Technical Report

Geology, Geomorphology and Vulnerability of the Pilbara Coast, in the Shires of Ashburton, East Pilbara and Roebourne, and the Town of Port Hedland, Western Australia

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Department of Planning

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Cover Photograph

View north over tidal flats and mangroves to West Intercourse Island and the Buccaneer Archipelago west of the Burrup Peninsula.

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Cover Photographs

View north over tidal flats and mangroves to West Intercourse Island and the Buccaneer Archipelago west of the Burrup Peninsula

Disclaimer

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EXECUTIVE SUMMARY

The Pilbara coast is a region of extremes. It is noted for its areas of high tide and the occurrence of extreme weather systems, particularly the seasonal impact of tropical cyclones and storm surges in an otherwise arid environment. These deliver floods and marine inundation events that leave their mark on the landscape and drive geomorphologic change on a coast which has a highly diverse range of landforms. Tidal, surge and runoff interactions are significant and occur across the Pilbara's extensive coastal lowlands, up to 20km inland. The river channels, riverine outwash plains, river deltas, tidal flats, coastal dunes, cheniers and spits, wide subtidal terraces and extensive sand shoals of the coast are all subject to significant change under extreme meteorologic and oceanographic conditions. These active landforms abut and overlie a very complex and old terrain cut into the hard-rock Archaean geology of the Pilbara Craton and the more recently formed sedimentary rocks it supports.

When defined as the interface between the land and the sea, the Pilbara coast is a zone of variable width, naturally dynamic in response to tide, weather and climate variations. Coastal landforms, including river deltas and tidal flats, extend more than 2km inland for the majority of the Pilbara. Even within less than extreme conditions, high water levels during spring tides may leave wrack lines kilometres inland on low lying parts of the coast. However, the nature of landform response varies according to the relative resistance of the coast, which is a combination of material types (geology, sediment type and presence of vegetation) and the coastal form (which may be plan form, profile, or configuration of landform elements). The factors of environmental forcing, materials and landform have considerable interaction, in which variation of one factor potentially changes the other two. In this context there is a disconnection between the fixed geologic framework and unconsolidated inshore sediment bodies.

The Pilbara coast is an inherited coast, with many sedimentary coastal landforms reflecting historic environmental conditions, centuries or millennia before present. Its ancient hard-rock terrain is commonly overlain or abutted by sediments of coral reefs, flood plains and river deltas deposited through multiple phases over the past 2 million years. In places the riverine sediments have been lithified. Along with old reef structures and beachrock, these now form coastal limestones outcropping along the shore. More mobile sediments are intermittently delivered to the coast by numerous rivers and flowing streams, the largest being the Ashburton, Fortescue and De Grey Rivers. Not all streams and rivers discharge directly into the ocean, with many releasing water and sediments into tidal flat basins. However, these systems are connected to the coast via tidal creeks and irregularly contribute sediment to the coast at times of flood.

The geographic distribution of the rivers and their intermittent flow results in the sediment availability along the coast being extremely variable. Where sediment supply is limited, coastal variability is largely constrained by the rock framework and old landforms forming its inherited structure. Conversely, for areas of the Pilbara coast where sediment supply is effectively unrestricted, landform changes are highly variable and readily adjust to fluctuations in coastal processes.

APPROACH

This project identifies land systems and the landforms they contain that are likely to alter in response to changes in meteorologic and oceanographic processes along the Pilbara coast between Hope Point in Exmouth Gulf and Tryon Point north of Eighty Mile Beach. The examination was focussed on:

(a) provision of regional planning guidance, management strategies and direction on appropriate future use of coastal land broadly in the Pilbara through the identification of compartments defining coastal stability and susceptibility to change; and

(b) determination of the vulnerability of landforms in greater detail for those coastal sediment cells which include areas of planning interest.

Changes of interest are those occurring over two time scales: observable landform changes presently taking place over sub-decadal time scales; and those projected to occur over a planning horizon of 100 years. Both may be locally obscured by the geological and geomorphological inheritance prevalent along the region's coast.

The study helps to inform regional coastal planning for the Shires of Ashburton, East Pilbara, Roebourne and the Town of Port Hedland. A key task was to provide a high level assessment of coastal land systems and landforms (tertiary coastal compartments) potentially threatened by natural variation in metocean processes or which may be affected by projected climate change. This task builds on the approach developed for the coast from Moore River to Exmouth (Eliot *et al.* 2011b, c, d) for assessing coastal vulnerability to changing metocean processes that is applicable and consistent across a wide range of planning scales.

