Chapter 1

The ecosystem service value of protected areas for cyclone protection in Queensland, Australia

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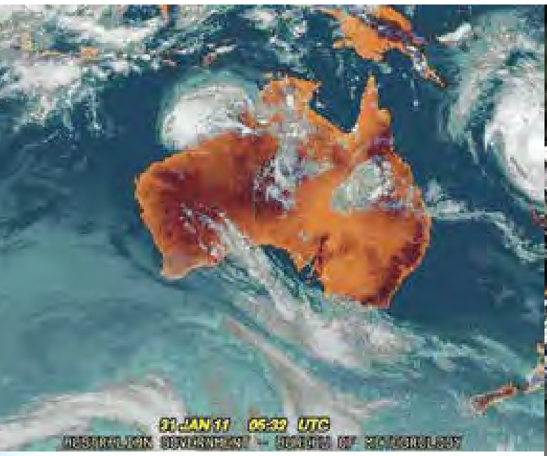


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Top Left: Source: Bureau of Meteorology (2011). Severe Tropical Cyclone Yasi Satellite Loop. Satellite image for Monday 31 January 2011 05:30 UTC.

Bottom left: Source: Property Causality 360° (2011). Top Disasters of 2011 – Slideshow. Cyclone Yasi Feb. 2 Struck Queensland, Australia as a Category 5.

Main Photo: Source: Smashed boats at the Hinchinbrook Marina. Source: The Courier-Mail

Abstract

Protected areas and the natural environment deliver a wide range of ecosystem services that contribute to human wellbeing. Here we examine the value of protected areas for cyclone and coastal protection in Queensland, Australia. Natural events such as cyclones threaten the health or wellbeing of human society however we can plan to minimize their impacts. Sea level rise, as well as an increase in cyclone intensity and storm surges associated with climate change will result in the erosion of shores and habitats, increased salinity of estuaries and freshwater aquifers, altered tidal ranges in rivers and bays, changes in sediment and transport, and amplified risk of coastal flooding that, in turn, will increase the vulnerability of coastal populations. Coastal wetlands, such as mangroves and floodplains, barrier islands and coastal vegetation all play a critical role in reducing the impacts of floodwaters produced by coastal storm events and tropical cyclones as well as in physically buffering climate change impacts. In an era when mankind's activities are the dominant force influencing biological communities and ecosystems, proper management requires understanding of the pattern and process in biological systems and development of assessment and evaluation procedures that assure protection of biological resources. That assessment must also include the value of ecosystem services and the role they play in disaster and risk reduction.

1. Introduction

1.1 Study area

The Tully-Murray catchment is located in Far North Queensland, Australia and is bordered by the Wet Tropics World Heritage Area (WT WHA) in the west and by the Great Barrier Reef World Heritage Area (GBR WHA) in the east (Figure 1). The study site comprises an area of 278,886 ha and contains six primary and twenty-six secondary land use classes (as defined in the Australian Land Use Management Classification Version 7, 2010[1]). The higher elevations and upper reaches of the rivers and creeks are primarily occupied by tropical rainforest and sclerophyll forests, while the coastal floodplain has largely been cleared and drained for agricultural purposes (Johnson, 1988). Remnant patches of rainforest are found on the alluvial plains and in wetlands and estuaries near the alluvial coast. While 64% of the natural forest in the Tully-Murray catchment is protected and included in the Wet Tropics World Heritage Area, in National Parks or State Forests, as well as in Nature refuges, the remaining 36% of natural forest is under environmental pressure. The area of floodplain vegetation in the catchment is approximately 20.8 km^2, and has decreased by approximately 80% compared to pre-European settlement (Furnas, 2003) due to increased agricultural development.

