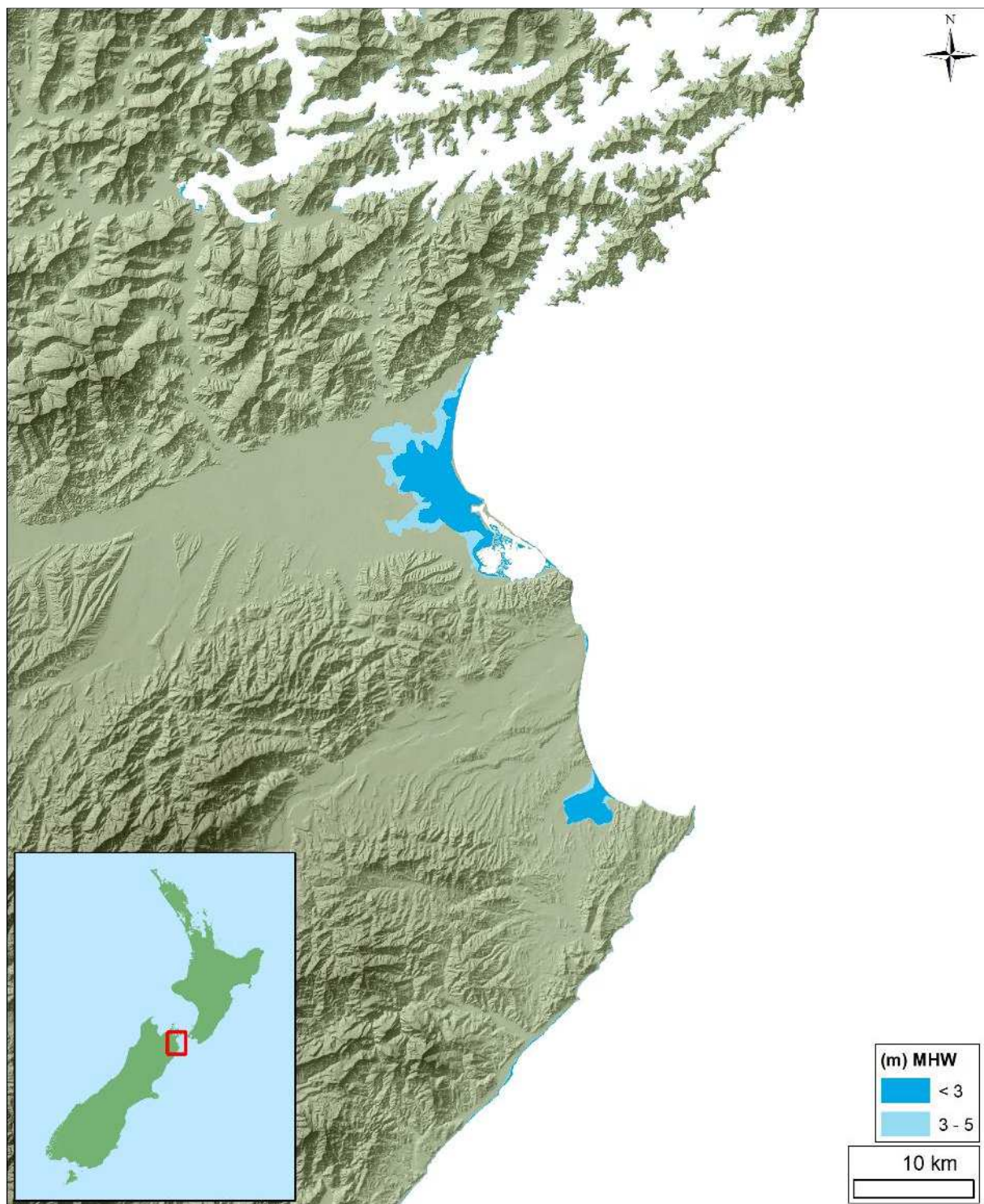


Wellington/Lower Hutt area

