Quantifying rock fishing hazards using marine and terrestrial aerial laser surveying.

David M. Kennedy [1], Barbara Brighton[2], Daniel Ierodiaconou[3], Adam Weir [4] and Colin D. Woodroffe [5]

[1]Department of Resource Management & Geography, The University of Melbourne, Parkville, VIC
[2]Surf Life Saving Australia, Rosebery, NSW
[3]School of Life and Environmental Sciences, Deakin University, Warrnambool, VIC
[4]Surf Life Saving New South Wales, Belrose, NSW
[5]Department of Earth & Environmental Sciences, University of Wollongong, Wollongong, NSW

Abstract

The rocky coast is a hazardous environment; there were 178 fatalities accounting for 19% of coastal drowning in Australia between 2004 - 2014. It has recently been identified that morphological elements of the shore, namely the depth at the front of the platform and the platform elevation are key to understanding the likelihood of wave overwash; however to quantify these parameters in the field is often prohibitively time consuming and expensive especially when analysing large coastal regions. The advent of aerial marine and terrestrial LiDAR surveying now provides researchers with the capability to quickly and quantitatively map the coast thereby allowing for regional assessments of coastal morphology. In this study we show the utility of this laser surveying using data sets from the Victorian coast. It is found that LiDAR is highly valuable for the assessment of hazard and can provide managers with the ability to rapidly assess and map drowning risk.

Introduction

Management of drowning on the coast is approached in four principal ways: firstly physical prevention of drowning through lifeguard and lifesaving supervision, secondly education to provide people with the survival skills that enable them to safely experience the water, thirdly education and education on hazards, and finally a denial of access and improvement of infrastructure (George, 2011). On the open-coastline of Australia, this management has been traditionally focused on beaches. Volunteer lifesavers and the Australian Lifeguard Service (ALS) are provided by Surf Life Saving Australia (SLSA) on more than 300 beaches, supplemented by additional professional local-council lifeguard services.

Since the mid-1990's education has also played a critical role in beach safety, the aim being to inform beach users of the hazards present on an individual beach should they wish to visit a particular location. This education is provided through the Australian Beach Safety and Management Program (ABSAMP) which provides hazard and risk ratings for every open-coast beach in Australia (Short et al., 1993). The ratings developed within ABSAMP are a product of multiple variables ranging from wave condition at a given time, shape of the beach, ease of access and distance from emergency services. The core element of the system is the beach morphodynamic state which is a function of wave height and period and sediment size (Short and Hogan, 1994; Short et al., 1993).

These systems have been very effective at reducing the incidence of drowning deaths on beaches throughout Australia. Fatalities occurring in beach locations have fallen 9% under the 10-year average (2004 – 2014), despite an exponential increase in numbers of people visiting the beach. We have not, however, seen the same reduction in fatalities occurring on rocky coasts which are currently 6% above the 10-year average (SLSA, 2014a, b). The difficulty for management is beach-based systems cannot be directly transferrable to rocky coasts. Surf clubs cannot be built on the rear of shore platforms and the ABSAMP beach models cannot be applied to landforms which are made of solid rock.

Rocky coast locations account for 19% of costal fatalities, which highlights the need to include these landforms in safety planning (SLSA, 2014a, b). Ideally a rocky coast equivalent of ABSAMP would be developed whereby a few attributes of the landscape can be used to estimate the potential hazard of a particular area. It has recently been suggested that the hazard level of rock platforms may be a function of shore platform elevation and the depth at its seaward edge (Kennedy et al., 2013). Platforms of lower elevation will be subject to more frequent wave overtopping, whereas those with deeper water closer to shore will be exposed to higher wave energy; Kennedy et al. (2013) termed this relationship ‘morphological exposure’. Such a relationship holds considerable potential for developing a hazard rating for rocky shores.

Measurement of the key variables needed to calculate ‘morphological exposure’ requires detailed field work in locations which are often difficult to access. Such data collection is therefore very expensive. Recent advances in aerial laser mapping may, however, provide a cost-effective way to collect the required morphological data over wide areas, especially when both bathymetric and terrestrial datasets can be acquired at the same time. This paper therefore sets out to test the utility of these new surveying techniques for acquiring the key morphological data for the calculation of morphological exposure.

