

Vulnerability of Indigenous Heritage Sites to Changing Sea Levels: Piloting a GIS-Based Approach in the Illawarra, New South Wales, Australia

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Introduction

The risks posed by sea level rise to many coastal archaeological sites have driven a number of investigations and projects over the last decade. In the United Kingdom and France, for example, charity-driven initiatives have been implemented to investigate rising sea levels and their impacts on heritage sites. In Scotland, there is Scottish Coastal Archaeology and the Problem of Erosion (SCAPE; see Graham et al. this edition); in England, the Rapid Coastal Zone Assessment Survey (RCZAS); and, in France, Archéologie Littorale et Réchauffement Terrestre (ALeRT) (Reeder-Myers 2015). These national initiatives usually focus on surveying the entire coastline and any nearby heritage sites, helping to identify the sites most at risk to the impacts of erosion and sea level rise. Similar approaches are less useful, however, in countries with much longer coastlines, like the United States and Australia (Reeder-Myers 2015).

Along the coastline of the Illawarra region of New South Wales, Australia (fig. 1), the traditional home of the Dharawal people, there are many

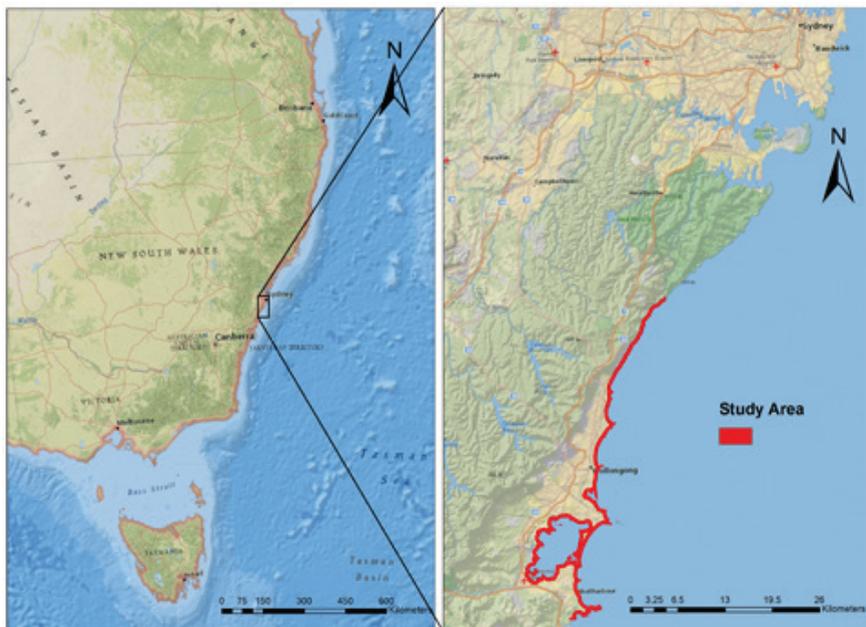


Fig. 1. Map showing the location of the Illawarra region of New South Wales, Australia.

coastal occupation and midden sites, dating from the terminal Pleistocene at c.20 kyr to recent times (Bowdler 1976; Organ and Speechley 1997). From about 20,000–17,000 years ago, during the Last Glacial Maximum, sea levels were around 120–130m lower than the present mean sea level for much of eastern Australia (Lewis et al. 2013). At this time, shorelines for the Illawarra region would have been several kilometres east of the present coast. The rise and movement of the sea inland, towards the present day coastline, would have potentially drowned many older Indigenous sites that were situated on the palaeoshoreline (Rowland and Ulm 2012).

Sea level rise appears to be accelerating due to anthropogenic climate change (Church et al. 2013; Erlandson 2012; Rahmstorf 2007). Rising sea levels have the potential to put many coastal archaeological and heritage sites at risk. Indeed, the United Nations has listed sea level rise and coastal erosion as one of seven key processes resulting from anthropogenic climate change that will have a negative impact on World Heritage Sites (WHS)

(Daire et al. 2012). Coastal sites have long been at risk from threats such as coastal modifications, destruction of wetlands and marine erosion, as well as population growth and development. The increased rates of sea level rise will add to these risks considerably through erosion and the increased number and intensity of storm cycles and inundation (Erlandson 2012).

The study presented here aims to apply the techniques traditionally used in vulnerability and sensitivity models for coastal environments to a heritage context. The application to heritage sites is based on the assumption that such sites are inherently linked to the land on or in which they are situated. It also acknowledges that heritage management resources are overstretched and that channelling resources in the most effective way requires informed and strategic planning.

Approach and Methods

Archaeological investigations along the coastline of the Illawarra region have been patchy, mostly undertaken by consulting archaeologists rather than academic researchers. The archaeological record at Bass Point, Shellharbour, has evidence of some of the earliest Indigenous occupation in the region, with uncalibrated radiocarbon ages of up to 17,000 ±650 BP (Derbyshire 1999). Bass Point is considered to be one of the most significant Aboriginal archaeological sites to be excavated in the state of New South Wales (NSW) and is a rare example of established occupation that continues to be of exceptionally high significance to the Aboriginal people of NSW (Office of Environment and Heritage 2016). The Bass Point sites have been studied since the late 1960s, and the area is one of the best documented in the region (Bowdler 1976).

