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Assessing vulnerability of coasts to climate change: A review of approaches and their application to the Australian coast

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Keywords

Illawarra coast

Disciplines

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ASSESSING VULNERABILITY OF COASTS TO CLIMATE CHANGE: A REVIEW OF APPROACHES AND THEIR APPLICATION TO THE AUSTRALIAN COAST

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ABSTRACT

This paper reviews approaches to assessing vulnerability of coasts to climate change and gives details of one of the approaches, coastal vulnerability index (CVI). The CVI ranks the following in terms of their physical contribution to sea-level rise-related coastal change: dune height, barrier type, beach type, relative sea-level change, shoreline erosion and accretion, mean tidal range and mean wave height. These variables are seen to be more useful to the Australian coast. The ranking for each input variable were combined and an index value calculated for selected beaches on the Illawarra and Batemans Bay coasts. The results are presented here.

Keywords (5): COASTAL VULNERABILITY INDEX, ASSESSMENT, ILLAWARRA BEACHES, CLIMATE CHANGE, AUSTRALIA

INTRODUCTION

Review of approaches used to assess vulnerability of coasts to climate change

Climate change will affect the coast disproportionately. Current coastal development patterns are increasing vulnerability to climate change and placing additional stresses on the sustainable management of the coastal zone. Whereas sea-level rise has been a prime focus of several of the global scale studies of coastal vulnerability, there is an increasing recognition, both internationally and within Australia, that there are likely to be additional impacts as a result of climate change. Coastal hazard research has generally focused on physical characteristics of coastal vulnerability rather than socio-economic factors.

Many international approaches for assessing vulnerability of a coast to climate change have developed from the IPCC *Common Methodology for vulnerability assessment* developed in 1991. These include; Synthesis and Upscaling of Sea-level Rise Vulnerability Assessment Studies (SURVAS), wetland loss modelling, DINAS-Coast and DIVA, Simulator of CLIMate Change Risks and Adaptation Initiatives (SimCLIM), Community Vulnerability Assessment Tool (CVAT) and Coastal Vulnerability Indices such as CVI, CSoVi and PVI. Most of these approaches are based on the Bruun Rule. Several of these approaches involve segmentation techniques that rank segments of the coastline according to a semi-quantitative index. For example, the coastal vulnerability index (CVI) is a relative ranking based on scaled indices for geomorphology, coastal slope, relative sea-level rise, shoreline erosion/accretion, mean tidal range and mean wave height used by the United States Geological Survey (USGS). A social vulnerability index (SoVI) uses socio-economic variables in a principal components analysis (PCA) to produce the overall coastal social vulnerability score (CSoVI). The Coastal Services Center of National Oceanographic and Atmospheric Administration (NOAA), based in Charleston, have developed a Community Vulnerability Assessment Tool (CVAT), which supports the linking of environmental, social and economic data in the coastal zone. The SimCLIM Open Framework Software System is an aid to decision-making under changed climate conditions and it allows rapid generation of place-based sea level scenarios. The SURVAS (Synthesis and Upscaling of Sea-level Rise Vulnerability Assessment Studies) project developed a global assessment of vulnerability of the coastal zone using a common assessment methodology, involving a network of international experts on vulnerability and adaptation studies. DINAS-Coast (Dynamic and Interactive Assessment of national, regional and global vulnerability of Coastal Zones to Climate Change and Sea-level Rise) is a European methodology involving a tool called DIVA (Dynamic Interactive Vulnerability Assessment) that enables analysis of a range of mitigation and adaptation scenarios.

Indices, and in some cases metrics, have been developed as rapid and consistent methods for characterising the relative vulnerability of different coasts. The simplest of these are assessments of the physical vulnerability of the coast, while the more complex also examine aspects of economic and social vulnerability. An early attempt to develop a coastal vulnerability index to climate change, particularly sea-level rise, was developed for the United States by Gornitz and Kanciruk (1989), considering inundation and flooding and susceptibility to erosion. It has been suggested that this index could be applied in a global context by Gornitz (1991). Gornitz recognised that the index could be improved with a term for storm frequency, and terms related to population at risk (Gornitz et al., 1991). The Gornitz coastal vulnerability index has been incorporated into analysis of US shorelines by Thieler of the United States Geological Survey (USGS) (Table 1). This coastal vulnerability index (CVI) is derived to show relative vulnerability; it combines the coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions, yielding a relative measure of the system's natural vulnerability to sea-level rise.