Regional Setting

The southeast facing section of the Great Ocean Road coast from Grass Creek to Cape Otway Lighthouse (Fig. 1) was used as a study site due to its uniform geology composed of Late Jurassic to lower Cretaceous sandstones (Douglas and Ferguson, 1976) which form part of the Eumeralla Formation within the Otway Basin; (Duddy, 2003). This coast is microtidal with a spring tidal range of 1.6 m (Port of Melbourne, 2013). The mean significant wave height for the Victorian coast is 2.4 m with a period of 8.4 sec (Hughes and Heap, 2010) and modelling indicates the mean annual wave height in the study site is 1.4 m (WaterTech, 2004). Mean annual maximum and minimum air temperatures for Lorne, in the center of the study area, are 11.0 and 18.9 °C, with a mean annual rainfall of 827 mm (BoM, 2012).

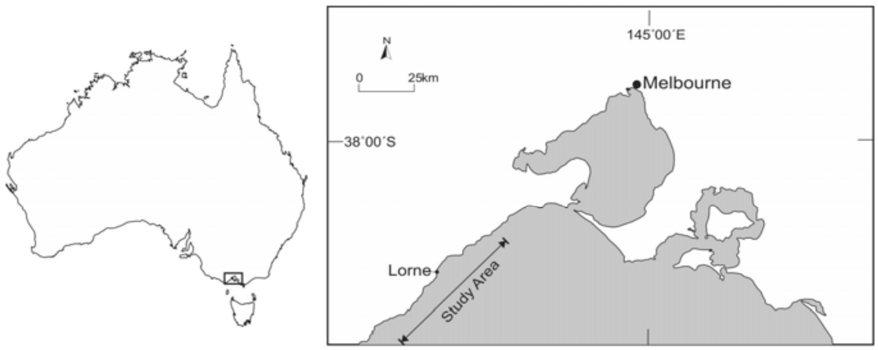

Figure 1: Location of coastline analysed

Methods

Airborne Light Detection and Radar (LiDAR) data were collected in 2007 by the Department of Environment and Primary Industries of the Victorian State Government. The surveying was conducted using a LADS Mk II system coupled with a GEC-Marconi FIN3110 inertial motion sensing system and a dual frequency kinematic geographic positioning system (kGPS). This dataset was processed to produce a seamless terrestrial-marine mosaic from elevations of +10 m to depths of -25 m (Quadros and Rigby, 2010). A final raster grid comprised a continuous 2.5 m resolution topographic and bathymetric surface which was created and analysed in ArcMap (v. 10).

Within ArcMap, profiles were manually drawn at c. 100 m intervals along the rocky shoreline. On each line data was extracted at 2.5 m intervals including variables such as elevation/bathymetry and bottom reflectance. Data was then manually queried and classified to delineate rocky surfaces from bare sand flats with the aid of georectified aerial photography. Topographic cross sections were drawn in order to extract the key morphological elements namely, elevation of the platform and depth of the seaward edge. This analysis was restricted to those sections of the shoreline where shore platforms were found.

Results

Platform Morphology

Several types of rocky coast are identified in the LiDAR surveys, unmodified hillslopes, shore platforms, gravelly-beaches, and subtidal reefs. In this analysis only the shore platforms are examined as these are the areas which are predominantly used for rock fishing. The morphology of the shore platforms is generally typical of microtidal settings around the globe. They generally have a semi-horizontal mid section which is backed by either a beach or vertical cliff. On their seaward side ramparts are common along the entire coast and often a seaward cliff of metre-scale relief is present extending from around mean sea level elevations to several metres depth. Not all elements however are found on every platform and in particular the morphology of the intertidal parts of the platforms is variable. It is the intertidal and nearshore subtidal zones that are most important for the estimation of morphological exposure as the depth immediately in front of the platform (front depth) is a key proxy for wave energy (Sunamura, 1991, 1992) and therefore fishing hazard (Kennedy et al., 2013). Four broad types of seaward morphology are found: (1) a steep-ramped ‘cliff’, (2) a ramp, (3) sub tidal reefs, and (4) subtidal shelf.

