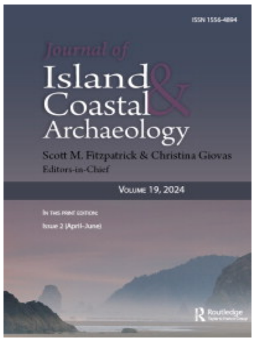

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Aotearoa New Zealand's coastal archaeological heritage: A geostatistical overview of threatened sites

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ABSTRACT

Coastal hazards threaten properties, infrastructure, and cultural sites around Aotearoa New Zealand's (hereafter Aotearoa) coastline and sea-level rise (SLR) will escalate this problem. At present it is unclear how archaeological sites will be affected by future coastal erosion and inundation. In this paper we combine national-scale archaeological and environmental datasets to provide a first-pass overview of archaeological heritage at risk in Aotearoa. Two key national-scale datasets are utilized: (1) coastal sensitivity index (CSI) developed by the National Institute of Water and Atmospheric Research; and (2) ArchSite, Aotearoa's archaeological site database. The integrated datasets produce insights into the sensitivity of coastal archaeology to SLR and associated hazards, which are vital to planning for the loss of coastal archaeological sites. More than half (∼55%) of recorded coastal archaeological sites around Aotearoa are midden ($n = 4938$) and about 25% ($n = 2271$) are earthworks. In total, ca. 12% (9054) of all known archaeological sites are within 1000 m of soft shore shorelines. Of this total, only about 3% (302) of sites are burials, but the loss of these 302 burial sites would have very high cultural impact. Coastal erosion is a particularly important threat to archaeology as it would permanently remove sites, whereas the risk of site removal by coastal flooding inundation is lower. Our results show that about 22% (1954) of coastal archaeological sites are located on landforms that are sensitive to SLR-driven erosion: 29% (2660) of archaeological sites are located on foredune barrier beaches, 23% (2059) on foredune barrier plains, 14% (1283) on beaches, and 9% (808) on beach ridge barriers. This work draws attention to the scale of coastal archaeology in Aotearoa that needs adequate documentation, preservation, and potentially protection in the face of SLR. Robust coastal erosion and inundation datasets are needed to more deeply understand potential SLR-driven impacts on coastal archaeology and provide a scientific foundation for considering future adaptation options.

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Supplemental data for this article can be accessed online at https://github.com/Thepastfromabove/National_Archaeological_Risk_Aotearoa.

Introduction

Sea-level rise (SLR) and changing wave patterns will reshape Aotearoa New Zealand's (hereafter Aotearoa[1]) coast over the next century and beyond (Lawrence et al. 2018). SLR will result in more frequent and extensive coastal inundation (flooding), especially in areas surrounding shallow harbors, river mouths, and estuaries (Bell et al. 2017; Mullan et al. 2016; Wratt et al. 2004). Coastal erosion rates are expected to accelerate under SLR, although there will be considerable local-scale variability due to complicating factors such as the effects of local sediment supply to shorelines (Mullan et al. 2016; Rouse et al. 2017).

Assets in the coastal zone are at risk from erosion and inundation, including infrastructure, housing, and archaeological sites. The latter are the relics and ruins of the past located on land, in water, or in the coastal marine area (Bickler, Clough, and Macready 2013; Bickler 2018). In Aotearoa, an archaeological site is defined as "any place in New Zealand … that was associated with human activity that occurred before 1900 … and provides or may provide, through investigation by archaeological methods, evidence relating to the history of New Zealand" (Heritage New Zealand Pouhere Taonga Act (2014) (HZPT), section 6). The potential loss of coastal archaeological sites in Aotearoa is of concern as these sites are of both high scientific and cultural value (Carmichael et al. 2018; Phillips and Allen 2010; Whangapirita, Awatere, and Nikora 2003). In particular, some Māori archaeological sites contain wāhi tapu: places that are sacred to Māori in the traditional, spiritual, religious, ritual, or mythological sense (HZPT 2014, section 6). At present, Aotearoa lacks a current national assessment of the erosional risk to coastal archaeological sites contextualized within the broader coastal hazard risk posed by SLR, which makes it challenging to make robust decisions around archaeological site management in the face of ongoing SLR and climate change.

Coastal archaeological risk is a function of the susceptibility of coastal areas to inundation and erosion processes (Anfuso et al. 2021; Giesen et al. 2014; Mattei et al. 2021; Pethick and Crooks 2000), and the capacity of those areas to adapt to changing environmental conditions, such as SLR. Understanding the adaptive capacity of risk usually encompasses a component where archaeological site vulnerability "is determined by its exposure (the scale of the potential impact of a climatic event) and its sensitivity (or degree to which it could be affected by that exposure)" (Dawson et al. 2020, 8281). Dawson et al. (2020) suggest a four-step process to address the risk and vulnerability of archaeological impacts related to SLR: (1) prepare an inventory of existing archaeological site data (location, type, date); (2) update the inventory by surveying the coastal margin to identify new sites and check the condition of known sites; (3) determine archaeological site vulnerability based on the data from (1) and (2); and (4) provide strategies and recommendations to minimize risk. Similar processes that implement some or all of these steps have been used globally in studies that explore archaeological vulnerability to SLR on local and regional scales (Table 1). The majority of studies focus on the effects of coastal inundation rather than erosion (Table 1), which is concerning as erosion, as we argue here, is likely to be the greater threat. Importantly, Dawson et al. (2020) and other studies (Daire et al. 2012; Reeder-Myers 2015) suggest that geomorphological data are needed to consider the true risk to archaeological sites.

Table 1. Yes/No rubric showing research which deals in part or fully with Dawson et al.'s (2020) four-step process and whether the study addresses erosion and/or inundation risk.

Inventory[a]	Survey[b]	Vulnerability index[c]	Strategies/ Recommendations[d]	Risk studied	References
Yes	Yes	Yes	Yes	Inundation/ Erosion	Bickler, Clough, and Macready (2013)
Yes	Yes	No	No	Erosion	Brooks, Walter, and Jacomb (2008)
Yes	Yes	Yes	Yes	Inundation	Dawson et al. (2020)
Yes	Yes	Yes	No	Inundation	Daire et al. (2012)
Yes	No	Yes	No	Inundation	Fenger-Nielsen et al. (2020)
No	No	No	Yes	Inundation	Flatman (2009)
Yes	Yes	Yes	No	Inundation	Hil (2020)
Yes	No	Yes	No	Inundation	Mattei et al. (2019)
Yes	No	Yes	No	Inundation	McCoy (2018)
No	No	Yes	Yes	Inundation	Murphy, Thackray, and Wilson (2009)
Yes	Yes	Yes	No	Erosion	Ramsay (2014)
Yes	No	Yes	No	Inundation	Reeder-Myers (2015)
Yes	Yes	Yes	No	Inundation	Westley et al. (2011)
Yes	Yes	Yes	Yes	Inundation	Walton (2007)
Yes	No	Yes	No	Inundation	Tait (2019)

[a]National, regional, or local scale inventory of existing archaeological site data.
[b]Update archaeological site inventory by surveying the coastal margin to identify new sites and check the condition of known sites.
[c]Determine archaeological site vulnerability based on the data from 1 and 2.
[d]Provide strategies and recommendations to minimize risk based on findings of 1, 2 and 3.