The following steps were completed in order to accomplish this task and fulfil the objectives of the project:

1. Identify natural resource management units at scales commensurate with regional and local planning scales recommended by the WAPC (2003a, 2013);
2. Describe and map the geology and coastal land systems comprising each tertiary compartment;
3. Describe and map coastal landforms for Areas of Planning Interest;
4. Review available information describing metocean processes, including coastal processes affecting land system development;
5. Modify the framework for assessment of coastal vulnerability that is consistently applicable at all planning scales to include criteria relevant for the Pilbara region; and
6. Apply the framework for coastal vulnerability at broad scale regional and local planning scales through its application to tertiary coastal compartments and sediment cells; and
7. Through comparison of the physical features in each planning unit, determine areas of coastal land likely to require different planning and management approaches.

Consequences for the resulting vulnerability estimates were then interpreted for each compartment or sediment cell (planning unit), compared and form the basis of recommendations made in the report.

RESULTS

Bedrock geological control, land systems and metocean processes were used to identify discrete coastal compartments, with landforms and metocean processes at a more detailed scale used to identify sediment cells. Changes to land systems and landforms in one part of a compartment or cell were highly likely to affect adjoining landforms within the compartment or cell but with potentially limited effect on adjoining compartments or cells. Susceptibility, instability and vulnerability ratings were then estimated at a detailed scale for both tertiary scale compartments and sediment cells.

The Pilbara coast comprises five primary, fourteen secondary and thirty four tertiary compartments, which progress from higher towards lower scale and degree of containment. In its eastern reaches the Study Area partly extends into a sixth primary compartment. To the west it overlaps with the Eastern Gulf compartment that includes the Yannarie salt flats. The vulnerability of the five complete primary compartments, including the Wallal, De Grey, Roebourne, Dampier, and Barrow compartments has previously been considered for strategic planning. Land systems for the fourteen secondary compartments were identified; however, coastal vulnerability was assessed at tertiary compartment scale in this report, given its dual focus on regional and local area planning. Land systems for the 34 tertiary compartments have been identified, mapped and their geology and geomorphology described. Further information on the land systems, including the associated landforms, is available from relevant rangelands documents.

In addition to the tertiary compartments, three Areas of Planning Interest were considered in detail at a landform scale appropriate to local area planning. The areas examined include Onslow, Karratha and Port Hedland. Landforms have been identified and mapped for 12 tertiary compartments spanning the Areas of Planning Interest, with two compartments for Onslow, nine for Karratha and one for Port Hedland. The landform maps extend 10km inland from the Landgate Mean High Water Mark. Each landform is described and attributed an instability rank, with maps demonstrating which landforms have low, moderate or high instability. These maps do not incorporate susceptibility or vulnerability and also neglect any landform connectivity.

Tertiary sediment cells were considered in detail at a landform scale appropriate to local area planning for the three Areas of Planning Interest. The Areas of Planning Interest included four primary and ten secondary sediment cells. They provide an incomplete coverage of the higher order cells over the Study Area. The landforms for each tertiary sediment cell were identified, mapped and described at a finer spatial scale than that used to describe the compartments. Twenty seven tertiary sediment cells were examined, with 22 tertiary cells selected to cover the sites of planning interest. The landforms for each tertiary sediment cell have been described at a finer spatial scale than that used to describe the tertiary compartments although the cells are larger in some cases. Descriptions have been presented for ten groups of cells within the three Areas of Planning Interest.

The analyses at compartmental and sediment cell scales was intended to be indicative rather than prescriptive and has application for regional planning purposes as a first step to more detailed risk assessment procedures.

Susceptibility of Land Systems in the Tertiary Compartments

The major natural structural features of the tertiary compartments were described and ranked according to their likely susceptibility to change. Three (9%) of the 34 compartments have a low susceptibility; eighteen (53%) are moderately susceptible and 13 (38%) are highly susceptible. The implications of the groupings into low, moderate and high categories have been summarised for each compartment.

Tertiary compartments have low susceptibility to change where the coast is protected by islands, with low wave and surge climates; has rock in the subtidal shoreface; is not an embayment facing NW to NE; has continuous bluffs, rocky coast or platforms; or is a high rocky coast with rock extending more than 5m above high tide. Compartments considered moderately susceptible are exposed to moderate waves and moderate surge, or high waves and low surge or low surge and high waves; have patch reefs or intertidal/subtidal terraces in the subtidal shoreface; have lower elevation rock features such as a gently sloping rocky coast or near continuous intertidal platforms or perched beaches; have stationary/receded barriers, wide spits and cheniers or some outwash/deltaic plains.

