SALT
ECOLOGY

Evaluation of a simple GIS-based methodology to determine estuary extent and assess potential changes in response to sea level rise

Prepared for
Greater Wellington Regional Council
January 2021

Salt Ecology
Report 057

RECOMMENDED CITATION

Stevens LM, Southwick M. 2021. Evaluation of a simple GIS-based methodology to determine estuary extent and assess potential changes in response to sea level rise. Salt Ecology Report 057, prepared for Greater Wellington Regional Council, January 2021. 11p.

GLOSSARY

DEM	Digital Elevation Model
GIS	Geographic Information System
GWRC	Greater Wellington Regional Council
MHWS	Mean High Water Spring tide
MLWS	Mean Low Water Spring tide
NEMP	National Estuary Monitoring Protocol
LiDAR	Light Detection and Ranging
SLR	Sea Level Rise
SMHZ	Salt Marsh Habitat Zone

DEFINITIONS

Unrestricted flow areas are within the theoretical estuary boundary, but remain connected to regular tidal flows. They include the existing estuary extent, and areas the estuary may expand into under the defined SLR scenarios. These areas include low-lying farmland and urban parkland. The assumption in this report is that barriers are not put in place to prevent such flows.

Restricted flow areas are within the theoretical estuary boundary, but tidal flows are excluded from them and they are currently not part of the functioning estuary. The assumption in this report is that existing barriers will remain in place and continue to restrict tidal connection, i.e. restricted flow areas will not be inundated by predicted SLR due to flow barriers. It is also likely that, in future, additional barriers will be constructed to protect developed areas (residential housing, etc.) from being inundated. For this reason, all currently urban developed areas were categorised as restricted.

ACKNOWLEDGEMENTS

Many thanks to Roger Uys, Megan Melidonis and Megan Oliver (GWRC), and Helen Kettles (DOC), for proposing this work, for input on the methodology, and feedback on the draft report. Roger Uys and John Gibson (GWRC) provided the supporting GIS layers needed to undertake the project.

Evaluation of a simple GIS-based methodology to determine estuary extent and assess potential changes in response to sea level rise

Prepared by

Leigh Stevens

and Megan Southwick

for

Greater Wellington Regional Council

January 2021

leigh@saltecology.co.nz, +64 (0)21 417 936

www.saltecology.co.nz

SALT ECOLOGY

For the People
Mō ngā tāngata

TABLE OF CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

BACKGROUND

Greater Wellington Regional Council (GWRC) engaged Salt Ecology to conduct a pilot study to assess the suitability of using an elevation-based GIS approach for modelling estuary extent and potential migration in response to sea level rise (SLR). The purpose was to evaluate a simple, standardised methodology to assist GWRC in decisions regarding planning and development around estuary margins, and to see if the approach has potential to be applied more widely at a regional and national level using available data.

Two estuaries with different typologies were selected for appraisal, Te Awarua-o-Porirua and Waikanae. Te Awarua-o-Porirua comprises a large shallow subtidally-dominated basin system, whereas Waikanae is a tidal river-dominated estuary. The elevation-based modelling involved 'flooding' defined estuary and land margin contours (derived from existing digital elevation model (DEM) data) under different SLR scenarios to see which areas were inundated. For this study, three scenarios (+0.4m, +1.4m, +2.4m) were assessed representing estimated lower, mid and upper estimates of SLR over the next 100 years. Existing broad scale mapping data were then used to delineate the current estuary boundaries and the upper and lower limits of salt marsh vegetation – termed the 'salt marsh habitat zone' (SMHZ). The inundation modelling was then used to predict the future extent of the estuary and changes to the SMHZ for each of the SLR scenarios.

To distinguish areas with different levels of tidal connection, two categories of tidal flow were defined:
i. ***Unrestricted flow areas*** are within the theoretical estuary boundary, but remain connected to regular tidal flows. The assumption in this report is that barriers are not put in place in future to prevent such flows.
ii. ***Restricted flow areas:*** are within the theoretical estuary boundary, but tidal flows are excluded from them and they are not currently part of the functioning estuary. The assumption in this report is that existing barriers will remain in place and continue to restrict tidal connection.

KEY FINDINGS

Existing DEM data (~20cm vertical resolution) provided sufficient resolution to model the selected SLR scenarios and provided an efficient basis for predicting change.

Existing broad scale habitat mapping data closely matched the upper estuary boundary predicted for current sea level in unrestricted areas. In restricted flow areas, the theoretical upper boundary was difficult to accurately define without local knowledge of flow barriers, particularly in extensively modified urban areas.

Elevation-based modelling of Te Awarua-o-Porirua showed that currently ~65% of the potential SMHZ was unrestricted (tidally connected), with ~35% restricted by causeways, bunds and flap gates. With +0.4m of SLR there was a 35% reduction in existing saltmarsh, and with +1.2m of SLR a 97% reduction in existing salt marsh. As existing barriers limit the capacity of the estuary to expand, due to the predicted level of inundation there will likely be no appreciable salt marsh remaining in Te Awarua-o-Porirua within ~50 years.

Elevation-based modelling of Waikanae Estuary showed the potential SMHZ increased slightly with 0.4m of SLR, and then increased significantly at +1.4m of SLR. This positive shift reflects that, while there is likely to be an almost complete loss of the existing salt marsh, it has the potential to be offset by the projected expansion of new salt marsh areas further inland, assuming suitable habitat remains undeveloped and connected to the estuary. In reality, any significant relocation of salt marsh into new areas is likely to be significantly less than that estimated, thus the predicted increase in salt marsh may not eventuate.

Overall, the modelling predicted large changes in the likely spatial footprint of each estuary and SMHZ, and identified terrestrial areas vulnerable to inundation under defined SLR scenarios. While obviously a high-level screening assessment, the approach was able to identify areas which should be protected from inappropriate development, and highlight areas previously reclaimed or disconnected from tidal flow which could be suitable for future estuary expansion, restoration or enhancement.

RECOMMENDATIONS

Assess additional estuaries in the Wellington region for which DEM data are available.
To assist in Council planning, generate spatial mapping outputs that identify vulnerable areas.
Develop a web-based portal for sharing the results.

1. INTRODUCTION

1.1 Background

Estuaries are one of the most productive habitats on earth and support a wide variety of ecological features including soft sediment flats, cobble and gravel beds, zootic reefs, seagrass beds, shellfish beds, and salt marsh. These habitats in turn provide features supporting a wide variety of species including fish, birds, plants, insects and invertebrates. Estuaries also fulfil a variety of functions of benefit to humans, including carbon sequestration, maintenance of water quality, fisheries, nutrient and waste assimilation, coastal protection and aesthetic and recreational uses.

Despite these high values, estuaries have historically been subjected to significant human modification, particularly around their terrestrial margins, commonly through extensive drainage, reclamation and armouring. Inputs of sediment and nutrients from developed catchments have also often exceeded the assimilative capacity of estuaries leading to increasing muddiness and nutrient enrichment.

As the recognition of estuarine values has increased, greater efforts have been put into protecting, managing and improving their current condition. This is often done within a relatively static planning framework assuming that the estuary is in a stable state. However, estuaries are dynamic and constantly respond to broad physical changes, predominantly catchment sediment inputs, coastal erosion and deposition, and sea level changes.

