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Development and application of GIS datasets for assessing and managing coastal impacts and future change on the central coast of Western Australia

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Abstract The coastal zone between Guilderton and Kalbarri, north of Perth, Western Australia, is a highly dynamic area of high landscape and conservation values under increasing development pressures. Intensification of terrestrial and coastal impacts has highlighted the need to develop a georeferenced data base for land management. The Coastal Assessment and Restoration project aimed to document the natural resources and coastal developments to the region and to identify & assess threats to the coastal strip through the creation of GIS datasets. GIS datasets provide a key source of reference information which can be accessed by a number of stakeholders for future coastal planning and management and provide a basis for developing a risk management assessment of the coastal zone and a strategy for coastal managers in our climate change future.

Keywords Coastal zone management · GIS · Spatial analysis · Risk · Climate change · Western Australia

Abbreviations

CAR	Coastal Assessment and Restoration
ESRI	Environmental Systems Research Institute
GIS	Geographic information system
IPCC	Intergovernmental Panel on Climate Change
NACC	Northern Agricultural Catchments Council
NAR	Northern Agricultural Region

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Introduction

The coastal zone of south-western Australia north of Perth (at latitude 32°S) to the rural centre of Geraldton (latitude 29°S) and northward to Kalbarri (latitude 27°S) is sparsely populated over a distance of some 500 km with scattered small coastal centres which service fishing operations, rural activities and coastal and terrestrial recreation (Fig. 1). Much of this coastal landscape consists of aeolian limestones and poorly consolidated calcareous dunes vegetated by coastal heath and open woodland. The relatively undeveloped hinterland is bordered by white sandy beaches interrupted by rocky headlands with seagrass substrates offshore. Through a combination of low population density and dispersed land use the region has retained its values for both traditional commercial uses and recreation, tourism and conservation activities. A lack of sealed roads in the coastal zone has seen the growth over the last 50 years of four wheel drive vehicle track networks which provide coastal access and service small, unofficial coastal settlements which are used for residential and recreational purposes.

The growth in population along the Australian coastline and resulting intensification of land use is increasing pressure on the environment in many areas (Standing Committee on Climate Change, Water, Environment and the Arts 2009). The impending intensification of terrestrial and coastal impacts highlights the need for a new perspective on coastal management. This paper outlines the Geographic Information System (GIS) component of the Coastal Assessment and Restoration (CAR) project for the Northern Agricultural Region (NAR) of Western Australia. The project was undertaken in partnership with the Department of Environment and Conservation (DEC) and funded by the Northern Agricultural Catchments

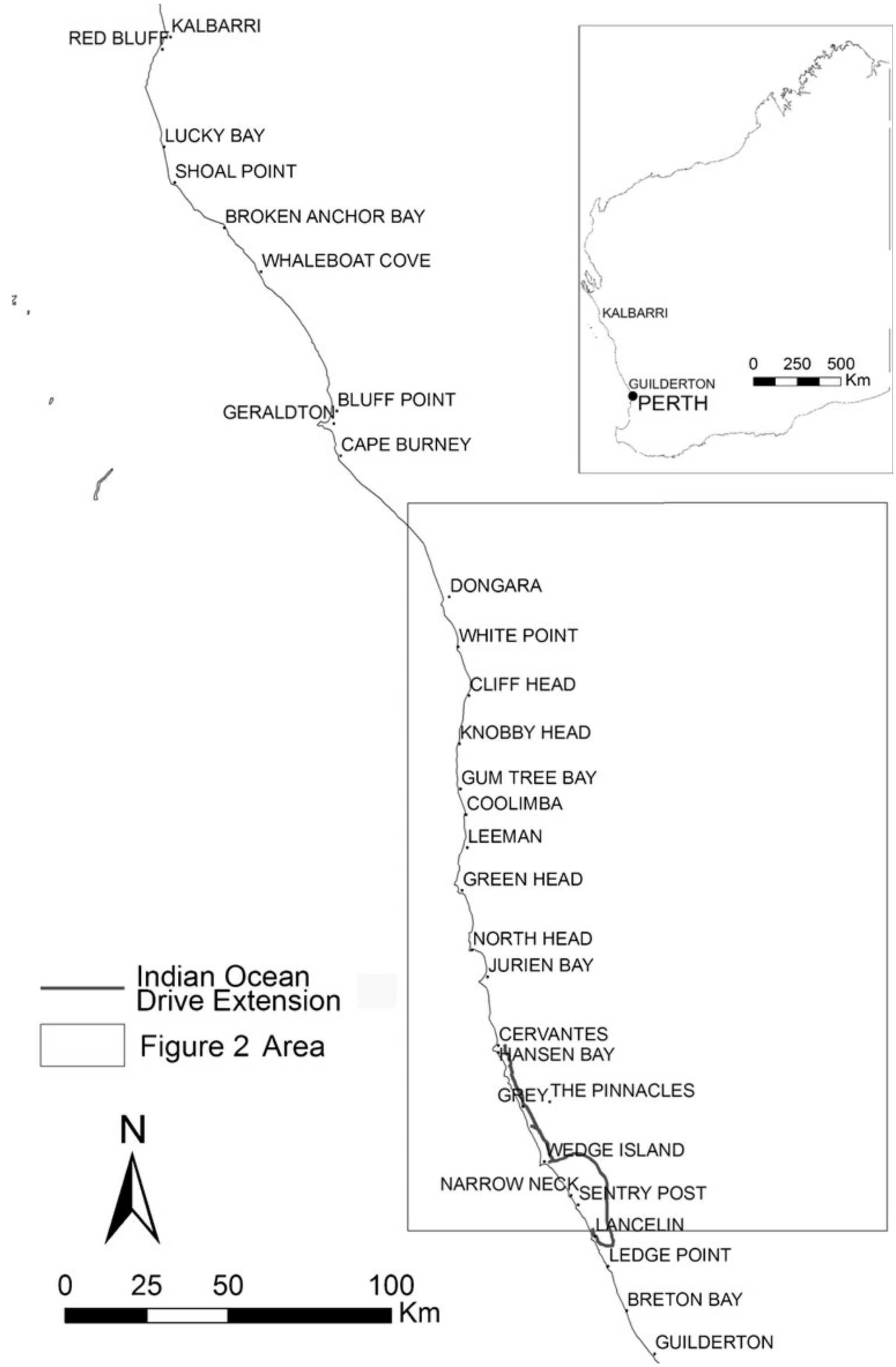

Fig. 1 Study Area

Council (NACC). The purpose of the CAR project was to document the natural resources and coastal developments of the NAR, to identify and assess threats to the coastal strip through the creation of GIS datasets and to address those threats through proposed on—ground work such as track consolidation.

The NAR extends from Guilderton to Kalbarri (Fig. 1), encompassing some 500 km of coastline. The coast of the NAR is defined as the 'narrow strip of mainly sandy deposits of Holocene (last 10,000 years) age along the coast, varying in width between 1 and 10 km, with most areas being about 5 km' (NACC 2005) and is the focus of sometimes competing land uses including increasing development, nature based tourism, four wheel driving, fishing, surfing, camping, squatters shacks, pastoral and military activities. With the extension of the Indian Ocean Drive between Lancelin and Cervantes (Fig. 1) landuse patterns, impacts and pressures will change as areas previously accessible only to four wheel drive vehicles become available to the wider community. Human pressure on the coastal zone was recognised as a crucial issue in coastal management at the 1992 United Nations Conference on Environment and Development (Vallega 2005) and this is especially true in Australia where over 80% of the population lives in the coastal zone (IPCC 2007) and all the State Capitals are on the coast (Department of Climate Change 2009). By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding (IPCC 2007). In the light of these projections the GIS datasets developed provide a dynamic database for ongoing coastal management and conservation.