Tracts of coast highly susceptible to structural change are commonly low-lying, containing the unconsolidated sediments of active deltas, inherited basins, outwash plains and narrow spits and cheniers, including:

- The two compartments from Hope Point to Bare Sand Point with outwash plains and deltaic plains of the Yannarie River, Chinty Creek and Ashburton River;
- Hooley Creek to Coolgra Point with deltaic plains of the Ashburton River that are susceptible to metocean forcing;
- Pelican Point to West Intercourse Island with the Yanyare and Maitland River deltas;
- The two compartments from Cinders Road to Cleaverville Creek, incorporating Karratha townsite, with the Nickol River and the mudflats joining Nickol Bay to Mermaid Sound. These compartments are susceptible to metocean forcing;
- The two compartments from Cape Lambert to Cape Cossigny with the Sherlock, East Harding, Harding and George Rivers;
- The two compartments from Cape Thouin to Downes Island with the outwash plains of the Yule and Turner Rivers;
- Beebingarra Creek to Wattle Well with the Ridley River and the deltaic plains of the De Grey;
- Yan Well to Condini Landing with the active De Grey River mouth; and
- The unconsolidated beaches and foredune plains of the Eighty Mile Beach Caravan Park to Samphire Bore with an absence of a bedrock framework.

Stability of Land Systems in the Tertiary Compartments

Half of the tertiary compartments, 17 of the 34 (50%) have high instability, which is to say they are unstable compared to other compartments in the region. Four tertiary compartments (12%) have low instability and 13 (38%) have moderate instability.

Tertiary compartments are relatively stable and display low instability where the coast has: a limited amount of sediment stored inshore with sheltering by inshore reefs or rocky pavement; a nearly continuous rocky shoreface and hinterland; no rivers or only small coastal catchments; a high and wide frontal dune complex; a continuous lithified chenier ridge; or narrow saltflats. Moderate landform instability is indicated for a compartment in which the inshore seabed contains approximately 50% bare sand and includes a river with a moderate sized inland catchment; river mouths discharging into a basin; a tidally dominated river delta with open mouth; the shore has one or two tidal creeks per 10km; the frontal dune complex is low and wide, moderately high and moderately wide or high and narrow or broad salt flats with tidal creeks and a vegetated margin.

The highly unstable tracts of coast contain unconsolidated sediments and irregular shorelines along active deltas of moderate to large river catchments; inherited basins; outwash plains; broad mudflats with residual mounds, palaeochannels and tidal creeks; and shores fronted by low storm bars or low frontal dunes, including:

- Hope Point to Locker Point with the outwash plains of the Yannarie River with broad mudflats;
- Bare Sand Point to Hooley Creek with the active Ashburton River delta overlying rock pavement and platforms;
- Coolgra Point to James Point with five tertiary compartments with numerous tidal creeks, active deltas, inherited basins and outwash plains of the Cane, Robe and Fortescue Rivers set within a bedrock framework;
- Pelican Point to West Intercourse Island with the Yanyare and Maitland Rivers interacting with tidal creeks;
- The two compartments from Cinders Road to Cleaverville Creek, incorporating Karratha townsite, with the Nickol River and the mudflats joining Nickol Bay to Mermaid Sound with common tidal creeks and storm bars;
- The two compartments from Cape Lambert to Cape Cossigny with the outwash plains and lagoonal basins of the Sherlock, East Harding, Harding and George Rivers, incorporating mudflats and well developed tidal creeks;
- The two compartments from Cape Thouin to Downes Island with mudflats and tidal creeks draining the outwash plains of the Yule and Turner Rivers; and
- The three compartments from Beebingarra Creek to Condini Landing with the Ridley River, deltaic plains, palaeochannels, tidal creeks and active mouth of the large De Grey River.

Tertiary Compartment Vulnerability

Differences between the rankings for susceptibility and instability assigned to the same compartment are notable and highlight the significance of long-term versus short-term change due to metocean forcing. These factors were drawn together in determination of overall vulnerability. A compartment or cell ranked at one level is highly likely to contain a range of components with different levels of susceptibility or instability. In particular, a compartment or cell ranked at a moderate level may have elements that are highly susceptible to change in the metocean regime or have landforms that are currently unstable. This qualification is particularly important at increasingly broad spatial scales in the land system hierarchy where a wider range of land systems and landforms is included at each compartmental scale. Evaluation of land-use which may be affected by sub-scale variations of stability or susceptibility (e.g. a road) may need to consider higher resolution assessment.