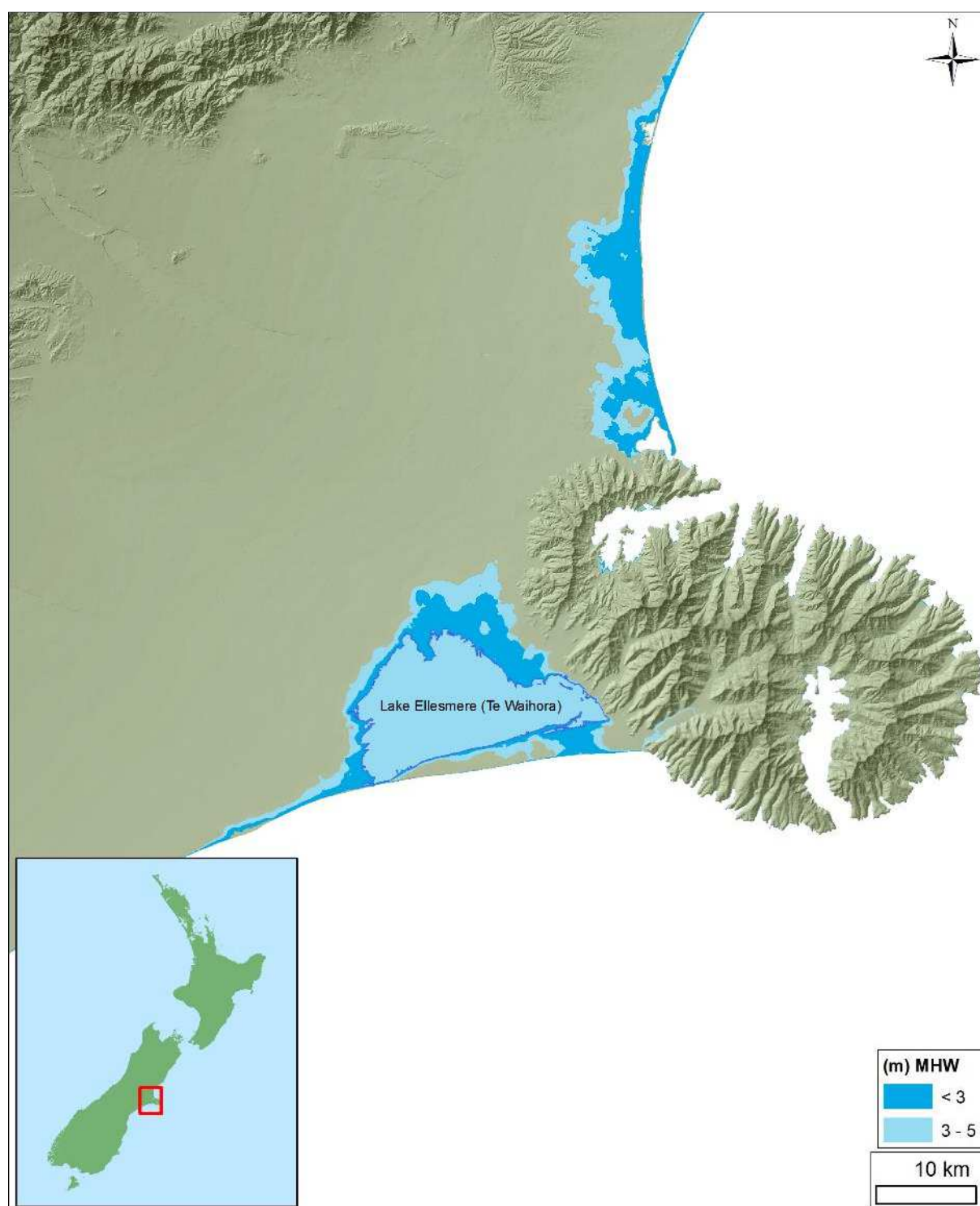


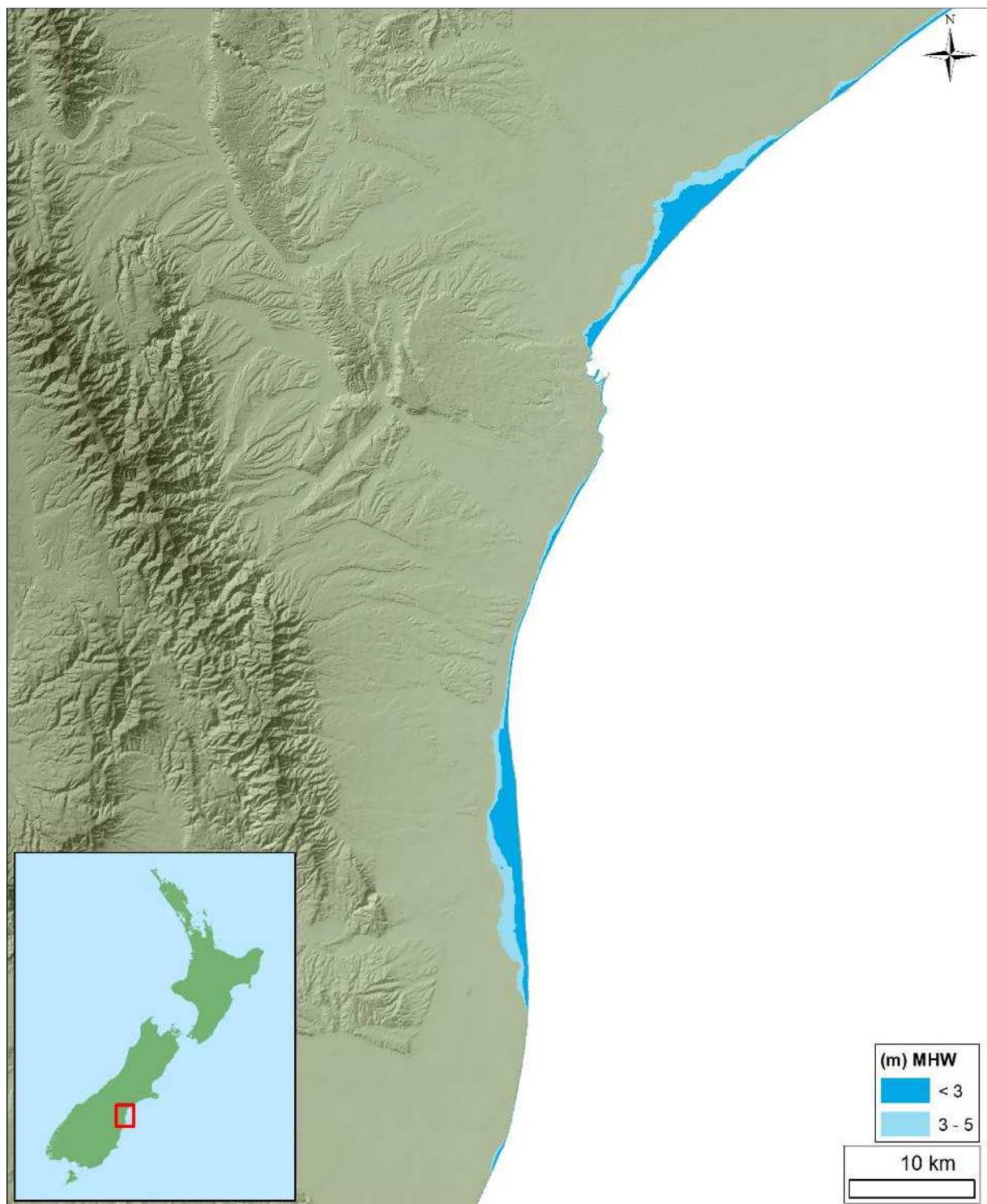