On the first type of platform, a steep-ramped ‘cliff’, the seaward edge is marked by a steeply sloping ramp that descends to below low tide level (Fig. 2a). This morphology is well represented just north of Lorne, a very popular rock fishing location. The seaward edge has a slope of up to 15° sloping from at or just above MHWS elevation to a depth of 2 – 2.5 m over a distance of 30 m. The base of the ramp is marked by an abrupt change in slope where the profile contacts with the sandy sea bed which has a gradient of < 3°. These platforms commonly have a rampart 0.6 - 1.5 m high on their outer edge which protects the horizontal central parts of the platform from direct wave breaking. On some platforms the base of this ramp may lie in the intertidal zone such as north of Wye River /Separation Creek and in this instance the profile merges with intertidal rocky reefs. On these types of platform, the front depth is relatively straight forward to delineate in the LiDAR as it is marked by a sudden change in slope and often the appearance of a sandy sea floor. These platforms are most similar to the classic type-B (horizontal) morphology described around the world.

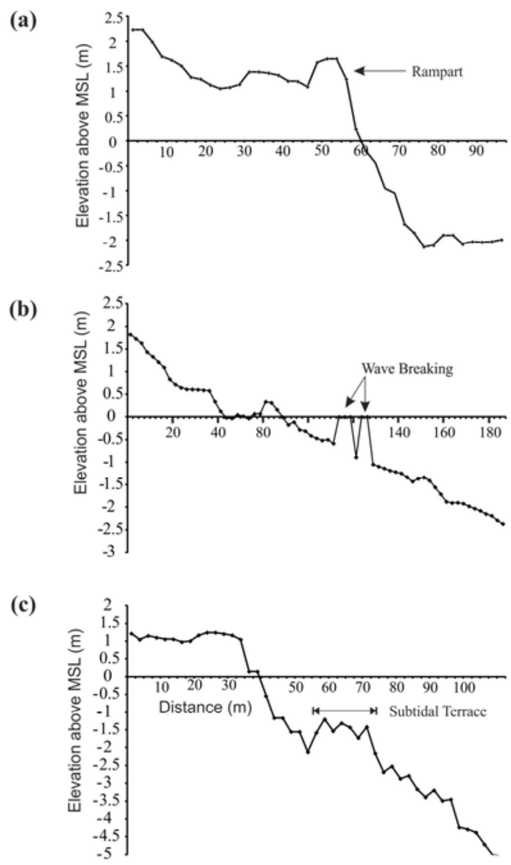

Figure 2: Typical shore normal profiles found in the study area.
(a) a type-B platform with a steep-ramped ‘cliff’, (b) a seaward ramp platform showing a data gap due to wave breaking, and (c) a subtidal terrace.

A marked (> 10°) change in slope at the seaward edge does not occur on all platforms (Fig. 2b). Some, for example, have a ramp over 100 m wide, which has a gradient of 3 – 6° and can include a 20 m wide surf zone extends seaward of a semi-horizontal intertidal surface. This ramp can extend to over 5 m depth with little change in gradient. On these platforms the front depth is taken either at the bottom of the ramp or where there is some relief at the first break in slope seaward of MSL.

The third morphological type is characterised by the presence of subtidal rocky reefs. These reefs are often tens of metres wide and have a relief of several metres rising to intertidal elevations in places. The seaward edge of the platform is delineated where there is a change in slope at the base of the seaward ramp. This position does not necessarily mark the transition to a sandy sea floor and often marks the base of a shallowing of the sea floor up to the crest of a rock reef.

The final morphological type found in the LiDAR data consists of platforms where a subtidal terrace extends from the platform edge (Fig. 2c). On these platforms the base of the intertidal platforms seaward ramp terminates on a distinct low gradient terrace. These terraces are often of similar dimensions to the platform that occurs in the intertidal zone, although their surface is often a few degrees steeper. They generally occur between 0.8 to 2 m water depth and have a seaward edge that is similar to the morphologies described above. For these types of platforms, the front depth can be taken from the rear of the terrace.

Morphological Exposure

Key morphological data was extracted from the LiDAR, specifically platform elevation (taken as the horizontal part of the platform in the intertidal zone) and front depth, using the criteria outlined above. These variables were then used to calculate the morphological exposure of 180 transects along the Great Ocean Road using a modified version of the Morphological Exposure (Me) Index (Kennedy et al., in prep). It should be emphasised that at present this exposure index is a relative value and the relationships between each platform are non-linear. In this analysis only those platforms which occur above Mean Low Water Spring (MLWS) elevation are analysed.

The morphological exposure of the platforms analysed ranges from 0.02 – 21.12 (average 2.36). In general lower platforms are more exposed than higher platforms (Fig. 3, 4). The most exposed platforms occur on headlands, although there is little correlation between the northern and southern sides. For example on Grey River Head, the platforms on the southern side have a Me of 1.06 – 2.86, with the tip of the point having the lowest value of 0.80 (Fig. 5). On the northern side the exposure values are higher, generally > 4 with the highest value for the analysed section of coast (21.12) occurring halfway between the tip of the point and the beach. Ramp-type platforms are dominant at this site.

