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Climate-Induced Sea-Level Rise Implications on Archaeological Taonga at Te Pokohiwi ō Kupe – The Wairau Bar, Aotearoa New Zealand

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Abstract

The northwest portion of Te Pokohiwi ō Kupe (the Wairau Bar) in the Marlborough Region is where one of Aotearoa New Zealand's earliest archaeological heritage sites dating back to the early 1300's is located. This paper describes a baseline study to map the effects of present-day and future sea-levels on archaeological heritage land at Te Pokohiwi ō Kupe. Results suggest that approximately 20% of the heritage land is susceptible to a 100-year storm wave inundation under present climate and sea-level conditions. With 1 m of SLR likely to be reached between the decades 2070–2130, approximately 75% of heritage land becomes compromised by a 100-year storm inundation event. These results imply that heritage land at Te Pokohiwi ō Kupe is already susceptible to inundation by significant storm waves, potential erosion and loss of archaeological sites, with these effects becoming more severe as sea level continues to rise over time.

Keywords

Climate change, coastal flooding, hazard risk, taonga, wāhi tapu, Wairau Bar

Introduction

Context and Background

Climate induced sea-level rise and extreme events over the next century is expected to increase flood frequency and intensity in coastal low-lying areas of Aotearoa New Zealand (Aotearoa NZ), increasing the exposure of assets and potential losses (Paulik et al. 2023). Indeed, the accelerating pace of climate change has reshaped global environmental systems (Pettorelli et al. 2021), with sea level rise emerging as one of the most serious consequences (Kopp et al. 2014; Neumann et al. 2015; Vitousek et al. 2017; Kulp and Strauss 2019). Driven by the melting of polar ice caps, thermal expansion of seawater and altered oceanic patterns, sea levels have risen at an unprecedented rate over the past century, with many parts of the Pacific region experiencing rates higher than the global average (WMO 2024). Coastal zones, which are already ecologically sensitive and densely populated, are amongst the most vulnerable to these changes (Trégarot et al. 2024).

Apart from the immediate threats of coastal erosion, infrastructure damage, resource pressures, human displacement and biodiversity loss, there is a less visible but equally significant impact: the loss of archaeological and cultural heritage (e.g., Jones et al. 2024). Archaeological sites capture centuries to millennia of human history and provide crucial records of past societies and their interactions with the environment (e.g., Rowland et al. 2024). Such sites hold significant cultural, spiritual, and social significance for local communities. However, the accelerating threat from rising sea-level, coastal erosion and storm intensification places many of these sites at imminent risk of being submerged, damaged, or entirely erased from the landscape. This in turn presents challenges pertaining to: 1) the loss of irreplaceable evidence and knowledge about past civilizations; and 2) the severing of cultural connections that modern societies maintain with their heritage.

This paper assesses the effects of climate change-induced sea level rise on an archaeological heritage site in Aotearoa NZ: Te Pokohiwi ō Kupe (the Wairau Bar) – one of Aotearoa NZ's earliest and most significant cultural heritage sites. We map the present and future scale of sea-level inundation at the site under a warming climate and assess the implications for archaeological site loss. Findings are discussed in the context of cultural preservation and the urgency for implementing interdisciplinary strategies that combine environmental science, archaeology, and heritage management to mitigate the loss of these taonga (treasured belongings) before they are lost beneath the rising tides.

Study objectives

Here, we explore the implications of climate change induced sea-level rise (SLR) inundation and likely areas of coastal erosion on one of Aotearoa New Zealand's premier archaeological sites – Te Pokohiwi ō Kupe (the Wairau Bar) (Figure 1). Using available iwi-hapū geospatial information about archaeological taonga and wāhi tapu (sacred sites) across the northwest portion Te Pokohiwi ō Kupe, along with high resolution topographic data of the area, we analyse and map the exposure risk to these sites from permanent spring tide and coastal storm inundation at present sea-level and future SLR.

Future SLR are linked with climate change scenarios consistent with the latest guidance from the Intergovernmental Panel on Climate Change (IPCC), to estimate the future timing of each SLR inundation scenario. The coastal erosion hazards analysis evaluates historical erosion rates using historical aerial and satellite imagery (1947 to present). The analysis also estimates the future position of the shoreline associated with slow onset SLR.

Figure 1: Te Pokohiwi ō Kupe in northeast Te Waipounamu, showing the present heritage land boundary relative to topographic contours.

This study represents the first high resolution assessment of SLR and coastal change for the northwest portion of Te Pokohiwi ō Kupe at a local scale. Previous national scale studies of SLR for Aotearoa New Zealand which encompassed Te Pokohiwi ō Kupe (e.g., Paulik et al., 2023), were developed for SLR risk screening purposes and were thus output at a coarser resolution than what was required for the purposes of this study. While the focus of this present study is on developing first-order, high resolution, representations of SLR to inform the dialogue on potential adaption/rescue options associated with wāhi tapu, the area is known to be at risk from tsunami inundation as evidenced by paleotsunami studies previously carried out in the area (e.g., Clark et al., 2015, 2019; King et al., 2017).