Along the mainland coast are low-lying deltas that are periodically inundated during cyclonic floods. In the past, storm surges and high winds have caused enormous human and economic devastation in these areas. Agriculture, tourism, fishing, ports and transport, as well as ecosystems, have suffered from the impacts of extreme weather. The Wet Tropics bioregion in Far North Queensland is a region of high economic importance and exceptional environmental value (McDonald & Weston, 2004). It contains the highest biological diversity in Australia, and occupies less than 2% of Queensland, yet provides 10% of the State's agricultural activity and 23% of tourism activity.

The Great Barrier Reef (GBR) is one of the largest and most diverse coral reef ecosystems on Earth, spanning 2,300 km along the east coast of Queensland, Australia[2]. The Great Barrier Reef catchment covers 86,602.6 km^2 (Figure 1). As a World Heritage listed

Figure 1: Location of the Tully-Murray catchment (study area) relative to the Great Barrier Reef and Wet Tropics world heritage areas, Queensland, Australia.

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[1] http://www.daff.gov.au/ABARES/aclump/Pages/land-use/alum-classification-version-7-may-2010/alum-classification-version-7-may-2010.aspx.

[2] Great Barrier Reef Marine Park Authority (2009) Great Barrier Reef Outlook Report 2009.

area, the Great Barrier Reef plays an important role in community life. Coastal communities and the Great Barrier Reef have a mutually beneficial relationship: communities benefit from their proximity to the GBR, allowing easy access and a sense of connection to reef ecosystems. In deriving benefits from the GBR, these communities also have impacts on the reef, some of which are negative. The Reef provides local residents, tourists and visitors with a wealth of cultural ecosystem services particularly recreational services including beach combing, snorkelling, diving, whale watching, boating, fishing and island camping. The Reef and its catchment bring AUS$ 5.77 billion into the Australian economy each year through Reef-dependent industries such as tourism and commercial fishing, and provide jobs for almost 69,000 people[3]. In 1981 The Great Barrier Reef was inscribed on the World Heritage List in recognition of its unique attributes of Outstanding Universal Value. The Great Barrier Reef Marine Park is jointly managed by the Commonwealth and Queensland governments as a multiple use park, allowing a wide variety of human activities to occur including tourism, commercial fishing, recreation, scientific research and Indigenous traditional use. It is also used extensively as an international waterway for vessels transiting the Reef with eleven ports operating adjacent to the GBR, accounting for some AUS$ 17 billion of Australia's export trade (AMSA, 2010). The export movement of bulk cargoes and imports of essential fuel and manufacturing inputs are crucial to the economic and social wellbeing of the country. The ports service a population of around 1 million in northern regional Queensland or 27% of Queensland's population (AMSA, 2010).

Recently the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Committee, have raised concerns about the international and national sensitivity and visibility of proposed port developments and associated shipping in and around the Great Barrier Reef World Heritage Area (GBRWHA). Two reports have been prepared to analyse the future risk of shipping and provide port industry vessel forecasts (Braemar Seascope, 2013; PGM Environment, 2012). The Queensland commodity market is and will continue to be dominated by the coal trades, with coal representing 81.8% of total trade in 2015 in terms of both tonnage and shipping traffic volumes (Braemar Seascope, 2013). It has been estimated that the average annual growth in coal ship traffic between 2011 and 2025 will be approximately 6.31% (Braemar Seascope, 2013) assuming expansion of ports to their full capacity. Despite in excess of 8,000 ship movements each year within the GBR, there has only been a small number of collisions and groundings, with 5 out of 26 'major' oil spills recorded in Australian waters having occurred in the GBR and Torres Strait (PGM Environment, 2012). Cyclones can occur the entire length of the GBR, with the northern sections at greater risk than the southern and as a precaution ships are cleared from anchorages and directed to proceed out to sea when cyclones threaten the GBR. This is typically initiated to allow ships enough time to clear the GBR and to ride out the storm at sea, which is the safest place for them and voids the risk of the ships dragging their anchors. For a further critical review of environmental management and other issues associated with the GBR readers are referred to Brodie and Waterhouse (2012).