In the Illawarra region, sea level rise scenarios have been modelled, notably by Cardno Lawson Treloar Pty Ltd (2010) in a project that was completed on behalf of Wollongong City Council. The sensitivity of the Wollongong Coast to the impacts of rising sea levels has also been investigated outside of the council and government framework (Abuodha and Woodroffe 2010). The modelled increase in mean sea level will certainly have geomorphological effects on the coastline, although individual coastal areas will likely respond differently and over differing time scales, with direct

repercussions for the survival of coastal archaeological sites. Broadly, the major coastal change usually associated with sea level rise is erosion, but sediment accretion and burial of heritage sites are also possible (Daire et al. 2012; Lewis 2000). In high-energy areas, sites may suffer damage that scatters archaeological remains, and, in some cases, sites may be completely destroyed due to dynamic erosion processes (Erlandson 2012; Westley et al. 2011). As a result of the spiritual values attached to archaeological sites, often considered to be atemporal and sacred, their loss can be devastating to Indigenous communities (Australian National University 2009).

The high frequency of heritage sites along the Illawarra coastline, coupled with threats stemming from rising sea levels and limited resources, poses particular challenges for site monitoring and management by regional councils and the New South Wales Office of Environment and Heritage (OEH). Our study was developed as a pilot to assess how desk-based analysis can reliably identify those sites most at risk. The aims were to, firstly, develop a Coastal Site Sensitivity Index (CSSI) for sites located near the current coastline in open marine contexts, using GIS-based analyses; secondly, work at multiple scales to identify the appropriate scale of resolution to generate meaningful results; and thirdly, ground truth the desk-based model to ensure that GIS-generated predictions play out on the ground.

Our approach to developing a regional Coastal Site Sensitivity Index draws on a model developed by Abuodha and Woodroffe (2010), who examined the biophysical vulnerability of estuaries to both coastal and terrestrial hazards. The approach not only includes factors used in similar, previous studies undertaken in North America and Europe (Reeder-Myers 2015; Westley et al. 2011), but further variables developed explicitly for a New South Wales South Coast context. The regional sensitivity analysis was performed within the ArcGIS programme, utilising the Spatial Analyst extension. Digital Elevation Model (DEM) data were used primarily to calculate slope. This dataset was updated to the Shuttle Radar Topography Mission (SRTM) DEM developed by Geoscience Australia, as opposed to the 25m DEM provided by the NSW Department of Lands and Property, which was used by Abuodha and Woodroffe (2010). The analysis also used a raster-based approach with ~28m cells based on the SRTM DEM, compared with the broader >1km regional cells used by Abuodha and

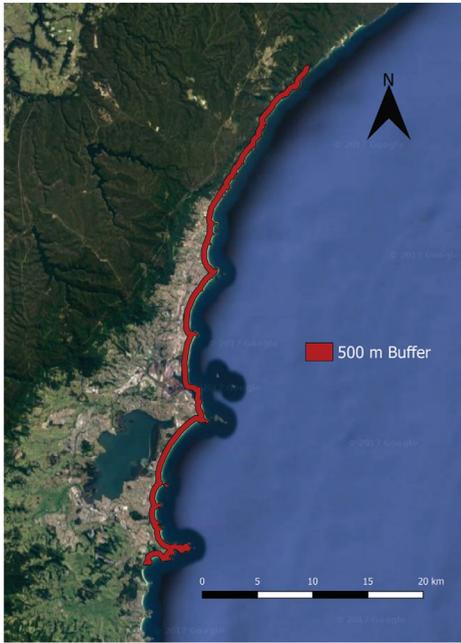


Fig. 2. Map showing the extent of the study area.

Woodroffe (2010). The increased spatial resolution allowed analysis of specific landscape points, which are important for determining local site sensitivity. The current analysis focused on open coastal segments and excluded estuarine areas because of the differing effects of wave actions and tides, which may be amplified or diminished due to specific estuarine morphology (Rogers and Woodroffe 2016).

The data used to create the CSSI included both Process and Structural variables. The variables consisted of Wave Height, Tidal Range, Relative Sea Level Rise, Coastal Slope, Rock Type, Shoreline Exposure, Distance to Shoreline and Geomorphology

(see table 1). The equation used to calculate the CSSI was also adapted from Abuodha and Woodroffe (2010) (fig. 2). Distance to Shoreline was added to the variables utilised by Abuodha and Woodroffe (2010) as a means of more accurately representing site-specific sensitivity. For example, a site 500m from the shore will have a different level of sensitivity to coastal processes than one that is 2m from the shore, even with all other variable conditions remaining the same. The use of Distance to Shoreline as a variable is common in studies that assess individual site sensitivity (Bickler et al. 2013; Reeder et al. 2012; Reeder-Myers 2015).

The study area was determined to be a 500m buffer inland from the shoreline of the Illawarra region in southern NSW,¹ but the CSSI excluded the shoreline of Lake Illawarra. The study area's northern boundary was at Otford and encompassed a 500m ribbon that terminated at Killalea

	Variable	VERY LOW 1	LOW 2	MODERATE 3	HIGH 4	VERY HIGH 5
	<i>Structural Variables</i>	Geology	-	Spoilhaven Group & Gerringsong Volcanics	Narrabeen Group	Illawarra Coal Measures
Coastal Slope (degrees)		Cliffed Coast (>45)	Steep Slopes (20-45)	Moderate Slopes (10-20)	Gentle Slopes (6-10)	Low Plains (0-6)
Geomorphology		High Hard Rock Sea Cliffs	Medium Hard Rock Sea Cliffs	-	Sandy Shores Backed by Bedrock & Artificial Structures	Sandy Shores Backed by Dunes & Plains
Shoreline Exposure (degrees)		-	Sheltered (>135)	Semi-Exposed (45-135)	Exposed (30-45)	Fully Exposed (0-30)
Distance to Shoreline (metres)		(101-500)	(201-300)	(101-200)	(51-100)	(0-50)
<i>Process Variables</i>	Sea Level Rise (mm/year)	(< 0.0)	(0.0 - 0.9)	(1.0 - 2.0)	(2.1 - 3.0)	(> 3.1)
	Mean Wave Height (metres)	(0.0 - 0.5)	(0.6 - 1.0)	(1.1 - 1.5)	(1.6 - 2.0)	(> 2.1)
	Mean Tidal Range (metres)	(> 2.1)	(1.6 - 2.0)	(1.1 - 1.5)	(0.6 - 1.0)	(0.0 - 0.5)

Table 1. Site Sensitivity Value Criteria (adapted from Abuodha and Woodroffe 2010).