The majority of the tertiary compartments, 31 of the 34 (91%), have moderate, moderate-to-high or high vulnerability rankings. Ten compartments (29%) were each classified as moderate-to-high and high vulnerability categories. Eleven compartments (32%) have moderate vulnerability, no compartments (0%) have low-to-moderate vulnerability and three compartments (9%) have low vulnerability. The implications of the groupings into low, low-to-moderate, moderate and moderate-to-high categories are discussed.

Tertiary compartments with low vulnerability are those with less susceptible natural structural features and low landform instability. The areas with low vulnerability, which have few constraints to coastal management at a tertiary compartment scale, are sections of rocky coast such as the Burrup Peninsula. There are no compartments with low-to-moderate vulnerability. Those with moderate vulnerability have moderately susceptible natural structural features and display moderate landform instability. These are areas with moderate constraints to coastal management at a tertiary compartment scale. They are often located within a bedrock framework which reduces susceptibility in comparison to coasts without rock. The compartments may be associated with mudflats and irregular shorelines with one to two tidal creeks, perched sandy beaches or deltas, basins or outwash plains of *large creeks or moderate* sized river catchments.

The tertiary compartments with moderate-to-high vulnerability are those with highly susceptible natural structural features or high landform instability. These are areas where coastal processes are likely to provide significant constraints to coastal management at a tertiary compartment scale. Nine of the ten compartments are associated with the active river deltas, deltaic plains, outwash plains, palaeochannels, tidal creeks and active mouths of *moderate to large* river catchments within a bedrock framework. These compartments are often susceptible to metocean forcing. The tidal creeks are likely to be connected to distributaries of rivers. The unconsolidated beaches and foredune plains of the coast from Eighty Mile Beach Caravan Park to Samphire Bore, with an absence of a bedrock framework, is the only compartment with moderate-to-high vulnerability not directly associated with rivers.

Tertiary compartments with high vulnerability are those with highly susceptible natural structural features and high landform instability. These are areas subject to major constraints to coastal management at a tertiary compartment scale. The compartments are associated with active river deltas, deltaic plains, outwash plains, palaeochannels, tidal creeks and active mouths of *larger or numerous* river catchments often susceptible to metocean forcing. Most of the tidal creeks in these compartments are directly connected to distributaries of rivers. Compartments subject to high vulnerability are:

- Hope Point to Locker Point, with outwash plains of the Yannarie River and broad bare saltflats;
- Pelican Point to West Intercourse Island with the Yanyare and Maitland Rivers interacting, with tidal creeks;

- The two compartments from Cinders Road to Cleaverville Creek, incorporating Karratha townsite, with the Nickol River and the mudflats joining Nickol Bay to Mermaid Sound with common tidal creeks. These compartments are susceptible to metocean forcing;
- The two compartments from Cape Lambert to Cape Cossigny, with the outwash plains of the Sherlock, East Harding, Harding and George Rivers;
- The two compartments from Cape Thouin to Downes Island, with the outwash plains of the Yule and Turner Rivers;
- Beebingarra Creek to Wattle Well, with the Ridley River and the deltaic plains of the De Grey; and
- Yan Well to Condini Landing, with the active De Grey River delta and river mouth.

Areas of Planning Interest

Twenty-two tertiary cells were considered for the Areas of Planning Interest with one ranked as low vulnerability, four as low-to-moderate, four as moderate, five as moderate-to-high and eight as high vulnerability. The more detailed assessment at the tertiary cell level also included the identification of landforms most at risk and other coastal constraints related to environmental forcing.

Many of the cells have a higher vulnerability ranking when considered at a finer spatial scale than the tertiary compartments because features of relatively higher coastal risk often represent a higher proportion of the coast of interest. Features with higher coastal risk include susceptible natural structures, such as narrow spits and cheniers or inherited basins, and more unstable landforms, such as floodplains and saltflats with residual mounds, palaeochannels and tidal creeks.

More detailed vulnerability assessments for each Area of Planning Interest also incorporated analysis of geomorphic processes, a description of the planning context, advice for coastal management and identification of further studies required for the site.

Overview

The Pilbara contains a broad range of coastal types, for which existing planning policies provide an equally broad range of vulnerability assessment techniques, and often suggest case-by-case evaluation. The application of simple conceptual models, such as *Schedule One* of the State Coastal Planning Policy, produces a highly varied risk profile, in which the results more strongly reflect the applicability of the model than anticipated coastal dynamics. Due to the complexity and variability of the Pilbara coast, there are numerous locations in which secondary processes, neglected in a simple model, are dominant. Coast types where existing planning policies are difficult to implement directly are prevalent across the Pilbara, such as mixed sand and rock coast, large river deltas or low-lying tidal flat morphology. Consequently, an approach was developed, assessing coastal vulnerability based on land system and landform information. The approach used published descriptions of the relative susceptibility of coastal land systems to respond to metocean processes variability; as well as the present stability of individual landforms comprising them.