Archaeologists in Aotearoa have emphasized the risk to coastal archaeological sites from SLR for 20 years (Bickler, Clough, and Macready 2013; Campbell and McGovern-Wilson 2009; Law 2021; McFadgen 2001, 2007; Ramsay 2014; Walton 2007). Despite this, work is still needed in Aotearoa on updating and refining the four steps outlined by Dawson et al. (2020). Only two large-scale archaeological risk studies have been conducted (McCoy 2018; Tait 2019), alongside a handful of regional (Bickler, Clough, and Macready 2013) and local (Hil 2020; Ramsay 2014) studies. For instance, Bickler, Clough, and Macready's (2013) regional study of the Whangārei District provides a GIS-based analysis of the impact of climate change and was not specifically coastal in focus as it included consideration of land stability data for the region. Bickler, Clough, and Macready (2013) suggest that given the large number of coastal sites in the Whangārei District, coastal erosion and inundation are the major contributors to archaeological risk, but as storms increase, the effects of landslips and river-based erosion are likely to increase.

Ramsay's (2014) study demonstrates novel applications of modeling risks to coastal archaeology by using the invest coastal vulnerability model (ICVM). The ICVM model could not be fully operationalized by Ramsay (2014) due to a lack of datasets, which meant only elevation, beach slope, wind, and wave data in the inner Hauraki Gulf could be utilized. Coastal geomorphology, natural habitats, and sea-level projections were not included in the broader CVM model applied by Ramsay (2014). The Ramsay (2014) application of CVM for the inner Hauraki gulf provided a coarse understanding of how wind and waves influenced the survivability of archaeological sites along the coastal margins. The one limitation of Ramsay's (2014) study was the lack of available data sources to refine the vulnerability index. Ramsay's (2014) study highlights the need and ability to integrate local-scale geomorphological datasets to understand coastal archaeological risk.

Table 2. Datasets used, source URL locations and notes on each dataset.

Data	Description	Notes	Source
ArchSite	Archaeological location and type	• National database • 70+ years of recording • Site types • Auxiliary information • Recording and location inconsistency • Inaccurate location (often) • Unknown site extent (often) • Unknown number of unrecorded sites • Locational inaccuracy ~100m+ (often)	https://nzarchaeolog y.org/ArchSite
LINZ mean high water	Shoreline position	• Incomplete coastal classification • Authoritative position of shoreline	https://data.linz.govt.nz/layer/105085-nz-coastline-mean-high-water/
LINZ Topo50	Lake, River and Sea extent	• Authoritative national dataset	https://data.linz.govt.nz/layer/50767-nz-topo50-maps/
University of Otago Digital Elevation Model	Digital Elevation Model (15 m)	• Coarse resolution • Designed for topographic analysis	https://www.otago.ac.nz/surveying/research/geospatial/otago040574.html#nzsosdem
NIWA NZ Coastal Sensitivity Index	Coastal erosion and inundation Index	• Qualitative scoring • Open soft shore coasts • Last update was 2011	https://catalogue.data.govt.nz/dataset/nz-coastal-sensitivity-index-csi-erosion1

Hil's (2020) study sought to address the locational inaccuracy in ArchSite at the local level by combining high resolution GPS data of archaeological site location and extent data with light detection and ranging (LiDAR). Inundation modeling and shoreline change analysis highlighted current and future risk to 21 sites at Blueskin Bay, Dunedin. However, this work did not specifically consider how the dynamic landform types (mudflats, floodplains, cliff faces, and dune systems) are likely to respond to future SLR. Tying in landform response is an important consideration for archaeological risk, given ongoing and future sea-level rise and expected coastline response.

The studies described above (Hil 2020; Ramsay 2014) operated at the local scale and highlighted the importance of geomorphological datasets tied to accurate archaeological site location extents and accurate GPS coordinates, whereas McCoy (2018) and Tait (2019) undertook assessments to estimate archaeological site inundation vulnerability on a national scale. Tait (2019) identified archaeological sites in the coastal zone located on Department of Conservation (DOC) land at risk to inundation. This analysis determined a "potential coastal inundation risk zone" (PCIRZ) by using a baseline elevation band of 0–3 AMSL (above mean sea-level, see Table 3 for definition). The elevation data were based on a contour elevation shapefile provided by the National Institute of Water and Atmospheric Research (NIWA). DOC assets (archaeological sites) intersecting the PCIRZ were at potential risk of current and future inundation. While Tait's (2019) analysis identified 420 archaeological sites on DOC land to be at risk, only a small portion (5%) of Aotearoa's archaeological site database (ArchSite) was considered. Furthermore, the impacts of coastal erosion were not considered alongside inundation

Table 3. New site typology/code and associated definition used in this study. The site type designation used in this paper, the definition of site type, the range of previous site types and description in ArchSite are all shown sequentially in the columns below.

New code	Definition	Description in ArchSite
Artifact	Item of archaeological significance made or given shape by humans in the past	Artifact of any kind, anchor, barge, canoe, graffiti, source, grinding stone
Burial	Area or feature of archaeological significance related to human remains	Burial, cemetery, grave
Cave	Area of feature in subterrain caves with material or human remains related to the past. Caves are particularly important in Aotearoa and are of high significance which is the reason for the division between burials/rock art and caves (Bickler 2018; Golson and Green 1958)	Cave, rock shelter, skeletal remains,
Eco-fact	Organic material with archaeological significance	Bark, charcoal, ocher, cleared bush, dendroglyph, karaka grove, spring, taro, tree
Midden	The term encompasses all material found in these deposits, including shell, animal bones of a range of species, environmental evidence, such as wood, charcoal, pollen, oven stones, artifacts, and koiwi Tangata (human remains). Some middens contain Māori artifacts such as fishhooks, adzes, and sharp stone flakes made from a variety of stones, including mata (volcanic glass)	Midden
Earthwork	Area or feature of archaeological significance modified by humans in the past (sub surface or on the surface)	Water race, trench, track, terrace, tailings, soil made, soil garden, sod fence, sluicing's, shaft, saw pit, scarp, rubbish dump, road, rifle pit, redoubt, prospecting pit, posthole, pond, platform, pā, pit, oven, gum holes, occupation layer, audit of any kind, bullock heap, culvert, mound, cutting, dredge, drive, garden, ban, burrow pit, canal, drain, ditch depression, canoe landing
Stoneworks	Area or feature of archaeological significance composed primarily of stone and modified by humans in the past (commonly not a part of a standing structure and the remains of past boundaries)	Ballast, working area, cairn, ford, oven stones, quarry, stone alignment, stone heap, stone retaining, stone row, stone wall,
Structure	Structure or feature of archaeological significance primarily the remains of a structure constructed by humans in the past (remnant or free standing)	Whaling station, wharf, working area, well, tunnel, tramway, stockade, stockyard, stamper battery, signal station, sheep dip, sheep yard, ruins, sawmill, reservoir, ramp, railway, portal, pillbox, pipeline, observation post, mill, mine, mining workings, monument, military camp, magazine, machinery, kauri timber dam, kiln, landing, lighthouse, hut floor, hulk, harbor wall, house floor, gun emplacement, foundry, freezing works, furnace, foundations, forge, fish trap, flax mill, flour mill, footpath, fireplace, fence, eel weir, abattoir, aerial cableway, dam cow byre, creamery, causeway, cob cottage, channel, chimney, church, chute, cistern, cellar, building, anchorage, bridge, brickworks, aqueduct of any kind, workshop, boatyard, boiler
Rock art	Area or feature of archaeological significance composed related to rock art	Drawing, petroglyph
Misc	Archaeological complexes or features which do not fit in any category due to limited information or unclear shared similarity	No site type provided
Shipwreck	A feature, structure, or area below average mean sea-level AMSL[a]	Shipwreck

[a]Height above mean sea level (AMSL) is the elevation (on the ground) relative to the average sea level datum.

in Tait's (2019) study. McCoy's (2018) assessment was derived using elevation data from an 8 m resolution digital elevation model (DEM) and considered archaeological sites at risk of partial and/or complete inundation given projected global SLR. This study suggested that 14% (9430 sites) of all known archaeological sites are within 5 m of the current sea level and 1.6% (1096) are within 1 m of the current sea level. McCoy (2018) concluded that about 12% of known archaeological sites are likely to be impacted by SLR-influenced inundation.