The categories of mean tidal range in Thieler's approach are the opposite to that of Gornitz and Kanciruk. For example, a tidal range of over 6 m is considered to be of highest vulnerability by Gornitz whereas Thieler considers it to be of lowest vulnerability (cf. Gornitz and Kanciruk, 1989, Table 1 with Hammer-Klose and Thieler, 2001, Table 1). Table 1 shows a summary of coastal vulnerability indices that have been applied in different countries.

When considering the range of variables applicable to the Australian coast under the CVI developed by Gornitz and Kanciruk, 1989, it is clear that, with respect to relief, low lying beaches, which mostly have a relief of less than 5 m rank as very high risk under this CVI. Also, when considering the variables rock types and landforms, then areas of unconsolidated sediment, beaches, estuaries and lagoons rank as very high risk under this CVI. This accounts for 100 % of the studied beaches. It is therefore appropriate to develop variables that would be more applicable to the Australian coast.

Table 1. Summary of coastal vulnerability indices, their geographical application and the variables needed to implement them

Index	Geographical application	Variables considered	Reference
Coastal vulnerability index (CVI)	USA	Relief, rock types, landform, relative sea-level change, shoreline displacement, tidal range and maximum wave height	Gornitz and Kanciruk (1989), Gornitz (1991), Gornitz et al. (1991)
Coastal vulnerability index (CVI)	USA	Geomorphology, shoreline erosion and accretion, coastal slope, relative sea-level change, mean wave height and mean tidal range	Thieler and Hammer-Klose (2000) and numerous other USGS reports
Social vulnerability index (SoVI)	USA	Principal components analysis of Census-derived social data	Boruff et al. (2005)
Coastal social vulnerability score (CSoVI)	USA	Combination of CVI and SoVI	Boruff et al. (2005)
Sensitivity index (SI)	Canada	Relief, rock type, landform, sea-level change, shoreline displacement, tidal range and maximum wave height	Shaw et al. (1998)
Erosion hazard index	Canada	As SI, plus exposure, storm surge water level, slope	Forbes et al. (2003)
Risk matrix	South Africa	Location, infrastructure (economic value), hazard	Hughes and Brundrit (1992)
Sustainable capacity index (SCI)	South Pacific	Vulnerability and resilience of natural, cultural, institutional, infrastructural, economic and human factors	Yamada et al. (1995)
Sensitivity index	Ireland	Shoreface slope, coastal features, coastal structures, access, land use	Carter (1990)
Vulnerability index	UK	Disturbance event frequency, relaxation (recovery) time	Pethick and Crooks (2000)

Several modifications have been proposed to the original CVI. Several researchers have seen a need to incorporate data on storm and storm-surge occurrence and frequency. It has also been viewed as important to incorporate social data on people at risk, the most detailed social vulnerability analysis being the synthesis by Boruff et al. (2005). The social vulnerability index (SoVI) uses socio-economic variables on a coastal county basis in a principal components analysis (PCA) to produce the overall coastal social vulnerability score (CSoVI).

Application of the approaches to the Australian coast

With only a few exceptions, coastal development on the Australian coastline has been undertaken behind natural foredunes or at sufficient setback that relatively little of the coast is presently in need of protection, relatively few beaches are sustained by sand nourishment, and there are relatively few hard engineering structures. The unique physical setting of the Australian continent, its distinct and highly variable climate, and its unusual pattern of human use of the coastal zone mean that many of the approaches adopted to assessing coastal vulnerability overseas are either not directly applicable, or will require modification before adoption and application in Australia (Abuodha and Woodroffe, 2006).

Australian approaches to vulnerability assessment

In considering the extent to which assessment strategies similar to those used overseas should be adopted in assessing the vulnerability of the Australian coastal zone to climate change, it is important to recognise that several assessment methodologies have already been developed specifically for the Australian coast by Australian researchers. Development and application of the IPCC Common Methodology (CM) in the 1990s represented a milestone in the development of international coastal vulnerability assessments. CM has been a foundation on which the majority of subsequent overseas methodologies have been based. In Australia, the National Coastal Vulnerability Assessment Case Studies Project (NCVACSP) was undertaken during 1994-95, comprising 9 case studies (one study in each state, with two in each of Victoria and the Northern Territory) and several deficiencies with the CM approach were identified (Waterman, 1996).