Estuaries have a natural tendency to trap sediment and can accommodate slow changes in sea level without a shift in location. If sediment accumulates at the same rate as sea level rise (SLR), the estuary bed slowly rises, and the estuary salt marsh remains relatively unchanged. However, if SLR outpaces sediment accumulation, estuarine species, salt marsh in particular, must change location to remain within their tidal inundation tolerance range. At the same time, SLR will alter the inland boundary of the estuary, which will effectively migrate inland as tidal waters flood low-lying land.

As a consequence of predicted SLR, the rate of change is expected to accelerate over the coming decades and existing estuaries will need to expand into surrounding terrestrial areas if they are to continue to exist. To enable effective planning and management of these changes, it is important to be able to define current estuary boundaries, and predict where they may migrate to in response to SLR, and to apply risk assessments regarding likely consequences (e.g. Bell et al. 2016).

At present, most upper estuary boundaries are relatively poorly defined. While there are many different definitions, the boundary is commonly set at the upper extent of saltwater inundation. As this may only occur occasionally under spring tide or storm surge conditions, it is the salt marsh community (plants specifically adapted to be tolerant of salt) that often indicate the upper boundary. While the boundary can be mapped using standard approaches such as described in the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002), such methods are relatively time and cost intensive.

Another approach is to use LiDAR or bathymetric elevation data to indicate which low-lying areas are likely to be tidally inundated. These data sets are becoming increasingly available at a national level, which potentially enables a more systems-based spatial mapping approach to be used to remotely define estuary extent.

Elevation-based GIS approaches for modelling estuary extent have been successfully applied internationally (Brophy 2018, Brophy & Ewald 2017, Lanier et al. 2014), and provide a template for applying similar approaches in New Zealand.

1.2 Scope

Greater Wellington Regional Council (GWRC) engaged Salt Ecology to conduct a pilot study to assess the suitability of using an elevation-based GIS approach for modelling estuary extent and potential migration in response to SLR. The purpose was to apply a simple but standardised methodology to quickly define current estuary boundaries and identify areas likely to be impacted by SLR, to assist GWRC in decisions regarding the planning and development around estuary margins. In particular, the aim was to highlight currently undeveloped areas that may transition to estuarine habitat in response to predicted future SLR so that they can be protected from inappropriate development.

To develop the methodology, the pilot study looked at two estuaries with different typologies (see Hume et al. 2016 for further detail) within the GWRC region; Te Awarua-o-Porirua and Waikanae estuaries. Te Awarua-o-Porirua comprises a large shallow subtidally-dominated basin system, whereas Waikanae is a tidal river-dominated estuary. If the modelling approach could be successfully applied to these different estuaries types (the estuary types most commonly modified in New Zealand), then there is the potential for the approach to be applied more widely at a regional and national level.

This report presents an overview of the approach undertaken to assess the two estuaries, and provides comment on the merit of applying it in a wider context.

2. APPROACH TAKEN

2.1 Sea level rise predictions

Global average sea level has risen by about 16–21cm since 1900, with almost half of this rise occurring since 1993 as oceans have warmed and land-based ice has melted (Fig. 1). Relative to the year 2000, sea level is very likely to rise 0.3-1.3 m by the end of the century. Emerging science regarding Antarctic ice sheet stability suggests that, for higher scenarios, a rise exceeding 2.4m by 2100 is physically possible, although the probability of such an extreme outcome cannot currently be assessed (U.S. Global Change Research Program Fourth National Climate Assessment, 2018).

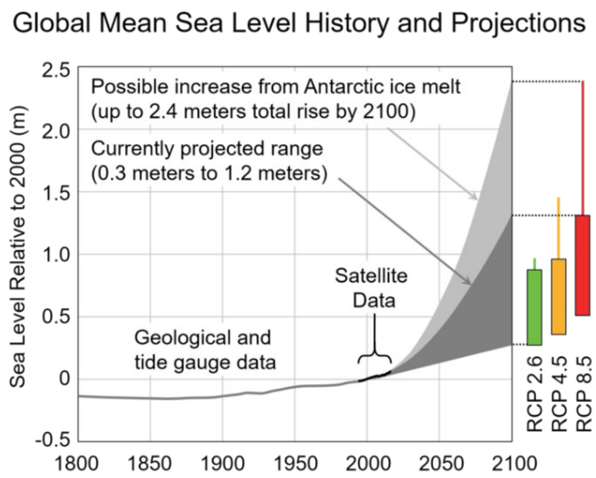


Fig. 1 Historical sea level reconstruction and projections up to 2100 published in January 2018 by the U.S. Global Change Research Program for the Fourth National Climate Assessment.

RCP=Representative Concentration Pathways. These are scenarios widely used in the climate research community that include time series of emissions and concentrations of the full suite of greenhouse gases, and aerosols and other chemically active gases, as well as land use/land cover. The word "representative" signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term "pathway" emphasises that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome.

As part of GWRC planning, inundation modelling has been undertaken and has defined several scenarios for use in planning. For this study, 0.2m SLR increments were modelled to enable assessment of three of SLR scenarios (+0.4m SLR, +1.4m SLR, +2.4m SLR), relating to estimated lower, mid and upper estimates of SLR over the next 100 years.

2.2 Elevation-based modelling

Elevation-based modelling involves 'flooding' measured land contours with seawater to verify which areas are inundated under present conditions, and then to assess how inundation patterns may change under future SLR scenarios. In the current assessment, bathymetry data were not available to determine the relative elevation of the intertidal area between mean low water spring (MLWS) and MHWS10 (the elevation that mean high water spring tide exceeds 10 percent of the time). However, from above MHWS10, Wellington 2013 LIDAR 1m Digital Elevation Model (DEM) data were available at ~20cm vertical resolution.

To determine the current upper limit of the estuary we utilised the 2013 DEM elevation data provided by GWRC, rectified colour aerial imagery (2012), and existing ground-truthed GIS-based field maps of estuary habitat (Stevens & Robertson 2013, 2015). The ground-truthed habitat maps were overlain on the elevation surface to determine which contour most closely matched the upper extent of mapped estuary habitat for the current situation (+0 SLR). MLWS was considered to represent the lower estuary boundary.

For Te Awarua-o-Porirua and Waikanae estuaries, the upper limit of salt marsh vegetation was approximately +0.8m above MHWS10. It was also noted that the MHWS10 line correlated closely with the lower elevation at which salt marsh species were present. These two values (MHWS10 and MHWS10 +0.8m) were subsequently used to model the elevation range within which salt marsh was theoretically capable of inhabiting. This was termed the 'salt marsh habitat zone' (SMHZ).

Delineating the upper and lower extent of the SMHZ enables two key aspects to be predicted under change scenarios:

- An elevation-based approach enables the identification of areas where salt marsh vegetation would be expected to grow, but is not currently present. These most likely reflect parts of the estuary disconnected from tidal flow by artificial barriers such as causeways, seawalls, bunds or flap gates. In this way, elevation-based modelling can provide insight into historic salt marsh habitat loss; identify areas that will be vulnerable to inundation under SLR scenarios if flow-barriers fail; and highlight areas that could be restored if barriers to flow were removed. However, because many parts of estuaries were historically infilled, elevation data alone will not be a reliable measure of historic salt marsh or estuarine extent.
- As SLR increases, the lower and upper SMHZ boundaries will seek to move inland in response to increasing water depth. Where the upper estuary boundary is fixed and salt marsh cannot migrate inland, coastal squeeze will occur, and salt marsh will reduce in spatial extent. From this, changes in the spatial footprint of the current salt marsh can be predicted.