State Park, just south of Bass Point. A polygon representing this area was created to allow clipping of relevant data to the defined area. The data for the Indigenous heritage sites came from the Aboriginal Heritage Information Management System (AHIMS), in which site locations are represented as points with additional attributes attached, such as the type of site (including Artefact, Shell, Burial, Potential Archaeological Deposit [PAD], Scarred Tree, Aboriginal Resource Gathering, Aboriginal Ceremony and Dreaming); source of location data (including 1:250,000 Imperial, 1:25/50/100k conversion, Differential GPS and non-Differential GPS) and contribution to primary importance.

The specific details of the individual criteria are given in Table 2. The DEM used for the regional analysis was part of the SRTM data released by Geoscience Australia. Elevation data are represented in cells of one arc second, which is equivalent to just under 28m. These data were used to create a slope dataset in raster format (fig. 4a). The underlying geological data for the study area were sourced from the NSW seamless geology package, produced by NSW Department of Trade and Investment, and converted to a sensitivity ranked raster (fig. 4b).

Variable	Input Data	Process
Slope	<ul style="list-style-type: none"> Geoscience Australia SRTM DEM 500 m Study Area Buffer 	Coastal slope was calculated in degrees. Degrees of slope were then classified into 5 sensitivity categories, to give each raster cell a value according to the CSSI (see Figure 4a).
Rock Type	<ul style="list-style-type: none"> NSW Dept. of Trade & Investment – NSW Seamless Geology Package 500 m Study Area Buffer Geoscience Australia SRTM DEM 	Polygon layers that intersected the study area were exported and clipped. A raster dataset was created by converting these layers into the raster format to align with the SRTM DEM cell position and sizing. The raster was then classified with values for each cell determined by the sensitivity category of each rock type according to the CSSI (Figure 4b).
Shoreline Exposure	<ul style="list-style-type: none"> NSW LPI – NSW Aerial Imagery NSW LPI – 1 m LiDAR DEM Geoscience Australia SRTM DEM 	The exposure of the shoreline with regards to the predominant swell direction was determined by creating a polyline layer, capturing the orientation of the shore. Polylines were digitised according to NSW aerial imagery and 1m Light Detection and Ranging (LiDAR) derived DEM datasets. The shoreline was determined as between -0.5 and 0.5m elevation, and then crosschecked with the NSW Land and Property Aerial Imagery. The polyline was separated at the vertices; the orientation of each individual line was then able to be determined from North. This made it possible to obtain comprehensive data on the orientation of individual beaches and shoreline sections in relation to predominant swell. The shoreline orientation data were used to create buffer zones, to determine areas that were within 500m of the various orientation categories (Figure 5a). Areas that were influenced from more than one category of exposure due to the shoreline orientation were assigned the highest applicable value.
Geomorphology	<ul style="list-style-type: none"> NSW LPI – 1 m LiDAR DEM NSW LPI – NSW Aerial Imagery NSW Dept. of Trade & Investment – NSW Seamless Geology Package Geoscience Australia SRTM DEM 	Geomorphology of the study area was classified into four categories based on the CSSI value table. The geomorphology was derived using 1m LiDAR DEMs to establish elevation and slope, in conjunction with NSW Aerial Imagery and NSW Seamless Geology data layers. The Geomorphology for each section of coast was created using polyline classification of the shoreline, which then enabled the application of a buffer. The buffered areas were converted to raster format (Figure 5b), assigning values to the study area according to the CSSI (Table 1).
Distance to Shoreline	<ul style="list-style-type: none"> BoM AHGF Shoreline Hydroline Geoscience Australia 	A raster dataset was created using a Euclidean distance calculation. This dataset was used to assign values to cells based on their distance to

	SRTM DEM	the shoreline. The distance measurements were then used to group cells into sensitivity classes. Areas 0-50m from the shore were given a value of 5 (Very High), 51-100m were valued at 4 (High), 101-200m were 3 (Moderate), 201-300m were 2 (Low) and 301-500m were 1 (Very Low) (Figure 6). Euclidean distance calculations are based on the raster cell size. The cell size for this raster was ~28m, as it was made to fit the template of the SRTM DEM.
Tidal Range	<ul style="list-style-type: none"> • Geoscience Australia SRTM DEM • 500 m Study Area Buffer 	Tidal range was taken as 1.2m and applied uniformly across the coast, and buffered to apply to the study area. The raster for the study area was given the value of 3 according to the CSSI sensitivity category.
Sea Level Rise	<ul style="list-style-type: none"> • Geoscience Australia SRTM DEM • 500 m Study Area Buffer 	Sea Level Rise was given the value of 5 for the study area. This was applied as a raster based on the cell size of the Geoscience Australia SRTM DEM.
Wave Height	<ul style="list-style-type: none"> • Geoscience Australia SRTM DEM • 500 m Study Area Buffer 	Wave height data were obtained from Short (2007), with a mean wave height of 1.6m. The value of each cell was determined to be 4 for this variable. Cell values were assigned according to the Geoscience Australia SRTM DEM cell positioning.