Table 2. Principal methods adopted to assess vulnerability of the Australian coast to climate change

Approach	Geographical application	Principal methods	References
Wetland mapping	Northern and north-western coasts	Wetland mapping in Kakadu and elsewhere in the NT, in line with Ramsar wetland assessments	Finlayson et al. (2002) Eliot et al. (2005)
Landform mapping	South Australia	Holocene landform mapping as a guide to vulnerability	Bryan et al. (2001) Harvey et al. (1997, 1999)
Storm surge zones	Queensland	Queensland Climate Change and Community Vulnerability to Tropical Cyclones project	Queensland Government (2004)
Beach vulnerability	New South Wales	Fuzzy and probabilistic modelling	Cowell et al. (2006) Cowell and Zeng (2003)
Beach vulnerability	Tasmania	Mapping beaches for Bruun rule and assessing inundation risk	Sharples (2004)

Table 2 summarises the main approaches that have been adopted since the Australian Coastal Vulnerability Assessment Project (ACVAP). Coastal vulnerability assessment of the Northern Spencer Gulf produced an overview of the biophysical and socio-economic characteristics of the region (Harvey et al., 1999). In that study, coastal vulnerability was considered in the context of both inundation and erosion categorised from very high (1) to very low (5) vulnerabilities (Bryan et al., 2001). Whereas sea-level rise has been a prime focus of several of the global scale studies of coastal vulnerability, there is an increasing recognition, both internationally and within Australia (Harvey et al. 1999), that there are likely to be additional impacts as a result of climate change.

Complementing the approaches in Table 2, the National Committee on Coastal and Ocean Engineering (NCCOE) has produced a framework for analysis of response to climate change drivers (NCCOE, 2004). NCCOE guidelines provide a template at a series of spatial scales enabling prioritisation of climate drivers in national or regional assessment, suitable for local scale assessments. The climatic drivers interact with coastal environments in often-complex ways to drive coastal evolution.

Coastal vulnerability indices, as trialled in several countries (Table 1), have not been applied to Australian coasts, and the applicability on a local and regional scale of such a risk analysis procedure based on an assessment of global coastal hazards (Gornitz and Kanciruk, 1989) is discussed in the following section. A detailed index of vulnerability is developed that incorporates features relevant to Australian shorelines. This new index is then applied to selected beaches in the Illawarra and at Moruya in order to assess whether such an approach to coastal vulnerability and risk analysis will help coastal planners, managers, engineers and developers in addressing appropriate responses to future climatic change.

AUSTRALIAN ESTIMATES FOR SEA-LEVEL RISE

Assessments by the Intergovernmental Panel on Climate Change (IPCC) identify that Australian coastal systems are threatened by climate change, and as a disproportionate percentage of the population lives along the coast, climate impacts on coasts will be amongst those environmental issues of most concern to Australia over the 21st century. Low-lying coasts around Australia might be expected to experience increased levels of inundation, accelerated coastal erosion, and saline intrusion into coastal waterways and water tables. Evidence points to a severe impact potential, but presently knowledge of the vulnerability of coastal areas to sea-level rise and wider climate change remains incomplete. There is uncertainty about the rates of change and it is difficult to separate extreme events exacerbated by climate change from those that represent part of the current natural variability of climate. Increasingly, Australians are moving to live, retire or make a living at the coast. Some 83% of Australians lived within 50 km of the coast in 1996 (Australia State of the Environment, 2001). Australia is remote from former ice sheets; it is tectonically stable, and around much of its southern shorelines it is exposed to high-energy wave action that can result in erosion of large volumes of sediment (and their gradual return over decades, see Short, 1993; McLean and Shen, 2006). Present sea level was reached around most of the Australian coast about 6000 years ago (Nakada and Lambeck, 1989). In fact, around much of the coast, that 6000-year shoreline appears to have been slightly higher than the present shoreline, but its elevation varies from place to place. The overall trend of sea level relative to much of Australia over the past few thousand years has been a slight fall, although tide gauge records do suggest that sea level is now gradually rising relative to Australia, at rates close to or slightly below the global average of about 1.8 mm/year (e.g. Hunter et al., 2003).

METHODOLOGY

The approach involves deriving a CVI index for parts of the coast and comparing these results with patterns of shoreline change observed in the selected field areas. Two sets of aerial photographs were used in this study. The first comprises orthorectified aerial photography of the entire Wollongong LGA flown by, and acquired from, AAMHatch in 2000 for Wollongong City Council (WCC). These aerial photographs are the most recent and cover Wollongong area from Sharky Beach in the north to Perkins Beach in the south. The other orthorectified aerial photography was purchased from the Department of Lands (NSW). The aerial photographs were flown in the period 1999 to 2002. These are of lesser quality and have been used for Stanwell Park Beach, Warilla Beach down to Seven Mile Beach. A linear coastline shapefile representing low tide water mark has been used in this study obtained from the Australian Bureau of Statistics (ABS), but without metadata supplied.