Rationale

The northwest portion of Te Pokohiwi ō Kupe is one of Aotearoa New Zealand's most significant historical sites which contains the remains of some of the earliest settlers to these lands (Meihana and Bradley, 2018; McFadgen and Adds, 2019). The site is in a hazardous area and is exposed to multiple hazards such as earthquakes which can cause subsidence, tsunamis, and extreme weather events such as storms and subsequent inundation. However, there are limited studies which evaluate the longer-term influence of climate change induced SLR and its implications in the area.

This project represents the first site-specific assessment of the potential impacts and implications of climate change induced SLR inundation and coastal erosion on Māori heritage and archaeology. It also provides a template for evaluating the impacts of SLR on similar taonga [Māori assets of cultural and/or historical significance] in coastal areas around Aotearoa New Zealand.

Given the high certainty that a significant proportion of Māori heritage and archaeological resources relating to Māori occupation over the past millennium will erode away unrecorded, this work aims to support knowledge exchange and decision-making about what should be rescued, recorded, why, and when. While it may not be possible to answer the question of how long do we have with absolute certainty, outputs of this work are expected to help focus dialogue and inform decisions about adaptation and resilience options.

Coastal Inundation Mapping

Topography and Digital Elevation Model

Te Pokohiwi ō Kupe is located in the Wairau Lagoons Wetland Management Reserve, and is characterized by an 8 km long gravel bar that is bound to the Vernon Hills in the southeast (Clark et al., 2015; King et al., 2017) (Figure 1). The 1 km stretch on the northwest of the gravel bar where the heritage land is located, is approximately 600 m in width with the highest elevation approximately 4–5 m above mean sea-level (MSL). Light detecting and ranging (LiDAR) topography data reveals that the heritage land is predominantly located in an area that is less than 3 m above MSL.

The availability of high-resolution LiDAR enables the development of an accurate digital elevation model (DEM) for use in simulating representative coastal inundation models in the area. A 1 m resolution DEM was created by averaging the 2014 Blenheim LiDAR point cloud (LINZ, 2018). Only points classified as "ground" were used for the DEM generation. The 1 m gridding was calculated by averaging all the point values located within 1.4142 m from each cell centre. The vertical datum of the DEM was NZVD2016 (EPSG: 7839), same as the original dataset. Bathymetry data for the ocean and estuary were not included in the DEM. Bathymetry data are required for dynamic inundation modelling but not necessary for static inundation modelling of this study.

Tide, datum and extreme storm-tide

Analysis of coastal inundation requires an assessment of the Mean High-Water Spring (MHWS) tidal level. For this study, MHWS was calculated as the 10th highest percentile of 18-years of astronomical high tide as predicted by the New Zealand tidal model (Goring, 2001) (sometimes referred to as MHWS-10). The value for MHWS-10 was calculated as 0.74 m above MSL.

Using the same methodology, the 7th highest percentile of high tides (MHWS-7) was calculated at 0.77 m above MSL. This value is useful in determining extreme storm-tide levels. Using tide gauge data for around Aotearoa/New Zealand, Stephens et al. (2020) found linear relationships between MHWS-7 and extreme storm-tide level for given return intervals (Figure 2). Using these relationships, the 100-year Average Recurrence Interval (ARI) can be calculated. The 100-year ARI represents the storm-tide conditions that are, on average, exceeded once in a 100-year period. This does not, however, mean that the average period between such events is 100 years and there is a possibility (although low probability) of observing such events multiple times in any given year. For Te Pokoiwi-o-Kupe, the 100-year ARI storm-tide was calculated as 1.30 m MSL.

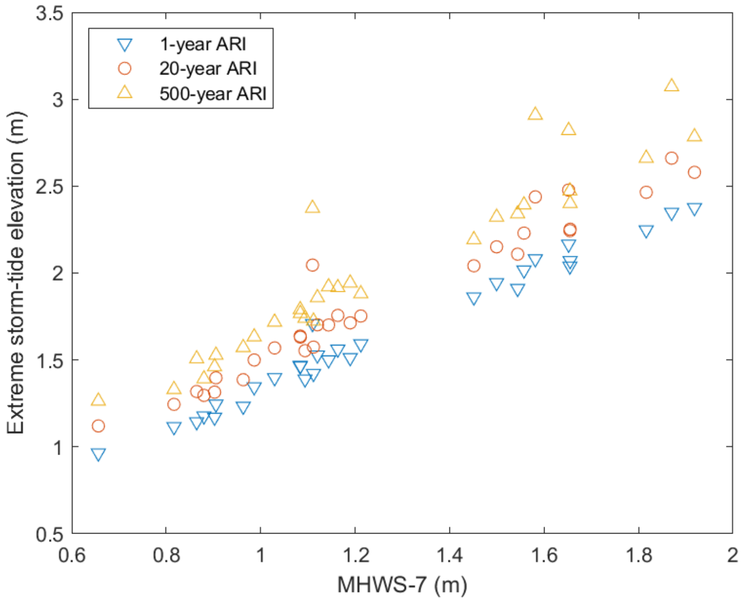

Figure 2: Linear relationships of storm tide and MHWS-7. Data points are from tide analysis and extreme value analysis of Stephens et al. (2020) using individual tide gauge records from around NZ.

Wave contribution to inundation was simplified as a single value of 0.5 m of wave setup. This is an over-simplification of wave contribution to inundation, but this can provide a first order assessment of inundation.