Table 2. Additional details on the individual variables used in the construction of the CSSI.

The exposure of the shoreline was determined with datasets produced by NSW Land and Property Information. These data made it possible to obtain orientations of individual beaches and shoreline sections in relation to predominant swell (fig. 5a). The predominant swell direction in the region is south/southeast (Kulmar et al. 2013). Geomorphology of the study area was classified into four categories, based on the CSSI value table and represented spatially in a raster layer (fig. 5b). The distance of sites from the shoreline was included into the index calculation to account for diminishing sensitivity with larger distances from the coastline (fig. 6).

The tidal range for the NSW beaches is uniform across all relevant beaches in the study area, and the spring tide average range is 1.2m, with a 0.8m Neap tide (Short 2007). Therefore, for the purpose of our study, the tidal range was taken as 1.2m, applied uniformly across the coast and buffered for the study area. Wave height data were also obtained from Short (2007), with a mean wave height of 1.6m.

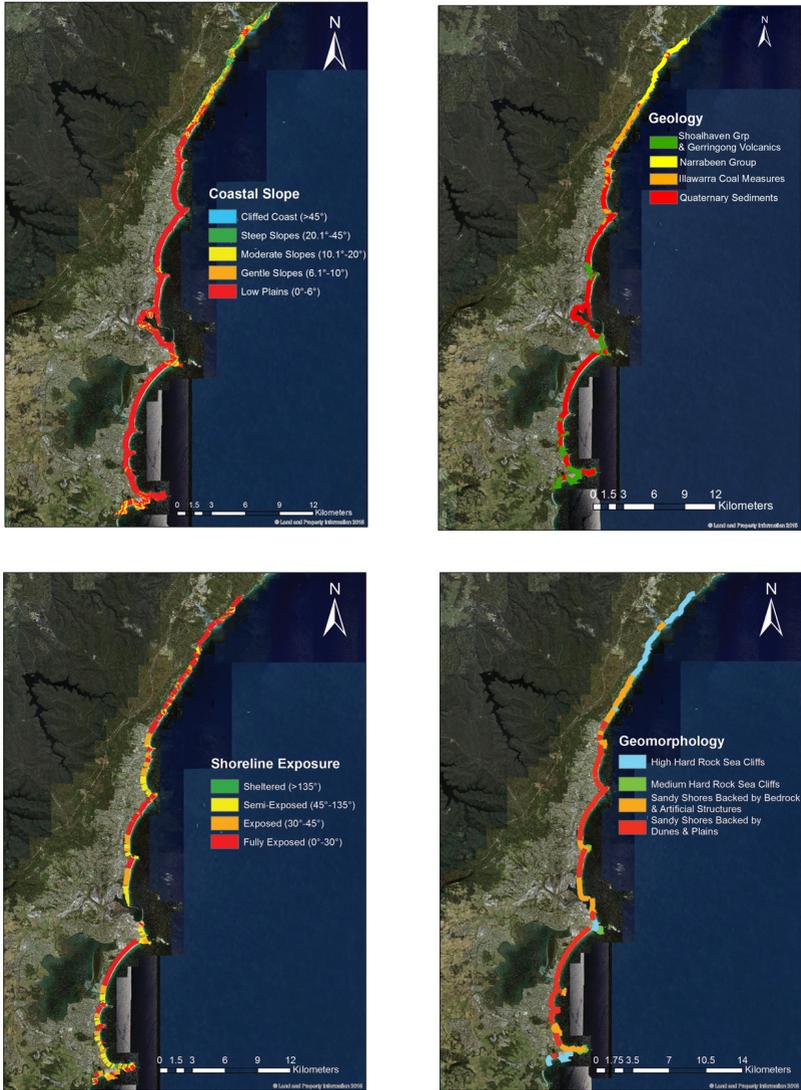


Fig. 4a. (top left), Fig. 4b. (top right) Map showing (a) slope and (b) geology CSSI plotted along the study area. Fig. 5a. (bottom left), Fig. 5b. (bottom right) Map showing (a) shoreline exposure and (b) geomorphology along the study area.

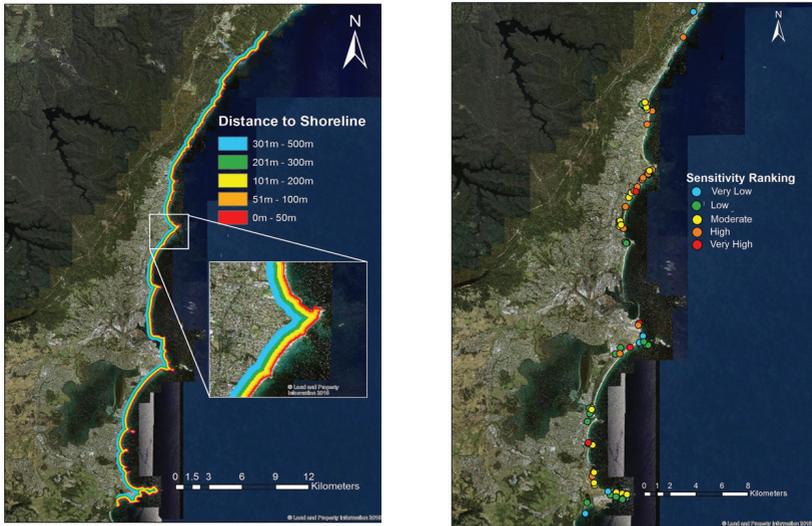


Fig. 6. (left) Map showing distance to shoreline calculations plotted along the study area. Fig. 7. (right) Map showing regional results of the application of the CSSI.