Susceptibility of coastal land systems is defined by characteristics of natural structures, including materials, and encompasses the capacity for coastal change to reach critical thresholds or tipping points. Susceptible systems are usually affected by gradual environmental changes. Instability relates to the degree to which landforms are responsive to short-term environmental variability, and captures the cyclic or progressive nature of disturbance and recovery. The technique of combining inherent structural susceptibility and observed instability aims to account for both gradual and rapid responses to environmental change. Along the Pilbara coast, extensive geologic and geomorphic inheritance commonly causes dissociation between susceptibility and instability. This has implications for the use of *Schedule One* of the State Coastal Planning Policy, which is strongly tied to modern observations and therefore provides an indication of instability only.

The vulnerability analysis provides a foundation for more extensive risk assessments which could identify the processes of change in more detail; examine social and economic implications; determine the consequences of projected and existing patterns of coastal change; and plan and implement adaptation strategies. To some extent, some of the adaptation strategies are embedded in the *Coastal Zone Management Policy for Western Australia* and these provide the principles and rationale for advice arising from examination of vulnerability on the Pilbara coast.

Compartments or cells with a high vulnerability ranking were areas where the potential effect of metocean processes was considered a major constraint to development due to weakness of the natural structures or poor natural resilience. These areas potentially require high ongoing management requirements and typically are suitable for limited development. Sufficient justification to address major constraints usually occurs only if there is a very strong economic and social imperative, such as large-scale infrastructure requiring coastal access for marine-based industries, major harbours or port facilities. Detailed investigations are recommended as the basis for establishment of such infrastructure, including geotechnical studies (site assessment of elevation and coverage of underlying rock using drilling or other appropriate technique), sediment budget analysis (approximate volumetric rates of sediment transport including sources and sinks) and numerical modelling (such as wave, current and sediment transport modelling to provide further context for the volumetric rates of sediment transport).

Lower levels of estimated vulnerability for each compartment or cell identify more specific constraints to potential land use and whether the constraint is linked to long-term susceptibility to landform change or short-term instability. In general, susceptibility requires engineering intervention to alleviate potential problems whereas instability is commonly addressed by less obtrusive management including the use of coastal setback to development.

WEB SUMMARY

The aim of this project was to determine the vulnerability of landforms along the Pilbara coast to changing weather and oceanographic conditions, including projected changes in climate. The Pilbara coast is a region of extremes. It is an inherited coast with an ancient hard-rock terrain that is commonly overlain or abutted by sediments of coral reefs, flood plains and river deltas deposited over the past 2 million years. In places the riverine sediments have been lithified. With old reef structures and beachrock these now form coastal limestones outcropping along the shore. Numerous rivers and flowing streams intermittently deliver sediment to the coast. The region is also noted for its extreme weather systems, particularly the seasonal impact of tropical cyclones and storm surges in an otherwise arid environment. These deliver floods and marine inundation events that leave their mark on the landscape and drive geomorphologic change on a coast with a highly diverse range of landforms.

The geographic distribution of the numerous rivers and their seasonally intermittent flow results in availability of sediment along the coast being highly variable. Consequently certain landforms and coastal features are more vulnerable to climate and sea level variation than others. Where sediment supply is limited coastal variability is largely controlled and its variability constrained by the rocky framework and old landforms forming its inherited structure. Conversely, coasts where sediment supply is unrestricted are free coasts on which landform changes are highly variable and readily adjust to fluctuations in coastal processes. Along much of the coast low-lying riverine plains and deltaic landforms are highly susceptible to extreme metocean events; particularly marine inundation due to storm surge and fluctuation in sea level and river flooding resulting from high rainfall during tropical cyclones.

Landform vulnerability was estimated as a combination of the susceptibility of the geological structure supporting the landforms to environmental change and the current condition of the landforms as indicated by existing evidence of erosion. Together, a geological or geomorphic structure and the landforms it supports define a land system. The assessment linked the integrity of the geological or geomorphologic structures of land systems and the stability of the landforms in a matrix to estimate five grades of vulnerability (Figure A). The analysis was intended to be indicative rather than prescriptive, with applications for regional to local planning purposes as a first step to more detailed risk assessment procedures.