Regional setting and management context

The project area covers the strip of high energy, wave and wind dominated and low sediment supply coastline between the coastal towns of Guilderton and Kalbarri (Fig. 1). The coastal zone is predominantly sandy beaches interspersed with rocky outcrops and cliffs, particularly in the north, while the coastal landscape is dominated by extensive mobile dune sheets in the south with less numerous large dune sheets and smaller mobile dunes to the north, coastal foredunes, linear beach ridges, hummocky dunes and blowouts. The coastal plain rises gradually inland to a limestone plain throughout the project area.

The geology of the area is dominated by both stable and extensive Holocene mobile aeolian dunes and vegetated linear and parabolic dunes which are interspersed with Pleistocene (last 2 million years) Tamala Limestone in small areas along the coast and larger areas further inland. Exposed limestone dominates the topographic highs of the area and much of the coastal dunes and sand overlies the older limestone to varying depths. The mobile dunes are blanket-like deposits of Holocene sediment overlying the Tamala Limestone. Where the Tamala is significantly exposed the area is more likely to be on the older, more stable Spearwood Dune System rather than the younger Quindalup Dune System (see Fig. 2).

The geomorphology of the area from the coast inland comprises foredunes, beach ridges, blowouts, linear ridges, mobile dunes with scattered hummock dunes along the edges throughout. Linear dunes were built inland during Holocene time; sea level regression formed linear beach ridges which have eroded to form individuated hummock dunes closer to shore. Further inland is an extensive flat limestone plain with occasional small ridges and steep sided cemented hummocks; this is in marked contrast to the coastal area and is a direct consequence of the change in geology from sand to limestone. Sand is present as a thin veneer over limestone which is often exposed where the sand has been eroded, such as areas of high traffic (tracks) or wind deflation. Surface limestone is microkarstic with calcrete (secondary carbonate deposits) and dominates the topographic highs where it is thinly covered and close to the surface. Hummock dunes (Elliot et al. 2000) are small aeolian dunes formed around remnant vegetation on devegetated dunes and on the edges of mobile sand sheets (Fig. 3).

Extensive mobile sand sheets dominate the landscape of the southern part of the region and can be found mainly along the coast. Also, along the coast are steep sided beach foredunes, rocky headlands and cliffs. Inland from the dunes are hummocky dune ridges and linear dune ridges with a general north–south trend. The dune systems, coast and shoreline movement of the NAR are highly dynamic and subject to seasonal change. During winter storms beaches may be eroded to the foredune face.

Geomorphologically the area is elongate north–south with large, low lying areas and dunes, rising more than 100 m above sea level. The soft sandy coastline makes for a dynamic, often eroding, foreshore where the primary dune is alternately built and eliminated seasonally or by storm seas (CALM 2000). The area has high conservation and recreational values, with the conservation estate managed by DEC and the remaining area either managed by local and state government or owned by private landholders.

Coastal types

The coastal morphotypes recognised in the study area are similar to those described by Priskin (2003) with some modifications to include the area between Dongara and Kalbarri (Table 1).

The NAR coast is dominated by straight stretches of exposed sandy coast with offshore limestone reefs and islands. Long stretches of rocky coast are rare mainly alternating with sandy coast and embayments. The dominance of sandy coast was confirmed by analysing the intertidal attribute of the Smartline dataset (Sharples et al. 2009) which defined 72% of the NAR coast as sandy beaches. Sharples et al. (2009) defines the intertidal as ‘areas regularly but not permanently inundated and washed by waves’.

There are 3 prominent cuspate forelands in the region, considered at high risk of climate change impacts due to their low lying nature. Two of these, Jurien Bay and Cervantes, are significant population centres under increas-

Fig. 2 Physiography and major drainage from Lancelin to North of Dongara (Mory and Iasky 1996). Note position of Quindalup and Spearwood Dunes. See Fig. 1 for location

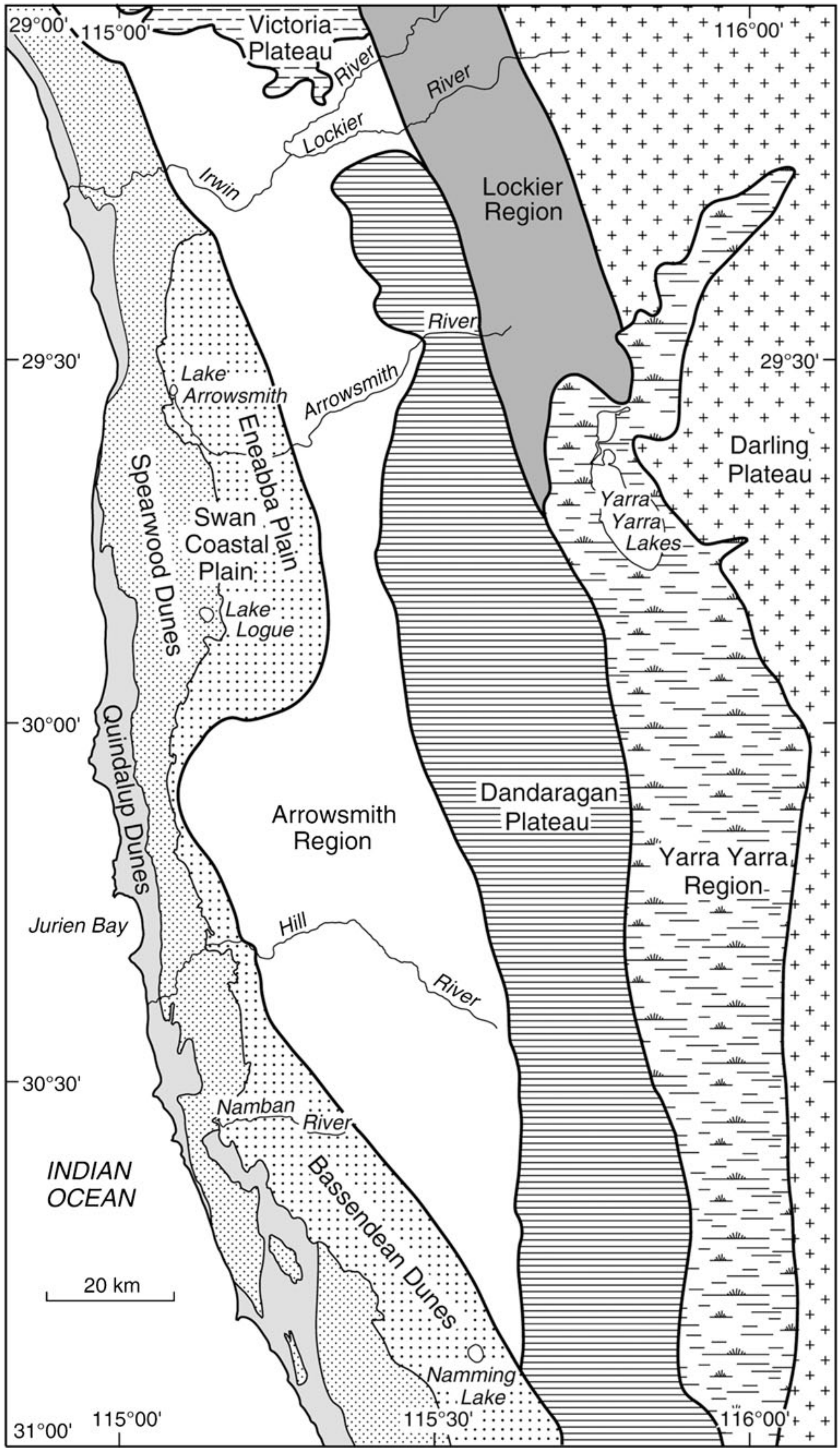

Fig. 3 Hummock dune as part of a devegetated dune mobilised by fire damage, 5 km south of Cervantes (see Fig. 1 for location)

ing development pressure. The third is adjacent to Wedge Island, is part of the Nilgen Nature Reserve and is home to the main unofficial shack settlement of the NAR. It is unlikely this area will ever be extensively developed, however there are long term plans (CALM 2000) for low impact ecotourism including day visits and overnight accommodation dependent upon the removal of squatter shacks and rehabilitation of the area.