Particularly vulnerable areas were identified in the northern half of both the North Island and South Island, as well as in shallow harbors and on offshore islands that were often targeted by Māori for intense settlement. McCoy (2018, 13) argued that if "sea level rise is more-or-less constant, then this result suggests the most rapid impacts will be in the immediate future, followed by a steady rate of loss." McCoy (2018) did not specifically state the SLR projections that were used in this work, but it is worth noting that future rates of SLR are likely to accelerate rather than be constant, so the conclusion regarding future rates of loss requires further consideration (Mason-Delmotte et al. 2021).

McCoy's (2018) and Tait's (2019) work provide valuable first attempts to estimate inundation risk to archaeological sites. Neither work considers risk associated with coastal erosion nor the morphodynamic character of the coast, including the variability of different types of coastal landforms around the country. This is unsurprising because aside from the work of Gibb (1978) more than four decades ago, no national coastal erosion assessment is available.

In this paper we describe a new national-scale assessment of coastal archaeological risk in Aotearoa that integrates two key national-scale datasets: (1) coastal sensitivity index (CSI) developed by the NIWA; and (2) Aotearoa's archaeological site database "ArchSite" (data accessed in May 2020). Results presented in this paper highlight the risk posed to coastal archaeology specifically as it relates to erosion, which is vital to planning for the loss of coastal archaeological sites.

Materials and methods

Two primary datasets were utilized for the analyses in this paper. Aotearoa's archaeological site database (ArchSite) was reclassified with a focus on the coastal zone. Information on coastal erosion and inundation sensitivity due to SLR for open coast sandy shore was sourced through the National Institute of Water and Atmospheric Research (NIWA) coastal sensitivity index (CSI) published online in September 2020 and updated March 2022. Secondary datasets utilized were the mean high-water level data from Land Information New Zealand and elevation data from the University of Otago digital elevation model (DEM) (Table 2). Geospatial statistics for archaeological sites were generated using a compilation of these data sources. The workflow followed a three-step process: (1) data procurement; (2) data standardization; and (3) data analyses.

Data sources

The Aotearoa spatial dataset of archaeological sites "ArchSite" (detailed information contained in the Supplementary Information) was the primary dataset to which other datasets were joined using the ArcMap tool "spatial join." ArchSite, maintained by the New Zealand Archaeological Association, is the largest archaeological dataset in the Pacific, with recording in Aotearoa beginning in the 1960s (ArchSite.org.nz).

Any form of archaeological risk calculation should include data sources such as ArchSite, especially at the national level (Bickler 2018). ArchSite has limited locational precision due to being a dot estimate of location with an unknown error. For example, cases exist where site coordinates intersect with lakes, rivers, or the sea extents; in other cases, the dot location may be an unknown distance away from the actual location; or finally, sites may have been destroyed by natural or anthropogenic causes with the record being out of date (Bickler 2018). At the national level, due to the scale and breadth of analysis, these errors do not disqualify a thorough geostatistical analysis. However, at the local level the errors in ArchSite need be improved to allow for robust risk analysis (see Bickler 2018; Bickler, Clough, and Macready 2013; Hil 2020; McCoy 2018). At the national level, the analysis presented here should be continually reviewed and re-run as the data in ArchSite are updated when the locational accuracy issues are corrected.

Archaeological sites are distributed throughout Aotearoa (Figure 1), particularly along the coastal margin of all three major islands: Te Ika-A-Māui (North Island), Te Waipounamu (South Island), and Rakiura (Stewart Island), and along major internal waterways. Of all recorded archaeological sites (as of May 2020), 68% (29,223) are documented as pre-European (i.e., pre-AD 1769) and are of particular interest for the present study due to the large number of these sites that are located on the coast. A second important data source for this study is the NIWA CSI, which provides a description of coastal landform type, and an indication of the potential sensitivity of different types of soft (i.e., unconsolidated sandy) shore landforms to coastal inundation and coastal change associated with SLR (erosion and accretion) (Nigel et al. 2012). The CSI ranking is based on expert evaluation of landform sensitivity (see supplementary information on CSI (section 2), and Nigel et al. 2012). It scores sensitivity on a scale of 0–5, where 0 is not sensitive, 1 slightly sensitive, 2 somewhat sensitive, 3 sensitive, 4 very sensitive and 5 severely sensitive. For example, the average expert evaluation for beaches suggests a CSI value of 4.8 for erosion. The sensitivity relates to how experts expect the different types of soft coast landforms will react to SLR-driven erosion and inundation. Archaeological sites are contained within these coastal landforms and using the CSI values provides a proxy opportunity to assess how sensitive archaeological sites are likely to be under SLR-driven coastal erosion and inundation.

Data standardization

ArchSite has 129 listed archaeological site types ranging from individual places where cultural artifacts were found to historic structures (Table 3). The large number of categories limits the capacity to evaluate general sensitivity to coastal hazards. Similar categories were grouped under single terms to allow more general analyses of potential