Converting values of MSL values to NZVD2016 is not trivial in the Blenheim region because of ongoing post-seismic land movement following the 2016 Kaikōura earthquake. However, Stephens and Paulik (2023) recently published an update of the relationship of MSL and NZVD16 for New Zealand's main seaports. They report a datum shift of -0.12 to -0.13 m for the closest ports to Blenheim (i.e., Wellington and Picton).

Inundation Modelling

Inundation extent and depth were calculated using a static inundation assessment, which is also referred to as a bathtub assessment. The storm-tide and wave setup level are intersected with the DEM to derive inundated surfaces. All the values of inundation level above ground are considered wet, regardless of their connectivity to the ocean or estuary. While this is a conservative estimate, it provides insight of the potential for inundation by shallow ground water that is uplifted by storm-tide or spring tides.

Timing of Sea-Level Rise Scenarios

The modelled SLR scenarios were then correlated with the corresponding SLR projections for Aotearoa NZ consistent with the latest Intergovernmental Panel on Climate Change's 6th

Assessment Report (IPCC AR6, 2021) to estimate the future timing which each modelled SLR scenario is likely to be reached (Figure 3 and Table 1).

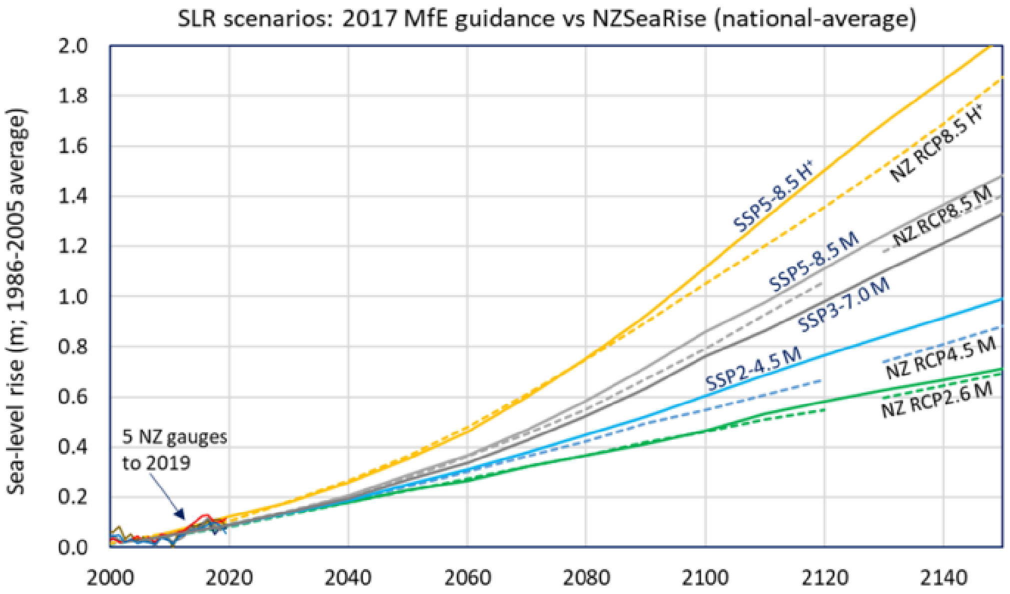

Figure 3: Comparison of SLR prediction for New Zealand from the 2017 guidance (dash lines) and the 2022 update (plain lines). Source: NZ Ministry for the Environment, 2022.

Table 1: Approximate years when various national sea-level rise increments could be reached. Source: NZ Ministry for the Environment, 2022.

SLR (m)	Year achieved for SSP1-2.6 (median)	Year achieved for SSP2-4.5 (median)	Year achieved for SSP3-7.0 (median)	Year achieved for SSP5-8.5 (median)	Year achieved for SSP5-8.5 H+ (83rd percentile)
0.3	2070	2060	2060	2055	2050
0.4	2090	2080	2070	2065	2060
0.5	2110	2090	2080	2075	2065
0.6	2130	2100	2090	2080	2070
0.7	2150	2115	2100	2090	2080
0.8	2180	2130	2110	2100	2085

SLR (m)	Year achieved for SSP1-2.6 (median)	Year achieved for SSP2-4.5 (median)	Year achieved for SSP3-7.0 (median)	Year achieved for SSP5-8.5 (median)	Year achieved for SSP5-8.5 H+ (83rd percentile)
0.9	2200	2140	2115	2105	2090
1.0	>2200	2155	2125	2115	2095
1.2	>2200	2185	2140	2130	2105
1.4	>2200	>2200	2160	2145	2115
1.6	>2200	>2200	2175	2160	2130
1.8	>2200	>2200	2200	2180	2140
2.0	>2200	>2200	>2200	2195	2150

Heritage Land Exposure Mapping

The heritage area on the northwest portion of Te Pokohiwi ō Kupe delineated by Te Rūnanga a Rangitāne o Wairau was digitised in QGIS to produce a geospatial polygon representing the heritage land boundary. The polygon was then rasterised and gridded at the resolution of the baseline DEM (i.e., 1 m grid) using QGIS geoprocessing tools, with each grid representing a land area of 1 m^2.

This provided the exposure layer which was combined with each scenario SLR inundation model in the RiskScape multi-hazard impacts and loss modelling software (Paulik et al., 2023), to output metrics of total heritage land area (m^2) likely to be affected by inundation in each modelled scenario. That is, gridded cells from the heritage area polygon which intersected with a wet grid cell from each inundation model was output as being affected/exposed to inundation. A schema depicting the exposure modelling workflow is shown in Figure 4.