1.2 Tropical cyclones

In February 2011, Tropical Cyclone Yasi (roughly the size of Italy), one of the largest cyclones to occur in the region in the last one hundred years, crossed the north Queensland coastline near Mission Beach. Tropical cyclones develop over the warm oceans to Australia's north during the summer months from November to April, and can generate destructive winds, heavy rain and flooding to many coastal areas in Western Australia, Northern Territory and Queensland. The impact of a cyclone is generally felt over an area of hundreds of square kilometres, over many days with the most destructive winds experienced just outside the eye. These destructive winds can cause extensive property damage and generate windborne debris. The Bureau of Meteorology categorizes cyclones with increasing severity from Category 1 to 5 according to the maximum expected wind speed and minimum central pressure, as shown in Table 1. Cyclone Yasi was categorized as a category 5 in the centre of the study area, crossing the coast near Mission Beach, 138 km south of Cairns, with maximum sustained wind speeds of 205 km/hr and maximum wind gust of 285 km/hr. The lowest central pressure recorded was 292 hPa. Extensive seagrass and coral damage was recorded in a 300 km wide band across the continental shelf, with a reported area of 89,090 km^2 (15% of the total) of the Marine Park sustaining some coral damage and 6% classified as being severely damaged (GBRMPA, 2011).

Tropical Cyclone Yasi is one of the most powerful cyclones to have affected Queensland since records commenced[4].

Tropical cyclones are the main coastal hazard for low-lying lands along the Queensland coast. An average of 1.2 cyclones per year occur within 500 kilometres of Brisbane (Harper *et al*., 2001). The town of Cairns is considered vulnerable to the impacts of cyclones, with some critical infrastructure in low-lying areas including the airport, already vulnerable to the highest tides (Poloczanska *et al*., 2007) and Cairns Hospital. King tides regularly threaten homes along the Arlington Esplanade

Table 1: Bureau of Meteorology Cyclone Categories.

Cyclone	Gust wind speed at 10 m height in flat open terrain			Central Pressure
category	km/h	knots	m/s	hPa
1	90-125	49-68	25-35	>990
2	125-164	68-89	35-46	970-985
3	165-224	89-121	46-62	950-965
4	225-279	121-151	62-78	930-645
5	>280	>151	>78	>925

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[3] Deloitte access Economics (2013).

[4] *Source*: Bureau of Meteorology - http://www.bom.gov.au/cyclone/history/yasi.shtml.

in Clifton Beach, with residents having to sand bag their properties to prevent inundation in some cases (Steneck, 2008). Major cyclone, flood and storm events between 1967 and 1999 (approximately 70 events in total) have cost Queensland almost AUS$ 8 billion (1998 dollar estimates) (Johnson *et al*., 2005). In 2006, damage costs from Cyclone Larry were estimated at more than AUS$ 1 billion (Valentine & Johnson, 2004). Extensive damage to property and infrastructure from Cyclone Yasi has been costed at AUS$ 800 million.[5] In particular the Lucinda Sugar Terminal was damaged by Cyclone Yasi to a point that all exports ceased during repairs (Braemar Seascope, 2013). Additionally further impacts were felt as sugar plantations recovered from floods as a result of the cyclone in southern ports such as Mackay and Bundaberg, which also have large exports of bulk sugar.

1.3 Cyclones, storm surges and coastal vegetation systems

Cyclones not only cause significant damage to property and infrastructure, but can also be responsible for the triggering of subsequent storm surges through high wind velocities. Wave effects can increase the water level by the same elevation as the surge itself (Trollope *et al*., 1972). In a tropical system a storm surge can be 300-700 kilometres across, penetrate far inland and raise water levels for several hours (Feagin *et al*., 2010). There is general acceptance globally that coastal ecosystems such as mangroves and saltmarsh absorb energy from waves and storm surges making them less damaging and providing regulating ecosystems services such as protection of shores and prevention of erosion (Stolton, Dudley & Randall, 2008; UNEP-WCMC, 2006). Such global acceptance is evident, for example, by the naming of a sacred coastal grove in Southern India, which translates as 'the forest that controls the waves' (UNEP-WCMC 2006). Furthermore, around 90 per cent of fishers interviewed by Walton *et al*. (2006) in the Philippines believed mangroves provided protection from storms and typhoons.