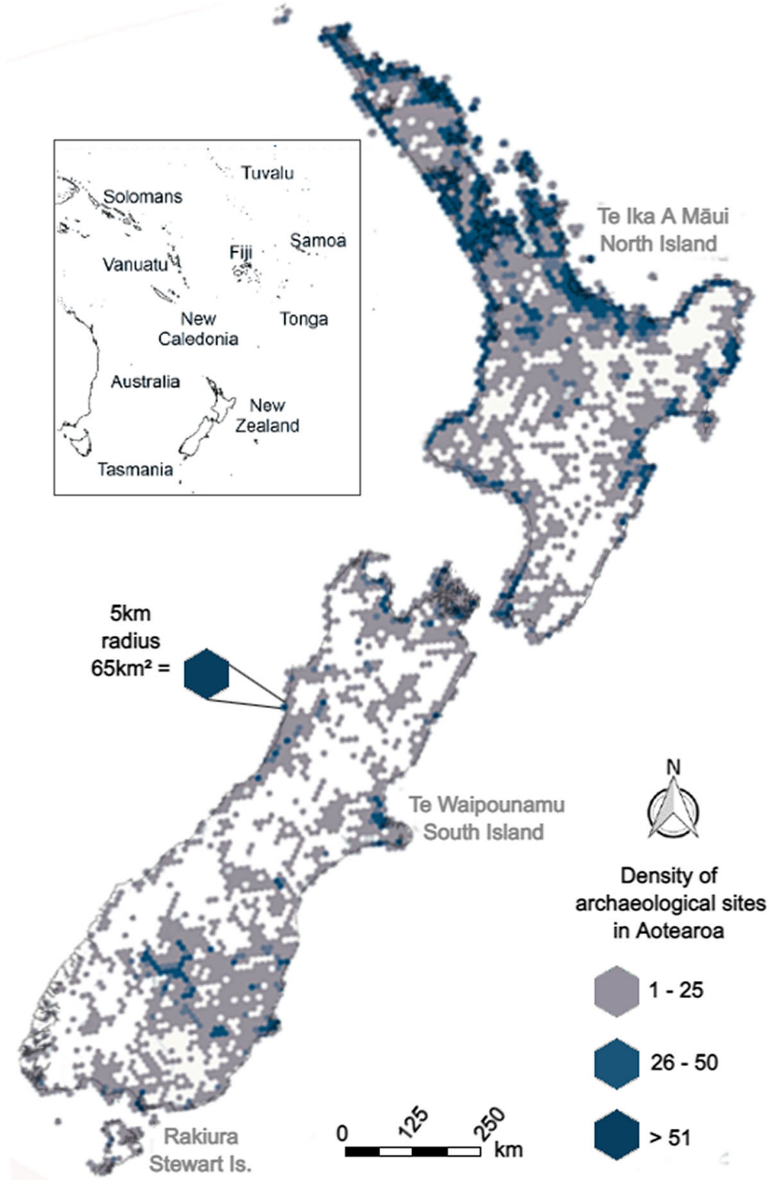

Figure 1. Number of known archaeological sites as of May 2020—approximately 73,400 sites are presented in total. Note the concentration of sites along coastal margins.

relationships between site typology and coastal vulnerability. For example, the individual site types of bark, charcoal, ocher, cleared bush, dendroglyph, karaka grove, spring, taro, and tree are all types of "eco-fact" (organic material with archaeological significance) (Darvill 2008). Similarly, graves, cemetery, and urupā all have the shared characteristics of being related to human remains and can be grouped as "burial." The original site typology in ArchSite was grouped into 11 new categories based on shared similarities (Bickler 2018; Golson and Green 1958) (see Table 3): artifact, burial, cave, eco-fact, midden, earthwork, stoneworks, structure, rock art, miscellaneous, and shipwreck. Both the original and simplified categories were retained within the database.

The categorization of ArchSite sites in Table 3 is very broad, as illustrated by the grouping of "pā" and "pit" with "gum holes," "sod fence," and "sluicing's" in the "earthwork" category. This grouping combines pre-contact categories with historic categories. The majority (88%, 7967 sites) of coastal archaeological sites within this category are pre-contact, but the 12% (1086) historic sites also include important cultural sites, such as Marae, cemeteries, shipwrecks, pā sites, and whaling stations, all of which hold valuable evidence of Aotearoa's history.Table 4 displays the proportion of each subgroup (pā, pit, etc.) within the previous ArchSite classification, along with its correlation to the grouping employed in this paper (earthwork, burial, etc.). For more information, please refer to the supplementary section 1.

To assess the locational inaccuracies of the ArchSite database, an analysis was carried out. This involved identifying archaeological sites that intersect with the extents of lakes, rivers, or seas using GIS layers from NZTopo50 2022 (Table 2) to determine the waterbody extents. The underlying assumption for this analysis is that archaeological sites located on land should not intersect with waterbodies. The findings of the analysis indicate that approximately 12% of sites (1146) within the coastal zone (9054) intersect with waterbodies. Out of this, only 0.4% (36) of sites intersect with lakes, 1.3% (120) with rivers, and 11.9% (990) with the sea (excluding historic wharves and shipwrecks). The sites that intersect with the sea are further categorized into burials, earthworks, and midden, with burials making up around 4% (41), earthworks making up approximately 26% (267), and midden making up 52% (521). Based on this analysis, it can be inferred that 12% of sites contained in ArchSite are inaccurate.

Data analysis

In total, 73,699 archaeological sites were filtered down to 9054 sites identified as coastal archaeological sites defined by elevation and distance thresholds. All archaeological sites within 1000 m of the LINZ mean high-water mark and below a 25 m elevation were extracted and defined as archaeological sites within the coastal zone and this is the basis of what is considered the archaeological coastal zone for the analysis presented in this paper. The ArcMap tools "extract by value" or the raster calculator were used to extract data from raster surfaces, whereas the spatial tool "join" was used to obtain database values for vector files. Distance of archaeological site from the shoreline was calculated using the Euclidean distance tool in ArcMap and site elevation was determined from the University of Otago 15 m DEM (for more detail see Table 2). Sites at risk of coastal hazards were then identified using the CSI erosion and inundation datasets, providing a first-pass indication of the archaeological areas at risk to coastal hazards. The relative score of the CSI coastal landform classification was used as the risk assessment for archaeological sites at a national level. Where the risk was assessed by relating archaeological sites to coastal landforms, the sensitivity of the site was based on the sensitivity of the landform on which it is located. The main limitation of this approach is it is based on expert judgment and not actual behavior of the coast.

Table 4. Percentage of Archsite types present in the coastal area.

	Artifact	Burial	Cave	Earthwork	Eco-fact	Midden	MISC	Rock art	Shipwreck	Stoneworks	Structure	(Blank)
Administrative	0	0	0	0.155	0.011	0	0.011	0	0	0.011	0.044	0
Agricultural/ pastoral	0.011	0.011	0	0.088	0	0	0.11	0	0	0.066	0.331	0
Art	0	0	0	0	0.022	0	0.011	0.121	0	0	0	0
Artifact find	2.717	0	0	0.011	0	0	0.144	0	0	0.022	0.022	0
Botanical evidence	0	0	0	0	0.663	0	0	0	0	0	0	0
Burial/ cemetery	0	3.203	0	0	0	0	0	0	0	0	0	0
Cave/ rock shelter	0.022	0.011	0.21	0	0.011	0.21	0.133	0.033	0	0.011	0	0
Cement/ lime works	0	0	0	0	0	0	0.099	0	0	0	0.033	0
Commercial	0.011	0.011	0	0.022	0	0	0.121	0	0	0	0.541	0
Educational	0	0	0	0	0	0	0	0	0	0	0.055	0
Fishing	0.011	0.011	0	0.033	0	0	0.022	0	0	0.011	0.088	0
Flax milling	0	0	0	0.022	0	0	0.011	0	0	0	0.144	0
Flour milling	0	0	0	0.011	0	0	0.011	0	0	0	0.033	0
Gum digging	0	0	0	0.022	0	0	0	0	0	0	0	0
Health care	0.011	0	0	0	0.022	0	0.166	0	0	0.011	0.099	0
Historic—domestic	0.221	0.033	0	0.133	0.022	0	0.353	0	0	0.011	1.193	0
Historic—land parcel	0.033	0	0	0.033	0.011	0.011	0.044	0	0	0.033	0.133	0
Hospital	0	0	0	0	0	0	0	0	0	0	0.01	0
Hulk	0	0	0	0	0	0	0.01	0	0.01	0	0	0
Industrial	0.011	0	0	0.331	0	0	0.144	0	0	0.044	0.442	0
Maori horticulture	0	0	0	1.347	0.011	0.088	0.674	0	0	0.574	0.022	0
Marae	0	0	0	0	0	0	0.033	0	0	0	0.022	0
Memorial	0	0	0	0.011	0	0	0	0	0	0	0.022	0
Midden/Oven	0	0	0	0	0	54.03	0	0	0	0.011	0	0
Military (non-Maori)	0.022	0	0	0.232	0	0	0.121	0	0	0	0.453	0
Mining	0	0	0	0.011	0	0	0	0	0	0	0.022	0
Mining—coal	0.022	0	0	0.022	0	0	0	0	0	0	0	0
Mining—gold	0	0	0	0.21	0	0	0.077	0	0	0	0.022	0
Mission station	0.011	0	0	0.011	0	0	0.044	0	0	0	0.044	0
NA	0	0	0	0	0	0	0.066	0	0	0	0.011	0
Pa	0	0	0	8.405	0	0	0	0	0	0	0	0
Pa—gunfighter	0	0	0	0.01	0	0	0	0	0	0	0	0
Pa—island/ swamp	0	0	0	0.199	0	0	0	0	0	0	0	0
Pit/Terrace	0	0	0	13.1	0	0	0	0	0	0	0	0
Power generation	0	0.011	0	0	0	0	0	0	0	0	0	0
Recreation	0.011	0	0	0.022	0	0	0.011	0	0	0	0.066	0
Religious	0	0	0	0	0	0	0.01	0	0	0	0.12	0
Sealing camp	0	0	0	0	0	0	0.01	0	0	0	0	0
Shipwreck	0.022	0	0	0	0	0	0.033	0	0.508	0	0.022	0
Source site	0.033	0	0	0.011	0.011	0	0.077	0	0	0.11	0	0
Timber milling	0	0.011	0	0.044	0	0	0.066	0	0	0	0.121	0
Traditional site	0.022	0	0	0.044	0	0	0.044	0	0	0	0.033	0
Transport/ communication	0.055	0	0	0.276	0	0	0.331	0	0.011	0.088	1.016	0
Unclassified	0.011	0.011	0	0.232	0.077	0.044	1.082	0	0.011	0.055	0.121	0
Whaling Station	0.044	0	0	0	0	0	0	0	0	0	0.276	0
Working area	0.331	0.022	0	0.033	0	0.155	0.287	0	0	0.641	0.011	0
(blank)	0	0	0	0	0	0	0	0	0	0	0	0

