Spatial risk assessment for coastal seagrass habitats in the Great Barrier Reef World Heritage Area

A case study of the Dry and Wet Tropics

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Acronyms Used In This Report

AIMS	Australian Institute of Marine Science
BBN	Bayesian belief network
EPA	Environmental Protection Agency (Queensland)
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GIS	Geographic Information System
JCU	James Cook University
QDPI&F	Queensland Department of Primary Industries and Fisheries
RRRC	Reef and Rainforest Research Centre Limited

Introduction

Seagrasses are specialised marine flowering plants that grow in the estuary and nearshore environments of most of the world's continents. There are relatively few species globally (about sixty) and these are grouped into just thirteen Genera and five Families. Most are entirely marine, although some species (such as *Enhalus acoroides*) cannot reproduce unless emergent at low tide.

There are fifteen species of seagrass in Australia's Great Barrier Reef World Heritage Area (GBRWHA). The high diversity of seagrass reflects the variety of habitats, the extensive bays, estuaries, coasts, lagoons and reefs that are available for seagrass colonisation. More than five thousand square kilometres of coastal seagrass meadows are in eastern Queensland waters shallower than fifteen metres and it is expected that approximately forty thousand square kilometres of the seafloor in the GBRWHA deeper than fifteen metres has some seagrass (Coles *et al.* 2007). This represents about 36% of the total recorded area of seagrass in Australia.

Seagrasses are breeding grounds and nurseries for crustacean, finfish and shellfish populations. As well as providing food for green sea turtles, fish species, waterfowl and for the marine mammal the dugong; which is on the IUCN red list as vulnerable to extinction (IUCN 2000), seagrasses are the basis of a detrital food chain (Walker *et al.* 2001). Seagrasses rank with coral reefs and mangroves as productive coastal habitats and strong linkages among these habitats make any loss of seagrasses a factor in the degradation of coastal ecosystems.

Destruction or loss of seagrasses has been reported from most parts of the world (Short and Wyllie-Echeverria 1996; Larkum *et al.* 2006), often from natural causes (den Hartog 1987) or storms (Poiner *et al.* 1989). However, destruction commonly has resulted from human activities, for example, as a consequence of eutrophication, or land reclamation and changes in land use (Cambridge and McComb 1984; Coles *et al.* 2003). Increases in dredging, development of the shoreline, damage associated with overexploitation of coastal resources, and recreational boating activities along with nutrient and sediment loading has dramatically reduced seagrass distribution in some parts of the world (Short and Wyllie-Echeverria 1996). Efforts are being made toward rehabilitation of seagrass habitat through transplantation, improvement of water quality, restrictions on boating activity, fishing and aquaculture, and protection of existing habitats through law and environmental policy.

While nearshore and coastal seagrasses in the GBRWHA have remained relatively stable in distribution (Coles *et al.* 2007) increases in coastal human population density and resource developments in mining and agriculture inevitably lead to negative pressures on the adjacent marine environment. These pressures can influence seagrass meadows at fine spatial scales of hundreds of metres as in marina developments, or at the broad spatial scale of the entire GBRWHA as in agricultural chemicals in river run off. They can have an absolute impact, removing seagrass entirely in an area, or a subtle impact merely slowing growth or limiting plant reproduction. Impacts can be intermittent, one off or occur regularly.

Because of this complexity, impacts on seagrass meadows from human activities can be hard to measure and to predict. The consequences of an impact are even harder to quantify as the concept of consequence in a marine environment involves features of ecosystem services and resilience; variables that are species specific and location dependent. Uncertainty and incomplete information can be a major constraint to the decision making process (Bacic *et al*. 2006). Decision-support tools, such as spatial risk assessments in a geographic information system (GIS), can assist in evaluating the risk to seagrass from their hazards in an uncertain environment. Risk assessment is the term ascribed to the methods for determining risk posed by a hazard (or threat) to the survival and health of a species. Risk is determined by measuring two components:

1) The consequences or the effects of an adverse event; and
2) The likelihood or probability of the event occurring.

A spatial risk assessment approach combines spatial data on the distribution of a species and anthropogenic impacts to identify sites of overlap between species occurrence and hazard occurrence. This allows the user to identify areas where management intervention is likely to be most effective because there is either a high likelihood of species presence and/or hazard occurrence (Theobald 2003; Andersen *et al.* 2004). GIS-based spatial risk assessments are particularly valuable in large geographic regions where information is limited as they can incorporate different kinds of quantitative and qualitative spatial data (including expert knowledge) to support the estimation, evaluation and comparison of alternative management interventions. There is a need to use expert knowledge when analysing risk to seagrass communities as there is some uncertainty about the biological thresholds of various seagrass species, current level of stress from seagrass hazards across various areas of the GBRWHA.

A risk assessment of seagrasses along the GBRWHA coast was conducted in 2007 incorporating some of these principles (Rasheed *et al.* 2007). Results of this risk assessment were generated from a workshop of experts critically examining the known seagrass values along the coast and the various risks and threats posed. A matrix of risks was developed and known seagrass areas along the coast were ranked according to their relative risk (Rasheed *et al.* 2007). In this paper we expand on the approach of Rasheed *et al.* (2007) by using a spatial risk assessment approach and modeled seagrass distribution combined with expert opinion to quantify the relative risk to coastal seagrass habitats from anthropogenic activities in the dry and wet tropics regions of the GBRWHA (Figure 1). We discuss the benefits and limitations of this approach.