Satellite altimeter readings have suggested Global Mean Sea Level (GMSL) rise up to $3.2\text{mm} \pm 0.4\text{mm/yr}$ over the last few decades (Church et al. 2013). However, recent work has shown that this increase is slightly overestimated due to instrumental drift. The more accurate estimation is between $2.6\text{mm} \pm 0.4\text{mm}$ and $2.9\text{mm} \pm 0.4\text{mm}$ per year (Watson et al. 2015). The figures produced by Watson et al. (2015) refer to Global Mean Sea Level (GMSL) rise but do not necessarily fit exactly with the Illawarra region of NSW. However, McInnes et al. (2015) suggest that the increase in Southern Australia is likely to be very close to that of GMSL, with local variation taken into account. In the Wollongong region, planning for the future impacts of sea level rise has taken place based on the former NSW government benchmarks (Lappin 2013; Wollongong City Council 2013). Many councils have been directed to continue using these projections until further advice is provided (Statewide Mutual 2013). The former NSW benchmarks were set at a rise of 40cm above 1990 levels by the year 2050 and 90cm by 2100; to reach these marks, yearly sea level rise would need to average 6.7mm/yr and 8.2mm/yr , respec-

tively. Taking into account both current and projected rates, sea level rise was estimated at >3.1 mm/year for the study area. These estimates align with current planning strategies of local councils and the significant increases projected for sea level rise rates over the coming decades.

Results: Regional, Local and Ground Truthing

The CSSI was applied to 126 sites in the Illawarra region's coastal strip. Each of the 126 sites was assigned a value derived from the CSSI, producing 34 unique sensitivity values, ranging from 18 to 153. These values were divided into quintiles and labelled as 'Very Low' to 'Very High' sensitivity. The distribution of the sensitivity values across the region is represented in Figure 7. All areas showed an array of values, with the steepness of the coastline being a major factor that protects sites close to the sea and low slopes and shoreline exposure being common factors that increase site vulnerability. Sites situated on the stable geological base of Shoalhaven group sandstone emerged as less vulnerable, as did sites that were protected from the dominant south/southeast wave action. Sites located on Quaternary sediments tended to be more vulnerable, especially when coupled with high exposure and low slope.

Overall, the results for the 126 sites showed that only 4.8 per cent (n=6) of sites were classed as 'Very High' sensitivity, and 12.7 per cent (n=16) were classed as 'Very Low' (table 3). The majority of sites were within the three remaining categories of sensitivity: 'Low', 'Moderate' and 'High'.

CSSI Category	Frequency	Percent
Very Low	16	12.7
Low	41	32.5
Moderate	36	28.6
High	27	21.4
Very High	6	4.8
Total	126	100.0

Table 3. Results of the application of CSSI to Illawarra coastal sites.

The largest individual class of sites was the 'Low' sensitivity group, representing 32.5 per cent (n=41) of all sites. 'Moderate' sensitivity sites made up 28.6 per cent (n=36) of the overall 126, with the remaining 21.4 per cent (n=27) in 'High' sensitivity. Important to note is that, while there were 126 sites individually listed in the study area, multiple sites were located at many 'individ-

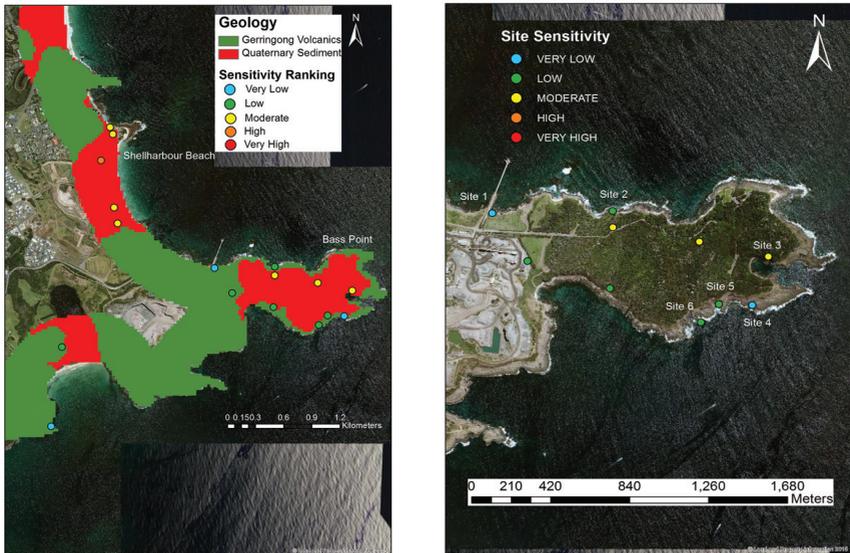


Fig. 8. (left) Map showing the application of the CSSI to the Bass Point zone at the southern limits of the study area. Fig. 9. (right) Sites physically visited at Bass Point.

ual' points. Consequently, some points represent more than one site, and this must be taken into account when interpreting site sensitivity data.

The results show that 33 sites, or roughly one-quarter of the 126 sites, were classed as 'High' or 'Very High' sensitivity to sea level rise within the study area. Twenty of these 33 sites were listed in the OEH register as 'Artefact'. Within the 'High' and 'Very High' categories, six sites were recorded as 'Shell' and five sites as 'Burial'. The remaining two of these 33 sites were a single 'PAD' site and one classed as 'Non-Human Bone and Organic Material'. The high occurrence of 'Artefact' sites in the higher sensitivity categories is in line with the regional total, with 52.4 per cent (n=66) of the full 126 sites being listed as 'Artefact'. Similarly 'Shell' sites make up 31.7 per cent (n=40) of the regional total. Sixteen sites in the region were qualified in the OEH register with 'Contributes to Primary Importance', and four of these qualified sites had 'High' sensitivity.