Table 5. Summary statistics for archaeological sites in Aotearoa's open ocean unconsolidated (gravel, sand, or silt) coastal zone.

Summary statistics								
Site type	Burial	Earthwork	Midden	Structure		Artifact		Total
%(no.) Site type within 1000 m	3.5% (320)	25.1% (2271)	54.5% (4938)	5.50% (505)		3.60% (329)		9054
%(no.) Site type within 100 m	4% (180)	25.2% (1122)	54% (2403)	5% (222)		4% (177)		4450
Landform sensitivity statistics								
%(no.) Archaeological sites on CSI landform values of 4 or higher	Erosion	Inundation		%(no.) Archaeological sites on coastal landforms	Beach		Foredune	Foredune barrier plains
	22% (1954)	17% (1564)			14.2% (1283)		29.40% (2660)	22.7% (2059)
Highly sensitive landform								
%(no.) Archaeological site type with a CSI landform sensitivity of 5	Burial	Earthwork	Midden					
Erosion	16.6% (50)	18.90% (429)	9.9% (490)					
Inundation	1.30% (4)	0.70% (15)	1.4% (67)					

Results

Proximity of archaeological sites to the shoreline

Aotearoa's coastal zone contains a high number (9054) of archaeological sites, or 12% of the total 73,699 (Figure 1 and Table 5). The concentration of archaeological site types increases with proximity to the coast (Figure 2). This trend is particularly evident for midden and burials and highlights the potential vulnerability of these types of sites to coastal hazards and SLR. The predominant coastal archaeological sites around Aotearoa are midden (54.5%, 4938) and earthworks (25.1%, 2271). Only 3.6% (320) of all sites are burials, but the consequences of exposure and loss of these 320 burial sites are culturally higher than for other site types. Forty-eight percent (4450) of all archaeological sites (9054) in the coastal zone are within 100 m (Figure 3 and Table 5); 56% (180) of burial sites, 50% (1122) of midden sites, and 42% (2403) of earthworks sites are located within this zone (Figure 3).

Coastal sensitivity and SLR-driven hazards

The CSI combined with ArchSite provides a useful proxy for archaeological sensitivity to coastal hazards (Figure 4). Approximately 29% (2660) of archaeological sites are located on foredune barrier beaches, 23% (2059) on foredune barrier plains, 14% (1283) on beaches, and 9% (808) on beach ridge barriers (Figure 4). All other landforms have less than 5% of archaeological sites. It is notable that the two landform types (foredune barrier beaches and plains) that contain most coastal archaeology are also associated with lower-than-average erosion and inundation risk. However, beaches contain 14% (1283) of all archaeology and are associated with the highest coastal erosion risk of any landform class. A national map of erosion and inundation risk for archaeological sites (Figure 5) indicates that erosion risk is concentrated in the North Island around Taranaki, Auckland, the Coromandel, and northern Hawkes Bay, and in the South Island around Tasman and parts of Otago and Canterbury. Inundation risk to

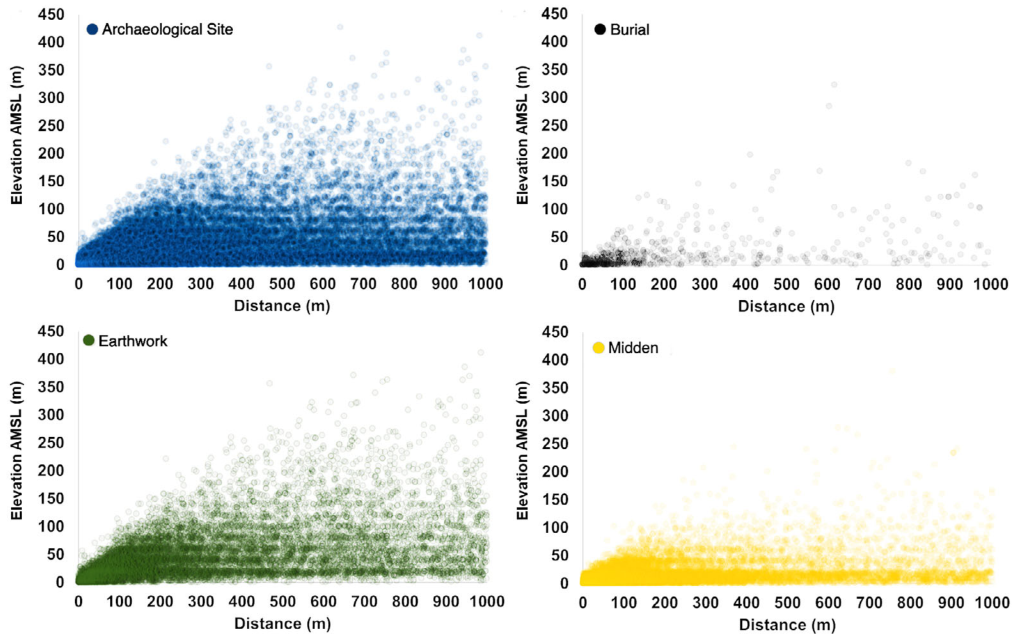

Figure 2. Density of all archaeological sites in Aotearoa (top left) and of burial, midden, and earthwork sites located within 1000 m of the shoreline.

archaeological sites appears to be less severe than erosional risk overall, with areas of local concern, such as the Firth of Thames. It is interesting that the CSI erosion will impact archaeological sites more than inundation. About 22% (1954) of archaeological sites are within landforms that are sensitive (4–5 CSI index) to SLR-driven erosion, whereas 17% (1564) of archaeological sites are within landforms that are sensitive (4–5 CSI index) to inundation (Figure 6). The majority of midden, earthworks, and burials are on landforms with a sensitivity value of 3 or higher. About 17% (50) of burials, 19% (429) of earthworks, and 10% (490) of midden are on landforms with the most extreme CSI value, whereas 1% of burials (4), earthworks (15), and midden (67) are on landforms with this value for CSI inundation (Figure 6).