Results included the identification of tertiary coastal compartments, with boundaries shown in Figure B. An estimate of the vulnerability of each compartment is shown in Table A and Figure C. Vulnerability rankings were determined on a five-point scale for each compartment. The majority, 31 of the 34 (91%), have moderate, moderate-to-high or high vulnerability rankings. Ten (29%) were classified as having moderate-to-high or high vulnerability. Eleven compartments (32%) have moderate vulnerability; none (0%) have low-to-moderate vulnerability and three (9%) have low vulnerability. The implications of the groupings into low, low-to-moderate, moderate and moderate-to-high categories are discussed. Detailed assessment of vulnerability has been completed at a sediment cell scale for three Areas of Planning Interest in the wider Onslow, Karratha and Port Hedland areas.

			INSTABILITY (CONDITION) (Existing morphologic change to land surface)		
			Low (Stable)	Moderate	High (Unstable)
			Example		
SUSCEPTIBILITY (STRUCTURE) (Potential change to geological structure)	Low	Barrier perched on extensive tracts of coastal limestone	(1) Vegetated swales in parabolic dunes landwards of a vegetated frontal dune ridge overlying coastal limestone above HWL	(2) Vegetated dunes landwards of a vegetated frontal dune ridge and perched on coastal limestone at HWL	(3) High foredune ridge and/or vegetated foredune plain overlying coastal limestone below HWL
	Moderate	Weakly lithified barrier with intermittent limestone outcrops	(2) Mainly vegetated swales in parabolic dunes landwards of a mainly vegetated frontal dune ridge	(3) Vegetated dunes landwards of a mainly vegetated frontal dune ridge (50 to 75% cover) and overlying coastal limestone	(4) Cliffed or discontinuous foredune fronting moderate numbers of mobile blowouts and sand sheets (<50% of the alongshore reach)
	High	Barrier comprised wholly of sand. No bedrock apparent along shore or in dunes	(3) Swales in parabolic dunes landwards of a partly vegetated frontal dune ridge	(4) Mainly vegetated dunes landwards of a partly vegetated frontal dune ridge with 25 to 50% cover	(5) No foredune. Eroded frontal dune with numerous mobile blowouts and sand sheets (>50% of the alongshore reach)

KEY — **Combined estimate of vulnerability**

- Low
- Low-to-moderate
- Moderate
- Moderate-to-high
- High

Figure A: Indicative Vulnerability Matrix for a Mixed Sandy and Rocky Coast with Dunes

Note: Susceptibility of a geologic structure to environmental change and the current instability of coastal landforms were estimated for each coastal cell on a three point scale as being low, moderate or high. In the matrix these were combined to provide a five point estimation of the vulnerability.

Table A: Susceptibility, Instability and Vulnerability Rankings for Each Compartment

Tertiary compartment	Susceptibility Rank	Instability Rank	Vulnerability Rank
Cape Jaubert to Tryon Point	L	L	L
Samphire Bore to Cape Jaubert	M	M	M
Eighty Mile Beach Caravan Park to Samphire Bore	H	M	M-H
Cooraidegel Well to Eighty Mile Beach Caravan Park	M	M	M
Shoonta Well to Cooraidegel Well	M	M	M
Cape Keraudren to Shoonta Well	M	M	M
Mulla Mulla Creek to Cape Keraudren	M	M	M
Condini Landing to Mulla Mulla Creek	M	M	M
Yan Well to Condini Landing	H	H	H
Wattle Well to Yan Well	M	H	M-H
Beebingarra Creek to Wattle Well	H	H	H
Downes Island to Beebingarra Creek	M	M	M
West Turner River to Downes Island	H	H	H
Cape Thouin to West Turner River	H	H	H
Cape Cossigny to Cape Thouin	M	M	M
Sherlock to Cape Cossigny	H	H	H
Cape Lambert to Sherlock	H	H	H
Cleaverville Creek to Cape Lambert	M	M	M
Karratha Back Beach to Cleaverville Creek	H	H	H
Cinders Road to Karratha Back Beach	H	H	H
Dolphin Island Point to Cinders Road	L	L	L
West Intercourse Island to Dolphin Island Point	L	L	L
Pelican Point to West Intercourse Island	H	H	H
Cape Preston to Pelican Point	M	M	M
James Point to Cape Preston	M	M	M
Mount Salt to James Point	M	H	M-H
Peter Creek to Mount Salt	M	H	M-H
Weld Island to Peter Creek	M	H	M-H
Yardie Landing to Weld Island	M	H	M-H
Coolgra Point to Yardie Landing	M	H	M-H
Hooley Creek to Coolgra Point	H	M	M-H
Bare Sand Point to Hooley Creek	M	H	M-H
Locker Point to Bare Sand Point	H	M	M-H
Hope Point to Locker Point	H	H	H