Published data (Short, 1993) on the Illawarra and Moruya beaches were used for calculating the CVI for each of the selected beaches. In the absence of geospatial data on the beaches, field measurements were acquired at GPS defined locations; measurements included dune height, assessed using 50 m tape measure and hand held clinometer to measure slopes and calculate dune height using trigonometry. Where low dunes occur, they were measured directly using the tape measure. Below is a brief description of the geologic and physical process variables considered in the CVI; whereas the approach used in the US and other countries uses broad categories for these variables, they have been customised for NSW beaches based on local studies of both the Quaternary geology and beach morphodynamics.

Geologic variables

Elevation **–** Whereas elevation is used in most CVI, it was considered that the greatest height of the dune would be the most useful representation of elevation in terms of coastal vulnerability. Dunes vary from less than 2m high, as at Stanwell Park Beach (Figure 3) to the much higher dunes of Perkins Beach (Figure 3). For example, the northern part of Warilla Beach is protected by natural vegetated sand dunes, 5.9 m high; the central and southern parts of Warilla Beach have been stabilised by huge boulders and the dune heights are 11.2 m and 4.8 m respectively. The southern part of Warilla beach is backed by beach front houses (Short, 1993) which were nearly washed away in the mid 1970's, which resulted in the stabilisation of the sand dunes by a seawall. Moruya Beach is backed by a parallel succession of dune ridges, 5 to 8 m high (McLean and Shen, 2006).

Barrier types were classified based on knowledge of depositional environments and histories (Thom et al., 1978). Five types of barriers were recognised; episodic transgressive, prograded, stationary, receded and mainland beach barriers. **Episodic transgressive dune barriers** can be attributed to locally high rates of sand supply at the downdrift terminus of a littoral drift system, implying an abundant sand supply (Chapman et al., 1982; Roy et al., 1994). **Prograded barriers** are typically characterised by multiple beach ridges (e.g. Moruya and Seven Mile Beaches). Average rate of barrier progradation (m/yr) at Moruya and Shoalhaven Heads (Seven Mile Beach) is 0.34 and 0.24 respectively, again implying an ongoing supply of sand (Chapman et al., 1982; Thom et al., 1978). **Stationary barriers** are generally narrower, characterised by dominantly vertical rather than lateral growth. They are recognised on the basis of the absence of significant morphological evidence of progradation (Chapman et al., 1982). Barriers in the Windang embayment (Perkins, Warilla), and perhaps as far south as the Kiama-Gerringong area are stationary barriers (Jones et al., 1979). **Receded barriers** are thin marine sand deposits that overlie estuarine or back-barrier sediments which outcrop on the shoreface. Most of the beach systems within the Wollongong embayment are of this type and have been receding (e.g. Bulli Beach) (Jones et al., 1979). **Mainland beach barriers** are an end-member of the barrier types that comprise thin veneers of beach mantling a pre-Holocene erosional substrate (Roy et al., 1994).

Beach types – A series of beach types (also called states as a beach may vary from one type to another over time) have been described by Short (1993, 1999). The 6 types are: Dissipative (D), Longshore Bar and Trough (LBT), Rhythmic Bar and Beach (RBB), Transverse Bar and Rip (TBR), Low Tide Terrace (LTT) and Reflective (R) beaches. **Dissipative beaches** have wide surf zones with shore parallel bars and channels and predominantly shore-normal circulation coupled with an abundant median to fine sand. An example is the northern part of Seven Mile beach. They tend to be relatively stable systems with low frequency of shoreline displacement events and spatially continuous, parallel, back-beach foredune scarps. **Intermediate beaches** occupy states between the fully dissipative and reflective. They are characterized by rip circulation, crescentic-transverse bars and megacusps. Examples are Stanwell Park, Coledale, Bulli, Perkins, Warilla, mid Seven Mile and Moruya Beaches. **Reflective beaches** are characterized by barless surfzone and steep, narrow, cusped or bermed beach. Fishermans Beach is an example, although not included in this study.