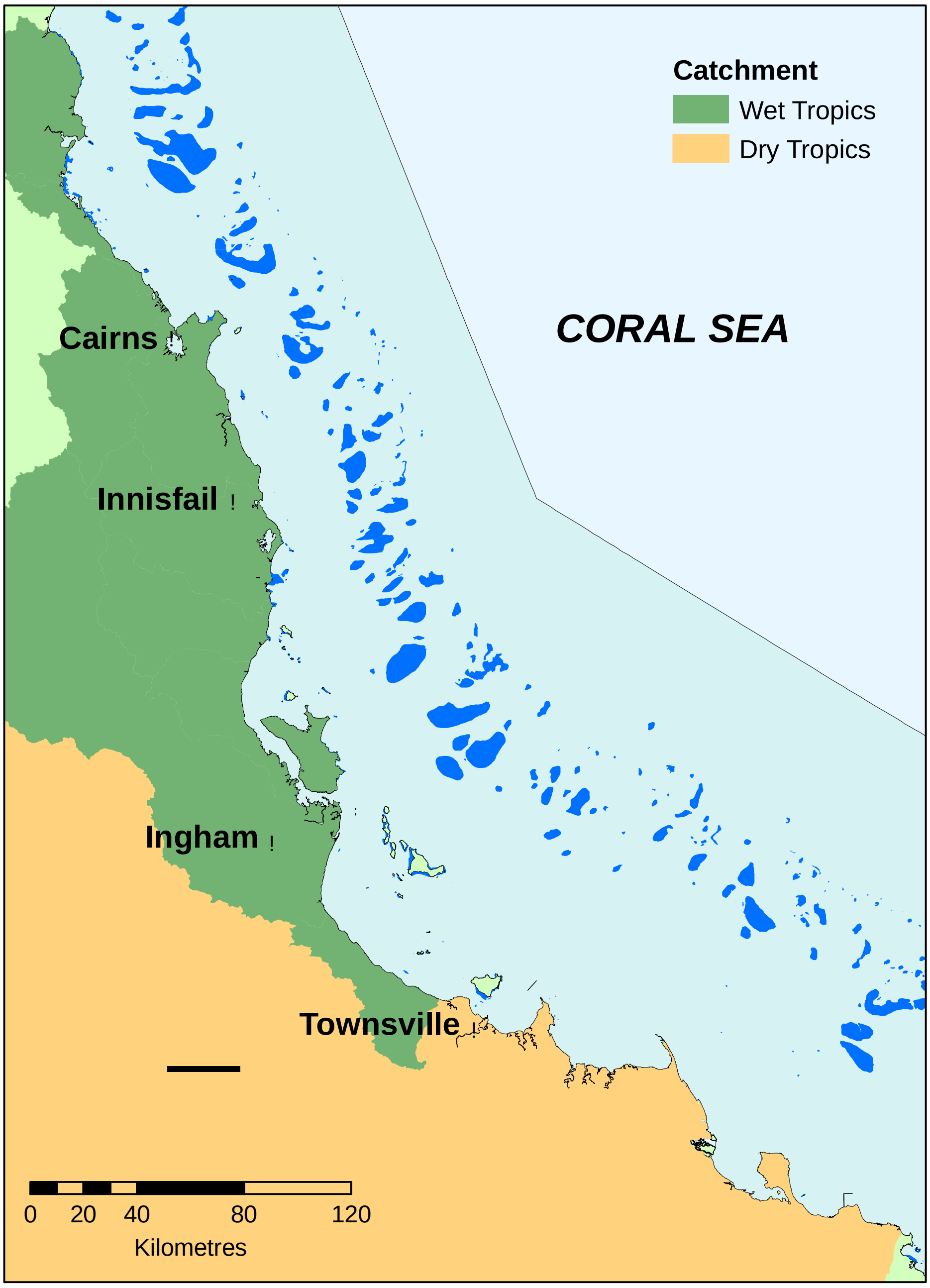

Figure 1: The spatial extent of the Dry and Wet Tropics of the Great Barrier Reef World Heritage Area. Major regional centres are labeled.

Methodology and Results

In our spatial risk assessment, we followed Sutur (1993) and estimated the risk to coastal seagrass habitats from various anthropogenic factors in the dry and wet tropical regions by identifying the hazards; quantifying the exposure of seagrass to these hazards; and estimating the risk to seagrass from the hazards.

Hazard identification

The Northern Fisheries Centre hosted a workshop of experts to assess the *present* risk to coastal seagrass communities from anthropogenic activities on 23 May 2008 at the offices of the Queensland Department of Primary Industries and Fisheries, Oonoonba, Townsville.

Experts on seagrass ecology and biology, marine and terrestrial management, water quality and spatial information were invited to attend the workshop. Attendees included Rob Coles, Jane Mellors, Len McKenzie, Helen Taylor, Phil Hales and Mike Rasheed (QDPI&F); Alana Grech, Michelle Waycott, Catherine Collier and Stephen Lewis (JCU); David Souter (RRRC); Katharina Fabricius (AIMS); Laurence McCook (GBRMPA); and Murray Whitehead, Niall Connolly and Mark Kelton (EPA). Apologies were given by Glenn De'ath (AIMS), David Wachenfeld (GBRMPA) and Jon Brodie and Michelle Devlin (JCU).

A Delphic approach was used at the workshop to identify the present hazards to inshore seagrass communities of the Dry and Wet Tropics. Experts identified hazards at both broad ($4km^2$ grid cells) and fine (inter-tidal, sub-tidal, coastal deep) spatial scales (Table 1). The experts identified thirteen hazards for all coastal seagrass habitats (broad spatial scale), ten hazards for inter-tidal seagrass habitats, ten hazards for shallow sub-tidal seagrass habitats and eleven hazards for coastal deep water seagrass habitats (Table 1).

In this reports analysis, we quantified the risk to coastal seagrass communities at a broad spatial scale (i.e. we did not quantify risk to inter-tidal, sub-tidal and coastal deep seagrass habitats).

Exposure quantification

During the workshop, experts identified spatial (GIS) data layers that delineate the distribution of the identified hazards. A summary of the spatial data layers for each identified hazard is provided in Table 2. All metadata of the spatial layers listed in Table 2 are available via the QDPI&F. We intersected digital GIS layers of the spatial risk from all hazards to form composite impact coverage.

To quantify the exposure of coastal seagrass communities in the Dry and Wet Tropics, we generated a GIS-based habitat model of seagrass presence and distribution at a regional and sub-regional scale. We choose a Bayesian belief network (BBN) to investigate dependencies among seagrass responses and environmental drivers that included: (relative exposure (a function of wind intensity and topography), bathymetry, presence of flood plumes, season, region, tidal range, and sea surface temperature. We found that at the scale of the entire GBRWHA, the main drivers of coastal seagrass presence are tidal range and relative exposure. The outputs of our analysis included a probabilistic GIS-surface of coastal seagrass presence and distribution for both the wet and dry seasons, and across four regions. We combined the two models to create a mean index of seagrass presence and distribution in the GBRWHA (Figure 2). The mean model was used as the basis for quantifying the risk of coastal seagrass habitats from their anthropogenic hazards in the Dry and Wet Tropics.