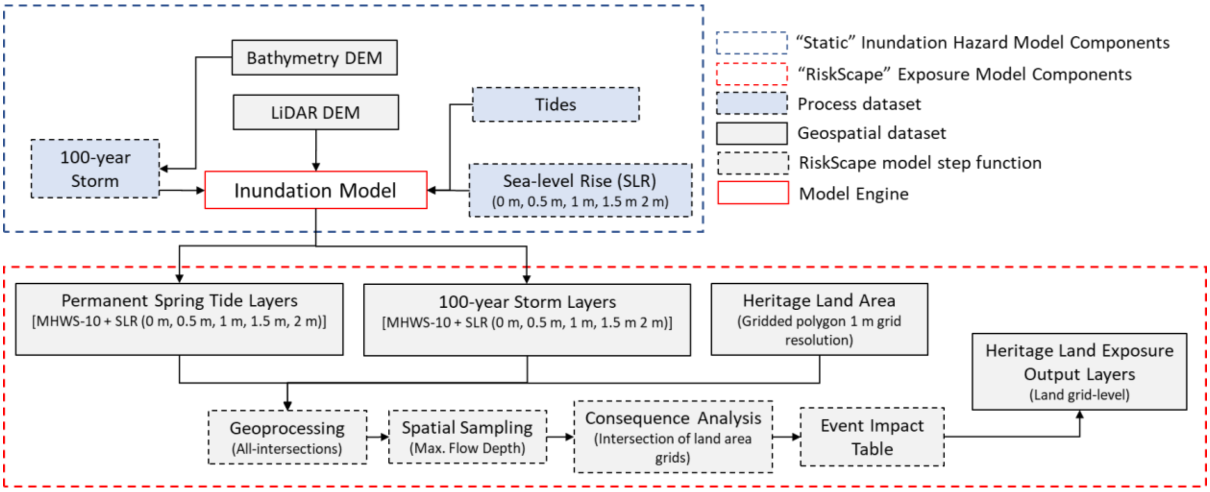

Figure 4: Schema of the RiskScape exposure risk workflow used to calculate the heritage land area exposure to each SLR scenario.

Results

Permanent Spring Tide Inundation and Heritage Land Exposure

The results shown in Figure 5 and Figure 6 indicate that permanent spring tide inundation with 0.5 m of SLR begins to affect approximately 16% of the heritage area by the decades 2045–2060. With 1 m SLR, approximately 53% of the heritage area becomes affected between the decades 2070–2130. By that time the through to the east of the heritage site will be flooded by MHWS tides.