Shoreline erosion and accretion – Rates of erosion, transport and deposition depend, amongst other things, on wave energy, the angle of wave approach to the coastline and the strength of wave generated currents (New South Wales Government, 1990). Over the past 33 years, coastal process studies have been undertaken at Warilla and Shoalhaven Heads (South Seven Mile beach). The results show a landward movement of the shoreline (erosion) of 0.9 and 1.0 m/yr at Warilla and Shoalhaven Heads respectively (Shoalhaven City Council, 2004). Warilla Beach has been subject to severe beach erosion and may have been undergoing slow shoreline recession through loss of sand into the entrance to Lake Illawarra, prior to engineering works to stabilise the tombolo (Clarke and Eliot, 1888). Previous studies indicate the northern part of Warilla Beach to be eroding while the southern part is accreting (Eliot and Clarke, 1982). Over three decades, Moruya Beach has undergone a succession of dramatic changes in morphology that included major recession in the 1970s and subsequent accretion over the next two to three decades (Thom and Hall, 1991). This involved changes from backshore → foreshore → backshore → incipient foredune → established foredune (McLean and Shen, 2006). There were 3 separate periods, from 1972 to 1974, an erosion dominated period (EDP), from 1974 to 1986 when accretion dominated (ADP), and a period of relatively little change since 1986 (McLean and Shen, 2006). The variable pattern of shoreline displacement means that it is difficult to assign a vulnerability ranking at Moruya.

Physical process variables

Australian **relative rates of sea-level change** appear to be within the eustatic rise of 1-2 mm/yr. The **mean tidal range** in New South Wales is 1.3 m, neap is 0.9 m, spring is 1.6 m and maximum range is 2.0 m (Eliot and Clarke, 1982; Short, 1993). Wave energy levels are moderate to high with median wave heights of 1.5 m. The **mean wave height** for NSW is 1.6 m and ranks as a very low risk. Mean period is 10-12 seconds; maximum wave heights of up to 12 m have occurred.

THE COASTAL VULNERABILITY INDEX (CVI)

To be able to apply the CVI on a more local scale applicable to the Australian shoreline, finer refinements were found necessary and a first assessment of the approach is presented in this paper (Table 3). The first three variables of the CVI developed by Gornitz and Kanciruk, 1989, (relief, rock types and landforms) have therefore been replaced by dune height, barrier type and beach type respectively (Table 3). Relief has been substituted with dune height and the categories remain the same as in the Gornitz and Kanciruk CVI. Dune height, barrier type and beach type are seen to be more applicable to the Australian coast at a local scale.

The coastal vulnerability index presented here is similar to that used in Thieler and Hammar-Klose (2000), Gornitz and Kanciruk, 1989, as well as to the sensitivity index employed by Shaw et al., (1998). The CVI allows the seven variables to be related in a quantifiable manner that expresses the relative vulnerability of the coast to physical changes due to future sea-level rise. This method yields numerical data that cannot be equated directly with particular physical effects. It may, however, highlight areas where the various effects of sea-level rise may be the greatest. Once each section of coastline is assigned a vulnerability value for each specific data variable, the coastal vulnerability index is calculated as the square root of the product of the ranked variables divided by the total number of variables;

$$CVI = \sqrt{(a1 \times a2 \times a3 \times a4 \times a5 \times a6 \times a7)/7} \quad \text{....eq1}$$

Where, a1 = dune height, a2 = barrier type, a3 = beach type, a4 = relative sea-level change, a5 = shoreline erosion and accretion, a6 = mean tidal range and a7 = mean wave height. The calculated CVI value is then divided into quartile ranges to highlight different vulnerabilities along the beaches. The CVI ranges (low - very high) reported here apply specifically to the studied beaches, and are not comparable to CVI ranges overseas, or on other Australian beaches where the CVI has not been employed. To compare vulnerability between Australian beaches, a national-scale study would need to be carried out. We wish to assess the approach used in this study to describe and highlight the vulnerability specific to the studied beaches.

Table 3. Ranking of coastal vulnerability index (CVI) variables for the Illawarra coast, NSW, Australia, adapted from the coastal risk classes of Gornitz (1991)

Category	**Very low**	**Low**	**Moderate**	**High**	**Very High**
VARIABLE	**1**	**2**	**3**	**4**	**5**
a1. Dune height (m)	≥ 30.1	20.1 - 30.0	10.1 - 20.0	5.1 - 10.0	0 – 5.0
a2. Barrier types	Transgressive	Prograded	Stationary	Receded	Mainland beach
a3. Beach types	Dissipative (D) Longshore bar trough (LBT)	Rhythmic bar beach (RBB)	Transverse bar rip (TBR)	Low tide terrace (LTT)	Reflective (R)
a4. Relative sea-level change (mm/yr)	≤ -1.1 Land rising	- 1.0 - 0.99	1.0 - 2.0 Eustatic rise	2.1 - 4.0	≥ 4.1 Land sinking
a5. Shoreline erosion/accretion (m/yr)	≥ + 2.1 accretion	1.0 - 2.0 Stable	-1.0 - + 1.0 Erosion	-1.1 - -2.0 erosion	≤-2.1 Erosion
a6. Mean tidal range (m)	≤ 0.99 Microtidal	1.0 - 1.9 Microtidal	2.0 - 4.0 Mesotidal	4.1 - 6.0 Mesotidal	≥ 6.1 Macrotidal
a7. Mean wave height (m)	0 - 2.9	3.0 - 4.9	5.0 - 5.9	6.0 - 6.9	≥ 7.0