Nelson/Tasman region





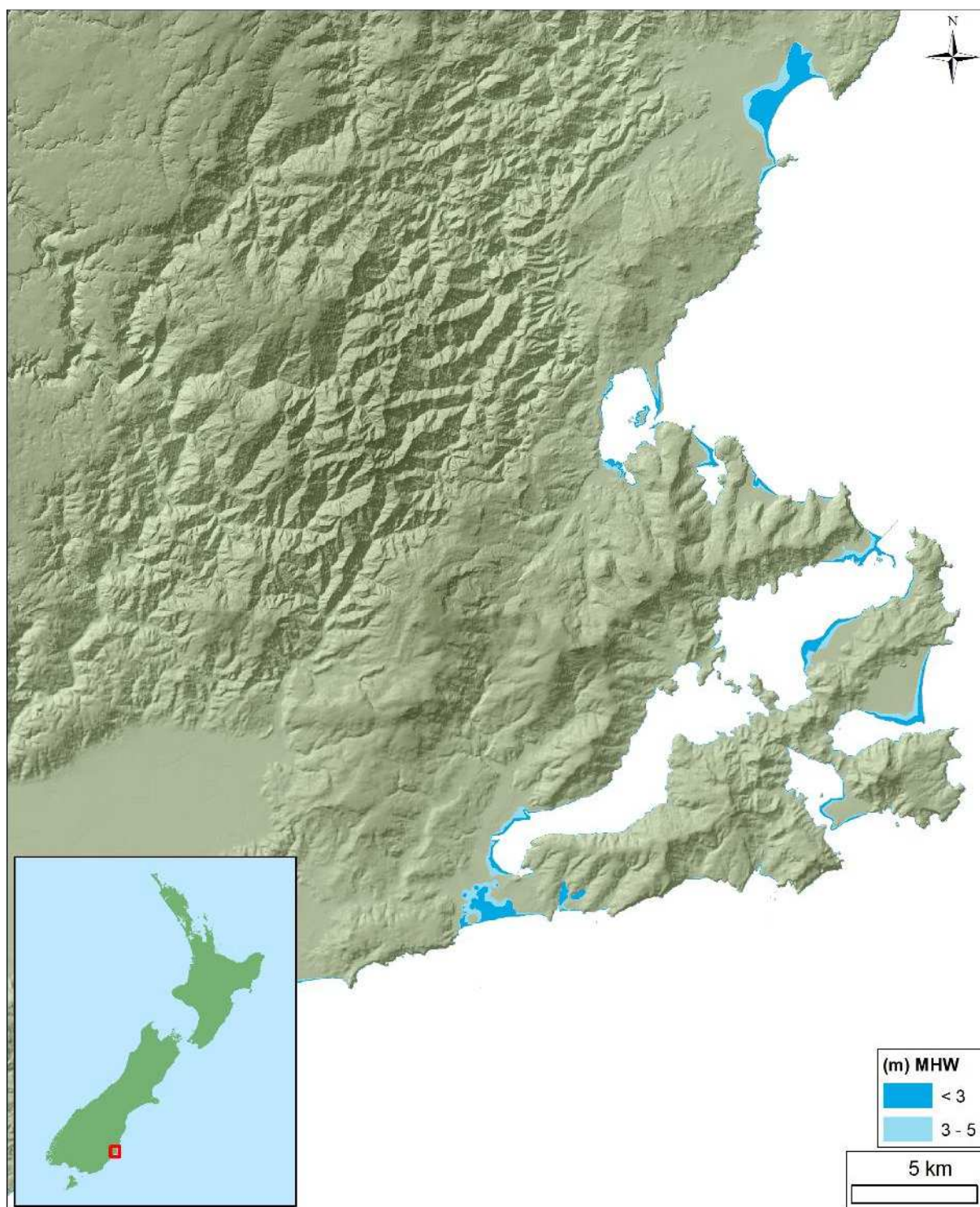