Table 1: The hazards identified by experts to coastal seagrass habitats at broad and fine spatial scales.

Broad Scale	**Fine Scale**		
4km^2 Grid Cells	***Inter-tidal***	***Sub-tidal***	***Coastal deep***
Agricultural runoff	Agricultural runoff	Agricultural runoff	Agricultural runoff
Boat damage (commercial)	Boat damage (recreational)	Boat damage (commercial)	Boat damage (commercial)
Boat damage (recreational)	Changes to water flow	Changes to water flow	Dredging
Changes to water flow	Dredging	Dredging	Dredging disposal
Dredging	Dredging plumes	Dredging plumes	Dredging plumes
Dredging disposal	Exotic pests	Exotic pests	Exotic pests
Dredging plumes	Other fishing	Other fishing	Other fishing
Exotic pests	Shipping accidents	Shipping accidents	Shipping accidents
Other fishing	Urban/industrial runoff	Urban/industrial runoff	Trawling
Shipping accidents	Urban and port development	Urban and port development	Urban/industrial runoff
Trawling			Urban and port development
Urban/industrial runoff			
Urban and port development			

Table 2: The hazards identified by experts to coastal seagrass habitats and the spatial (GIS) data layers that delineate their distribution. All metadata of the given spatial layers are available via the QDPI&F.

Anthropogenic hazard	**Spatial data layer**
Agricultural runoff	Reef exposure model (ACTFR; Maughan *et al.* 2008)
Boat damage (commercial)	Port Authority limits
Boat damage (recreational)	Model of vessel activity (JCU; Grech and Marsh, 2008)
Changes to water flow	Model of extent of flood plumes (ACTRF; Devlin *et al.* 2001)
Dredging	Port Authority limits
Dredging disposal	Port Authority limits
Dredging plumes	Port Authority limits
Exotic pests	Port Authority limits
Other fishing	6min fisheries grids (QDPI&F)
Shipping accidents	Port Authority limits
Trawling	Modelled VMS data (QDPI&F)
Urban/industrial runoff	2008 Census (ABS)
Urban and port development	2008 Census (ABS); Port Authority limits

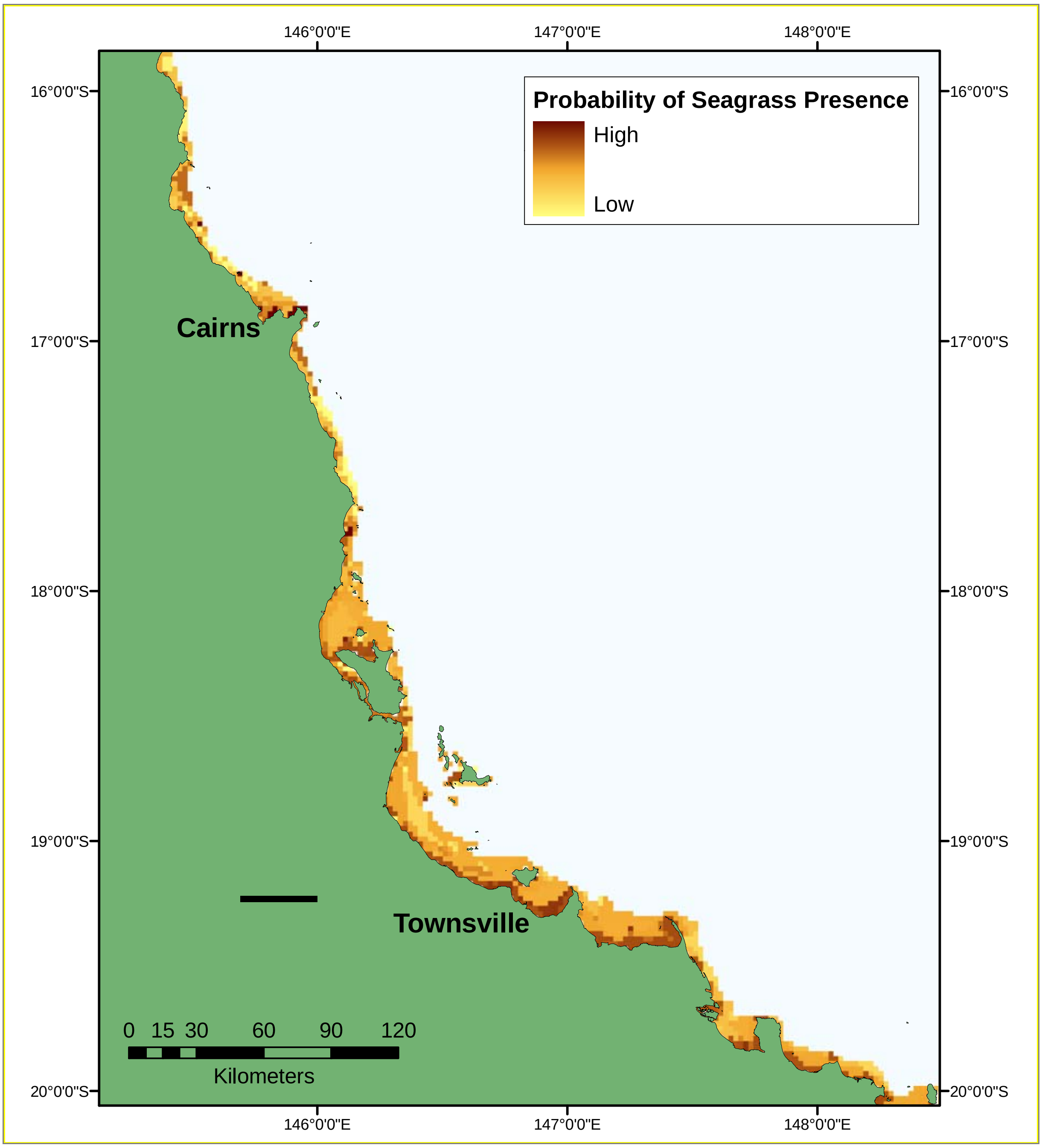

Figure 2: Probability model of coastal (<15m) seagrass presence in the Dry and Wet Tropics of the Great Barrier Reef World Heritage Area.