RESULTS

Having described the risk analysis procedure, its use is illustrated for selected beaches of the Illawarra coast. These beaches are Stanwell Park, Coledale, Bulli, Perkins, Warilla and Seven Mile Beach on the Illawarra coast and Moruya Beach due to availability of data.

The CVI values calculated for selected Illawarra and Moruya beaches range from 3.2 to 10.8. The mean CVI value is 7.8; the mode is 8.8 and the median is 8.8. The standard deviation is 2.5. The 25th, 50th, and 75th percentiles are 6.4, 8.8 and 9.6 respectively. Figure 1 shows the coastal vulnerability index for segments of selected beaches along the Illawarra coast. The CVI scores are divided into low, moderate, high, and very high-vulnerability categories based on the quartile ranges and visual inspection of the data. All the studied shorelines were found to have an erosion/accretion rate between -1.0 and +1.0 m/yr and are ranked as being of moderate vulnerability in terms of that particular variable. The rate of relative sea-level change is ranked using Australian rate of sea-level change eustatic rise (1.8 mm/yr) as moderate vulnerability. Mean wave height contributions to vulnerability rank very low (0- 2.9 m) and mean tidal range rank low (1.0- 1.9 m).

CVI values below 6.4 are assigned to the low vulnerability category. Values from 6.4 to 8.8 are considered moderate vulnerability. High-vulnerability values lie between 8.8 and 9.6. CVI values above 9.6 are classified as very high vulnerability. Figure 1 shows the percentage of selected Illawarra and Moruya shorelines in each vulnerability category. A total of 24.8 km of beach is evaluated and of this total, 9.1% of the mapped shoreline is classified as being at very high vulnerability due to future sea-level rise. 31.5% is classified as high vulnerability, 8.6% as moderate vulnerability, and 50.8% as low vulnerability (Figure 2).

DISCUSSION

The IPCC Common Methodology for assessing coastal vulnerability (which was designed for worldwide application) has a number of limitations and there have been problems with applying it directly in Australia (Kay et al 1996). However, it has been useful in stimulating further studies and development of derived methodologies and techniques for assessing coastal vulnerability which are suitable for the different legislation and coastal planning systems around Australia (Harvey et al., 1999). An important finding with the Northern Spencer Gulf study is that perhaps the threat of coastal vulnerability from sea-level rise is less important in some areas than the threat of human induced coastal hazards.

The variability of the CVI index is dependent upon the extent to which the contributing variables differ. In the case of the physical process variables there is almost no variability over the extent of the Illawarra shoreline. The geologic variables show the most spatial variability and thus have the most influence on CVI variability (Figure 1). The most influential variables in the CVI are dune heights, barrier type and beach type. Dune heights vary from low vulnerability at Seven Mile Beach to high vulnerability at Stanwell Park Beach, Perkins and Warilla Beaches. Barrier types vary from high vulnerability at Coledale and Bulli beach to low vulnerability at Seven Mile beach and Moruya. Beach types vary from very low vulnerability at Seven Mile Beach to high vulnerability at south Moruya Beach.

The purpose of CVI calculation is to assess coastal sensitivity to a rise in relative sea-level. This depends on the nature of the coast and impacts such as storm surges that accelerate coastal retreat and beach erosion. A modified version of the CVI of Gornitz (1991) presented here (Table 3) could be used to assess the sensitivity of Australian coastline. Table 3 could be adapted for a national assessment of vulnerability, in a similar way to the susceptibility mapping undertaken on the Canadian coast (Shaw et al. 1998).