Discussion

Coastal archaeological heritage, and the extent to which this might be impacted by future coastal erosion and inundation under SLR, should be an important consideration for coastal adaptation planning (Anfuso et al. 2021; Mattei et al. 2019, 2021; Mullan et al. 2016; Nicholls et al. 2021; Rouse et al. 2017). The research presented in this paper provides a first-pass national assessment of coastal archaeological sites in Aotearoa and the extent to which they may be vulnerable to erosion and inundation. Inventorying the location, elevation, and distance of archaeological sites from the shoreline emphasized the coastal concentration of archaeology in Aotearoa, and inclusion of coastal landform type provides a further avenue to assess coastal archaeological sensitivity to erosion, inundation, and SLR.

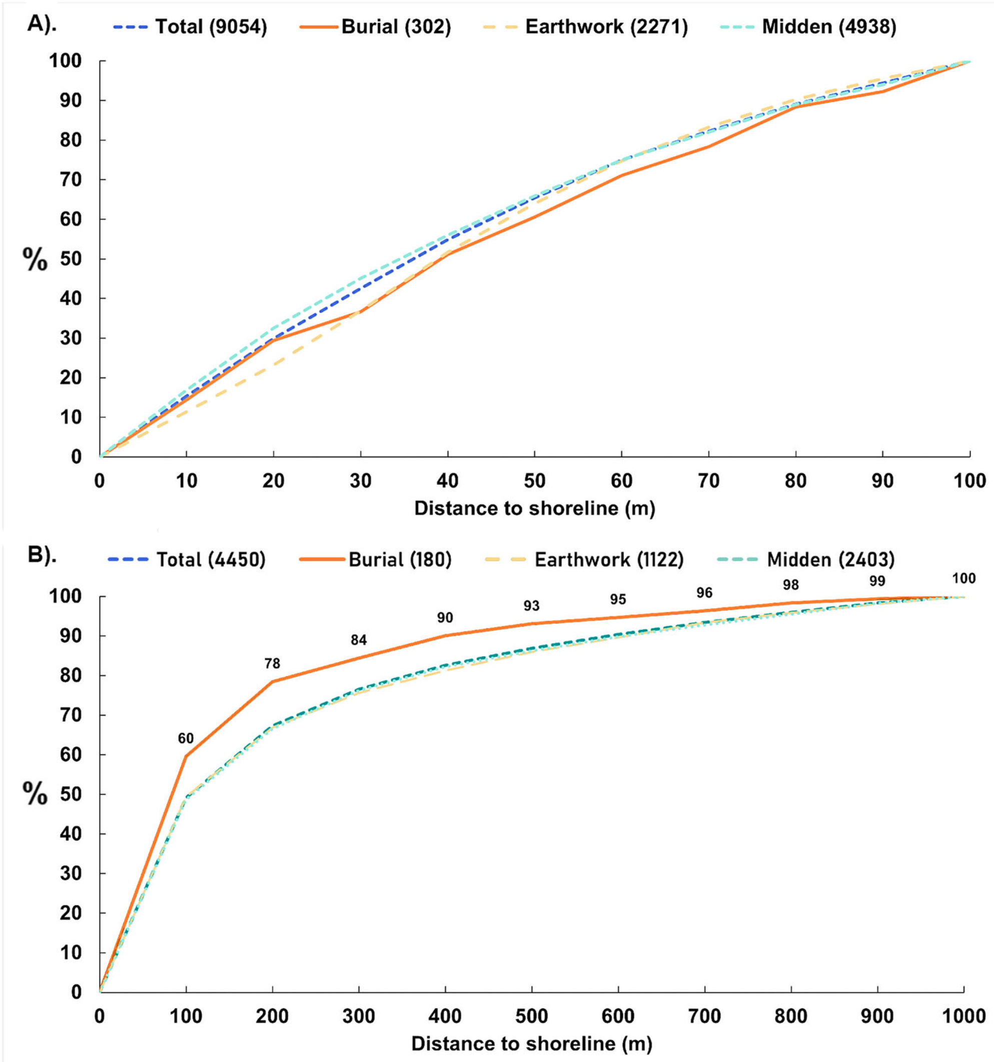

Figure 3. Cumulative % frequency graph of all archaeological site types and of burial, midden, and earthwork sites within 100 m (A) and 1000 m (B) of the shoreline.

Previous studies such as McCoy (2018) and Tait (2019) utilized archaeological site proximity to the shoreline or an elevation threshold as the basis to determine probable SLR impact. The coastline is, however, not a static entity, and different types of coastal landforms that hold archaeological material react in diverse ways (Hilton et al. 2018; Nigel et al. 2012). By combining environmental and archaeological datasets, our results reveal the sensitivity values of landforms for individual coastal archaeological sites. This research allows for a more nuanced understanding of coastal behavior's impacts on archaeological sites.

To properly evaluate the sensitivity of archaeological remains to erosion and sea-level rise, it is important to consider the environmental characteristics of different types of remains. Certain types of archaeological remains, such as fortified settlements like pā

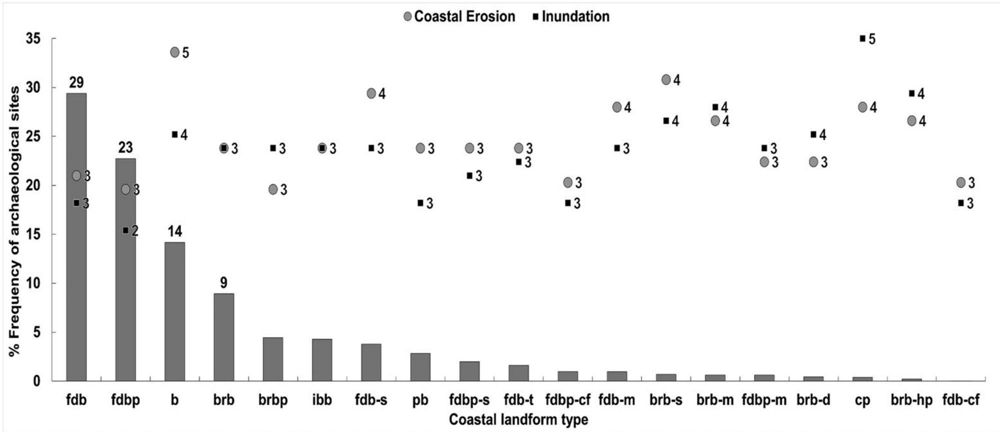

Figure 4. Percentage of archaeological sites on coastal landforms showing sensitivity to coastal erosion (gray circles) and inundation (black squares). Sensitivity number corresponds to the CSI Index. Categories: beach (b), beach ridge barrier (brb), beach ridge barrier delta (brb-d), beach ridge barrier hapua (brb-hp), beach ridge barrier modified (brb-m), beach ridge barrier plain (brbp), beach ridge barrier spit (brb-s), beach ridge barrier—tombolo, chenier plain (cp), foredune barrier (fdb), cuspate foredune (fdb-cf), foredune barrier modified (fdb-m), foredune barrier plain (fdbp), plain cuspate foredune (fdbp-cf), foredune barrier modified (fdb-m), foredune barrier plain spit (fdbp-s), foredune barrier spit (fdb-s), foredune barrier tombolo (fdb-t), incipient barrier beach (ibb), platform beach (pb).