Key	Vulnerability of environmental change	Implications for coastal management (see Table 2-12 in the full report for further description)
(green)	Low	Coastal risk is unlikely to be a constraint to coastal management
(light green)	Low -to-moderate	Coastal risk may present a low constraint to coastal management
(yellow)	Moderate	Coastal risk may present a moderate constraint to coastal management
(peach)	Moderate-to-high	Coastal risk is likely to be a significant constraint to coastal management
(red)	High	Coastal risk is a highly significant constraint to coastal management

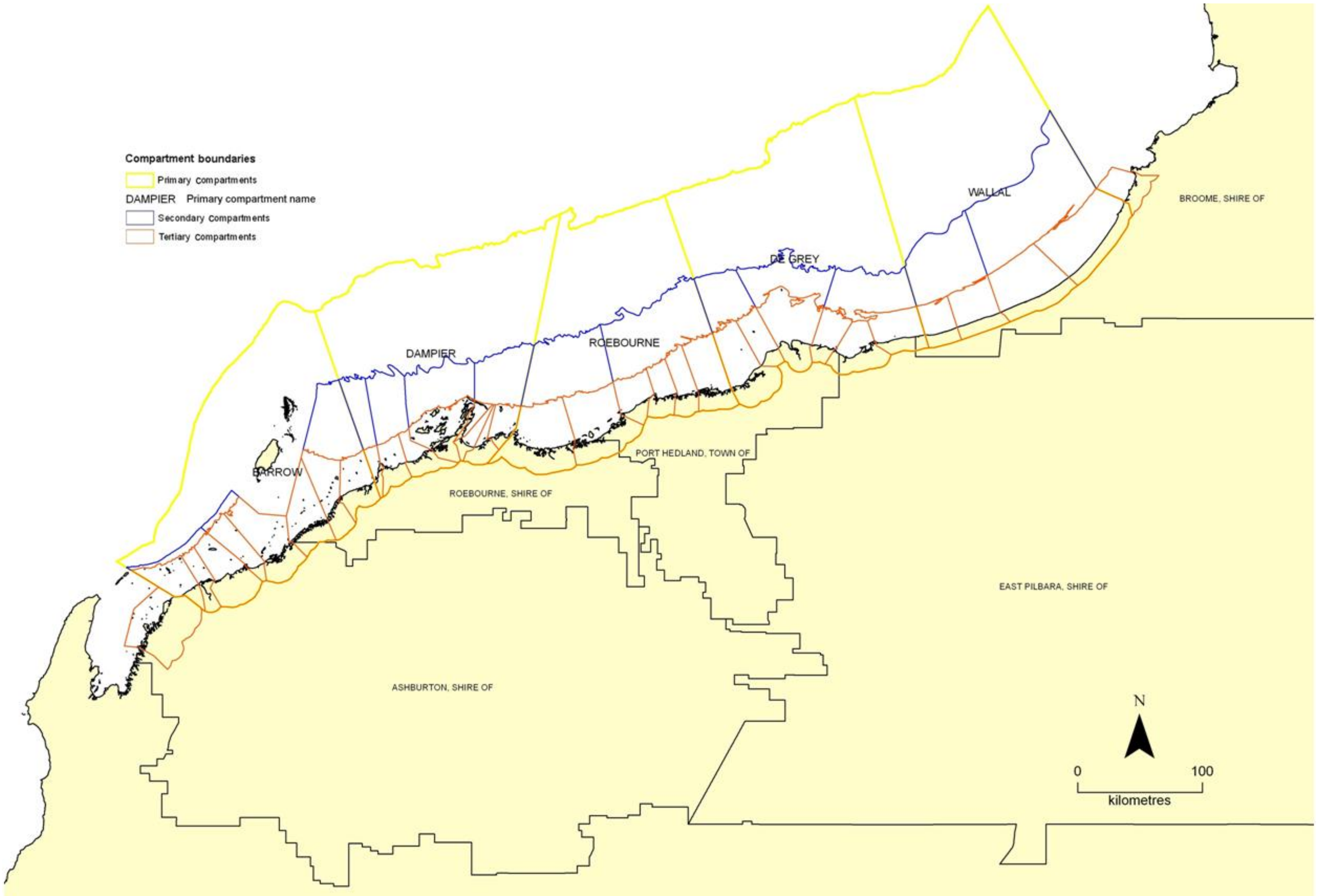

Figure B: Study Area and Compartment Boundaries for the Pilbara Coast

Note: Compartments were defined as large sections of coast with a common land system. Three levels were identified from primary to tertiary compartments, with the offshore boundaries at the 130m, 50m and 20m depth contours. Each compartment contained a number of sediment cells to which the vulnerability rankings were ascribed. The vulnerability rankings referred to the cell as a whole but not to individual landforms. Different landforms within each cell were likely to have higher or lower levels of vulnerability than the cell as a whole.