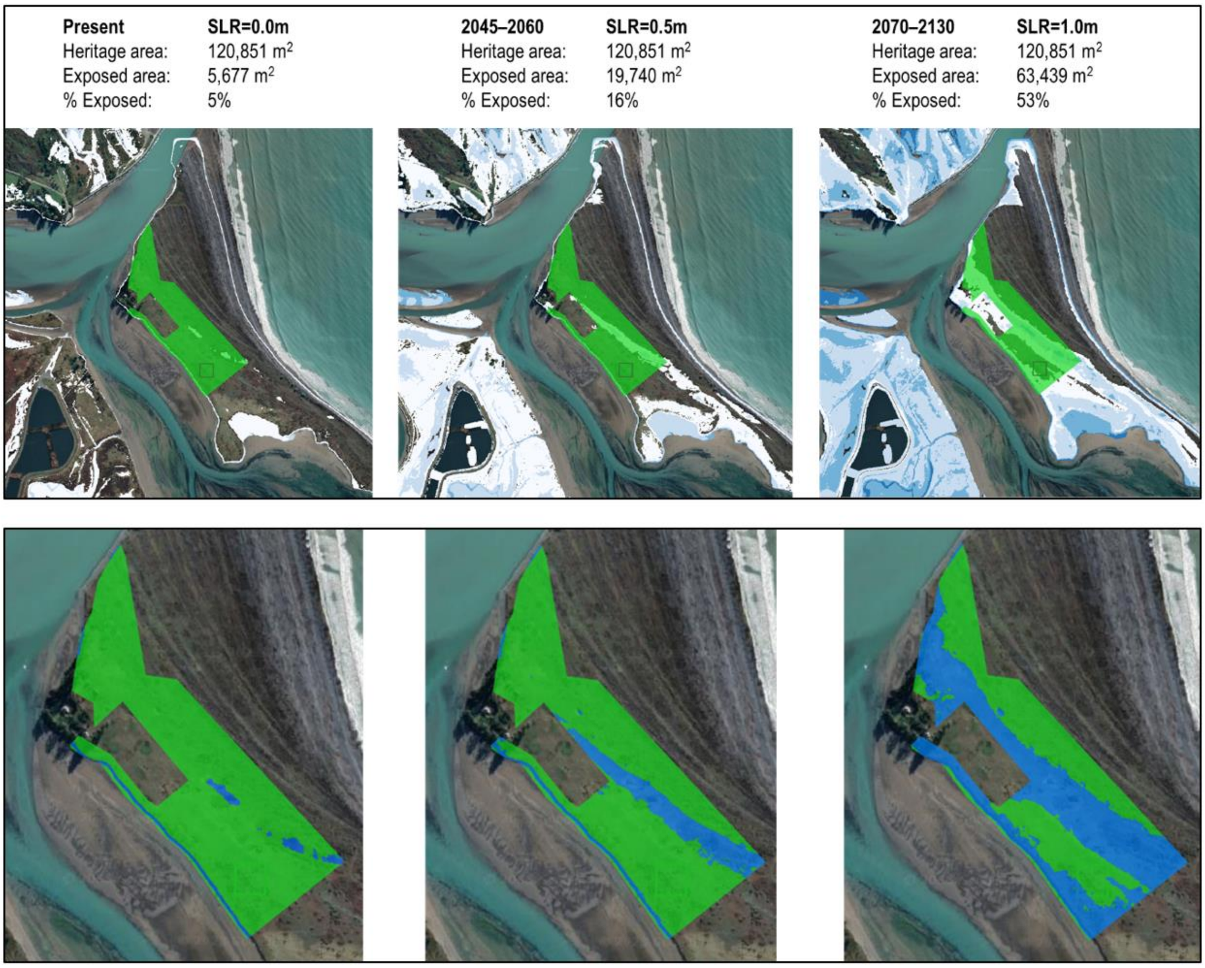

Figure 5: Results of heritage land area exposed to each permanent spring tide inundation scenario under present and future SLR. [Top panels] Permanent Spring tide inundation of the northwest portion of Te Pokohiwi ō Kupe under present sea-level (left), 0.5 m of SLR (middle) and 1.0 m of SLR (right). [Bottom panels] Permanent Spring tide inundation exposure (blue shading) of Te Pokohiwi ō Kupe heritage land under present sea-level (left), 0.5 m of SLR (middle), and 1.0 m of SLR (right). Green shading depicts areas not inundated.

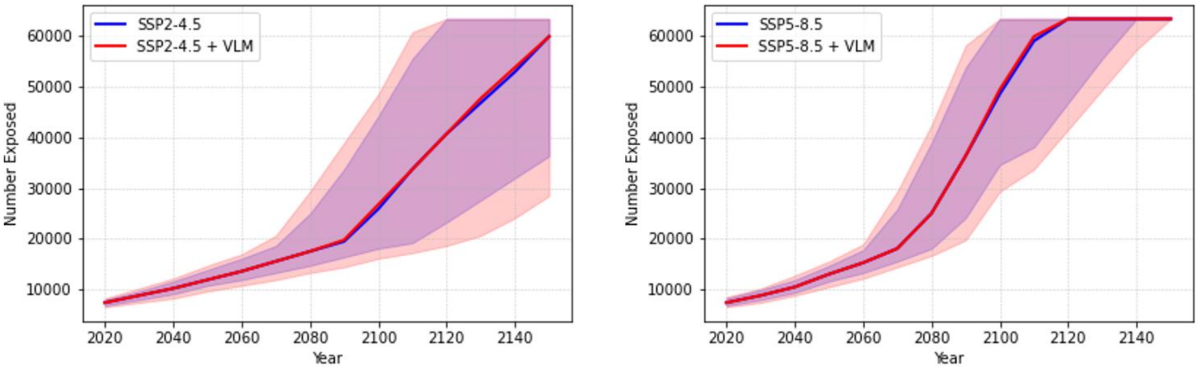

Figure 6: Estimated heritage land exposure (m^2) due to sea-level rise under a warming climate for permanent spring tide (PST) inundation under SSP 2–4.5 (left) and SSP 5–8.5 (right). VLM = Vertical Land Movement estimated for Aotearoa NZ (Naish et al. 2024).

100-year Storm Wave Inundation and Heritage Land Exposure

Figure 7 and Figure 8 shows that a 100-year ARI storm inundation under present sea-levels is likely to inundate approx. 20% of the heritage land area. With 1 m SLR, the 100-year storm inundation affects approximately 75% of the total heritage area by the decades 2070–2130.