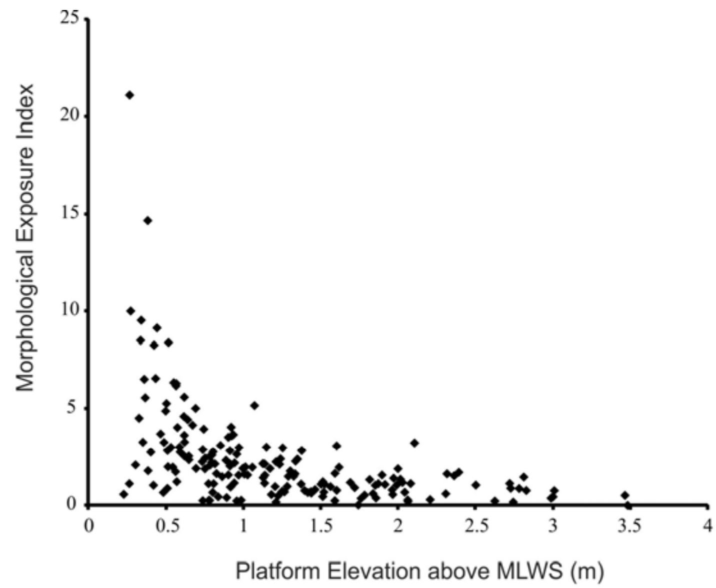

Figure 3: The calculated morphological exposure for 180 profiles subsampled for this study. In general exposure increases as platform elevation decreases, but the relationship is not linear.