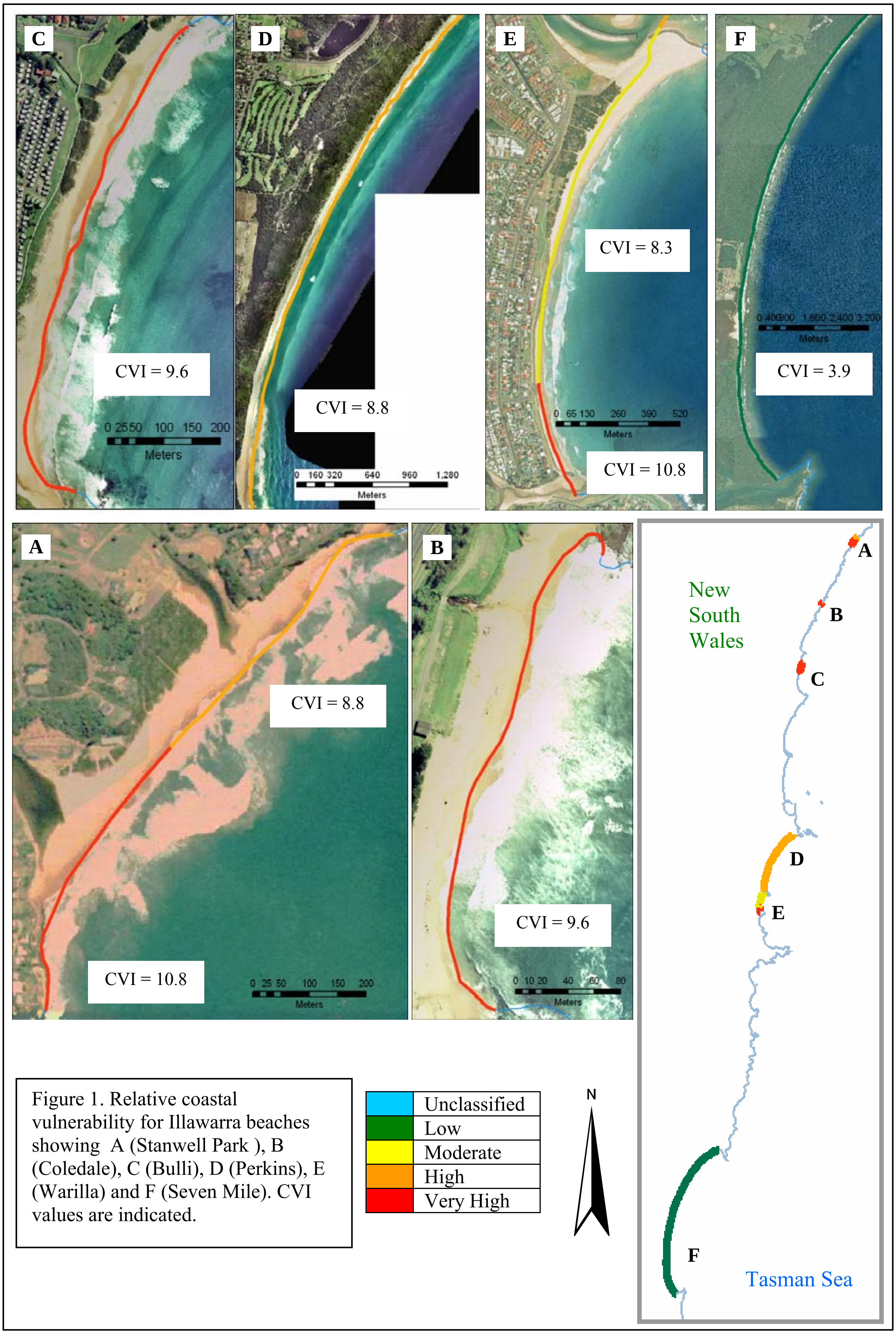

Figure 1. Relative coastal vulnerability for Illawarra beaches showing A (Stanwell Park), B (Coledale), C (Bulli), D (Perkins), E (Warilla) and F (Seven Mile). CVI values are indicated.