To distinguish present-day areas within the theoretical estuary boundary (determined from elevation data) that have different levels of tidal connection, two categories of tidal flow were defined: ***Unrestricted*** and ***Restricted***.

Unrestricted areas are within the theoretical estuary boundary, but remain connected to regular tidal flows. They include the existing estuary extent, and areas the estuary may expand into under the defined SLR scenarios. These areas include low-lying farmland and urban parkland. The assumption in this report is that barriers are not put in place to prevent such flows.

Restricted areas are within the theoretical estuary boundary, but tidal flows are excluded from them and they are currently not part of the functioning estuary. The assumption in this report is that existing barriers will remain in place and continue to restrict tidal connection. It is also likely that in future additional barriers will be constructed to protect developed areas (residential housing, etc.) from being inundated. For this reason, all currently urban developed areas were categorised as restricted.

To determine the SMHZ elevation range for each SLR scenario, the sea level elevation for each was added to the current upper and lower SMHZ elevations. As described above, the lower SMHZ elevation starting point was MHWS10 and the upper SMHZ elevation starting point was 0.8m above MHWS10 (Table 1), with both determined from an assessment of mapped estuary features overlain on elevation data.

Table 1. Sea level rise scenarios with correlating salt marsh habitat zone (SMHZ) elevation boundaries (height above MHWS10).

SLR scenario	Lower SMHZ	Upper SMHZ
+0m SLR (baseline)	0	0.8m
+0.4m SLR	0.4m	1.2m
+1.4m SLR	1.4m	2.2m
+2.4m SLR	2.4m	3.2m

3. METHODS

3.1 Detailed description of input data layers

The Wellington Region DEM adjusted to the MHWS10 datum was provided by GWRC. This DEM was derived from a laser airborne (LiDAR) survey commissioned by the WAGGIS consortium in 2013. The survey data were subsequently reprocessed in 2017 by Landcare Research with funding from LINZ. The DEM was then recalculated to match the MHWS10 datum using tidal values provided in a NIWA report for the Parliamentary Commissioner for the Environment in 2016 (See reports cited in https://mapping1.gw.govt.nz/GW/SLR/ for derivation of tidal offsets from NIWA data.

Coastal elevation contours for the Te Awarua-o-Porirua and Waikanae, adjusted to the MHWS10 datum, were provided by GWRC, comprising contour polygons based on 1m DEM for the estuaries and coastline area to 5m elevation. Original data had a datum of Wellington VD 1953 with values in decimetres above MHWS10.

Broad scale habitat mapping GIS outputs were available from GWRC for Te Awarua-o-Porirua Harbour 2012/13 (Stevens & Robertson 2013), and for Waikanae 2014/15 (Stevens & Robertson 2015). These data were used as the most closely matched to the timing of the DEM. The original broad scale habitat maps were produced through field verification of features evident on aerial photos. It is worth noting that due to practical constraints around ground-truthing, broad scale mapping requires interpolation regarding the upper extent of the estuary in many areas. This is particularly so where salt marsh transitions to terrestrial vegetation. Further, it is not always possible to readily see on aerial photos features such as barriers or armouring (e.g. bunds or flap-gates) that can limit the extent of seawater intrusion. Consequently, the extent of restricted and unrestricted habitat can be difficult to accurately determine.

NZ aerial imagery was sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 International license.

Sea-draining catchments were extracted from the Freshwater Ecosystems of New Zealand (FENZ) v1.0 geodatabase. Downloaded from:

https://data.mfe.govt.nz/layer/99776-sea-draining-catchments.

3.2 Step-wise description of GIS methodology

1. Add input DEM layer converted to the appropriate regional MHWS datum (Supplied by GWRC).
2. Clip DEM to the appropriate sea draining catchment.
3. Create elevation polygons (20cm increments) from the DEM (Contours_MHWS10 supplied by GWRC).
4. Determine the upper salt marsh habitat elevation by comparing broad scale mapping with DEM and imagery.
5. Create a restricted area polygon using available information on barriers to inundation (armouring, etc.) and the developed area visible on aerial imagery.
6. Create a river/water exclusion polygon and use to clip final output layers.
7. Create a maximum extent polygon and use to clip final output layers. The maximum extent polygons include all areas below the maximum SLR scenario being evaluated (+2.4m SLR). Include disconnected low-lying areas that meet either of the following conditions as follows:
   - Area ≥0.4ha AND within 10m of estuary.
   - Area ≥0.4ha AND connected through culverts, etc.
8. Create SMHZ and sea level inundation polygons for each SLR scenario.

4. RESULTS

4.1 Te Awarua-o-Porirua Harbour

Elevation-based modelling of Te Awarua-o-Porirua Harbour showed that currently ~65% of the potential SMHZ was unrestricted (tidally connected), with ~35% restricted by causeways, bunds and flap gates.

For the unrestricted (tidally connected) SMHZ, there was an initial increase in extent with +0.2m of SLR, followed by a steady decrease to near zero (Fig. 2). Table 2 shows a 35% reduction in saltmarsh area (i.e. reflecting the loss of existing salt marsh offset by the theoretical gain) with +0.4m of SLR, and a 97% reduction in salt marsh area with +1.2m of SLR. The reason for the reduction is that existing salt marsh is lost, and SLR creates limited new habitat, as existing barriers (such as such as roads, housing, commercial premises) limit the capacity of the estuary to expand. Hence, due to the predicted level of inundation there will likely be no appreciable salt marsh remaining in Te Awarua-o-Porirua within ~50 years.

Further, as SLR increases the elevation range at which salt marsh will grow shifts from being predominantly within the unrestricted (tidally connected) part of the estuary, to being almost exclusively within the restricted (unconnected) part. Therefore, while there is a steady increase in the total *potential* SMHZ (see Table 2 right hand column), salt marsh is unlikely to establish in the restricted zone due to existing development and the high likelihood of barriers to tidal flow remaining.

The spatial extent of the SMHZ under each of the SLR scenarios have been mapped and are included on the following pages. The orange areas represent the SMHZ, with the cross-hatching indicating where it is theoretically possible for salt marsh to grow in response to SLR, but where tidal flows are likely to be restricted by barriers.

Table 2. Change in SMHZ area with increasing SLR in Te Awarua-o-Porirua Harbour.