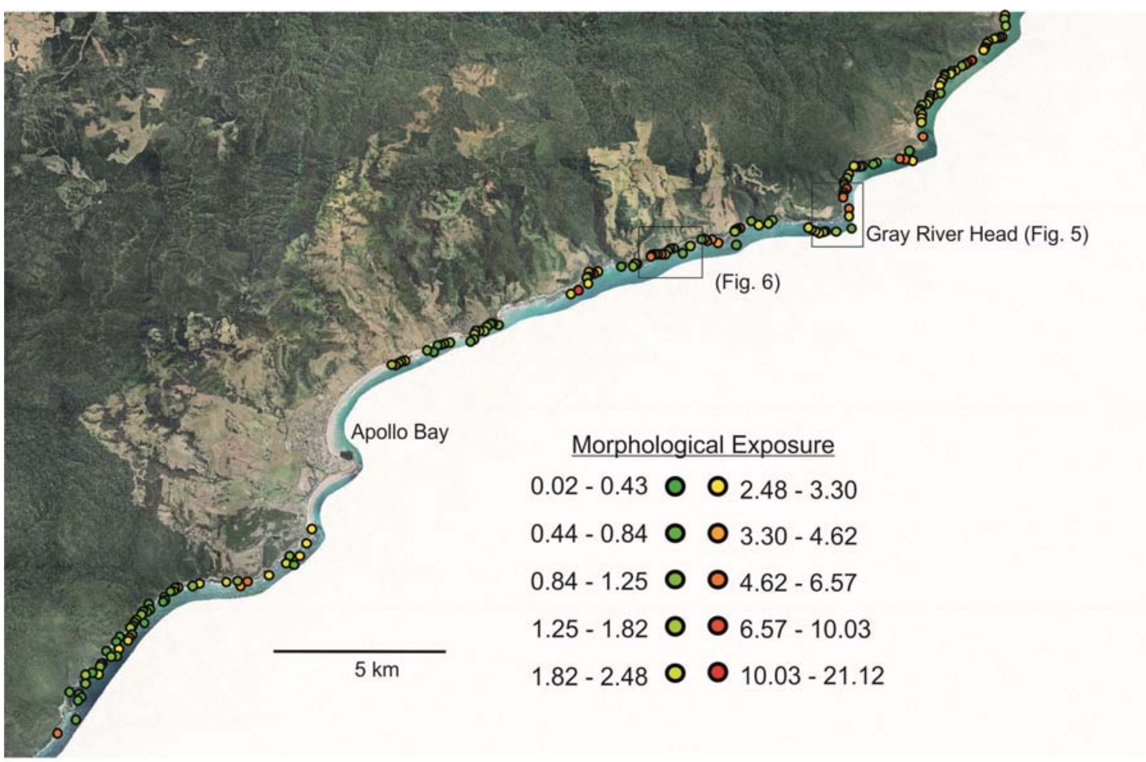

Figure 4: The distribution of exposure values along the Great Ocean Road coast

Steep-ramped 'cliff' and ramp platforms dominate the shore between Skenes Creek and Wongarra. The exposure index at this location ranged from 0.69 to 8.53 with higher values occurring both within and at the edges of embayments (Fig. 6). The higher exposure to waves with the embayment highlights that despite these sections being protected from the predominantly southern swell, when waves are able to enter the bay those sections of rocky coast are in fact quite dangerous.

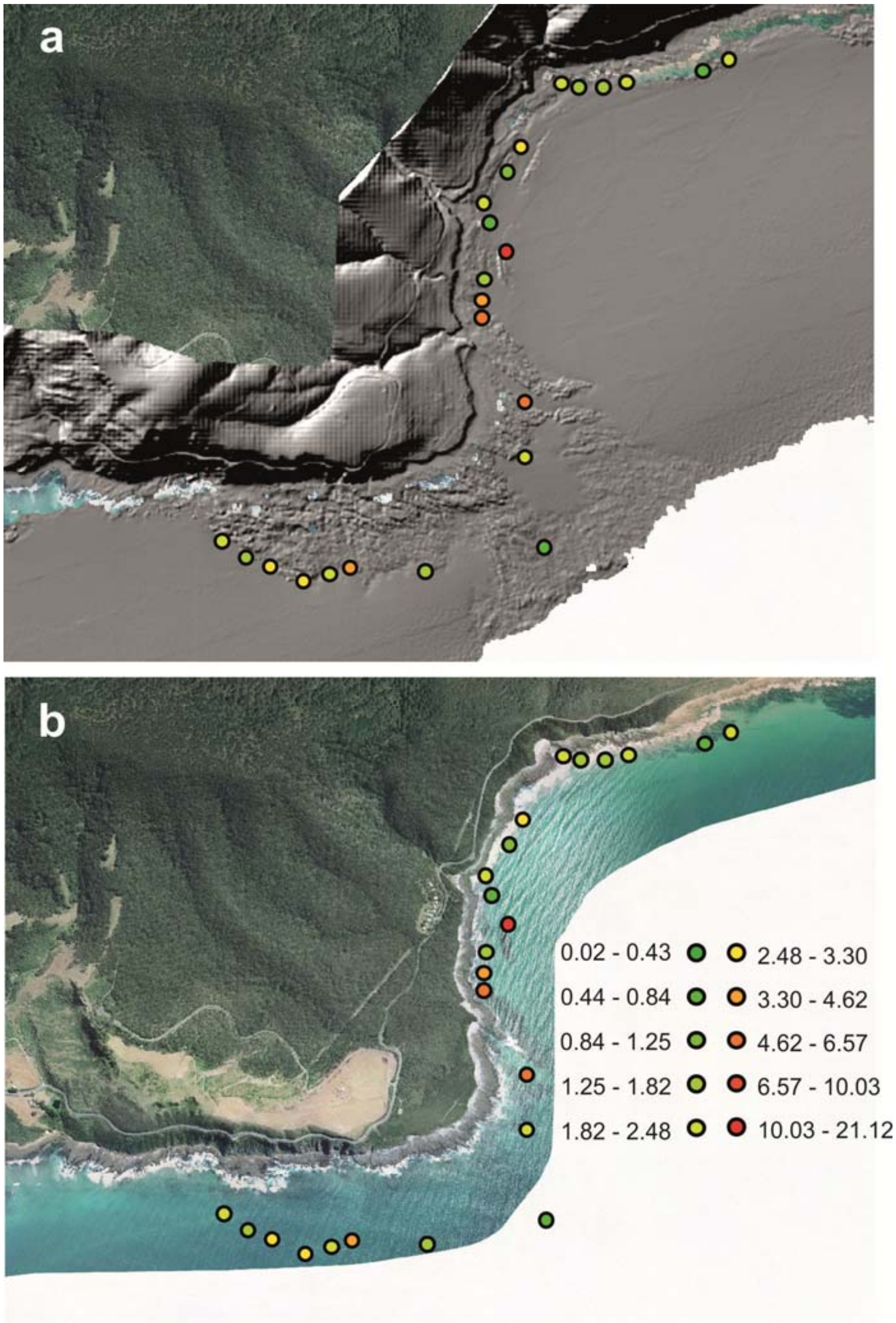

Figure 5: The distribution of exposure values around Gray River Head.
(a) Hillshade model of the LiDAR data, (b) aerial photo of the same section of coast.