Risk estimation

Information on seagrass mortality, trauma or stress from the various human factors identified in the Dry and Wet Tropics is incomplete or unavailable at scales required for risk analysis. In the light of this uncertainty, we used expert knowledge to rank the risks to coastal seagrass habitats. A Delphic approach was used at the workshop to rank and weight the relative risk to inshore seagrass communities from each of the identified hazards.

Experts choose to quantify the risk to coastal seagrass communities by assigning a rank and relative weight for two criteria: (1) the damage caused by a hazard; and (2) the proportion of seagrass that is damaged when exposed to a hazard. A summary of the ranks and relative weights for each hazard at a broad spatial scale are provided in Table 3. We derived a relative hazard score for each hazard by calculating the mean of relative weights for the damage caused by a hazard and the proportion of seagrass that is damaged when exposed to the hazard (Table 3). The experts agreed that dredging has the greatest relative impact on coastal seagrass communities, followed by: urban/port infrastructure development; dredging disposal; dredging plumes; agricultural runoff; urban/industrial runoff; boat damage (commercial); trawling; other fishing; shipping accidents; exotic pests; boat damage (recreational); and changes to water flow.

The hazards identified by the experts do not have a homogenous distribution. For example, some ports in the Dry and Wet Tropics are dredge more frequently than other ports, and some ports are not dredge at all. We used the relative hazard score derived from expert opinion and information about the distribution of hazards to derive a relative hazard score for each impact level within a hazard (Table 4). We removed other fishing, exotic pests, boat damage (recreational) and changes to water flow from the analysis because their relative hazard scores were very low (< 6). Dredging disposal and dredging plumes were also removed as they are: (1) a product of the hazard dredging (i.e. dredging has to be performed for a plume or disposal to take place); and (2) plumes and disposal share the same spatial layer as dredging. The relative hazard score for dredging remains as 100 as it has the greatest impact relative to other hazards. The relative hazard score for each impact level within a hazard was imported to the composite coverage of hazards generated above (Figure 3). Regions of the greatest composite hazard score include Trinity Inlet and Cleveland Bay.

We used the Getis-Ord Gi* statistic to identify clusters of cells with a high or low composite score of hazards (Figure 4). If a cells value is high, and the values for all of its neighboring cells is also high, it is a part of a hot spot. The local sum for a feature and its neighbors is compared proportionally to the sum of all features; when the local sum is much different than the expected local sum, and that difference is too large to be the result of random chance, a statistically significant Z score is the result. For statistically significant positive Z Scores, the larger the Z score is, the more intense the clustering of high values. For statistically significant negative Z scores, the smaller the Z score is, the more intense the clustering of low values. We identified seven statistically significant hotspots where the composite score of hazards is high: Trinity Inlet, two regions north and south of Innisfail, Lucinda, Cleveland Bay, and the region north of Upstart Bay.

We evaluated, spatially, the relative risk of seagrass communities by combining the composite impact coverage with our probabilistic model of seagrass presence and distribution, resulting in a hazard/consequence matrix (Figure 5). A risk/consequence grid that has a high score will have both a high composite hazard score and a high probability of seagrass presence; a grid that receives a low score can have a high composite hazard score and a low probability of seagrass presence or a low composite hazard score and a high probability of seagrass presence. We used the Getis-Ord Gi* statistic to identify clusters of cells with a high or low risk/consequence value (Figure 6). We identified four statistically significant hotspots where the probability of seagrass presence is high and the composite score of hazards is high: Trinity Inlet, Lucinda, Cleveland Bay and the region north of Upstart Bay.

The hot spots identified generally occur within the limits of Port Authorities as the composite impact coverage is swamped by the values of dredging and urban and port infrastructure development. We used a sensitivity analysis to identify the risk to coastal seagrass habitats from hazards that operate at broad spatial scales and occur with a high frequency. We removed from our composite impact coverage hazards that operate at fine spatial scales (i.e. dredging, boat damage, shipping accidents, urban/industrial runoff and urban and port development). We recalculated the composite rating of agricultural runoff and trawling and composite rating of impact level and generated new composite impact coverage. The new coverage was combined with our probabilistic model of seagrass presence and distribution, resulting in a new hazard/consequence matrix. We used the Getis-Ord Gi* statistic to identify clusters of cells with a high or low risk/consequence value (Figure 7). The identified hot spots have a greater spatial extent than the hot spots identified using information on the distribution of all hazards (Figure 6). Additional hotspots than those identified in the previous analysis include the region between Hinchinbrook Island and Cairns, Hinchinbrook Island, and the region between Bowling Green Bay and Upstart Bay. Cleveland Bay is no longer identified as a hot spot.

Table 3: Ranks and relative weights for each hazard identified by experts at a broad spatial scale based on two criteria: the damage caused by a hazard, and the proportion of seagrass that is damaged when exposed to a hazard. The relative hazard score was derived from the mean relative weight of the two criteria.

Hazard	**Ranking by criteria**			**Relative weight by criteria (out of 100)**		
	Damage caused by hazard	Proportion of seagrass exposed	***Composite Ranking***	Damage caused by hazard	Proportion of seagrass exposed	***Relative Hazard Score***
Dredging	1	1	1	100	100	**100**
Urban/port infrastructure development	2	1	2	95	87	**91**
Dredging disposal	3	2	3	75	63	**69**
Dredging plumes	4	3	4	60	32	**46**
Agricultural runoff	4	3	4	60	25	**43**
Urban/industrial runoff	4	5	5	60	5	**33**
Boat damage (commercial)	5	4	5	20	12	**16**
Shipping accidents	5	6	6	10	22	**16**
Trawling	5	4	5	11	13	**12**
Other fishing	7	4	6	5	7	**6**
Exotic pest	8	5	8	3	4	**4**
Boat damage (recreational)	6	6	7	4	4	**4**
Changes to water flow	8	6	9	1	2	**2**

Table 4: Individual and composite scores of the relative risk of anthropogenic hazards to seagrass derived from expert opinion and spatial (GIS) data layers.