Some literature exists to support the premise that coastal ecosystems can mitigate storm surges but does not quantify the mitigation potential. However, it is thought that coastal ecosystems mitigate storm surges through attenuating waves as they pass over or through wetlands, marshes and mangroves. The science on short-period wave attenuation may not necessarily be extrapolated to the conclusion that vegetation can reduce the effects of storm surges or tsunamis (Feagin *et al*., 2010). Wave energy is also lost through frictional drag as the wave passes mangrove or saltmarsh vegetation and through bottom friction in shallow water areas (Shepard, Crain, & Beck, 2011). Additionally, increased bed roughness as a result of vegetation trunks, branches and roots reduces currents and dissipates wave energy (Quartel *et al*., 2007). As a result, this reduces the strength of a storm surge, and can reduce its peak or delay its arrival inland (Wamsley *et al*., 2010). Additional benefits of vegetation that have been reported include trapping floating objects such as broken branches.

Trees can also mitigate damage by acting as a debris barrier. This was observed after Cyclone Tracy in Darwin (Cameron *et al*., 1983), Cyclone Winifred in Innisfail (Oliver & Wilson, 1986) and Cyclone Yasi in Townsville (Greening Australia & Calvert, 2011). Research has shown that there is a clear case for using natural assets in a holistic flood and cyclone hazard management approach and that natural assets will have the most impact on reducing or preventing flood and cyclone damage from events with a lower average return interval. The more extreme events (such as tsunamis) will overwhelm any approach (Kerr & Baird, 2007). The research shows however that natural assets interventions are likely to be more cost-effective in many cases than structural approaches (Department of Environment and Heritage Protection, 2012). They also provide other economic benefits through supporting ecosystem services, biodiversity, fisheries, drinking water treatment, recreation and tourism. A holistic approach should include land use planning, natural assets interventions balancing the needs of the catchment, ecology and community.

In this paper, we present an approach to mapping the value of protected areas and land use for cyclone and coastal protection, based on a case study of the Tully-Murray catchment, Cassowary Coast Regional Shire in the Wet Tropics and Category 5 Severe Tropical Cyclone Yasi. We believe that our research can serve as a template to assist in identifying areas for protection or 'hotspots' that need to be retained and rehabilitated because of their value in buffering the effects of cyclones, storm surges and associated flooding adjacent to the coast and in the swaths of cyclones.

2. Methodology

2.1 Datasets and analysis

The methodology adopted a spatial analysis approach to both visualize and analyse the six classes of land use in the Tully-Murray catchment/Cassowary Coast Regional Council area affected by Cyclone Yasi. Using ESRI ArcGIS 10.2 software the spatial datasets were assembled and compiled into one geodatabase. All of the spatial datasets were subsequently clipped to the study area boundary.

2.2 Creating cyclone buffers

The 'buffer' command was used to create the wind speed zones around Cyclone Yasi's track using the cyclone's wind speed attribute.

2.3 Natural resources – Regional ecosystems

Regional ecosystems have been defined for Queensland as '…vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil' (Sattler & Williams, 1999). These were clipped to the Cyclone Yasi wind speed shape file and calculations of the amount of hectares for each wind speed class and for each regional ecosystem Biodiversity Status[6] attribute (i.e. Endangered, Of Concern, and Not of concern) were calculated.

2.4 Land use

The 2009 Queensland Land Use Mapping (QLUMP) shape files were clipped to the buffered cyclone wind speed cover, and area calculations made for each land

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[5] Source: http://statements.cabinet.qld.gov.au/MMS/StatementDisplaySingle.aspx?id=73637.