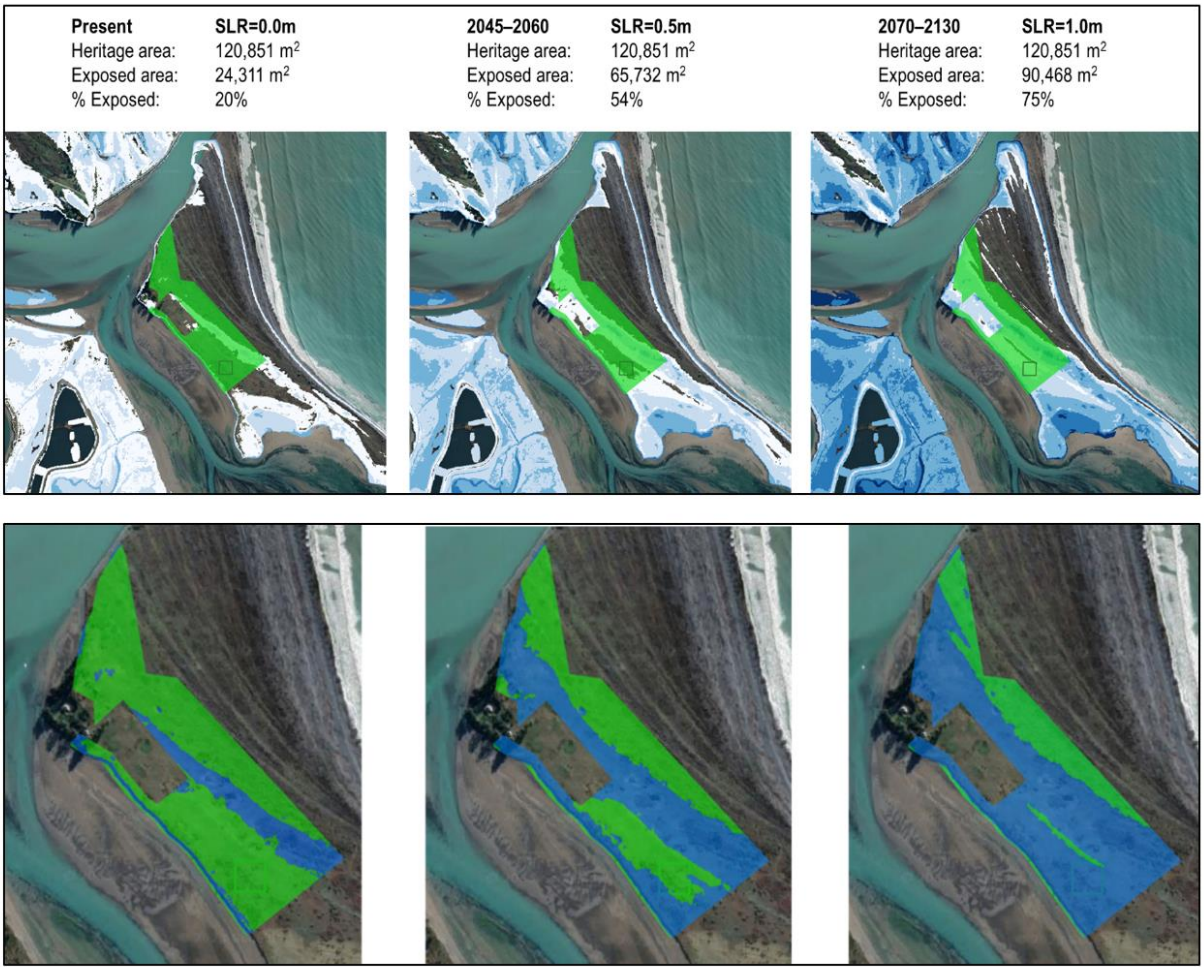

Figure 7: Results of heritage land area exposed to each 100-year storm inundation scenario under present and future SLR. [Top panels] 100-year storm inundation of the northwest portion of Te Pokohiwi ō Kupe under present sea-level (left), 0.5 m of SLR (middle) and 1.0 m of SLR (right). [Bottom panels] 100-year storm inundation exposure (blue shading) of Te Pokohiwi ō Kupe heritage land under present sea-level (left), 0.5 m of SLR (middle), and 1.0 m of SLR (right). Green shading depicts areas not inundated.

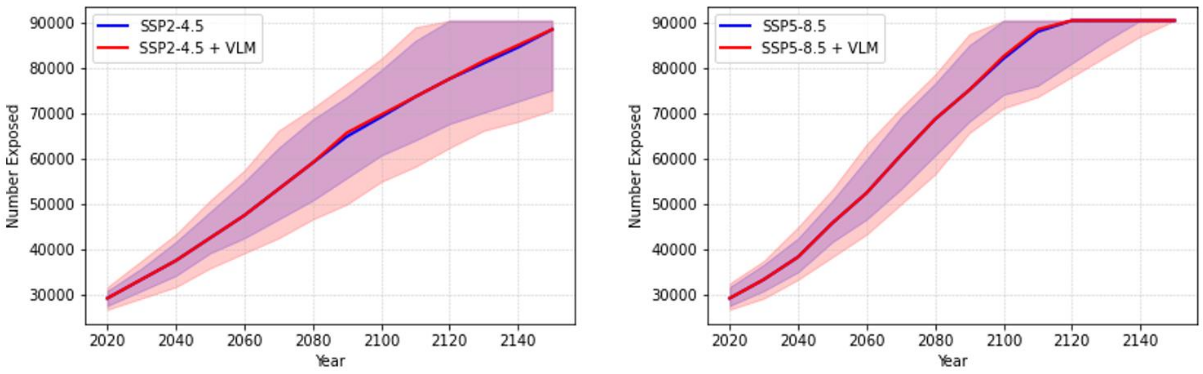

Figure 8: Estimated heritage land exposure (m^2) due to sea-level rise under a warming climate for permanent spring tide (PST) plus 100-year ARI extreme sea level inundation under SSP 2–4.5 (left) and SSP 5–8.5 (right). VLM = Vertical Land Movement estimated for Aotearoa NZ (Naish et al. 2024).

Discussion

Coastal Inundation Effects

The findings in this study suggest that approximately 20% of the heritage land is susceptible to a 100-year storm wave inundation under present climate and sea-level conditions. Approximately 54% of heritage land becomes affected by a 100-year storm inundation event with a 0.5 m increase in sea-level, which is likely to be reached between the years 2045–2060 (the next 22–37 years). With 1 m of SLR likely to be reached between the decades 2070–2130 (next 47–107 years), approximately 75% of heritage land becomes compromised by a 100-year storm inundation event.