The vegetation of the area was described by Beard (1975a, b, c, 1979) and from the coast inland are generally grasses (native and introduced) and low lying shrubs due to the windswept and unprotected nature of the coastal zone. The foredunes are vegetated with 'dune grasses, salt bush and associated communities' (CALM 2000), but these are rapidly lost in areas of high foot and vehicle traffic exposing the dunes to wind and erosion. The loss of vegetation on a dune creates areas of loose unstable sand which are highly susceptible to wind erosion. Elsewhere vegetation stabilises the dunes as the vegetated portions create a baffling effect by trapping sand while the root system binds and stabilises the sand. The most exposed areas such as drift sands are not totally devoid of vegetation but tend to be sparsely vegetated around their edges with small scattered vegetated hummock dunes. Further inland coastal heath and shrub land develops which is dominated by *Acacia*, *Banksia* and *Melaleuca* species with scattered stands of Mallee, Wandoo and York gum.

The NAR has a number of coastal and inland towns, one city, Geraldton, and a small number of squatter/fisher shack settlements dispersed along the coast. The majority of the NAR's coastal activity nodes are generally found within or in close proximity to the 'area of influence' of inhabited areas.

Much of the land along the coast is either conservation estate, agricultural land or population centres such as towns. Fisher shacks such as at Coolimba, south of Leeman, are generally on Crown reserve while the 'unofficial' shack settlements of Wedge and Grey are within Nature Reserve and National Park respectively and are gazetted as 'unvested, unclassified reserves as a temporary measure to enable the implementation of the State Government Squatter Policy' (CALM 2000). Within population centres land use is for residential, recreational, industrial and government purposes.

Table 1 Coastal morphotypes of the central Western Australian region, modified after Priskin (2003). See Fig. 1 for locations

Coastal type	Description	Locations
Straight coast	Predominantly straight & exposed sandy coastline.	Between Guilderton and Breton Bay, South of Jurien Bay, Cliff Head, South and North of Dongara, South of Whaleboat Cove, Lucky Bay, Cape Burney and Bluff Point, North of Red Bluff
Cuspate forelands	Occur along sandy coasts and are separated by large embayments. Develop along wave dominated coasts in the lee of islands and where reefs outcrop.	Wedge Island, Cervantes and Jurien Bay
Sandy embayments between small salients	Salients occur along the coast separated by medium to large embayments and are associated with sandy beaches of variable lengths. Exposed limestone reef often occurs in the nearshore zone.	South of Ledge Point, Lancelin Wedge Island and Shoal Point. Gum Tree Bay. South and North of Knobby Head.
Rocky promontories and small bays	Small sandy bays occur between rocky promontories and tombolos. These are associated with reef outcrops close to shore, reef pavements along shore and islands. Sandy beaches in these small embayments have varying degrees of exposure.	North of North Head and Green Head
Sandy embayments between forelands	Forelands and salients occur along sandy coasts and are separated by small to medium embayments. Forelands develop in the lee of islands in the nearshore zone and where reefs outcrop.	South of Sentry Post and Hansen Bay, Hansen Bay, White Point South of Geraldton
Alternating rocky coast and sandy embayments.	Predominantly rocky shoreline with frequent headlands and bluffs. Stretches of sandy beaches occur between headlands.	South and North of Grey, South of Green Head, South and North of Leeman, South of Broken Anchor Bay
Steep rocky cliffs	Steep to almost vertical high rocky cliffs.	South of Red Bluff

Outside of these centres land use is predominantly agricultural, conservation and recreational.

Wilderness values, recreation and coastal access provide the main attractions to the area. These attractions include four wheel driving, tourism values such as at the Pinnacles 'desert', a 'forest' of limestone columns, and the stromatolites at Lake Thetis, as well as fishing, boating, surfing, wildflowers and visiting the coast and dunes. These activities create their own issues and 'hotspots' including shack settlements, tourism nodes, coastal access nodes and conservation, management and development issues. The main coastal access to the area, especially in the south, is via an extensive system of uncontrolled four wheel drive tracks leading off main roads and 'controlled' access areas such as car parks and camping areas.

One of the most significant issues for the NAR coast is the extensive coastal track system that has developed over more than 40 years of unregulated access. This can be considered a consequence of a desire to access wilderness areas and recreation 'hotspots' in parts of the coast where controlled access, such as via roads, is not available. Four wheel drive vehicles and even foot traffic can cause significant damage to dunes and vegetation; the small mobile dune at Grey is a prime example of the consequences of uncontrolled access. The foredune has become devegetated and destabilised and has developed into a 'large mobile dune which is 'defying attempts to stabilise it' (CALM 2000), see Fig. 4.

Access to the Wedge Island settlement from inland is via a large dune sheet which is significantly devegetated, such that ongoing vehicle traffic has the potential to further destabilise the dune (Fig. 5). The presence and nature of the shack settlements is a significant issue in the southern part of the NAR. The settlements are focused nodes of relatively uncontrolled human habitation and activity which impact on the settlement area and the surrounding coastal zone.

Whilst the large dune sheets are naturally mobile, in light of climate change bringing with it sea level rise and increased erosion, monitoring of those dunes close to the coast can be undertaken using the GIS datasets and new orthophotos as they become available (Fig. 6). Further analysis of the current dune datasets can be used to determine those dunes most at risk from anthropogenic change such as the dunes at Lancelin which are used by off

Fig. 4 Foredune blowout at Grey Shack Settlement overwhelming coastal shacks, looking north

Fig. 5 Dune sheet to the east of Wedge Island settlement; note devegetation, vegetated hummocks and extensive vehicle track marks, looking east