[6] According to the Environment Protection Agency's degradation criteria, the Biodiversity Status is based on an assessment of the condition of remnant vegetation in addition to the pre-clearing and remnant extent of a regional ecosystem.

use category and wind speed. Using the ALUM classification system – Version 7[7], we examined the primary and secondary classes, which are related, to land use – the main use of the land, defined by the management objectives of the land manager. The primary and secondary classes of land use can be distinguished in order of generally increasing levels of intervention or potential impact on the natural landscape. A 'union' or topological overlay was performed using the Cyclone Yasi wind speed and land use spatial datasets which enabled us to retain all the features from both datasets and to create a new polygon dataset with all the features and attributes of both layers.

2.5 Terrestrial Protected Area Estates

The terrestrial Protected Area Estate started in Queensland with the proclamation of the *State Forests and National Parks Act 1906*. Over time the Protected Area Estate has grown from 131 hectares to total about 12.2 million hectares[8]. Protected areas were clipped to the buffered cyclone wind speed cover and area calculations made for each IUCN category and wind speed. A 'union' or topological overlay was performed using the Cyclone Yasi wind speed and protected areas spatial datasets.

2.6 Demographic and socio-economic data

The communities in our study area included Hinchinbrook, Cardwell, Tully Heads, Hull Heads, Bingil Bay and the Mission Beach area (North Mission, South Mission, and Wongaling Beach). All of the above communities lie in the jurisdiction of the Cassowary Coast Regional Council (CCRC). Additionally using the digital State Suburbs[9] and 2011 census data from the Australian Bureau of Statistics (ABS) we created spatial layers to represent human population distribution and density across the region. Other spatial layers created from the ABS 2011 census data included: population over 65 years old, indigenous people, sum of population per suburb, age, income, median weekly rent, employment and occupation. As old and dependent people are very vulnerable to natural hazards such as tropical cyclones, two groups were generated; population above 65, and children from the age of 0 to 19 years. The age group for children was chosen to include pre-ambulant children that cannot remove themselves from danger, children of an age not able to read (e.g. warnings) but also adolescent children because of their cognitive immaturity which can lead them to take unreasonable risks (UNEP, 2002). All of these layers were once again clipped to the wind speed and swath area of Cyclone Yasi and merged.

2.7 Freehold property valuation data

Property valuation data were obtained from the Cassowary Coast Regional Council for three time periods: 2010, 2011 and 2012. These data were based on valuations carried out by the Department of Natural Resources and Mines (DNRM) on the 1 October of each year. Data were provided on a locality basis[10] and a 'union' performed using the Cyclone Yasi wind speed and property valuation layers.

3. Results

Although only a relatively small population resides in the Cassowary Coast region, effects from Cyclone Yasi (Australia's second largest cyclone) were felt, particularly in areas where no coastal vegetation remains. Regional ecosystems exposed to the very destructive wind speeds of Cyclone Yasi are summarized in Table 2 and shown spatially in Figure 2. A small percentage (1.9%) of 'Endangered' regional ecosystems were exposed to 270 km/hr winds in the study area, with a further 16.1% of 'Of concern' regional ecosystems also affected. Hinchinbrook Island, a largely uninhabited island, and National Park, containing both 'Endangered' and 'Of concern' regional ecosystems also experienced 240 km/hr winds before Cyclone Yasi crossed the coast. Protected area estates, primarily National Parks (IUCN Category II) were the most affected by Cyclone Yasi in the Wet Tropics region with over 8 million hectares (97.6%) exposed to wind speeds in the range of 150-270 km/hr (Table 3, Figure 3).