With regards to permanent spring tide inundation, heritage land gradually becomes more inundated with approximately 16% affected once sea-level reaches 0.5 m above present levels in the next 22-37 years. By 2070–2130 when sea-level is estimated to reach 1 m above present levels, approximately 53% of heritage land becomes affected.

These results imply that heritage land on the northwest portion of Te Pokohiwi ō Kupe is already susceptible to inundation by significant storm waves, and that these effects become more prominent as sea-level continues to rise over time. In addition, close to a fifth of the total heritage area is susceptible to permanent spring tide inundation alone in the next 22–37 years, with more than half susceptible by as early as the next 50 years.

Future work to complement the baseline assessment presented here includes a coastal geomorphological change analysis under a warming climate to evaluate the potential effects of coupled inundation and erosion. This would encompass incorporating the potential effects of co-seismic land movement due to the possibility of large earthquakes, which are known to induce significant subsidence and associated erosion in the area (e.g., 1848 and 1855 earthquakes) (McFadgen and Adds, 2019), and how these processes potentially exacerbate the heritage land exposure estimates presented in this study.

Implications

Findings in this study, which represent first-order estimates of heritage land exposure and potential loss of archaeological taonga at Te Pokohiwi ō Kupe, highlight the urgency for identifying adaptation and implementation options to preserve and/or rescue wāhi tapu and taonga within the heritage area. Key questions which might emerge from the evidence presented in this study include, but are not limited to:

- What level of risk is acceptable and what level of urgency needed for preserving wāhi tapu at the site? Are decisions and actions required now or in several years to preserve and/or relocate wāhi tapu at threat to inundation? If relocation is an option, are there protocols to support and safeguard the rescue and relocation of wāhi tapu taonga, such as karakia for exhuming ancestral remains, etc? Is there an acceptable location identified for relocating wāhi tapu remains, if relocation is an option?

- What options are available and what needs to happen to implement potential rescue activities? Who needs to be involved, and/or endorsement/permissions received from? What implementation logistics are required?
- Resourcing and costs: What resources are available to implement adaption and/or rescue works? What are the main financial costs and available budget sources at local, regional and national scales?

The questions described above are not exhaustive nor intended to be prescriptive, but rather help provide guidance to support ongoing dialogue on potential next steps in relation to adaptation and rescue/relocation of archaeological taonga at the site. More importantly, these findings highlight the importance of undertaking similar local scale, site-specific, analysis on sea-level rise implications on archaeological taonga in other parts of Aotearoa NZ and in coastal environments across the Pacific region.

Uncertainties

The SLR inundation models developed are representative of LiDAR topography captured in 2014 and do not account for dynamic changes in the geomorphology (size/shape and composition) of the gravel bar including potential subsidence at future points/periods in time corresponding to the SLR scenarios presented. In addition, the compounding effects of sea-level plus fluvial flooding from the Wairau River on inundation at Te Pokohiwi ō Kupe was not considered in this analysis. Similarly, compounding effects of other extreme events such as tsunami inundation and how the exposure risk changes over time under a warming climate (e.g., Welsh et al. 2023), has not been considered in this study.

The estimated future timing of scenario SLR presented are based on climate change scenarios that are consistent with the IPCC AR6 Report, with the SLR models developed provides a first-order representation of likely scenario inundation under a changing climate at a localised scale, which can be used to inform dialogue on adaptation options associated with wāhi tapu in the area, as well as informs the directions for future investigations.

Climate change and SLR may affect Te Pokohiwi ō Kupe in ways that have not been analysed here. For example, SLR will also rise the level of groundwater and will also increase the salinity of the groundwater exposing assets that are not normally affected with ground water or saltwater intrusion may become affected (Bosserelle et al. 2022).

The challenges described above should be considered in ongoing, follow-up, studies at Te Pokohiwi ō Kupe to build on the baselines presented here.

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Conflict of Interest

The authors declare no conflict of interest.

References

Bosserelle, C., Hicks, M., Bind, J. (2019). Waitaki District Coastal Hazards. Prepared for the Otago Regional Council. NIWA Client report 2018035CH.

Bosserelle, A.L., Morgan, L.K., & Hughes, M.W. (2022). Groundwater rise and associated flooding in coastal settlements due to sea-level rise: A review of processes and methods. Earth's Future, 10, e2021EF002580. https://doi.org/10.1029/2021EF002580.

Clark, K.J., Hayward, B.W., Cochran, U.A., Wallace, L.M., Power, W.L., Sabaa, A.T. (2015). Evidence for past subduction earthquakes at a plate boundary with widespread upper plate faulting: Southern Hikurangi Margin, New Zealand. Bull. Seismol. Soc. Am. 105, 1661–1690. https://doi.org/10.1785/0120140291.

Grapes, R. & Downes, G. (1997). The 1855 Wairarapa, New Zealand, earthquake - analysis of historical data, Bulletin of the New Zealand Society for Earthquake Engineering 30: 271–369.

Goring, D. (2001). Computer Models Define Tide Variability. The Industrial Physicist, American Institute of Physics, 14-17.

IPCC (Intergovernmental Panel on Climate Change). Summary for Policymakers. In Climate Change 2021: The Physical Science Basis; Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In: Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., et al., Eds.; Cambridge University Press: Cambridge, UK, 2021.