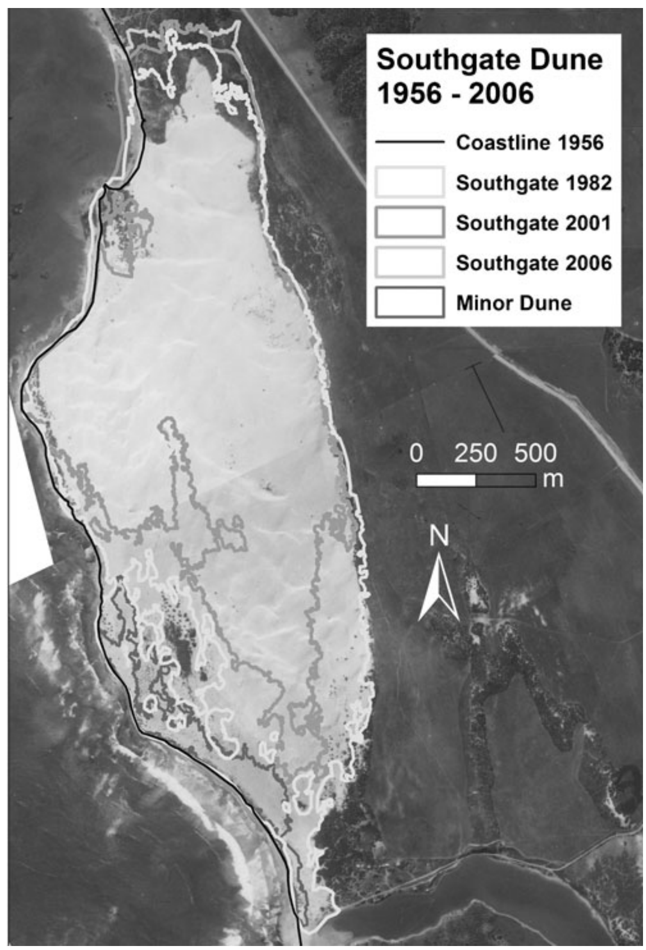

Fig. 6 Movement of the Southgate dune south of Geraldton (see Fig. 1) over 50 years from 1956 to 2006, note the amount of movement along the eastern and western edges of the northern end of the dune and the effect of tracks on the movement of the dune. Aerial photographs sourced from University of Western Australia and DEC

road vehicles and the numerous blowouts along the coasts. The mobile dunes are also used for recreation, including four wheel drive vehicle activities and sand boarding by tourist groups and local people.

Development in the region, both for residential purposes and the associated infrastructure places pressure on the coastal zone as it brings with it increased population pressure and a resulting desire for greater access to the coast. Coastal access nodes are numerous along the NAR coastline. This creates traffic in an unstable zone, such as through coastal foredunes which are susceptible to devegetation and, consequently, erosion. Damage is not restricted to the coastal node but extends around the node as turning areas are created and foot traffic further degrades the area (Figs. 7 and 8).

The NAR coast is a highly sought and dynamic area under increasing anthropogenic pressure. The CAR datasets provide stakeholders and coastal planners and managers with a 'decision support system involving the integration of spatially referenced data in a problem solving environment' (cf Cowen 1988).

As a response to issues and emerging problems the CAR GIS was established to document the region's values and problems that need to be addressed on a regional basis by coastal managers. The overall percentage of degraded area in the region is small but there is the potential for this to grow given the fragility of the coastal environment.

Methods

Regional GIS datasets covering 500 km of coast and extending up to 10 km inland were compiled to document available land information into an electronic database to provide a management tool which is georeferenced, can be updated, is responsive to change, has analysis capabilities and can be expanded through additional data layers. The datasets are also designed to provide a mapping framework for on—ground works which form an integral part of the CAR project.

Fig. 7 Example of a large vehicle turning area causing extensive devegetation and erosion at Narrow Neck (see Fig. 1 for location), looking east

Fig. 8 Devegetated and eroded foredunes from foot traffic on the northern side of the vehicle access at the 'Sentry Post' (see Fig. 1 for location) south of Wedge Island settlement

Using GIS, different types of geographic data from the same area can be integrated. These data can be queried and have value added to it or certain features derived from it. The coastal GIS datasets provide a system for creating and managing spatial data and associated attributes linking management, values, landforms, and ecosystems. They combine different types of data from different sources for the same geographic area. The GIS is, essentially, a decision enabling tool. From a coastal managerment point of view it serves as a decision support system.

The CAR GIS database contains five key elements plus other miscellaneous layers which are divided into sub-elements that can be mapped. (Fig. 9). Layers can be viewed singularly or overlain and viewed simultaneously.

Data were sourced from the Department of Environment and Conservation (Aerial Photos, Digital Elevation Model (DEM), shapefiles) and the Geological Survey of Western Australia: (Geology). The GIS datasets were created in ESRI's ArcGIS 9.1 and 9.2 and are compatible with other ESRI products such as ArcView and ArcExplorer where the datasets are converted to shapefiles. The coordinate system for the datasets is GDA1994 and Projection MGA50. The final GIS product is a Geodatabase with feature datasets

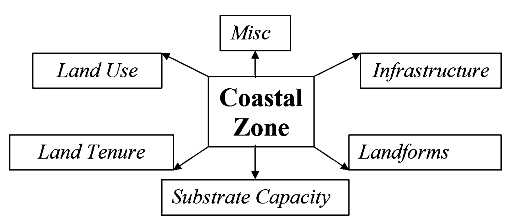

Fig. 9 Key elements of the coastal GIS database. The boxes represent datasets which contain layers that can be viewed singularly or superimposed

and classes/layers containing vector data (point, line and polygon). The datasets were either sourced from DEC and modified for the purpose of the project or created and digitised using orthophotos supplied by DEC. The modified features were land tenure and localities and the digitised features were landforms, infrastructure and landuse. The data and finished product are held by NACC and are in use by DEC.

Substrate capacity

Substrate capacity (SC), as used in this study, was devised by Blackwell (2002) as a modification of the scheme of Gonzalez et al. (1995) and is a semi-quantative measure of the capacity of a geomorphological or land unit's substrate to withstand environmental impacts from natural processes and/or land use activities. Substrate capacity index (SCI) was used to enhance land unit descriptions by incorporating a unit's capacity to withstand impacts. A scale of 1–5 was used to assign a low to high SCI, dependent on unit characteristics, particularly thickness, topography, stratigraphy, constituents and consolidation (Tables 2).

For the CAR project the method used to determine SCI was modified slightly from that used by Blackwell (2002) with the creation of a separate slope layer. A DEM with the capacity to produce contours to a resolution of 2 m was used to produce the slope layer in the substrate capacity datasets. Dunes and tracks, digitised from orthophotos, were also incorporated as a distinct feature within the substrate capacity datasets.

The final substrate capacity datasets contain geomorphology, geology, tracks, dunes, slope and a combined SC layer incorporating geology, dunes and tracks. Geology data was sourced from the Geological Survey of Western Australia (GSWA) in the form of shapefiles and digitised maps which were georeferenced and converted to shapefiles with the same attributes as the sourced shapefiles. The shapefiles were joined using the 'Union' tool in ArcGIS and a SCI was assigned to each geological unit based on the characteristics of the unit.

Tracks were digitised from orthophotos and, for the purpose of incorporation into SC, a buffer of 25 m (12.5 m either side from the middle of the track) was applied to the layer. This distance is the width of multiple parallel (up to 5) tracks and was determined by Blackwell (2002) to be the 'zone of influence' of the track. Based on on—ground data this is the area that may potentially to be affected by a track or its modification. Dune areas were digitised from orthophotos and cover a variety of dune types from track blowouts to large mobile dunes. Both the track and dunes were assigned a SCI of 1 indicating a low capacity to withstand pressure from anthropogenic influences, erosion and/or devegetation.

Two slope features were created using the DEM sourced from DEC, a low resolution dataset extending 10 km inland and a finer resolution dataset extending 2.5 km inland. The two different datasets were created due to file size limitations. The finer resolution dataset provides detailed data close to the coast which is considered the more vulnerable area due to its younger geology which, due to its generally less consolidated nature, has a lower substrate capacity whereas the lower resolution dataset provides slope for the entire project area. The final components of the SC datasets were slope, combined dunes and tracks and two SC layers. The first layer incorporated substrate capacity and a geological description, the second layer was substrate capacity only (Fig. 10).