To investigate the results in greater resolution, the archaeologically-important area of Bass Point was singled out for in-depth investigation and ground truthing. Site sensitivity rankings here ranged from 'Very Low' to 'High', with the 'Moderate' and 'High' sensitivity sites all situated on Quaternary sediment layers. These included the sites along Shellharbour Beach and the 'Moderate' sensitivity sites along the middle of the Bass Point headland. The 'Low' and 'Very Low' sensitivity sites were situated upon Bumbo Latite. Bumbo Latite is a member of the Gerringong Volcanics and was given a value of two, or 'Low', in the CSSI. This geological influence in part explains the difference in sensitivity ranking of sites that were geographically close yet defy the general trend, whereby sensitivity is lowered as distance from the shore increases (fig. 8). Shoreline exposure to predominant swell direction also had a substantial effect in differentiating sensitivity of sites in close proximity to each other, primarily because many small bays and points provide varying degrees of protection.

Six site points analysed in the CSSI were visited to evaluate on-the-ground applicability of the study. Sites were investigated to determine their location accuracy, and the CSSI-estimated site sensitivity categories were compared with the observable characteristics of the recorded site points. Site locations were determined from AHIMS point data. The sites were classed as being of 'Very Low', 'Low' and 'Moderate' sensitivity by the CSSI. Sites were present on both the northern and southern shorelines of the Point, and one site was located in the protected Bushrangers Bay (fig. 9). Each site point represented at least two site types within the AHIMS register. All points recorded both 'Shell' and 'Artefact' site types.

The sites at Bass Point were inspected during high tide. A handheld GPS was used to locate sites according to WGS1984 UTM Zone 56S (after conversion from the original Geographic Coordinates System GDA 1994). The recorded GPS position of Site One was adjacent to the Gravel Loader on the northern shore of Bass Point, where the CSSI determined 'Very Low' site sensitivity. The GPS coordinates located the site close to the water's edge, with the high water mark approximately 2m inland (GPS accuracy ~6m). We found no evidence of artefacts or shell midden within a radius of ~30m.

Site Two's GPS position was located on the northern shore of the Point and had a CSSI sensitivity of 'Low'. The GPS coordinates indicated that the site was on what is now an intertidal rock platform (GPS accuracy 5m). We found no evidence of artefacts or a shell midden. Approximately 60m from the Site Two coordinates, we recorded a storm-disturbed deposit of large shell taxa, which are characteristic of regional middens, but it is unclear whether this was the Site Two referred to in the AHIMS database.

Site Three's GPS position was located near the sheltered Bushrangers Bay, with 'Moderate' CSSI sensitivity. The GPS coordinates indicated that the site was on top of a cliff at the northern edge of the bay. GPS accuracy (~12m) was limited due to dense vegetation cover. We found no evidence of archaeological material within a radius of ~20m.

Site Four's GPS position was located on the southern shore of the Point, with 'Very Low' CSSI sensitivity. The GPS coordinates (accuracy 6m) indicated that the site was on what is now an intertidal rock platform, which was partially inundated by the high tide. We found no evidence of archaeological material. The nature of the location, with southern exposure and powerful wave action, suggested that any exposed shell midden or other archaeological material would have been quickly destroyed.

Site Five's GPS position was located on the southern coastline of Bass Point, and, as with Site Four, the GPS coordinates (accuracy 6m) indicated that the site was on what is now an intertidal rock platform. The location at the base of a depression in the rock was unsafe to visit, but from a distance we observed no signs of archaeological material. Powerful wave action at this location would likely destroy any archaeological material as soon as it was exposed.

It was not possible to visit the final selected site, with the GPS coordinates (accuracy 5m) indicating a location at least 20m off the coast. With an average spring tide range of 1.2m in the region (Short 2007), it is unlikely that this point would be on land even at low tide. The shoreline within 50m of the location was examined, and no evidence of archaeological material was found.

Discussion

The CSSI provided estimates of sensitivity for the registered heritage sites along the Illawarra coastline. The sensitivity of sites with regards to impacts associated with sea level rise was based on underlying landform sensitivity. Using landform sensitivity as a proxy is consistent with the assessment made by ANU (2009: xi), which indicates that “the preservation of unique cultural values—including Aboriginal middens, sea cave deposits, archaeological sites, rock art and cave art sites—is highly dependent on the maintenance and protection of their underlying landforms from climate change impacts”. That analysis found higher sensitivity for sites located on flat, sandy beaches and plains comprised of Quaternary sediments. This is also evident among the ‘High’ sensitivity sites found on Wollongong’s Northern Beaches, where sites are fully exposed to the predominant south/southeast swell.

The combination of multiple variables with relatively high spatial resolution allowed for individual site sensitivity values to be estimated. On the Port Kembla coastal segment, for instance, there were examples of sites from the highest and lowest categories of sensitivity present within a few hundred metres of each other. The top of the headland had sites ranked with ‘Very Low’ sensitivity, while the flat beaches on either side of the headland had sites ranked with ‘Very High’ sensitivity.

Out of the 126 sites analysed in the CSSI, six sites had ‘Very High’ sensitivity. The ‘Very High’ sensitivity sites were relatively spread out over the study area; however, they displayed many similar attributes. All were very close to the shore, on Quaternary sediment, with low slopes and high exposure to predominant swell direction. The ability to identify heritage sites with the highest estimated sensitivity over a relatively large area is an extremely useful tool for heritage management. These sites, which are likely facing the greatest risk of damage, can therefore be prioritised for further research or protection.