Marlborough region



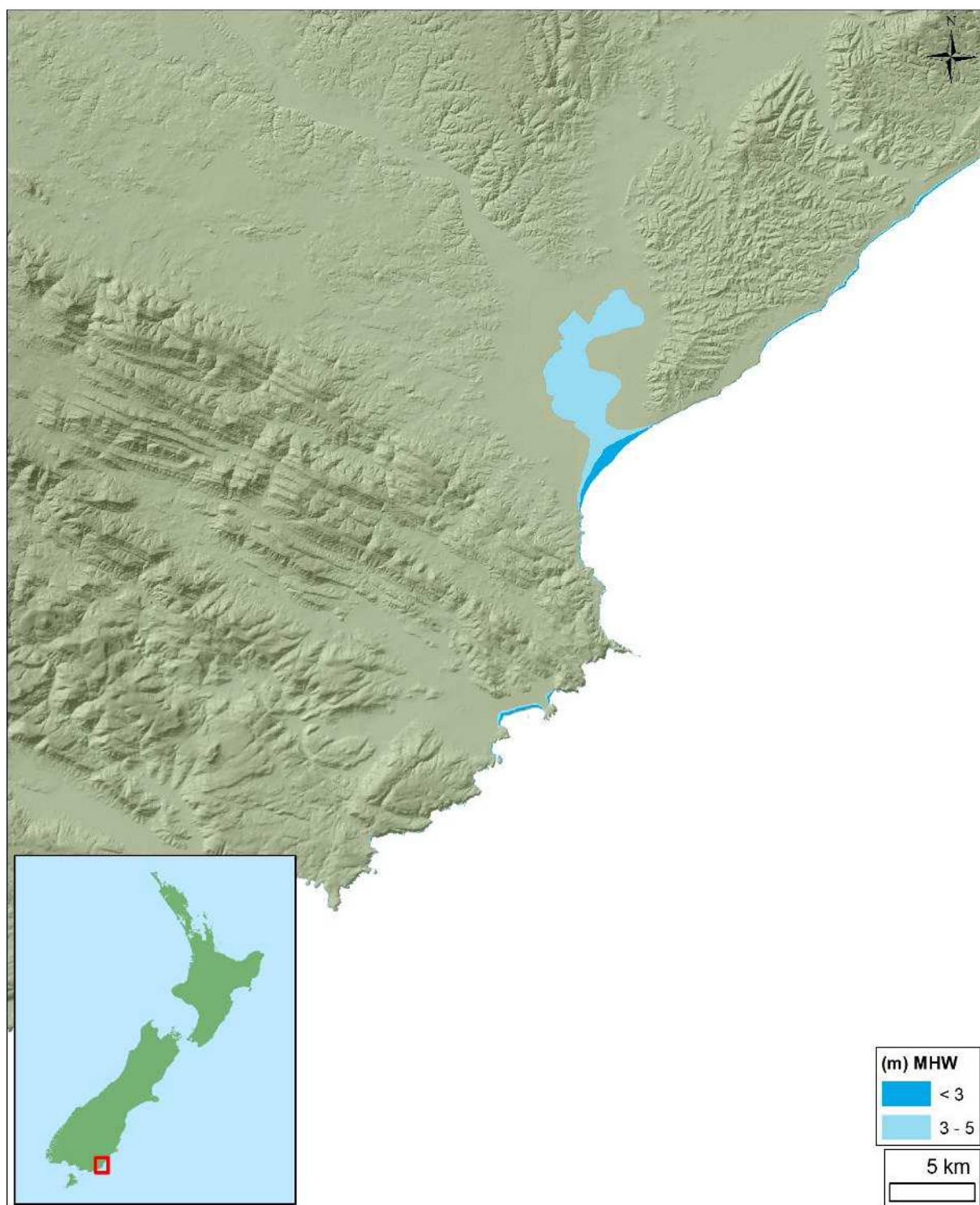