The slope layer for substrate capacity was created using the DEM. Slope was determined using degrees and then reclassified using qualitative values to provide a simple means of assessing the slope characteristics of an area. Table 2 above outlines the slope values which are a modified version of the boundaries determined by Gozzard (1989) and Hahesy (2004) in similar studies. The reclassified feature was converted to a polygon shapefile for ease of integration and use with the rest of the substrate capacity data (Fig. 11)

Table 2 Unit characteristics for the development of a substrate capacity index (SCI) for the coastal units of the CAR project. Risk zones are those where high use coincides with low SCI (after Blackwell 2002). SCI and slope are independent variables but are related and coincident

Substrate capacity index	1	2	3	4	5	
Characteristics	Very Low	Low	Medium	High	Very High	
Consolidation	Completely Unconsolidated	Unconsolidated	Semi consolidated	Semi consolidated	Consolidated	
Unit Thickness	Thick unconsolidated units over limestone base	Thick unconsolidated units over limestone base	Medium thickness units over limestone base	Medium thickness units over limestone base	Composed of solid rock unit	
Slope						
Slope (Degrees)	45–90°	30–45°	20–30°	10–20°	3–10°	0–3°
Characteristics	Very Steep to Cliff	Steep	Moderate to Steep	Moderate	Gentle	Flat

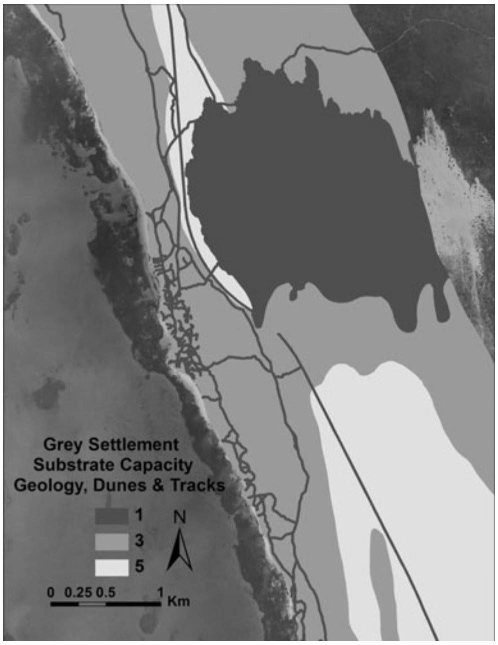

Fig. 10 Example of substrate capacity layer overlain on an aerial photo showing the capacity of the area to withstand pressure, note the mobile dunes and extensive track network; 1 indicates low SC, 3 moderate SC and 5 high SC. Location is the Grey squatter settlement (see Fig. 1 for location)

To further determine those areas of high use and high risk in order to highlight the areas of the NAR requiring the most intensive management the method employed by Blackwell (2002) for determining high use areas was modified slightly for ease of use. In order to separate high land use zones from low to medium use zones a cut off point of 280 m of track or 7,000 m^2 of buffered tracks in a 4-hectare square was used. The cut off was devised by Blackwell (2002) from both quantitative and qualitative methods and was determined as the most suitable separation between average and high land use. A grid of 4 ha squares was intersected with the buffered track layer creating an 'intersection' layer. From this intersection layer areas 7,000 m^2 and greater were extracted to create a 'high use zones' layer. This layer is intersected with the substrate capacity layer to determine areas of high use and low capacity, low capacity being an SCI of 1 or 2 with an SCI of 3 considered low to moderate and an SCI of 4 or 5 considered moderate to high capacity. It is then possible to extract those areas considered most at risk for ongoing monitoring and management. There are some limitations to this method mainly relating to the positioning of the grid and the scale of the geology layer which introduce small but tolerable inaccuracies.

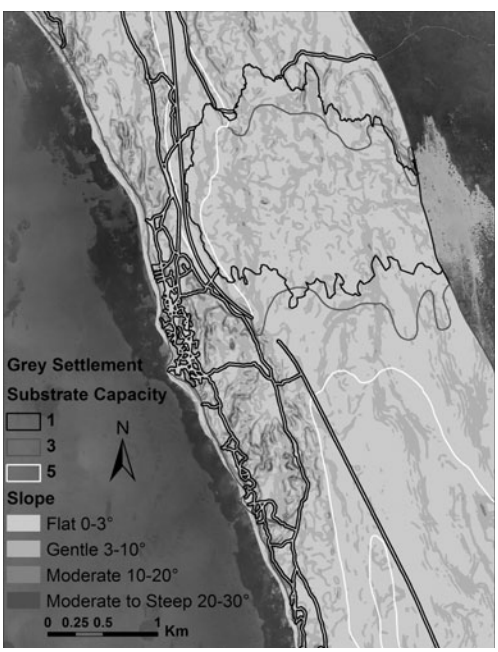

Fig. 11 Example of substrate capacity layer overlain on the slope layer and aerial photo, location is the Grey squatter settlement (see Fig. 1 for location)

Results and discussion

Benefits of a regional coastal GIS

GIS analysis helps users answer questions concerned with geographical patterns and processes (Malczewski 2004). The CAR GIS documents the coastal resources of the NAR on a regional scale, providing an essential overview for identifying the vulnerabilities and present status of the coast. An appropriate combination of layers will identify areas susceptible to future change or at greatest risk. The GIS datasets provide a monitoring tool for environmental change and a decision support package for future coastal planning at a number of levels with the results enabling effective planning and implementation of management strategies such as track closures and rationalisation and coastal infrastructure planning and placement.

It should be emphasised that the GIS datasets delivered a coastal planning and management product and metadata package which is a practical instrument that has been adopted by coastal managers and incorporated into coastal management strategies in the region. One of the significant benefits of GIS data is that they are not a static entity; they provide a dynamic database that can be updated to reflect on—ground work, new data and developments as changes occur to ensure the data retains its currency.

The datasets have aided in identifying problem areas/locations and providing insight into issues that require management and assessment. Problems specific to the area, such as the extensive coastal track system have been highlighted and insight gained into their regional and local impact through analysis of the data. The datasets will further aid in identifying suitable areas for on—ground works, such as track consolidation, and mapping on—ground change. The GIS datasets have the capacity to incorporate updates as required or on a regular basis as other related data, such as aerial photography, is updated or new data sourced.

The NAR coastal zone is highly dynamic and is an area of high landscape and conservation values (Table 3). The coast has a number of vulnerabilities; mobile dunes, devegetation and blowouts, and hazards; potential sea level rise, storm surge, tsunami and cliff collapse. These need to be taken into account when planning on—ground works for track consolidation and siting of facilities such as campsites.

Throughout the NAR off road driving, mainly using four wheel drive vehicles, has resulted in an extensive track network within 2.5 km of the coast. GIS based statistics, calculated from track data, show that these tracks are the most serious management issue in the region (Fig. 12). Within 2.5 km of the coast, in an approximately 1,250 km^2 area, there are about 1,960 km of tracks; overall there are about 2,200 km of non-agricultural tracks within 10 km of the coast.

The extensive track system is a consequence of the offroad capability provided by four wheel drive vehicles and the desire to access the coastal zone, even where it is regulated such as between Lancelin and Cervantes and Sandy Cape north of Jurien Bay (Fig. 1). There are limited sealed roads close to the coast, especially in the southern part of the region between Guilderton and Cervantes and tracks are often the only means to access the coast for camping, fishing and surfing. These access points or coastal access nodes have a significant impact on the area surrounding them, from both vehicle and foot traffic, which widens the area of impact of the node. Where they are through the unstable foredune areas these become devegetated and are more susceptible to erosion through a combination of human use and natural processes (Fig. 13).