Porirua Salt Marsh Habitat Zone (SMHZ)			
Sea Level Rise (m) *Sea level rise in metres above MHWS10*	Unrestricted SMHZ (ha)	Unrestricted SMHZ (ha) *Percent change from +0 SLR*	TOTAL SMHZ (ha) *Total (restricted + unrestricted) SMHZ*
+0 SLR	42.6	0%	64.0
+0.4 SLR	27.9	-35%	73.0
+1.4 SLR	1.3	-97%	79.8
+2.4 SLR	0.2	-99%	90.0

Note: Unrestricted SMHZ = loss of existing saltmarsh + theoretical gain of new salt marsh

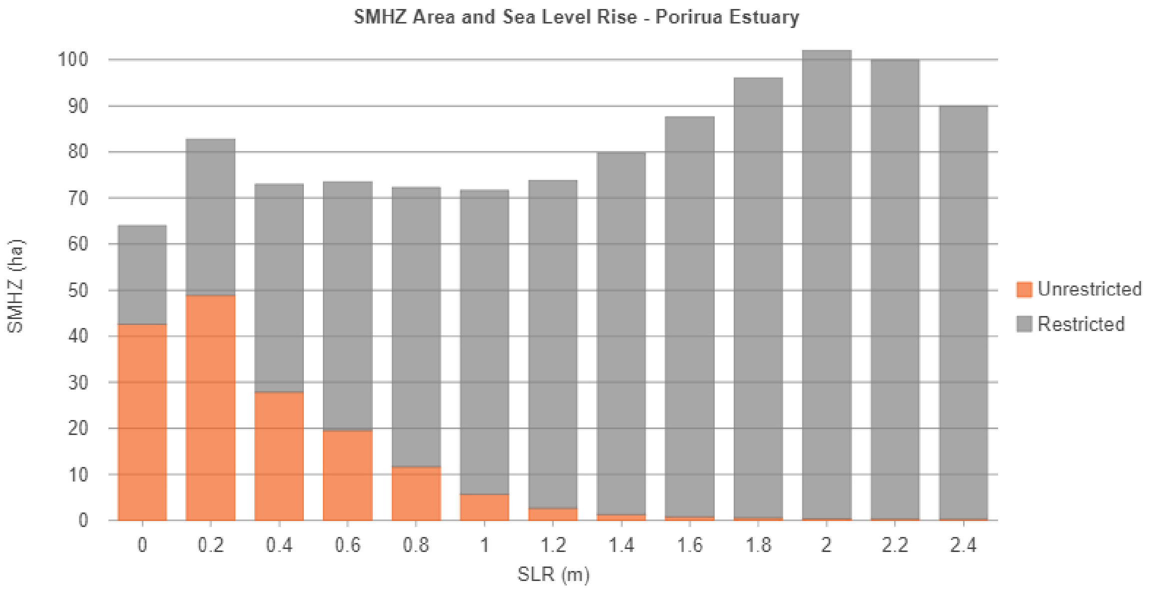
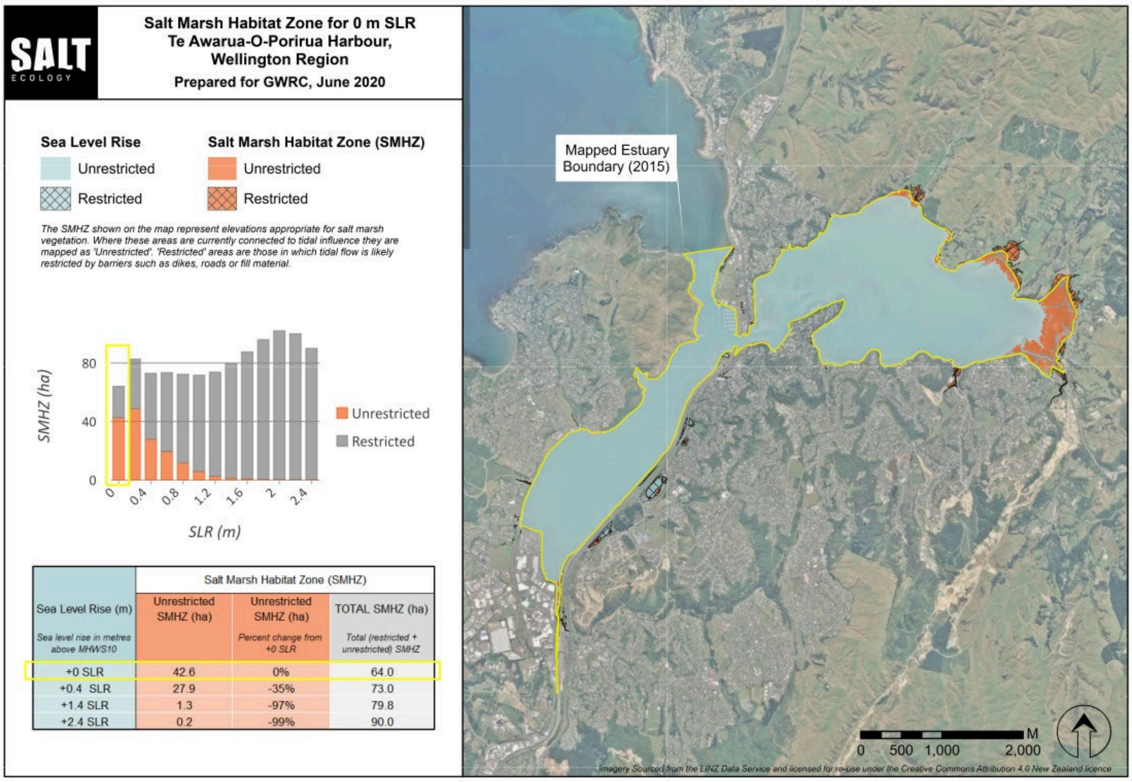
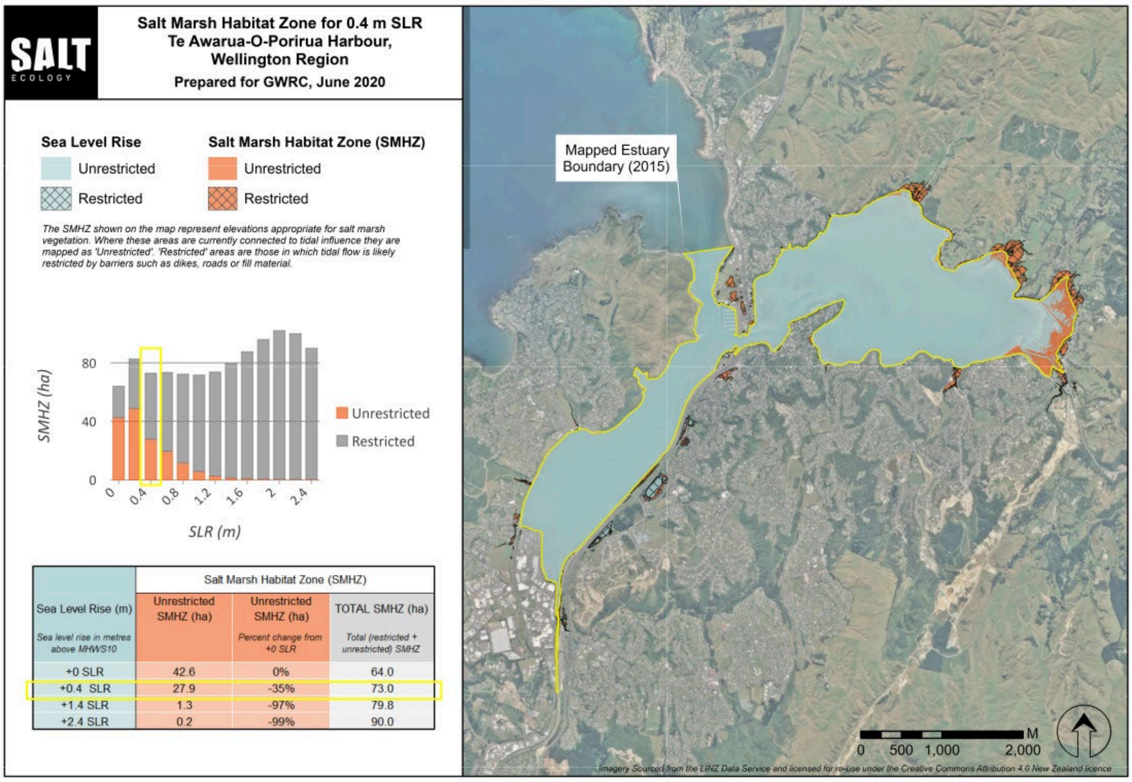


Fig. 2 Modelled salt marsh habitat zone (SMHZ) area in relation to sea level rise for Te Awarua-o-Porirua Harbour. Orange reflects predicted saltmarsh extent in areas connected to tidal flows, grey reflects *potential* saltmarsh habitat in areas where tidal inundation is prevented by flow barriers.