Timaru/Oamaru area

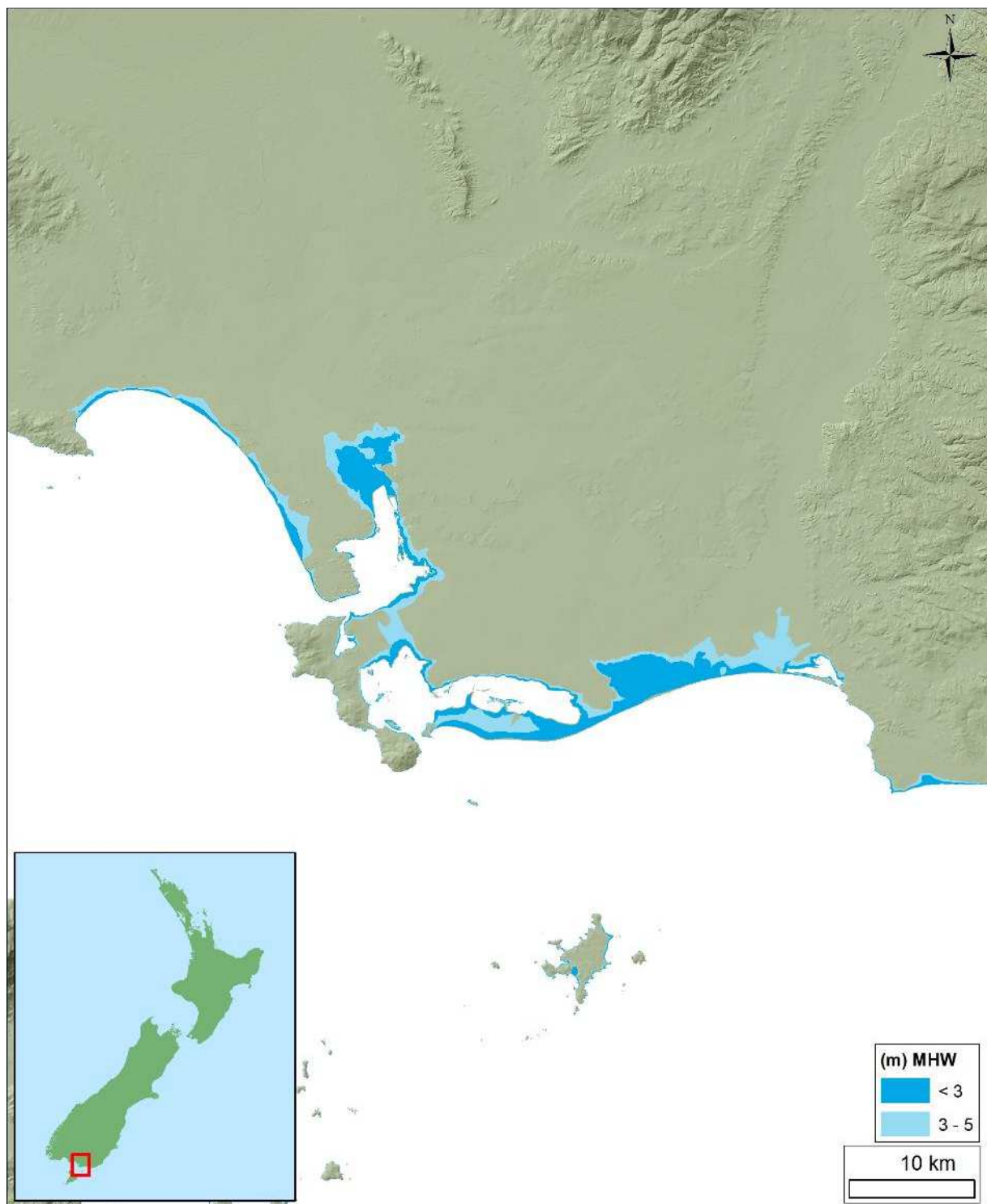




Dunedin area



Clutha River mouth



Invercargill area