Hazard	Relative Hazard Score	Composite rating of hazard relative to other impacts[a]	Impact level within risk factor	Rating of impact level within risk factor[b]	Composite rating of impact level[c]
Dredging	**100**	**32**	High	100	32
			Medium - High	30	10
			Medium	10	3
			Low	0	0
Urban/port infrastructure development	**91**	**29**	Present	100	29
			Absent	0	0
Agricultural runoff	**43**	**14**	High	100	14
			Medium - High	66	9
			Medium	33	5
			Low	0	0
Urban/industrial runoff	**33**	**11**	High	100	11
			Medium	50	5
			Low	0	0
Boat damage (commercial)	**16**	**5**	High	100	5
			Medium - High	20	1
			Medium	10	0.5
			Low	0	0
Shipping Accidents	**16**	**5**	High	100	5
			Medium - High	20	1
			Medium	10	0.5
			Low	0	0
Trawling	**12**	**4**	Present	100	4
			Absent	0	0

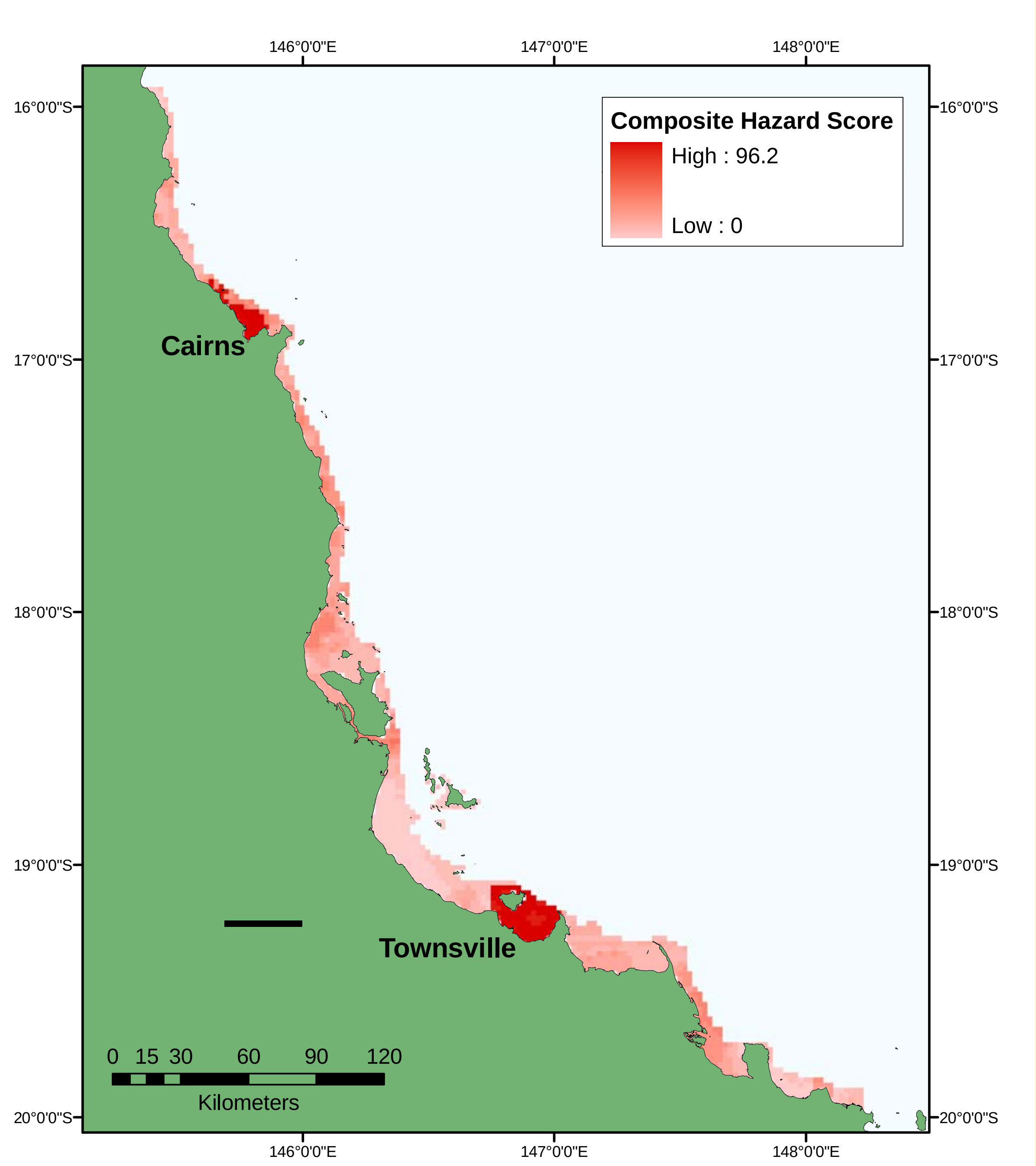

Figure 3: Composite hazard score for the coastal (<15m) region of the Dry and Wet Tropics derived from spatial information on the distribution of hazards and the relative hazard scores developed by experts.