Sea Level Rise (m)	Salt Marsh Habitat Zone (SMHZ)		
Sea level rise in metres above MHWS10	Unrestricted SMHZ (ha)	Unrestricted SMHZ (ha) Percent change from +0 SLR	TOTAL SMHZ (ha) Total (restricted + unrestricted) SMHZ
+0 SLR	42.6	0%	64.0
+0.4 SLR	27.9	-35%	73.0
+1.4 SLR	1.3	-97%	79.8
+2.4 SLR	0.2	-99%	90.0

Fig. 3 Te Awarua-o-Porirua Harbour: SMHZ for +0m SLR



Sea Level Rise (m)	Salt Marsh Habitat Zone (SMHZ)		
Sea level rise in metres above MHWS10	Unrestricted SMHZ (ha)	Unrestricted SMHZ (ha) Percent change from +0 SLR	TOTAL SMHZ (ha) Total (restricted + unrestricted) SMHZ
+0 SLR	42.6	0%	64.0
+0.4 SLR	27.9	-35%	73.0
+1.4 SLR	1.3	-97%	79.8
+2.4 SLR	0.2	-99%	90.0

Fig. 4 Te Awarua-o-Porirua Harbour: SMHZ for +0.4m SLR

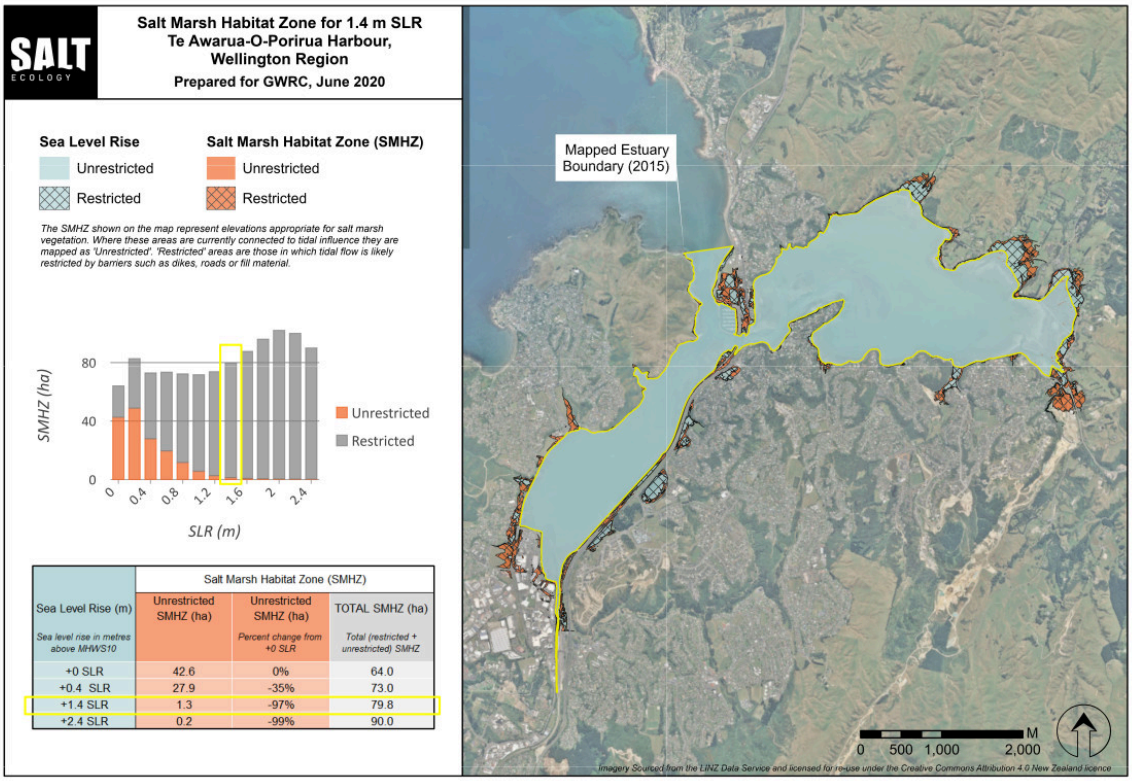


Fig. 5 Te Awarua-o-Porirua Harbour: SMHZ for +1.4m SLR

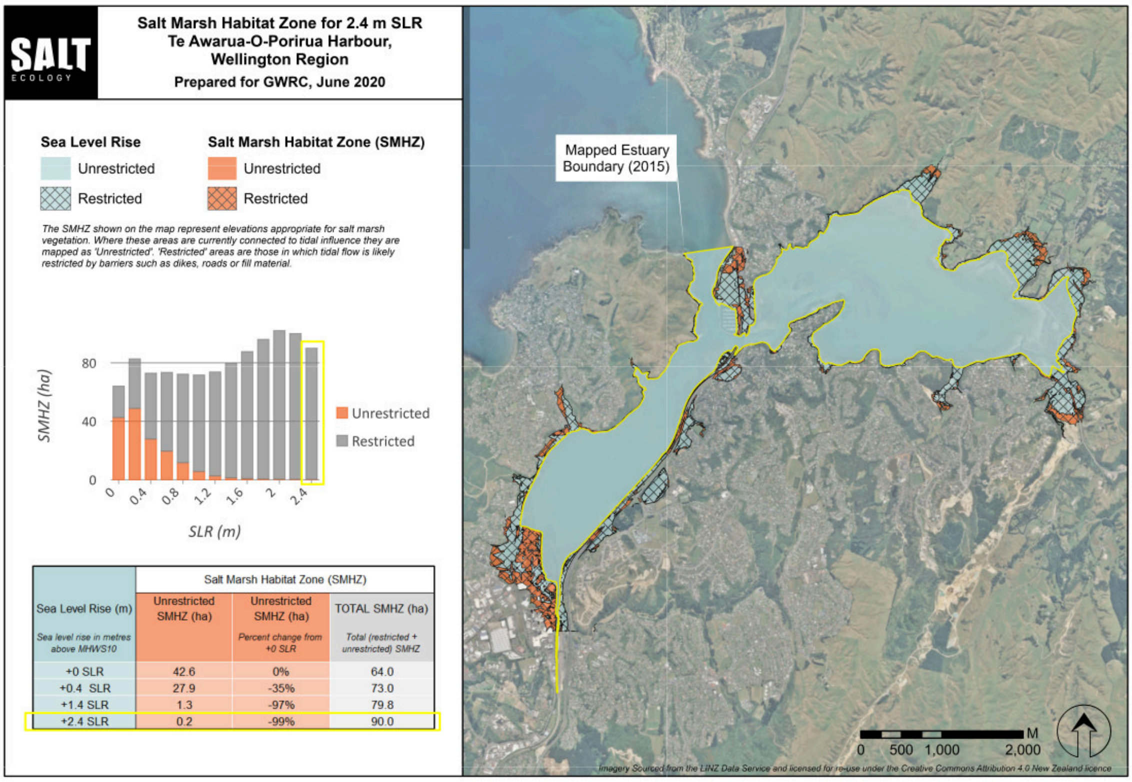


Fig. 6 Te Awarua-o-Porirua Harbour: SMHZ for +2.4m SLR

4.2 Waikanae Estuary

Waikanae Estuary was particularly challenging to model based on elevation, as the river-dominated estuary previously connected to an extensive coastal dune lake and estuarine system significantly different to its current extent. Consequently, the estuary is surrounded by many isolated low-lying areas with no apparent connection to the estuary. Low-lying areas with restricted tidal flow were identified manually using aerial imagery and expert judgement, and digitised as a *restricted* area polygon - a relatively time-consuming process. All other areas were categorised as *unrestricted*, with potential to develop into salt marsh habitat. Any current SMHZs that overlapped the restricted polygon were categorised as *restricted*.