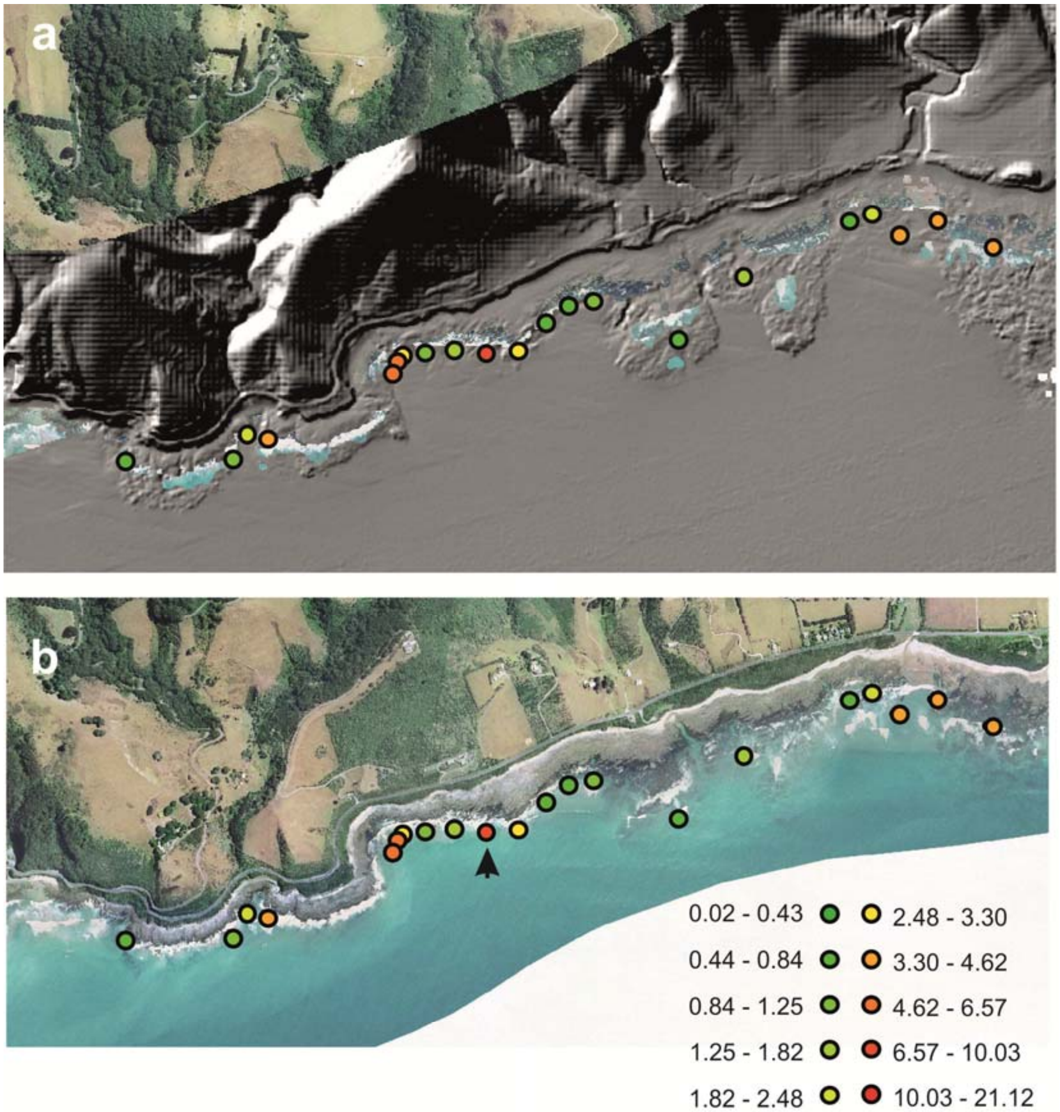

Figure 6: The distribution of exposure values along a relatively straight section of coastline. (a) Hillshade model of the LiDAR data, (b) aerial photo of the same section of coast. The effect of site-sepcific variations in the depth of the seaward edge on morphological exposure can is observed on the arrowed location. This spot has a much deeper seaward edge compared to the neighbouring platforms