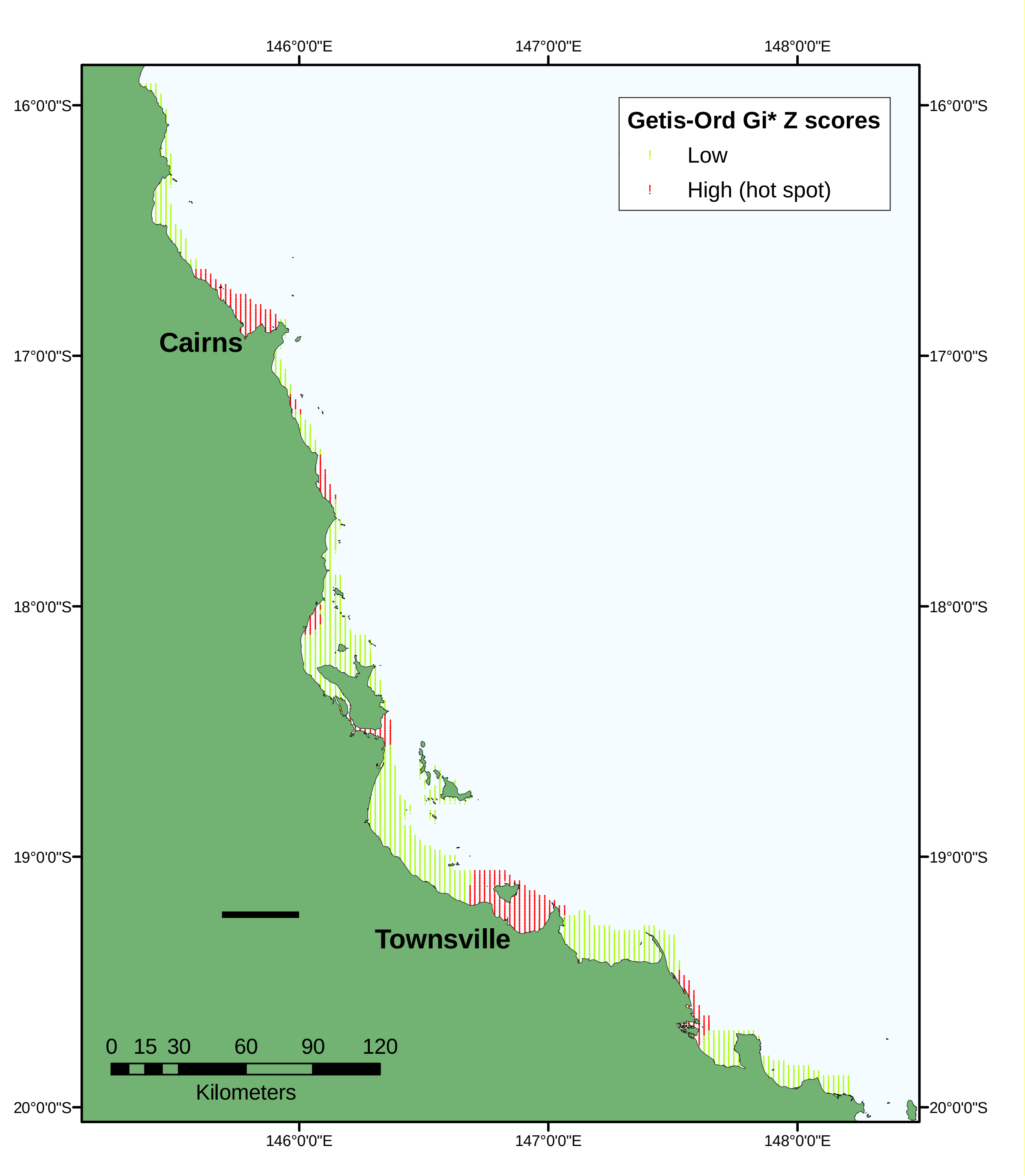

Figure 4: 'Hot spots' or clusters of cells of high composite hazards scores derived using the Getis-Ord Gi* statistic.