By contrast with Te Awarua-o-Porirua, elevation-based modelling for Waikanae Estuary predicts that the unrestricted (tidally connected) SMHZ remains above the current extent and is relatively consistent across all SLR scenarios (Table 3, Fig. 7). The theoretical potential total SMHZ (represented by the sum of unrestricted and restricted areas) increased slightly with 0.4m of SLR, and then increased significantly at +1.4m of SLR. These scenarios largely comprise an almost complete loss of existing salt marsh with the establishment of new areas on the coastal dunes near the estuary entrance and further inland. In reality, any significant relocation of salt marsh into new areas is likely to be significantly less than that estimated, and the predicted increase in salt marsh may not eventuate.

Table 3. Change in SMHZ area with increasing SLR in Waikanae Estuary

Waikanae Salt Marsh Habitat Zone (SMHZ)			
Sea Level Rise (m) *Sea level rise in metres above MHWS10*	Unrestricted SMHZ (ha)	Unrestricted SMHZ (ha) *Percent change from +0 SLR*	TOTAL SMHZ (ha) *Total (restricted + unrestricted) SMHZ*
+0 SLR	28.8	0%	36.8
+0.4 SLR	41.7	44%	57.3
+1.4 SLR	43.0	49%	113.1
+2.4 SLR	33.4	16%	118.3

Note: Unrestricted SMHZ = loss of existing saltmarsh + theoretical gain of new salt marsh

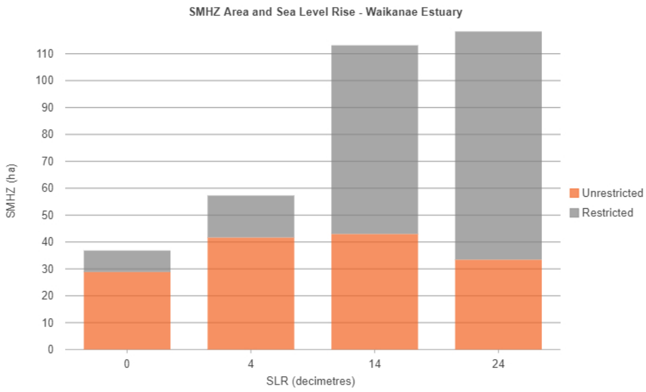
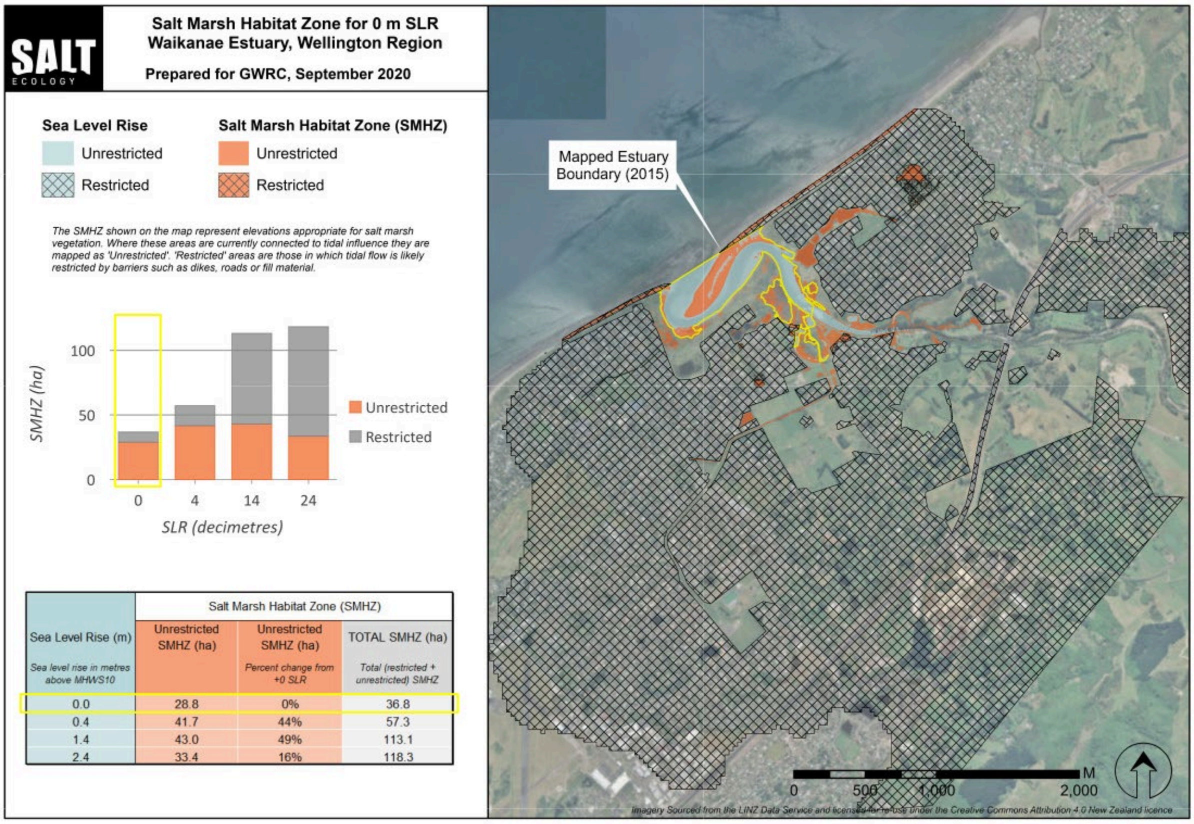