The shack settlements in the NAR are a significant conservation and management issue. CALM (2000) states that the 'settlements are unplanned, uncontrolled and have an adverse effect on the fragile coastal environments they are located on'. Current settlements are at Wedge Island and Grey and former settlements where the shacks have been removed or only fisher shacks now remain can be found mainly between Leeman and Dongara and at North Head north of Jurien Bay (see Fig. 1 for location). Fisher settlements are regulated by the fishers and have a reduced 'footprint' in comparison to the unregulated settlements; however, they still impact the fragile coastal environment in the form of degradation and possible pollution from fuel spills and other accidents. An issue that has arisen with the removed settlements is unregulated camping, such as at and near North Head (Fig. 14), and some of these areas remain as unregulated access nodes to the coast. North Head and the surrounding area are now the focus of an extensive effort to rehabilitate the area addressing erosion problems and track rationalisation by closing off replicated and badly positioned tracks. This will control vehicle access to the area by restricting access to the headland while still allowing controlled 'foot traffic' access through the creation of walking paths and boardwalks and the positioning of lookouts around the headland.

The areas surrounding the settlements of Wedge and Grey (Fig. 1) are Nature Reserve and National Parks respectively with high conservation values. The settlements are environmentally degraded with extensive track systems, introduced fauna and flora and localised disturbance around shacks and access points. At Wedge and Grey the squatter shacks and associated recreational land use, development of multiple vehicle and pedestrian tracks, unregulated camping and poorly sited buildings has led to the degradation and erosion of the settlements and surrounding landscape

Table 3 Attractions and Issues of the NAR coastal zone

Activities	Visitor attractions	Conservation & management issues
Four wheel and off road driving	Landscape related activities	Tracks (quantity, uses, degradation, proliferation)
Coast and coastal zone access for a variety of activities	Recreation	Coastal access nodes (access related issues)
Camping	Coastal landform experiences	Land degradation, waste disposal, access tracks
Fishing	Coastal & Marine values appreciation	Coastal degradation issues, access management
Surfing	Coastal uses	Coastal impacts, access issues, fire hazards
Unofficial settlements for temporary and permanent residents	Coastal Access, fishing, boating	Squatter settlements (presence, management and future)
Dune & Landscape Visits	Wilderness values appreciation	Access issues—frequency and intensity
'Wilderness'/remoteness appreciation	Coastal access, Wildflower touring	Coastal degradation issues, access management
National Park Visits	Landform & wildflower experiences	Access Management

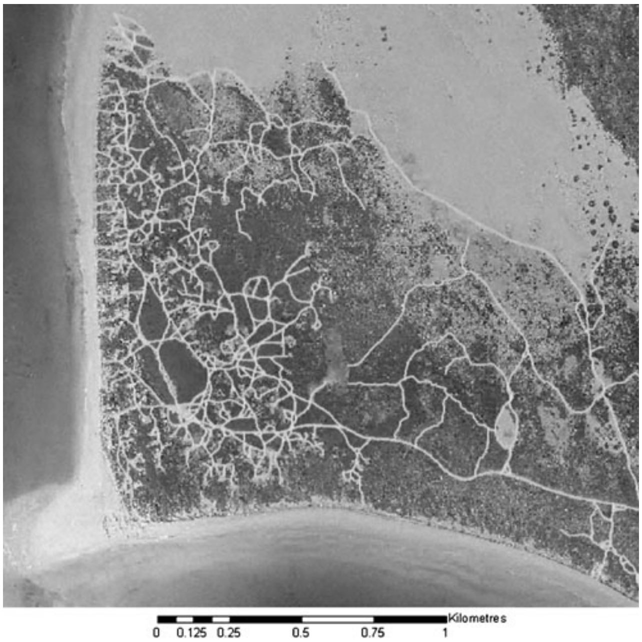

Fig. 12 Map of the tracks through the Wedge Settlement (see Fig. 1 for location), showing the proliferation of tracks in a fragile area, note mobile dune to the north. Aerial photo sourced from DEC

(CALM 2000). It is the 'ad hoc nature of shack development at Wedge and Grey that has resulted in the proliferation and duplication of vehicle tracks' in the Lancelin to Cervantes sector and 'most tracks have been established for convenience rather than necessity' (CALM 2000). At the Wedge Island settlement there are some 40kms of tracks, which is about 2% of the entire track network in less than 0.2% of the entire project area, within 2.5 km of the coast (Fig. 12).

At Grey an uncontrolled coastal access node has caused a foredune blowout (Fig. 15) which, as previously noted, 'has defied attempts by the Grey community to stabilise it' (CALM 2000).

The beach adjacent to the blowout is a 'pocket' beach subject to south to north long shore transport of sediment directly into the unstable area. Therefore, a long term sediment supply exists to feed the blowout. The Grey blowout demonstrates the fragility of coastal foredunes; continued uncontrolled access has devegetated the dune destabilising it and releasing a large amount of mobile sediment which is actively migrating.

Fig. 13 Devegetated and eroded foredune at the 'Sentry Post' (see Fig. 1 for location), south of Wedge showing the impact of vehicle and foot traffic on a foredune area

With the provision of a new sealed highway extension between Lancelin and Cervantes the "Indian Ocean Drive" will provide easy access to this remote and fragile coastal region and land use patterns through the area are likely to change. Whilst it is government policy to remove the unofficial coastal settlements (Selwood and May 2001) there will nevertheless be increasing land use pressures accompanying improved coastal access to a previously inaccessible area for recreational and other vehicles, as well as extension of coastal towns and their associated urbanisation along what has been promoted as the 'Turquoise Coast'.

Development in the area, both infrastructure and residential, places increased population pressure on a fragile zone. Appropriate residential setbacks are essential to protect against storm surge and sea level rise. New developments, such as the sealed highway from Lancelin to Cervantes, will increase traffic through the area and provide access to new areas for visitors and tourists. Increased visitation to the area for recreation and other purposes will also increase as will coastal access, urban development applications and pressure on current infrastructure and facilities.

Analysis of the substrate capacity dataset

Substrate capacity is a regional terrain assessment method developed with management concerns in mind. Substrate characteristics are defined in terms of the interconnectivity of rock/sediment type, constituents, consolidation, vegetation cover and runoff potential. The overall capacity of a land unit to withstand change based upon those variables is defined as 'substrate capacity' (Blackwell 2002). The substrate capacity component of the CAR GIS documents substrate capacity, providing coastal managers with the capability to distinguish spatial variations in capacity to withstand natural and anthropogenic impacts.