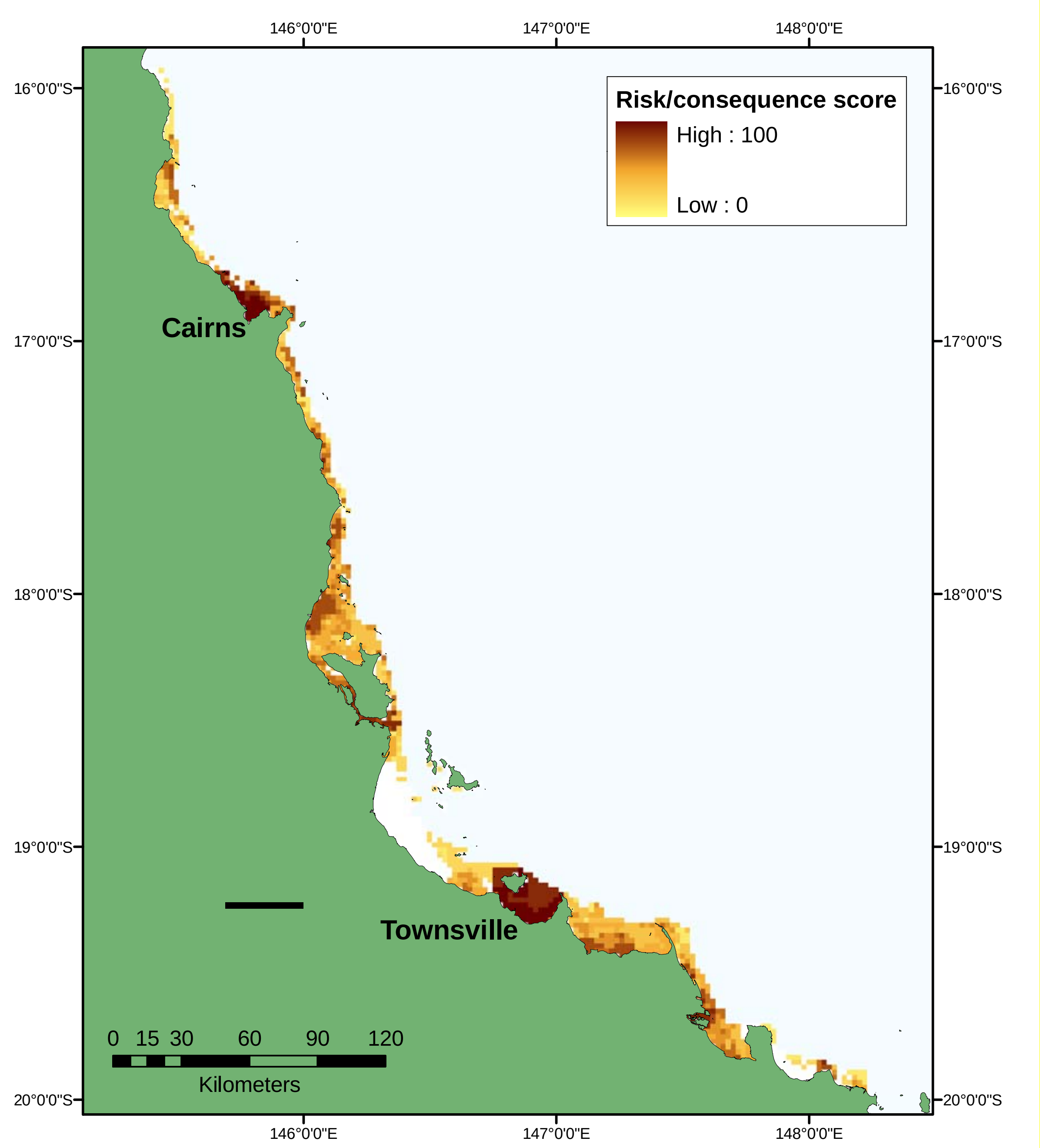

Figure 5: Risk/consequence matrix for the coastal (<15m) region of the Dry and Wet Tropics. A risk/consequence grid that has a high score will have both a high composite hazard score and a high probability of seagrass presence; a grid that receives a low score can have a high composite hazard score and a low probability of seagrass presence or a low composite hazard score and a high probability of seagrass presence.

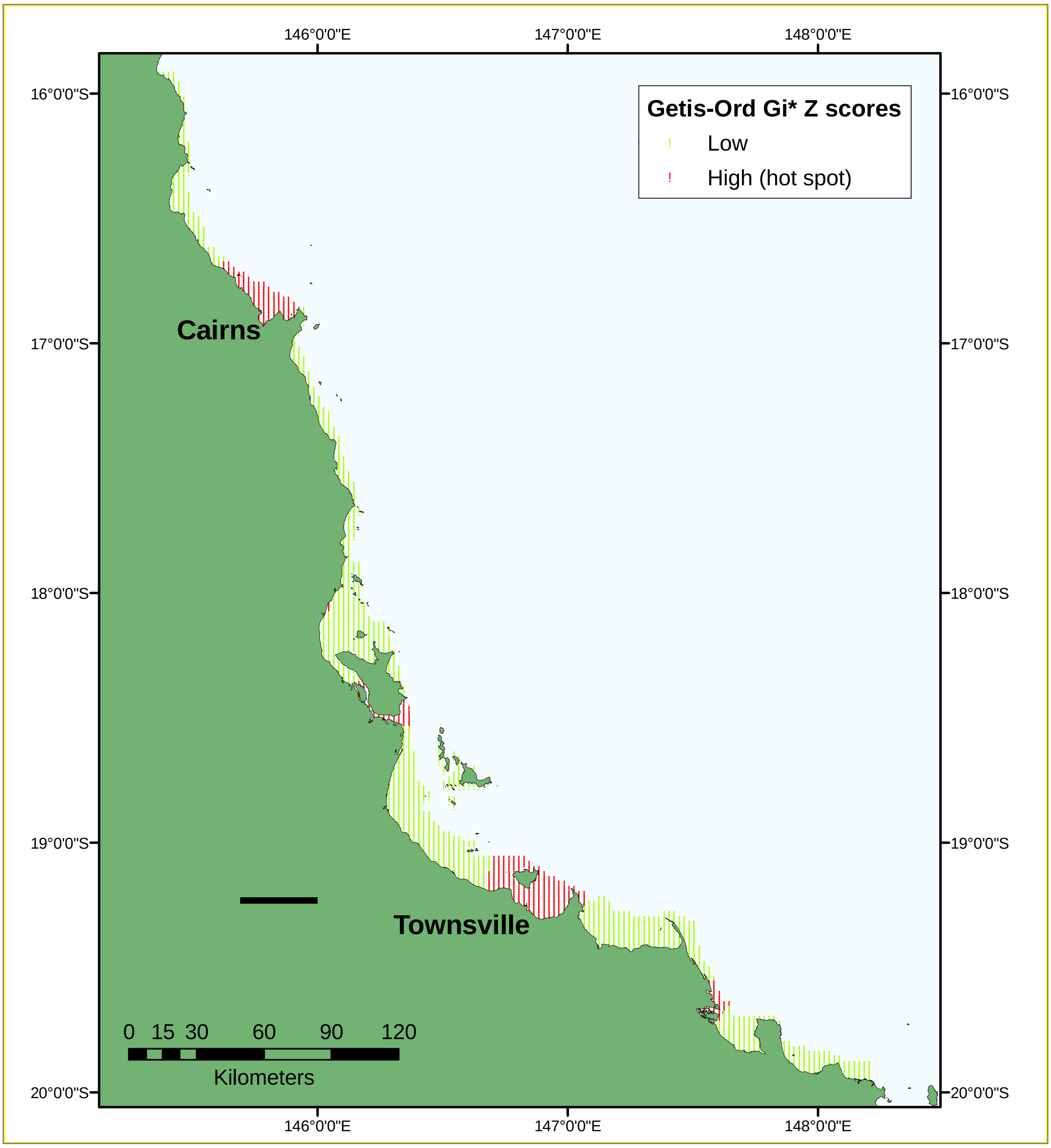

Figure 6: 'Hot spots' or clusters of cells of high risk/consequence scores derived using the Getis-Ord Gi* statistic.