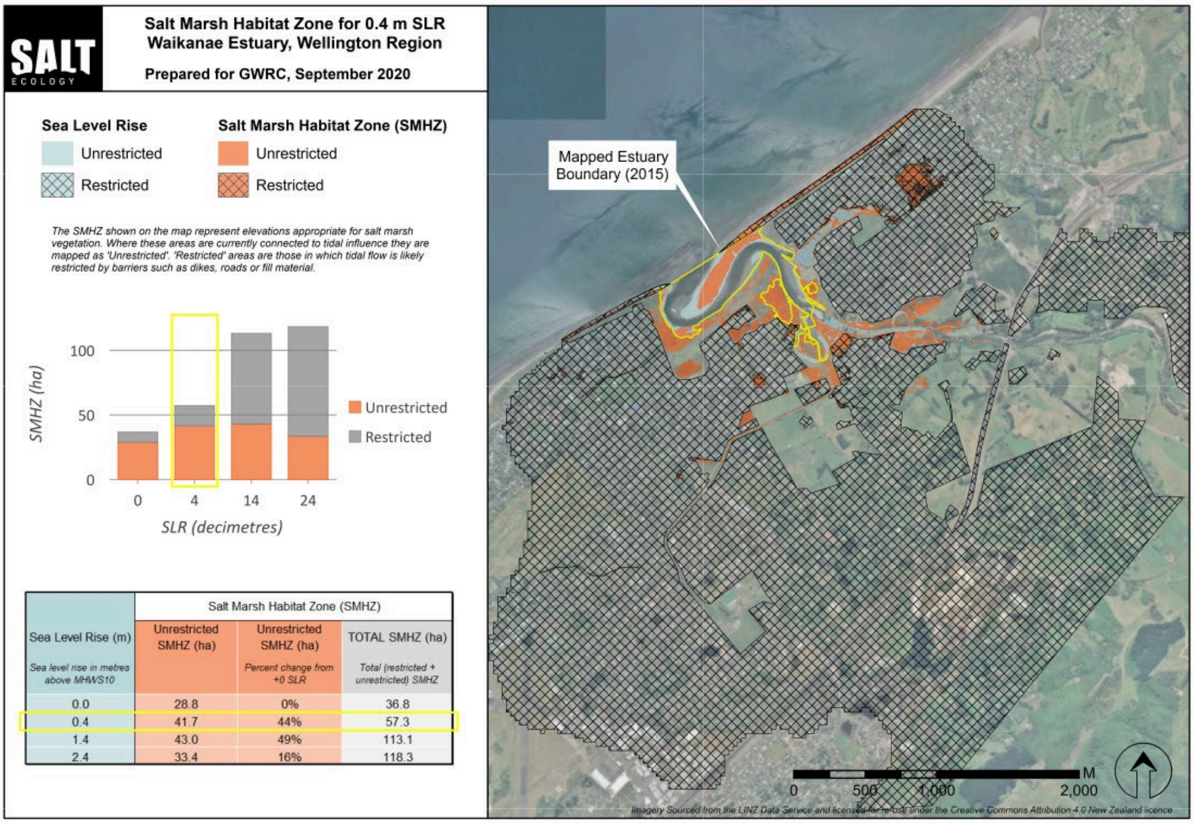
Fig. 7 Modelled salt marsh habitat zone (SMHZ) area in relation to sea level rise in Waikanae Estuary. Orange reflects predicted saltmarsh extent in areas connected to tidal flows, grey reflects *potential* saltmarsh habitat in areas where tidal inundation is prevented by flow barriers.

The spatial extent of the SMHZ under each of the SLR scenarios have been mapped and are included on the following pages.



Sea Level Rise (m)	Salt Marsh Habitat Zone (SMHZ)		
	Unrestricted SMHZ (ha)	Unrestricted SMHZ (ha)	TOTAL SMHZ (ha)
Sea level rise in metres above MHWS10		Percent change from +0 SLR	Total (restricted + unrestricted) SMHZ
0.0	28.8	0%	36.8
0.4	41.7	44%	57.3
1.4	43.0	49%	113.1
2.4	33.4	16%	118.3

Fig. 8 Waikanae Estuary: SMHZ for +0 m SLR. Note, urban areas were categorised as restricted (black cross-hatching)



Sea Level Rise (m)	Salt Marsh Habitat Zone (SMHZ)		
	Unrestricted SMHZ (ha)	Unrestricted SMHZ (ha)	TOTAL SMHZ (ha)
Sea level rise in metres above MHWS10		Percent change from +0 SLR	Total (restricted + unrestricted) SMHZ
0.0	28.8	0%	36.8
0.4	41.7	44%	57.3
1.4	43.0	49%	113.1
2.4	33.4	16%	118.3

Fig. 9 Waikanae Estuary: SMHZ for +0.4 m SLR. Note, urban areas were categorised as restricted (black cross-hatching)

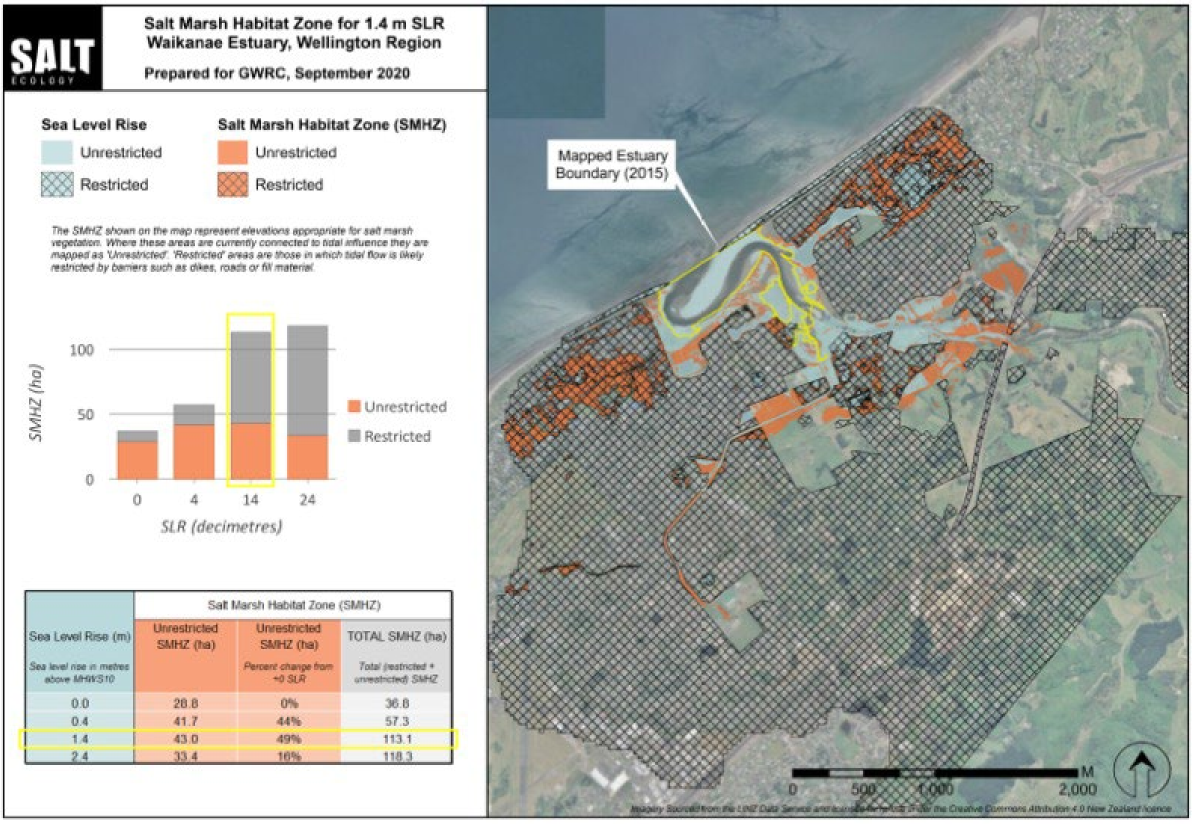


Fig. 10 Waikanae Estuary: SMHZ for +1.4 m SLR. Note, urban areas were categorised as restricted (black cross-hatching)