Analysis of the dataset which extends 2.5 km inland indicates that lower SCIs of 1–3 cover almost 61% of the area (Fig. 16), whereas 10 km inland the higher SCIs of 4–5 cover almost 66% of the area. When compared with the SCI of the buffered track area the lower 3 SCIs dominate both close to the coast and further inland, it should be noted that the majority of tracks are close to the coast, especially in the northern part of the area. Analysis and comparison of the substrate capacity data has shown trends in the distribution of substrate capacity in the 2 datasets which extend 2.5 km and 10 km inland respectively. These trends

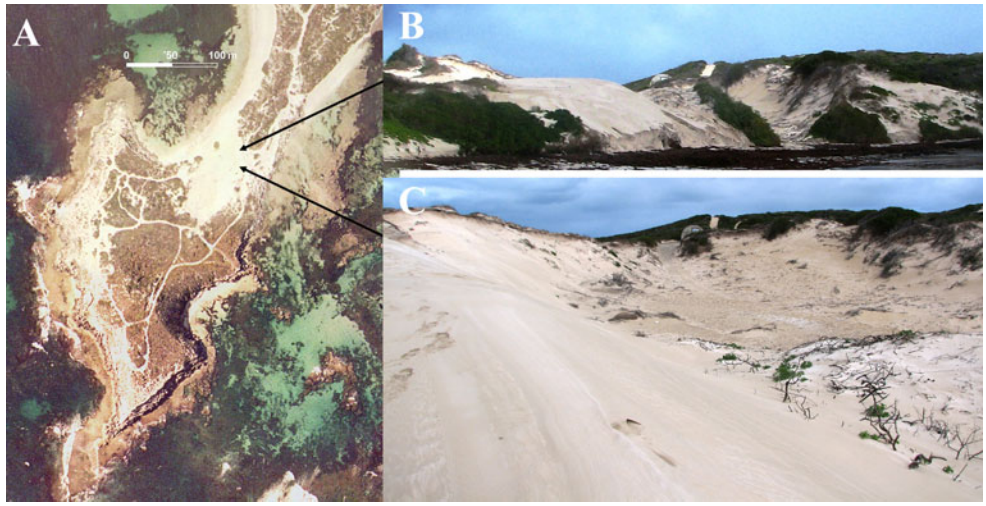

Fig. 14 North Head composite figure showing an aerial view of North Head (see Fig. 1 for location) and accompanying location photos, note the almost complete bisection of the headland by the mobilised dune in A. B was taken from the beach to the north of North Head. C was taken from on top of the northern end of the mobile dune

further highlight the significant issue of the vulnerability of the coastal zone to pressure, as indicated by the lower SCIs dominating the area closest to the coast, and the problem posed by the proliferation of access tracks along the coast, especially in those areas under greatest pressure such as coastal access nodes, locations within and surrounding coastal towns and unregulated shack settlements.

Analysis of the high use layers determined as outlined in methods has shown that some 17% of the area can be considered high risk (SCI = 1&2) and just over 56% is high to moderate risk (SCI = 3)while the remaining 27% can be considered as moderate to low risk (SCI = 4&5) (Fig. 17). Analysis of the occurrence of the high use vs. SCI for the north and south of the area and the area up to 2.5 km inland from the coast show similar trends; an SCI of 3 dominates, with SCI of 4&5 followed by the lowest capacities of 1&2 which is consistently between 14 and 18% of the overall high use area. Visual interpretation of known 'risk' areas (Fig. 18) using the high use layer overlaid on an orthophoto separate from or incorporating substrate capacity is also a useful tool to objectively study the area as a means towards focussing planning for monitoring and/or management.

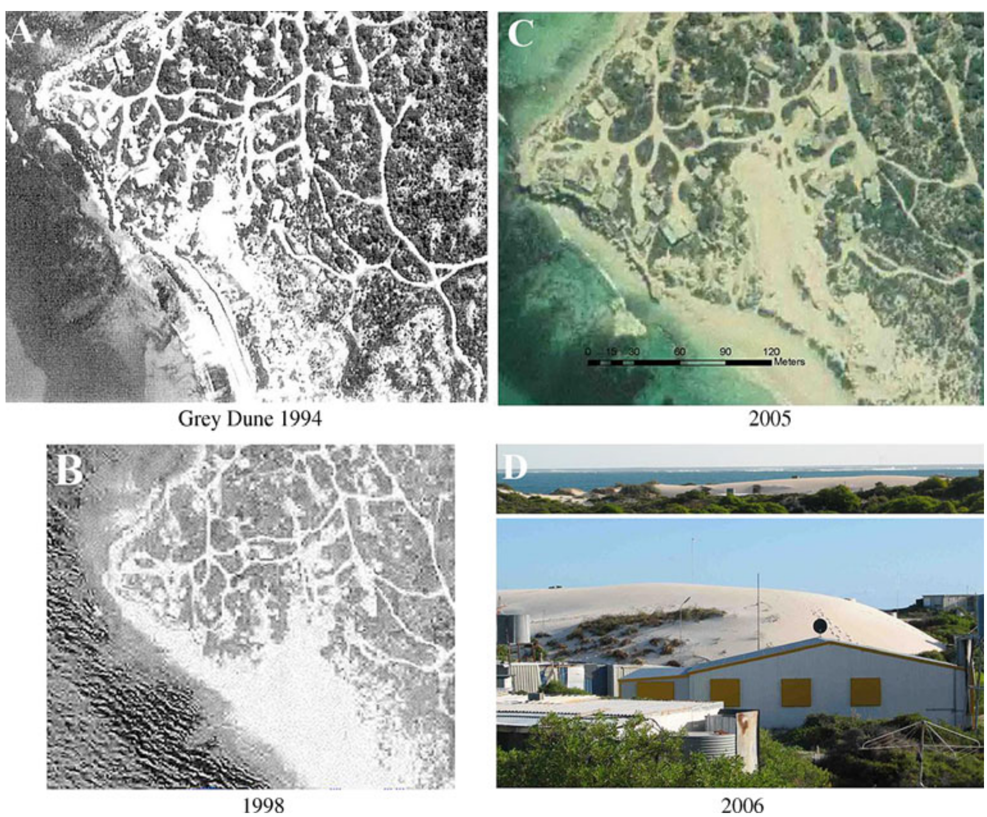

Fig. 15 Aerial Photo of the Grey dune blowout. Taken in 1994, 1998 and 2005, sourced from DEC. Note the positions of the mobile dune, tracks and shacks

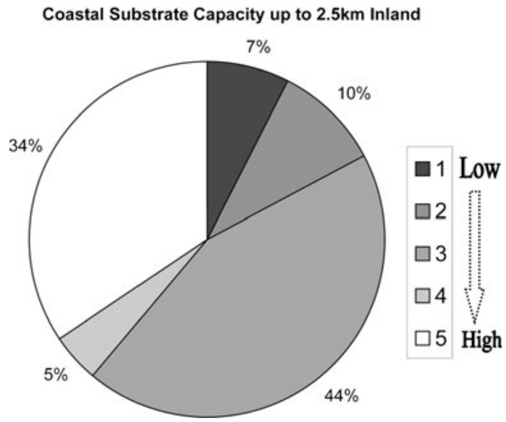

Fig. 16 Substrate capacity table of results/pie chart showing the percentage distribution of SC through the project area

The SC and high use data provides coastal managers and planners with an objective and cost effective method to analyse the coastal zone of the NAR and create a hierarchy of requirements for the area as a whole. A risk assessment using the data will allow the prioritisation of areas based on their use and capacity to withstand pressure.