and stone features, are likely to be more resistant to coastal erosion than others, such as shell heaps or middens. For instance, archaeological sites situated on rocky cliffs are less vulnerable to erosion and flooding than those located on sandy landforms due to being on a harder substrate. Similarly, stoneworks associated with Māori gardening on uplifted terraces are less susceptible to erosion despite being close to the shoreline. While our study primarily focuses on sandy shorelines, the examples provided above underscore the importance of assessing the unique characteristics and location of different types of archaeological remains at a local scale. The effects of erosion and sea-level rise on these remains can vary significantly, with some sites being more vulnerable to damage than others.

An important result from the current study is that the majority 56% (180) of all coastal zone burial sites are located within 100 m of the shoreline (Table 5). Location of pre-contact burials in Aotearoa is diverse with examples of burials in caves, swamps, trees, and sand dunes described in the literature (Best 1974; Crosby 2004; Hudson 2020; Taylor 1984). The high frequency of burial sites close to the shoreline reflects their predominance within sand dunes: for instance, the analysis presented here has shown that 27% (85) of burials occur within foredune barrier beaches. About 17% (50) of burials occur in the landform with the highest CSI erosion sensitivity category (beaches), which represents a monumental challenge to assessing how these burials will be impacted at the local community scale.

The accidental discovery of Māori human remains through coastal erosion has been highlighted before (Buckley and Petchey 2018; Hudson 2020). The consequences of exposure and loss of burials are high in terms of legislation and cultural significance (HNZ 2014). Under the Heritage New Zealand Pouhere Taonga Act (2014), a location at which human remains are found falls within the definition of an archaeological site

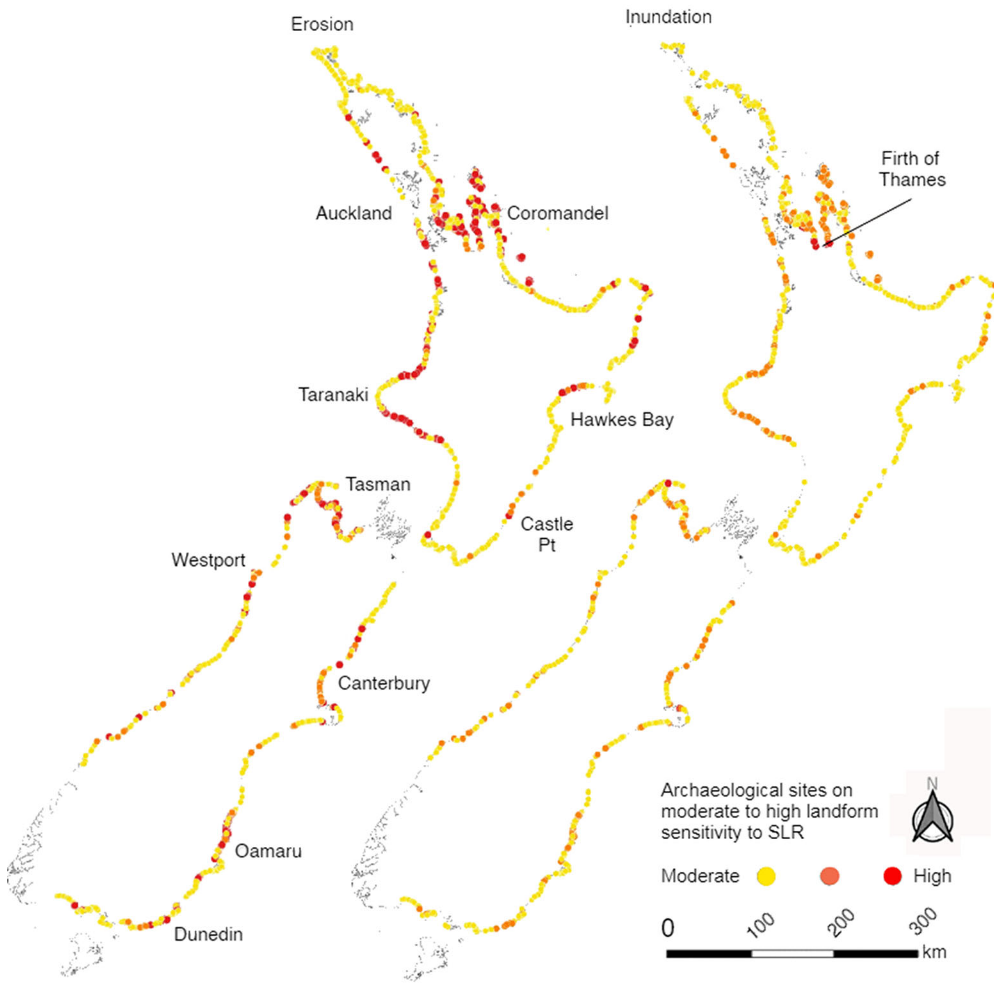

Figure 5. Coastal distribution of archaeological sites with CSI erosion and inundation landform sensitivity values of 3 or higher.

(see above) and cannot be modified without authorization (HZPT, section 42). Locations of human remains would be considered wāhi tapu by Māori, even if the location is not an urupā (Māori cemetery). Legislation associated with burials falls under separate acts in Aotearoa (Buckley and Petchey 2018; Hudson 2020). It is the combination of tikanga (protocols), legislation, governmental, social, cultural, and ethical elements that makes planning for the preservation and loss of human remains difficult (Buckley and Petchey 2018; Hudson 2020). Middens may also contain kōiwi tangata (Hudson 2020), which adds further complication. As Buckley and Petchey (2018) suggest "[F]or Māori, such [human] remains are the physical embodiment of their genealogy representing a direct link to the land on which their ancestors lived and died for the last six or so centuries."

Removing or altering burials in coastal zones to install hard or soft engineering to protect infrastructure will not be a straightforward process. Ethically, the special importance of human skeletal remains to Māori is acknowledged within the 1991 World

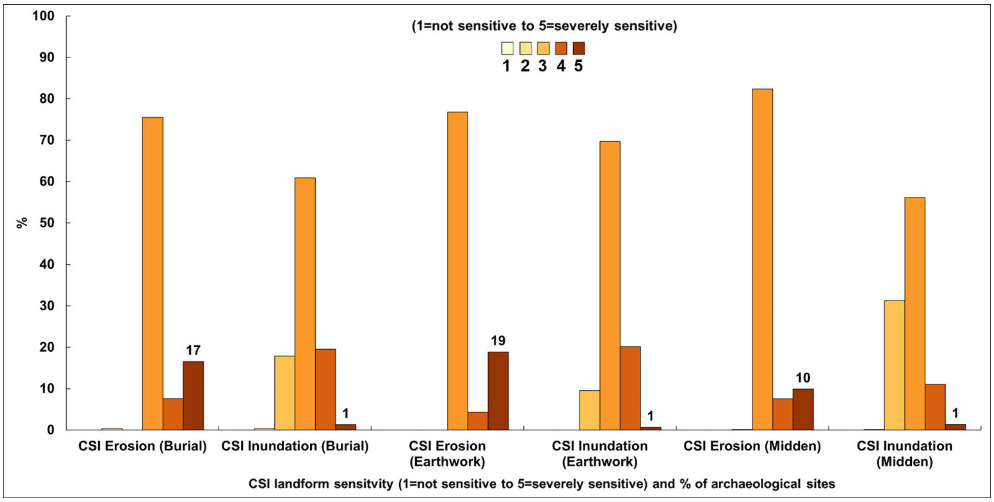

Figure 6. Percentage and number of archaeological site types (burial, earthwork, and midden) related to CSI landform erosion and inundation sensitivity values (Low 0 to 5 High).