In some cases, various issues were identified that had the capacity to affect the accuracy of the model. Possible sources of error came from the methods in the model itself, as well as from techniques used to

create particular datasets and their applications. One key issue was that our analysis assumed all variables had an equal impact on site sensitivity. The weighting of variables accounts for differential impacts of some processes over others. A number of previous coastal heritage studies have been completed without weighting variables (Shi et al. 2012; Westley et al. 2011), while others have applied weighting to variables in order to assess vulnerability through a more intensive analysis (Reeder et al. 2012; Reeder-Myers 2015). These weighted models rely on high-quality data for an entire study region, with the benefit of sensitivity estimates that more closely reflect complex shoreline responses to sea level rise.

The site investigations of Bass Point allowed a critical evaluation and effective ground truthing of the CSSI to take place. Although no archaeological evidence was found at the investigated site points, it was clear that there was a separation between the CSSI values and heritage site sensitivity. Sites Four and Five were experiencing active wave action. This is likely to be of very little concern for the resistant latite that forms the point, as well as for other headlands in the region (Oak 1984). However, an archaeological site such as a shell midden or artefact scatter would likely be at considerable risk from coastal erosion at these locations. These examples demonstrate a potential flaw in the model. Adapting landform sensitivity for use as a proxy for site sensitivity simplifies the relationship between sites and landforms. While it has been acknowledged that heritage sites rely on the integrity of the underlying landforms (Australian National University 2009), it is clear that highly resilient and stable landforms do not entirely negate risk to heritage sites. The same theoretically direct relationship may not always be true for lower sensitivity landforms, since unstable and highly sensitive landforms will surely contribute towards a higher sensitivity index for sites. Concurrently, the very nature of the site itself may render it susceptible to particular hazards, such as erosion. Greater weighting on variables such as distance to shoreline could be applied to account for this factor. The elevation of sites should also be a variable included in the weighting.

The accuracy of site data is equally important to consider in the study. No archaeological evidence was found at any of the visited site points. In fact, the landscapes at Sites Two, Four, Five and Six indicate that it is highly unlikely that previous researchers ever found surviving archaeolog-

ical material there. It is more likely that the original site coordinates were recorded inaccurately, because there was no evidence of any archaeological material found within 30m of any visited sites, and Site Six's coordinates placed it in the ocean. Location inaccuracy can come from a variety of sources. Methods of recording site data have changed over time, and some error may have been introduced into the original records (Environmental Resource Management Australia 2006; Reeder et al. 2012). The process of transferring original documentation to the AHIMS database may also have introduced some error (Environmental Resource Management Australia 2006). Further, heritage sites in the database are likely to vary in size and shape, and a single point may poorly represent a given site, as its boundaries may potentially be several metres from the recorded point (Westley et al. 2011). Finally, previous studies have found evidence of storm reworking of midden deposits at Bass Point (Hughes and Sullivan 1974), so the loss or scattering of the sites that could not be located is another possibility.

Conclusion

The pilot study presented here explicitly tackles the challenge of addressing the impact of sea level rise on the coastal heritage of long coastlines. If desk-based studies can provide guidance on high-risk areas and sites, particular resources and strategies can be targeted by heritage managers. However, heritage site points may represent an object or place that is less than a metre in size, and a regional scale analysis does not have the spatial resolution to operate effectively. In fact, with spatial resolution based on ~28m grid cells, the CSSI is likely stretching, or even exceeding, the capability of many of the datasets already used, which have been developed for large scale applications, as opposed to detailed local analysis. Regional analysis also overly simplifies many processes and variables acting on sites. Despite these issues, the approach has many positive qualities. The primary advantage of regional scale analysis is its quick application, allowing for the efficient estimation of site sensitivity over a large area in a relatively short time. The application of this approach in the Illawarra coastal region has shown that the CSSI is effective in providing robust estimates of site-specific sensitivity, with high potential for aiding the management of archaeological resources threatened by sea level rise.

The absence of currently visible archaeological evidence at the visited Bass Point locations is problematic and emphasises the importance of accurately recording site locations. Spatial accuracy of site locations is essential for the GIS-based analysis of heritage site sensitivity. The landforms investigated comply with what would be expected according to the classification of the CSSI and broadly validate the methods of the study. An important management implication, indicated by ground truthing in this study, is the need to assess site register locations based on accurate, precise physical investigation. The Bass Point field investigation also demonstrates the need for weighting variables, particularly to account for sites on highly resistant landforms. Desk-based modelling can be a powerful and efficient tool in planning and conservation, but it demands a high level of spatial resolution and accuracy.