Significant parts of both the Wet Tropics and Great Barrier Reef World Heritage Areas were also exposed to Cyclone Yasi (Figures 3-4). Within Cyclone Yasi's swath 5.47% of the Great Barrier Reef's cays and reefs were exposed to wind speeds between 150-270 km/hr, as well as a further 1.57% of islands (Table 3, Figure 4). Dunk, Bedarra and the Family group of islands were particularly hit hard experiencing 270 km/hr winds (Photos 1-3). Additionally, Hinchinbrook Island (183,272 hectares) and reef (1,207 hectares) also experienced 210-240 km/hr winds.

A total exposed area of 77,065 hectares (62.5%), classified as 'Conservation and natural environments' were subjected to Cyclone Yasi's very destructive winds, measured at around 270 km/hr (Table 5). Breaking the land use classes down further (using the secondary classification) reveals 42,605 hectares were affected by 270 km/hr winds, and an overall 53.8% of the entire study area

Table 2: Percentage and area (hectares) of regional ecosystems affected by Cyclone Yasi wind speeds.

Regional ecosystem	Wind speed km/hr					Total	%
	150	180	210	240	270		
Endangered	0	69.8	1,427.1	3,960.3	2,620.2	8,077.5	1.7
Of concern	0	827.1	26,668.4	33,541.2	12,707.9	73,744.6	15.8
Non-remnant	0	1,415.6	50,035.6	76,428.1	17,249.6	145,128.9	31.0
Not of Concern	0	81,249.4	104,220.5	95,124.2	33,687.1	241,181.1	51.5
Cleared	0	0	0	0	0.3	0.3	0.0
	0	10,461.9	182,351.6	209,053.8	66,265.1	468,132.5	100.0

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[7] Australian Land Use and Management Classification (ALUM) Version 7, May 2010 http://www.daff.gov.au/ABARES/aclump/Pages/land-use/alum-classification-version-7-may-2010/default.aspx.

[8] http://www.wildlife.org.au/conservation/issues/2012/protectedareas.html.

[9] For further information on State Suburbs ASGS Non ABS Structures Ed 2011 Digital boundaries see http://www.abs.gov.au/websitedbs/cens http://www.wildlife.org.au/conservation/issues/2012/protectedareas.html

[10] http://www.nrm.qld.gov.au/services_resources/item_details.php?item_id=32736.

(Table 6). A further 15% or 9,380 hectares of ‘Production dryland agriculture and plantations’ were also exposed to the very destructive winds (Table 5, Figure 3). Secondary land use classes affected included: cropping (12.9%), other minimal use (8.8%), and estuary/coastal waters (6.6%). Fortunately, only 1% (15,306 ha) of the total study area classified as residential was affected by Cyclone Yasi, with no residential areas in the 270 km/hr swath.

Although only a small component of the study area is classified as residential, an analysis of the 14,780 freehold property values in the study area (which includes rural residential and rural properties) reveals a substantial number of properties within the cyclone path had a value at the time of over AUS$ 2,465,515,395 (Table 7). Subsequently since then these property values have decreased in value to AUS$ 2,147,154,703 in 2011 and AUS$ 2,014,325,544 in 2012. Overlaying the ABS census statistics (Figures 5-6) also shows a high population density as well as a large Indigenous population, and people aged over 65 years old (Figure 5) that are concentrated along the coast, particularly in the north around the towns of Innisfail, Tully and Cardwell which were directly in the 270 km/hr wind zone area. Along with this residential area there comes a lack of remnant coastal vegetation and associated protected areas and national parks, further increasing the rate of flood and wave velocities leading to damaging flood waters especially along the Cardwell beach front.

Figure 2: Dominant regional ecosystems and IUCN protected areas affected by Cyclone Yasi, 2011.

Table 3: Percentage and total area (hectares) of protected area estates (IUCN categories) affected by Cyclone Yasi wind speeds in the Wet Tropics region.