Discussion

The use of terrestrial and bathymetric LiDAR has revolutionised the study of landscapes. It is commonly used for the prediction of coastal inundation from sea level rise (Cooper et al., 2013; McInnes et al., 2013; Runting et al., 2013) and tsunami (Joyce et al., 2014). It is also applied to the study of landform evolution on rocky shores in order to assess erosion rates of millennial timescales (Kennedy et al., 2014). While the potential to extract detailed information on the morphology of individual rock platforms has been proven (Kennedy et al., 2012; Palamara et al., 2007) it has not been used to analyse risk that coastal fishers might be exposed to in great detail. The dataset used in this study has shown the utility of LiDAR for analysing coastal hazards, specifically the exposure of individual shore platforms to waves. While this data does not provide information of actual wave energy, it is the critical first step in identifying those areas where the shape of the landscape makes it more exposed to wave overtopping.

LiDAR based analysis is not, however, a replacement for field investigations. Bathymetric LiDAR is sensitive to sediment within the water column meaning its use to restricted to coastlines with low turbidity (Kennedy et al., 2014). This is observed in the Victorian dataset where sediment entrained in breaking waves completely obscured the laser (Fig. 6). These data gaps were > 500 m long and up to 100 m wide in places, occurring entirely in the surf zone. Waves were observed to be breaking periodically along nearly the entire coast during the survey. The data gaps therefore appear related to the coincidence of an individual wave bore and the survey at that particular time. The resulting data gaps while inhibiting exposure calculations at that particular point did not mean it was impossible to calculate exposure. This is because breaks with the wave swash allow laser penetration to occur intermittently in the wave breaking zone. In addition it is possible to estimate wave exposure through extrapolating the platform morphology based on the platform type observed outside of the surf zone.

The major consideration in the interpretation of the LiDAR datasets is the delineation of the platform edge, which is where the front depth is measured. In this study a series of precise morphometric indicators were used to determine where the edge existed. For platforms with a wide subtidal ramp, or offshore reef, this results in the exposure being based on a depth at some distance seaward from what might be considered the shore edge by fishers. The critical aspect here is to differentiate between where the surf zone might occur and where wave energy will be concentrated. This has particularly been highlighted in the wide sloping shore platforms of Kaikoura, New Zealand. In this location extensive measurement of wave energy has shown that the intertidal portion of the platform received a similar amount of wave energy both in calm and stormy periods despite deep-water wave height varying by an order of magnitude (Stephenson and Kirk, 2000a, b). This was because as wave height increased waves interacted with the seabed further offshore thereby dissipating their energy before they reached the shoreline. The same likely applies on the Victorian coast, especially for platforms which are attached to rocky reefs, in that wave energy is dissipated before reaching the shore. Further research is necessary on how wave energy, and therefore exposure, varies across platforms with wide subtidal ramps or terraces.

Additional considerations also need to be made when considering wave run-up into the intertidal zone. Small-scale topographic interactions, such as waves entering related to gullies/gulches running through the platform or blow holes and wave reflection off vertical seaward faces of the platforms, still need to be considered. The morphological exposure index is likely applicable in these situation although this has not been tested in this study due to the 5 m resolution of the LiDAR dataset.

Conclusions

This study has shown the utility of bathymetric and terrestrial LiDAR for the calculation of wave hazards on shore platforms. Data extracted from this survey method means the hazard exposure of a section of coastline can be quickly before physically visiting sites.

The morphological exposure index appears to work best for calculating the potential hazard for rock fishers for platforms that have a very narrow surf zone. Platforms of this type are very common along the New South Wales coast (Kennedy, 2014) and work is in progress examining how to categorise them where bathymetric data is generally lacking.

Estimations of hazard can be made for all shore platform types, however the interpretation of the exposure needs to account for the likely wave interactions right at the shore. Research into the interaction of waves in the nearshore and their impact on hazard is currently being undertaken.

The use of the morphology hazard index combined with LiDAR surveys will provide managers and fishers with the first step of an integrated hazard model. Once the exposure to waves is identified then it can be combined with the actual wave height at the shore to produce a holistic assessment of hazard on the coast. A rocky coast version of ABSAMP appears to be achievable in the near future.

Acknowledgements

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