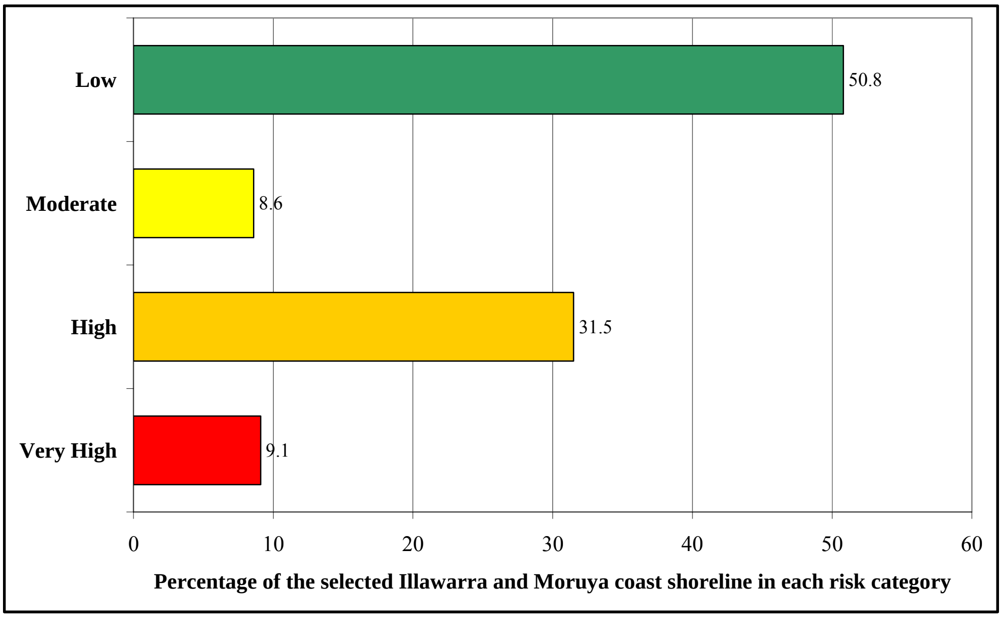

Figure 2. Bar graph showing the percentage of shoreline along the Illawarra and Moruya coast in each risk category.

Figure 3. Photographs of some of the studied beaches showing; A (Stanwell Park beach), B (Coledale beach), C (Bulli beach), D (North Perkins beach).

The CVI method yields a numerical metric, but this cannot be directly equated with particular physical effects; it does not measure rate of retreat, or volume of erosion. The index does not capture storm surge or sediment transport. It is important to incorporate social data on people at risk as in the synthesis by Boruff et al. (2005) who ranked coastal counties based on CVI and CSoVI. Social data have not been included in this study.

It would be possible to develop such a CVI for use at a variety of scales in Australia, including at a national scale to recognize those areas likely to be vulnerable. Once a high risk environment has been identified, detailed assessment of the impacts of sea-level rise may then be carried out on a case-study basis where appropriate. The vulnerability of the studied beaches to inundation due to sea-level rise appears primarily and directly related to dune height, barrier type and beach type. All the other variables remain the same and so do not provide much differentiation of vulnerability to sea-level rise or other hazards.

The CVI approach appears to offer potential for further development as a first-pass method of assessing the relative vulnerability of different parts of the coast. However, it remains to test whether the relative rankings correspond with the rates at which change is experienced on the coast. One means by which we propose to evaluate the index is to compare historical rates and patterns of change with the projected vulnerability index. Ultimately such a rapid assessment technique will not yield the precise indications of shoreline change that might be required at the local scale, but it may serve coastal managers as a first-pass tool for prioritisation. The choice of assessment technique in a region is dependent upon a number of factors including the required level of accuracy, data availability, technology and appropriate expertise (Bryan et al., 2001).

CONCLUSION

The coastal vulnerability index (CVI) may provide insights into the relative sensitivity of segments of coast to change in response to future sea-level rise. The maps and data presented here can be viewed in at least two ways: (1) as an indication of where physical changes are most likely to occur as sea level continues to rise; and (2) as a planning tool for the Illawarra beaches. As ranked in this study, dune height, barrier type and beach type appear the most important variables in determining the spatial variability of the CVI for Illawarra beaches. However it needs to be recognised that this is because discrimination between beaches is possible using the outcomes of beach morphodynamic and Quaternary geological studies. Relative sea-level change, shoreline erosion and accretion, mean tidal range and mean wave height do not contribute to spatial variability in the CVI. The Illawarra beaches are dynamic natural environments that must be understood in order to be managed properly. The CVI is one way that coastal managers can assess objectively the natural factors that contribute to the evolution of the coastal zone, and thus how the beaches may evolve in the future.

The CVI index developed in this study specifically applies to the selected beaches and the ranking obtained cannot be directly compared with other beaches in Australia or elsewhere in the world. In order to compare the vulnerability index between Australian beaches, a national assessment of beaches would need to be carried out extending the approach in Table 3. If validated, a similar approach could be extended to incorporate other coastal types such as coastal bluffs and cliffs, mudflats and estuaries, and perhaps even reefal shorelines.

The coastal vulnerability index is a static metric with limited predictive capability; it may be useful in prioritising decisions. Vulnerability classification can be performed in any number of ways and any number of classes can be constructed. In a sense, the specifics of vulnerability classification are not important. Preliminary regional vulnerability assessments can rarely provide absolute predictions about the impacts of sea-level rise. It may be preferable to use relative indices which provide information about the areas within a region most likely to be affected more severely than others, in order to determine those locations most in need of detailed local assessments.

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