Jones, B.D., Collings, B., Dickson, M.E., Ford, M., Hikuroa, D., Bickler, S.H., Ryan, E. (2024). Regional implementation of coastal erosion hazard zones for archaeological applications. Journal of Cultural Heritage, 67, 430-442. https://doi.org/10.1016/j.culher.2024.04.007.

King, D.N., Goff, J., Chague-Goff, C., McFadgen, B., Jacobson, G., Gadd, P., and Horrocks, M. (2017). Reciting the layers: Evidence of past tsunamis at Mataora – Wairau Lagoon, Aotearoa-New Zealand, Mar. Geol., 389, 1–16.

Kopp, R.E., Horton, R.M., Little, C.M., Mitrovica, J.X., Oppenheimer, M., Rasmussen, D.J., Strauss, B.H., Tibaldi, C. (2014). Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth’s Future, 2, 383–406

Kulp, S.A., Strauss, B.H. (2019). New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. Nat. Commun., 10, 4844.

LINZ (2018). Blenheim, Marlborough, New Zealand 2014. Collected by New Zealand Aerial Mapping Limited, distributed by OpenTopography and Land Information New Zealand (LINZ). https://doi.org/10.5069/G9WH2MXG.

Meihana, P.N., Bradley, C.R. (2018). Repatriation, Reconciliation and the Inversion of Patriarchy. Journal of the Polynesian Society, 127 (3), 307-324. http://dx.doi.org/10.15286/jps.127.3.307-324.

McFadgen, B.G., Adds P. (2019). Tectonic activity and the history of Wairau Bar, New Zealand’s iconic site of early settlement, Journal of the Royal Society of New Zealand, 49:4, 459-473, DOI: 10.1080/03036758.2018.1431293.

Naish, T., Levy, R., Hamling, I.,Hreinsdóttir, S., Kumar, P., Garner, G. G.,et al. (2024). The significance of interseismic vertical land movement at convergent plate boundaries in probabilistic sea-level projections for AR6 scenarios: The New Zealand case. Earth's Future, 12, e2023EF004165. https://doi.org/10.1029/2023EF004165.

Neumann, B., Vafeidis, A.T., Zimmermann, J., Nicholls, R.J. (2015). Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding—A Global Assessment. PLoS ONE, 10, e0118571.

Paulik, R., Horspool, N., Woods, R., et al. (2023). RiskScape: a flexible multi-hazard risk modelling engine. Nat Hazards 119, 1073–1090. https://doi.org/10.1007/s11069-022-05593-4.

Paulik, R., Wild, A., Stephens, S., Welsh, R., Wadhwa, S. (2023). National assessment of extreme sea-level driven inundation under rising sea levels. Front. Environ. Sci. 10:1045743. doi: 10.3389/fenvs.2022.1045743.

Pettorelli, N., Graham, N. A. J., Seddon, N., Maria da Cunha Bustamante, M., Lowton, M. J., Sutherland, W. J., Koldewey, H. J., Prentice, H. C., & Barlow, J. (2021). Time to integrate global climate change and biodiversity science-policy agendas. Journal of Applied Ecology, 58, 2384–2393. https://doi.org/10.1111/1365-2664.13985.

Rowland, M. J., Lambrides, A. B. J., McNiven, I. J., & Ulm, S. (2024). Great Barrier Reef Indigenous archaeology and occupation of associated reef and continental islands. Australasian Journal of Environmental Management, 1–24. https://doi.org/10.1080/14486563.2024.2336969.

Stephens, S., Paulik, R. (2023). Mapping New Zealand’s exposure to coastal flooding and sea-level rise. NIWA Report Number 2023098HN: 38 p.

Trégarot, E., D'Olivo, J.P., Botelho, A.Z., Cabrito, A., Cardoso, G.O., Casal, G., Cornet, C.C., Cragg, S.M., Degia, A.K., Fredriksen, S., Furlan, E., Heiss, G., Kersting, D.K., Maréchal, J., Meesters, E., O’Leary, B.C., Pérez, G., Seijo-Núñez, C., Simide, R., van der Geest, M., & de Juan, S. (2024). Effects of climate change on marine coastal ecosystems – A review to guide research and management. Biological Conservation, 289, 110394. https://doi.org/10.1016/j.biocon.2023.110394.

Vitousek, S., Barnard, P., Fletcher, C., Frazer, N., Erikson, L., Storlazzi, C.D. (2017). Doubling of coastal flooding frequency within decades due to sea-level rise. Sci. Rep., 7, 1399.

Walter, R., Buckley, H., Jacomb, C., Matisoo-Smith, E. (2017). Mass Migration and the Polynesian Settlement of New Zealand. J. World Prehist., 30:351–376. https://doi.org/10.1007/s10963-017-9110-y.

Welsh, R., Williams, S., Bosserelle, C., Paulik, R., Chan Ting, J., Wild, A., Talia, L. (2023). Sea-Level Rise Effects on Changing Hazard Exposure to Far-Field Tsunamis in a Volcanic Pacific Island. Journal of Marine Science and Engineering, 11(5):945. https://doi.org/10.3390/jmse11050945.

World Meteorological Organization (2024). State of the Climate in the South-West Pacific 2023. WMO-No. 1356, WMO, Geneva, Switzerland. https://library.wmo.int/idurl/4/68995.