Archaeological Congress Code of Ethics. The work herein has shown the scale of at-risk archaeological heritage, for which there are a range of actions spanning complete preservation through to letting nature take its course. As in any large grouping of people, there are a range of opinions as to what is preferable—there is not one universal Māori view (Awatere et al. 2021; Ministry for the Environment (MFE) 2020). The key for Māori is how connected they feel to the sites at risk, and in general burial sites are of greater importance than midden sites (Awatere et al. 2021). However, a sense of nostalgia is felt for all sites that have been lost as well as those at risk (Awatere et al. 2021). Coastal adaptation planning needs to consider the legislative, cultural, and archaeological implications highlighted above to plan for the future impacts of SLR and consider possible solutions that would appropriately preserve selected archaeological sites.

The results presented here highlight that 22% (1954) of coastal archaeological sites are on landforms considered highly sensitive to erosion and 17% (1564) on landforms considered sensitive to inundation associated with SLR. However, the timing at which archaeological sites will be impacted remains unclear. Forward modeling SLR impacts on coastal landforms and archaeological sites would be instructive in future research, as has been demonstrated at a regional level in the USA by Elliott and Williams (2021). For instance, the "Sea Levels Affecting Marshes Model" (SLAMM) was utilized in Texas, to determine the percentage of archaeology that might be impacted by erosion and inundation by 2100 (Elliott and Williams 2021). Their model incorporated high resolution topographic data, landform categories, sedimentation rates, and wave erosion as well as future SLR. One issue of relevance for modeling efforts is the difficult issue of "absences" within archaeological datasets (Dickson and Perry 2016; Perry and Dickson 2018). There is an unknown number of recorded sites that are now missing from the archaeological record and many that likely remain unrecorded. ArchSite does not consider missing or unrecorded sites (Bickler, Clough, and Macready 2013; Hil 2020; McCoy 2018), but land use practices and vegetation clearance have removed sites (Brooks, Walter, and Jacomb 2008; Holdaway et al. 2019). The distribution of known archaeological sites in Aotearoa reflects where archaeological fieldwork has occurred in the past (Bickler, Clough, and Macready 2013; McCoy 2018), particularly sites where surface visibility has enabled pedestrian surveys. However, a lack of evidence of recorded archaeological sites in other localities is not evidence of the absence of sites (Owen 2015). This difficult issue will ultimately require consideration in future modeling studies.

It is also important to consider the limitations of the ArchSite database when interpreting the findings presented in the paper (see Supplementary information section 1). The classification of archaeological remains as "sites" and their representation as dots within ArchSite may not accurately reflect their actual distribution and density within the landscape. For instance, a midden "site" recorded in a sand dune may fail to capture all unrecorded patches of midden within a 100-meter radius, while a pā "site" may more accurately represent the distribution of archaeological remains in the area. Consequently, a single recorded site may contain multiple unrecorded patches of remains, resulting in an underestimation of certain types of sites, such as midden or burials.

The impact of potential locational inaccuracies within ArchSite is somewhat mitigated by the large (national) scale of our analyses. However, improving positional accuracy in archaeological site records should be a key focus of future research, as should more sophisticated handling of uncertainties with existing records, perhaps using an archaeological land unit approach (see McIvor and Ladefoged 2016). A more detailed discussion of this can be found in the recent discussion by McCoy (2020). Such improvements would allow linking of high resolution environmental and archaeological data to more accurately assess regional to local-scale erosional impacts.

Further improvements in assessing coastal archaeological risk in Aotearoa will also require improved geomorphological datasets. National coastal erosion datasets are required to go beyond the coastal scientific expert judgments that underpin the CSI sensitivity values (Nigel et al. 2012; Rouse et al. 2017). Higher resolution topographic data are also required to improve estimates of inundation sensitivity in Aotearoa (Nigel et al. 2012; Pethick and Crooks 2000; Rouse et al. 2017). Several significant improvements in the availability of national-scale datasets for Aotearoa are being provided because of large research projects, including nation-wide relative sea-level forecasts, wave climate forecasts, historical coastal change analyses, and national coastal LiDAR. The next phase of coastal archaeological risk analyses could utilize these data sources to significantly build upon the first-pass stock take provided in this paper. Regardless, our research here highlights issues of concern and indicates potential focus areas. However, future analyses are needed to deliver local-scale outputs that will have value to stakeholders, community, hapū, and coastal planners.

Conclusions

It is uncertain how future coastal erosion and inundation will affect archaeological sites. Our analysis of national-scale archaeological (ArchSite) and coastal environmental datasets (the Coastal Sensitivity Index, CSI) provides a general overview of the archaeological and cultural legacy that is at risk in Aotearoa. The methodology and findings suggest that: (1) landform sensitivity provides a key proxy to understanding the archaeological risk from SLR; (2) more refined archaeological site location is needed at a national scale; and (3) coastal erosion is of greater concern in Aotearoa compared to inundation when considering archaeological risk.

In Aotearoa, the dominant coastal archaeological sites are midden (54.5%, 4938) and earthworks (25.1%, 2271). Only 3.6% (320) of sites are burials, but these important sites will be key for adaptation planning due to their high significant cultural value. Coastal erosion is a particularly serious threat to archaeology, in comparison with inundation, because erosion would permanently remove sites, erasing all contextual information that is important for archaeological preservation and investigation. Using the CSI, we estimate that 22% (1954) of coastal archaeological sites are on landforms that are vulnerable to SLR-driven erosion. About half of these sites are either on foredune barrier beaches (29.4%, 2660) or foredune barrier plains (22.7%, 2059), 14% (1283) are on beaches, and 9% (808) on beach ridge barriers. Spatial mapping of archaeological sites in at-risk areas indicates locations of regional sensitivity in the North Island around Taranaki, Auckland, the Coromandel, and northern Hawkes Bay, and in the South Island around Tasman and parts of Otago and Canterbury. A focus on regional level assessments within these sensitive locations could help to identify needs concerning documentation, preservation, and protection of coastal archaeology.

Note

1. Aotearoa is a Māori name for New Zealand's North Island. It is commonly used to mean all New Zealand (Hikuroa 2020), reflecting the nation's bicultural foundation.

Supplementary data

The supplemental files can be found in the github repository; https://github.com/Thepastfromabove/National_Archaeological_Risk_Aotearoa. The repository serves as a comprehensive collection of data pertaining to the research paper titled "Aotearoa's coastal archaeological heritage: a geostatistical overview of what is at stake." The paper, accessible at http://dx.doi.org/10.1080/15564894.2023.2207493, delves into an in-depth analysis of Aotearoa's coastal archaeological heritage.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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