Future coastal management issues

Climate change has the potential to interact with the coastal zone in a number of ways including inundation, erosion and salt water intrusion into the water table (IPCC 2007). Repeated scientific evaluations have shown that some degree of global warming is inevitable, and how we adapt to it in coastal areas is a test for governments and citizens of countries such as Australia, where the majority of residents live within 50 km of the coast and up to 30% live within 2 km of the coast (Vasey–Ellis 2009). The Intergovernmental Panel on Climate Change (IPCC 2007) states that "coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea-level rise. The effect

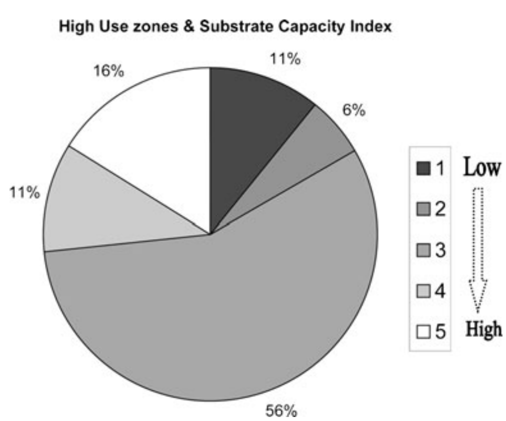

Fig. 17 Pie chart of high use areas vs substrate capacity, percentage figures show high use zones by substrate capacity. Note that almost 39% of the buffered track area is high use

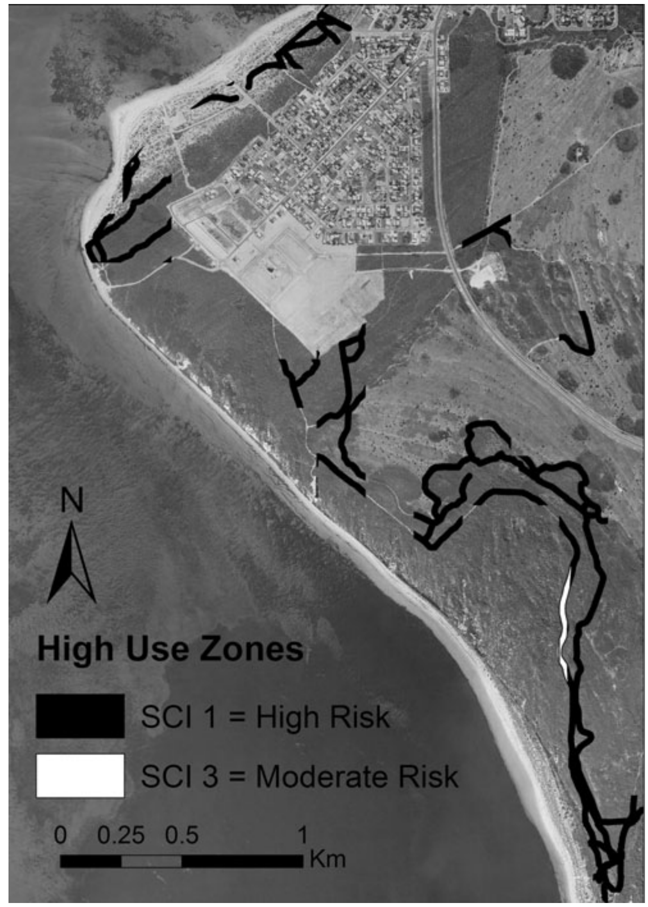

Fig. 18 High use layer intersected with substrate capacity of 1 (high risk) and 3 (moderate risk) and overlain on an orthophoto, just south of Jurien Bay (see Fig. 1 for location). Note extensive tracks (high use) through a low substrate capacity area (SC = 1) close to the coast

will be exacerbated by increasing human-induced pressures on coastal areas". Climate change is an issue that must be taken into account when studying the coastal zone. CSIRO and Australian Bureau of Meteorology (2007) has predicted that with increased temperatures there is a risk of increased storm frequency and sea level rise which leads to coastal erosion. Coastal growth and population growth exacerbate risks. There is also a risk to major infrastructure with an increase in the frequency and intensity of less common events, for example 1 in 50 year events may become 1 in 40, or even 25 year events.

Precision tidal records for the monitoring period 1991 to 2009 show that average sea level rise along the western Australian coast of 8.6 mm/year is close to 3 times the average for the global ocean (3.3 mm/year) (Warne-Smith and Madden 2009) If this trend is sustained into the future along the sandy coasts of the NAR then re-evaluation of coastal risk analyses and suitable setbacks for coastal urban planning will be required in the future. Based on the Brunn rule (Bruun 1962), along wave—dominated sandy coasts, for every 1 cm of sea level rise an equivalent 100 cm of coastal retreat occurs (Western Australian Planning Commision 2003). Disputed though it is (Dubois 1992; Cooper and Pilkey 2004) the Brunn rule is still used in framing local coastal planning legislation. In 100 years with the maximum predicted 56 cm rise (IPCC 2007) there is the potential for up to 56 m of coastal retreat, dependent upon the coastal type. Climate modeling is regularly revised and predictions of this kind are periodically adjusted as shown by the recent Australian Government report from the Department of Climate Change (2009) which, based on recent research presented at the Copenhagen climate congress in March, 2009, has taken the range quoted at the congress and selected the midrange value of 1.1 m sea level rise by 2100. This value is almost twice the maximum value quoted in IPCC 2007 and demonstrates the dynamic nature of climate change science as models are revised and fine tuned as new data becomes available. There is ongoing development of the GIS datasets to incorporate monitoring and assessment maps for areas of risk with an aim to produce future risk maps. Further assessment of issues regarding climate change and possible sea level rise is required. The topographic contour information provided in the GIS will be useful for risk evaluation, planning and monitoring.

The impact of climate change on coasts is exacerbated by increasing human-induced pressures and the unavoidability of sea-level rise, even in the longer-term, frequently conflicts with present-day human development patterns and trends (IPCC 2007). Development along the coast is ongoing, bringing with it the need for more coastal access and infrastructure, such that increased pressure and the nature of the coastal zone must be taken into account in planning. Proactive management will require assessment of the capacity of an area to withstand anthropogenic pressure. The substrate capacity data which has been produced as part of the overall GIS project will aid this and provide a tool to understand the relationship between recreation uses and the environment's natural ability to absorb impacts (cf. Priskin 2001).

Conclusions

The main aim of the project was to provide stakeholders with the tools and information to plan and conduct on—ground works, monitor environmental change along the coast and to implement management strategies. To meet this aim a number of objectives were determined including the need to document coastal resources on a regional scale, to identify the present status of the coast and identify areas susceptible to future change or risk. The documentation of the coastal resources of the NAR provides DEC, NACC and other stakeholders in the NAR such as shires and local community groups with a tool for future coastal planning at strategic, local and site levels. The GIS datasets provide a key source of reference information which can be accessed by a number of stakeholders for future coastal planning and management and provides coastal managers with baseline data on the current status of the coastline as well as a dynamic and updateable system for future coastal planning and management including the capacity to develop a risk management assessment of the coastal zone.

The coast of the NAR has many relatively unspoilt beaches, dune systems, and impressive coastal cliffs. The region is becoming increasingly well known and is being promoted as the 'Turquoise Coast' by the tourism industry. However, human pressures on the coast are increasing and degradation of these areas is emerging as a major issue as 'the attractions of the coastal environment are driving population growth and increased visitation. The consequence of this rapidly increasing use is the potential for further damage and deterioration' (NACC 2005) bringing with it greater management issues and requirements and highlighting the need for a georeferenced land management database. The recognition of climate change risks and issues for the Australian coast at senior parliamentary level (Standing Committee on Climate Change, Water, Environment and the Arts 2009) highlights the need and value of GIS based coastal assessment for present and future management of Australia's natural and human made coastal resources. The GIS component of this project will aid coastal managers in maintaining and conserving the natural values of the NAR coast and provide a basis for developing a risk management assessment of the coastal zone and a strategy for coastal managers in our climate change future.

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