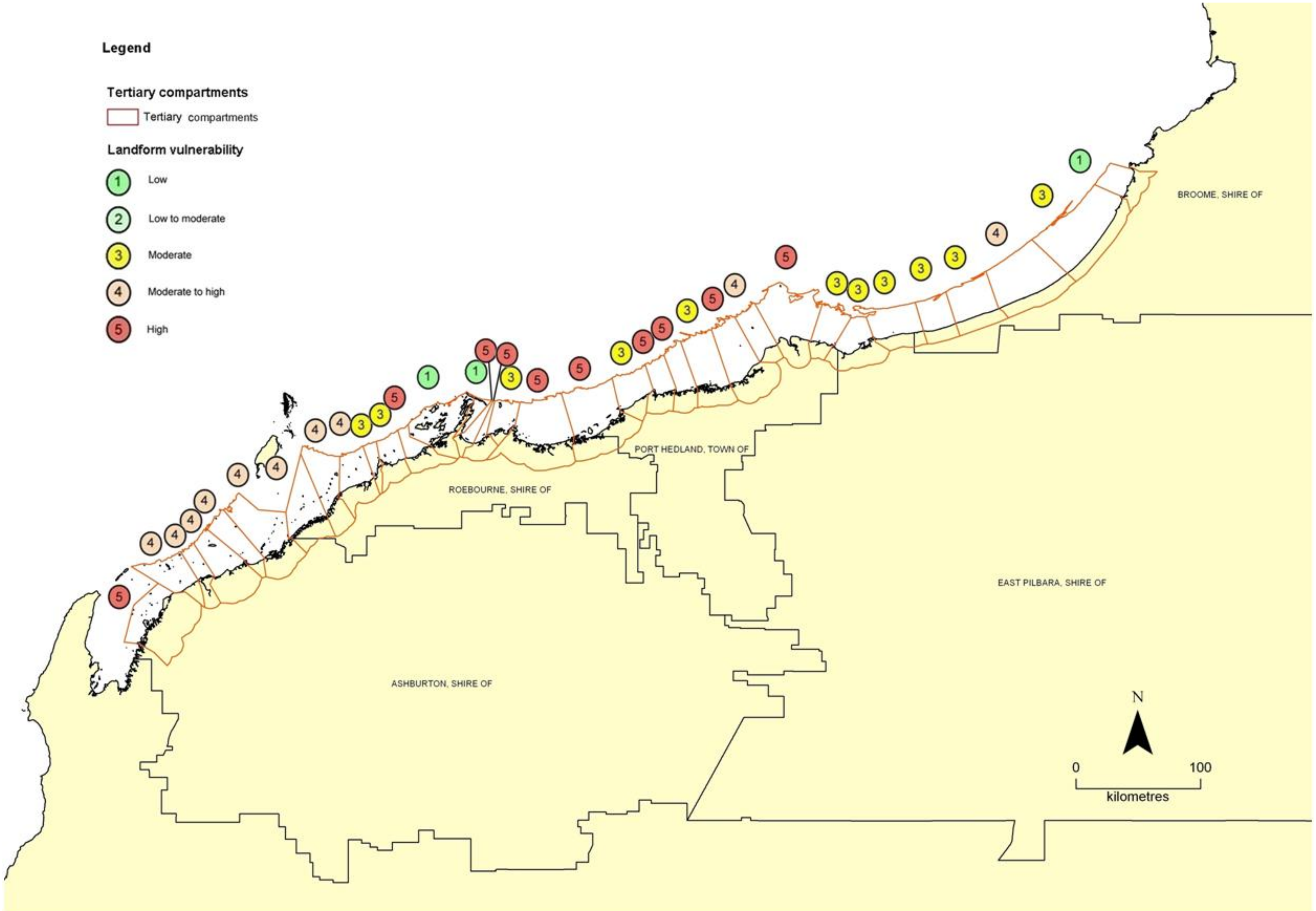

Figure C: Vulnerability Rankings of Compartments of the Pilbara Coast

Note: Compartment labels are contained within the report