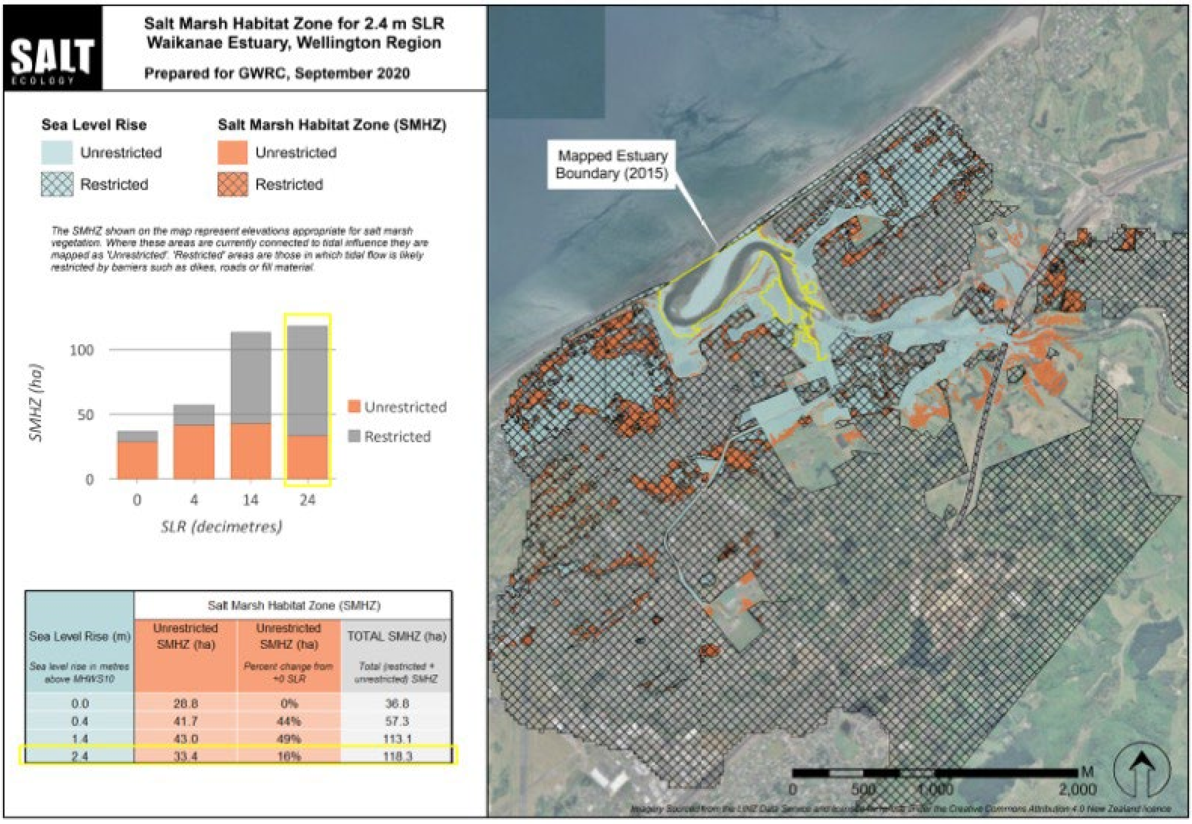


Fig. 11 Waikanae Estuary: SMHZ for +2.4 m SLR. Note, urban areas were categorised as restricted (black cross-hatching)

5. SYNTHESIS AND CONCLUSIONS

The elevation-based GIS approach provides a powerful and cost-effective way to quickly define potential changes to estuary boundaries, and to predict the location and extent of future salt marsh loss. From this it is possible to prioritise areas where future development should be restricted or carefully considered. Ideally, low-lying land surrounding estuaries should be retained as open space to maximise to opportunities for estuaries to naturally expand and maintain resilience to SLR impacts.

The ability to highlight vulnerability and show change in a spatial context is also a very helpful way of communicating information. It is readily facilitated in a GIS-based format which could be presented as an interactive on-line resource.

The approach used relies on access to DEM contour data at a resolution of ~0.20m, and to be able to relate the DEM and SLR increments to the local tidal range and datum.

Broad scale habitat mapping data was very helpful in defining the SMHZ, and local knowledge was important to enable judgements to be made regarding whether areas were flow restricted or unrestricted. Defining barriers to flows is particularly important in understanding whether estuarine habitat is likely to naturally re-establish in future, or whether intervention may be needed.

The inundation maps were helpful in defining the accuracy of the upper salt marsh / terrestrial interface, although this is highly sensitive to the resolution of the DEM and the linkage to tidal range and datum.

Although existing GIS layers were available for the current assessment, these may not be available at a sufficient resolution nationally for the method to be rolled out as a desk-top systems-based approach. Despite this limitation, as a first cut to identify of areas likely to be impacted by SLR, the approach is considered very helpful in setting priorities for more detailed assessment.

With regard to the specific results in Te Awarua-o-Porirua and Waikanae estuaries, many areas within the elevation range theoretically capable of supporting salt marsh have already been disconnected from tidal flow by elevated barriers and tide gates and/or converted to other land uses. Many previously estuarine areas have also been infilled, limiting future expansion. There is a high likelihood of ongoing development or inundation protection of margin areas, and disruption of the tidal connectivity. This makes it difficult to accurately predict the future estuary extent or potential for migration of estuarine species in response to predicted SLR.

However, using elevation-based modelling to identify inundation footprints and areas where future salt marsh habitat can potentially migrate to is an important step toward ensuring the long-term protection of estuary habitat and identify areas for restoration initiatives.

6. RECOMMENDATIONS

- Assess additional estuaries in the Wellington region for which DEM data are available.
- Generate spatial mapping outputs to assist Council staff in identifying vulnerable areas to assist in planning.
- Develop a web-based portal for sharing the results.

7. REFERENCES CITED

Bell RG, Paulik R, Wadwha S. 2015. National and regional risk exposure in low-lying coastal areas. Areal extent, population, buildings and infrastructure. Prepared for the Parliamentary Commissioner for the Environment. NIWA CLIENT REPORT No: HAM2015-006.

Brophy LS. 2018. Mapping tidal wetlands and their losses on the U.S. West Coast: new methods, new insights (Presentation). Pacific Marine & Estuarine Fish Habitat Partnership. Portland, Oregon. 55p.

Brophy LS, Ewald MJ. 2017. Modelling sea level rise impacts to Oregon's tidal wetlands: Maps and prioritization tools to help plan for habitat conservation into the future. MidCoast Watersheds Council, Newport, Oregon. 64p.

Hume T, Gerbeaux P, Hart D, Kettles H, Neale D. 2016. A classification of New Zealand's coastal hydrosystems. NIWA CLIENT REPORT No: HAM2016-062.

Lanier A, Haddad T, Mattison L, Brophy L. 2014. Core CMECS GIS Processing Methods, Oregon Estuary Project of Special Merit. Oregon Coastal Management Program, Salem, Oregon. 40p.

Robertson B, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A, Development; Part B, Appendices; and Part C, Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A, 93p; Part B, 159p; Part C, 40p plus field sheets.

Stevens LM, Robertson BM. 2013. Porirua Harbour: Broad Scale Habitat Monitoring 2012/13. Prepared for Greater Wellington Regional Council. 30p.

Stevens LM, Robertson BM. 2015. Waikanae Estuary: Broad Scale Habitat Monitoring 2014/15. Prepared for Greater Wellington Regional Council. 32p.

SALT
ECOLOGY
www.saltecology.co.nz