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References

- Abuodha, P.A.O. and Woodroffe, C.D. 2010. Assessing vulnerability to sea-level rise using a coastal sensitivity index: a case study from southeast Australia. *Journal of Coastal Conservation* 14: 189–205.
- Australian National University. 2009. *Implications of climate change for Australia's World Heritage properties: A preliminary assessment. A report to the Department of Climate Change and the Department of the Environment, Water, Heritage and the Arts*. Canberra: Fenner School of Environment and Society, Australian National University.
- Bickler, S., Clough, R. and Macready, S. 2013. *The Impact of Climate Change on the Archaeology of New Zealand's Coastline: A Case Study from the Whangarei District. Science for Conservation 322*. Wellington: Department of Conservation Te Papa Atawhai, New Zealand Government.
- Bowdler, S. 1976. Hook, line and dilly bag: An interpretation of an Australian coastal shell midden. *The Australian Journal of Anthropology* 10: 248–258.
- Cardno Lawson Treloar Pty. 2010. *Wollongong City Council Coastal Zone Study*. Report on file at Wollongong City Council.
- Church, J.A., Clark, P.U., Cazenave, A., Gregory, J.M., Jevrejeva, S.,

- Levermann, A., Merrifield, M.A., Milne, G.A., Nerem, R.S., Nunn, P.D. and Payne, A.J. 2013. Sea Level Change. In Stocker, T.F. (ed), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, 1137–1216.
- Daire, M.Y., Lopez-Romero, E., Proust, J.N., Regnauld, H., Pian, S. and Shi., B. 2012. Coastal Changes and Cultural Heritage (1): Assessment of the Vulnerability of the Coastal Heritage in Western France. *Journal of Island and Coastal Archaeology* 7: 168–182.
- Derbyshire, J. 1999. *The Illawarra Aboriginal Wodi Wodi people at Bass Point: a brief summary of the excavation studies undertaken by Dr Sandra Bowdler at Bass Point in 1969–70*. Unpublished manuscript on file. Shellharbour: New South Wales.
- Erlandson, J.M. 2012. As the world warms: Rising seas, coastal archaeology, and the erosion of maritime history. *Journal of Coastal Conservation* 16: 137–142.
- Environmental Resources Management Australia. 2006. *Aboriginal Heritage Assessment, Chapter 2. Environmental Resources Management Australia*. Sydney: Southern Employment Lands Greystanes Estate.
- Hughes, P.J. and Sullivan, M.E. 1974. The Re-disposition of Midden Material by Storm Waves. *The Royal Society of New South Wales* 107: 6–10.
- Kulmar, M., Modra, B. and Fitzhenry, M. 2013. The New South Wales Wave Climate Improved Understanding through the Introduction of Directional Wave Monitoring Buoys. Paper presented at the *Coasts and Ports Conference 2013*, Sydney.
- Lappin, C. 2013. Coastal Planning—Back to the Future? Paper presented at the 22nd New South Wales Coastal Conference 2013, Port Macquarie.
- Lewis, R.B. 2000. Sea-Level Rise and Subsidence Effects on Gulf Coast Archaeological Site Distributions. *American Antiquity* 65: 525–541.
- Lewis, S.E., Sloss, C.R., Murray-Wallace, C.V., Woodroffe, C.D. and Smithers, S.G. 2013. Post-glacial sea-level changes around the Australian margin: a review. *Quaternary Science Reviews* 74: 115–138.
- McInnes, K.L., Church, J., Monselesan, D. and Zhang, X. 2015. Information for Australian Impact and Adaptation Planning in response to Sea-level Rise. *Australian Meteorological And Oceanographic Journal* 65: 127–149.
- Oak, H.L. 1984. The boulder beach: a fundamentally distinct sedimentary assemblage. *Annals of the Association of American Geographers* 74: 71–82.
- Office of Environment and Heritage. 2016. *Bass Point Reserve*. Sydney:

- New South Wales Office of Environment and Heritage.
- Organ, M.K. and Speechley, C. 1997. Illawarra Aborigines. In Hagan, J.S. and Wells, A. (eds) *A History of Wollongong*. Wollongong: University of Wollongong Press, 7–22.
- Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science* 315(5810): 368–370.
- Reeder-Myers, L.A. 2015. Cultural Heritage at Risk in the Twenty-First Century: A Vulnerability Assessment of Coastal Archaeological Sites in the United States. *Journal of Island and Coastal Archaeology* 10: 436–445.
- Reeder, L.A., Rick, T.C. and Erlandson, J. 2012. Our disappearing past: A GIS analysis of the vulnerability of coastal archaeological resources in California's Santa Barbara Channel region. *Journal of Coastal Conservation* 16: 187–197.
- Rogers, K. and Woodroffe, C.D. 2016. Geomorphology as an indicator of the biophysical vulnerability of estuaries to coastal and flood hazards in a changing climate. *Journal of Coastal Conservation* 20: 127–144.
- Rowland, M.J. and Ulm, S. 2012. Key issues in the conservation of the Australian coastal archaeological record: Natural and human impacts. *Journal of Coastal Conservation* 16: 159–171.
- Shi, B., Proust, J.N., Daire, M-Y., Lopez-Romero, E. and Soazig Pian, H.R. 2012. Coastal Changes and Cultural Heritage (2): An Experiment in the Vilaine Estuary (Brittany, France). *Journal of Island and Coastal Archaeology* 7: 183–199.
- Short, A.D. 2007. *Beaches of the New South Wales Coast: a guide to their nature, characteristics, surf and safety*. 2nd edition. Sydney: Sydney University Press.
- Statewide Mutual. 2013. *Liability issues arising from selection of sea level rise benchmarks*. Legal Advice prepared by DLA Piper.
- Watson, C.S., White, N.J., Church, J.A., King, M.A., Burgette, R.J. and Legresy, B. 2015. Unabated global mean sea-level rise over the satellite altimeter era. *Nature Climate Change* 5: 565–568.
- Westley, K., Bell, T., Renouf, M.A.P. and Tarasov, L. 2011. Impact Assessment of Current and Future Sea-Level Change on Coastal Archaeological Resources-Illustrated Examples from Northern Newfoundland. *Journal of Island and Coastal Archaeology* 6: 351–374.
- Wollongong City Council. 2013. *Update on the Draft Wollongong Coastal Zone Management Plan*. Wollongong: Wollongong City Council.