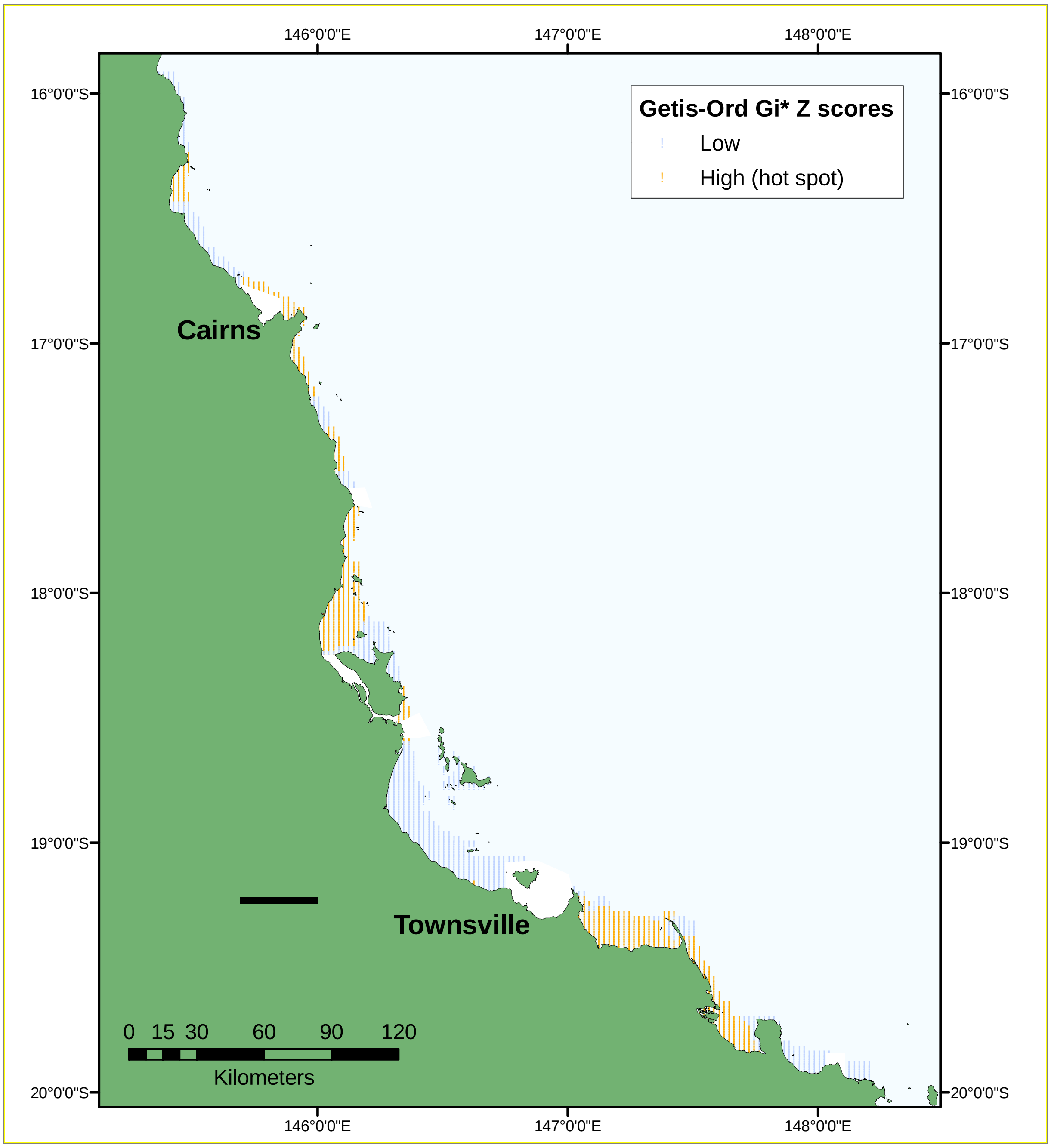

Figure 7: 'Hot spots' or clusters of cells of high risk/consequence scores for hazards that function over broad spatial scales after the removal of ports derived using the Getis-Ord Gi* statistic.

Discussion

Uncertainty in the information that contributes to management decisions can result in poor management actions (Carey *et al.* 2005). We minimise the uncertainty in our analysis of the relative risk to coastal seagrass habitats from each of the identified hazards by basing our assumptions on quantitative and qualitative information made available through the literature and expert opinion. Our models still contain uncertainties that are difficult to quantify as there is a lack of precise information on the characteristics and spatial distribution of hazards that impact coastal seagrass in the GBRHWA. As new information becomes available, our assessment can easily be improved by revaluating our assumptions, updating the geographic layers, and adjusting the expert weightings of hazards.

Previous analyses have identified areas of high risk by location, known exposure to hazards and the ability to capture that knowledge based on the availability of information and the feasibility of a management response (Rasheed *et al.* 2007). The spatial risk approach we have adopted in this report provides an automated analytical interpretation that utilizes the most current spatial information collected by government and non-government organisations and allows us to examine exposure from lower levels of risk at broad spatial scales. All models have boundary conditions and in limiting this analysis to coastal seagrass meadows and to scales of 4km^2 some small systems where risk has been identified previously such as Mourilyan Harbour (Rasheed *et al.* 2007) are not included.

By using a spatial risk-assessment approach, we were able to compare and rank risks in order to identify the most severe risks first, and to locate specific sites that require further management attention. We found sites of a high probability of seagrass presence and a high composite hazard score, including Trinity Inlet, Lucinda, Cleveland Bay and the region north of Upstart Bay (Figure 6). For management to be effective in species conservation over large geographic regions, it is essential to manage effectively those areas where the species are most vulnerable (Roberts *et al.* 2001). It may be unreasonable to protect seagrass by restricting anthropogenic factors that pose a hazard to the species for an entire region’s coastline, but management plans can be successful by protecting sites where seagrass are abundant. Furthermore, targeting management initiatives to ensure these areas are resilient to anthropogenic impacts will further enhance conservation goals.

Management arrangements that control the risk to seagrass meadows and the species that depend on them for ecosystem services are complex. The arrangements are more complex than in other parts of the world because of the presence of the Commonwealth administed GBRWHA, but many parts of the world share similar resourse development and conservation trade offs (Coles and Fortes 2001). McGrath (2003) identifies nearly fifty legislative instruments, International, Commonwealth and State that make up the Queensland environmental legal system all of which have potential to influence seagrass management. Like the risks and issues they are designed to address they also have a spatial dimension in application. Intense and small scale impacts such as dredging are well defined in legislation and have a high level of management intervention. Broad scale impacts that cross jurisdictions such as the affect on seagrass meadows from run off from the adjacent coast are less intensely managed. The spatial approach we have adopted in this analysis provides a step towards recognising and separating out those levels of risk and management intervention.

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