IUCN Protected Area	Conservation Park	Forest Reserve	National Park	State Forest	Resources Reserve	Total Area (ha)	%
I	0	0	0	0	0	0	0
II	0	0	273,122.6	0	0	273,122.6	96.2
III	692.5	0	0	0	0	692.5	0.2
IV	0	0	0	0	0	0	0
V	0	0	0	0	0	0	0
VI	0	1,056.1	0	9,042.4	4.8	10,103.2	3.6
Total	692.5	1,056.1	272,8357.5	9,042.4	4.8	283,918.3	100

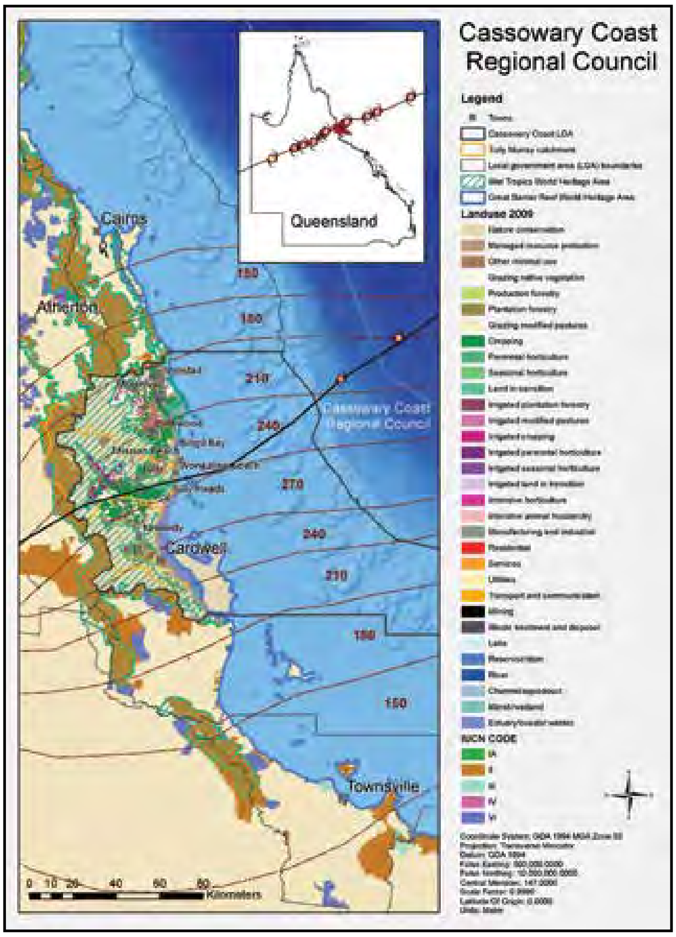
World Heritage Areas	Wind speed km/hr					Total
	150	180	210	240	270	
Wet Tropics	0	8,846.7	92,571.5	87,143.8	36,329.4	224,891.4
Great Barrier Reef	348	22,856.8	66,610.4	64,927.0	28,250.3	182,933.1
Total	348	31,703.5	159,181.9	152,070.8	64,579.7	407,824.5

Table 4: Great Barrier Reef World Heritage Area (GBR WHA) and features exposed to Cyclone Yasi wind speeds within the Cassowary Coast Local Government Area (LGA).

Wind speed km/hr	Area (hectares)	% of GBR WHA within Cassowary Coast LGA	% of total GBR WHA
150	436.44	0.04	0.00
180	160,511.27	13.93	0.46
210	397,844.84	34.52	1.14
240	382,227.53	33.17	1.10
270	211,416.45	18.35	0.61
Total	1,152,436.56	100	3.31

GBR Feature	Wind speed km/hr					Total	%
	150	180	210	240	270		
Cay	0	0	0	15.4	2.7	18.1	0.01
Island	0	0	20,508.4	19,566.9	583.1	40,658.4	22.2
Reef	348.7	22,855.6	46,067.5	45,340.6	27,664.5	142,276.9	77.7
Rock	0	1.2	34.4	4.0	0	39.6	0.03
Total	348.7	22,856.8	66,610.4	64,926.9	28,250.3	182,993.1	100

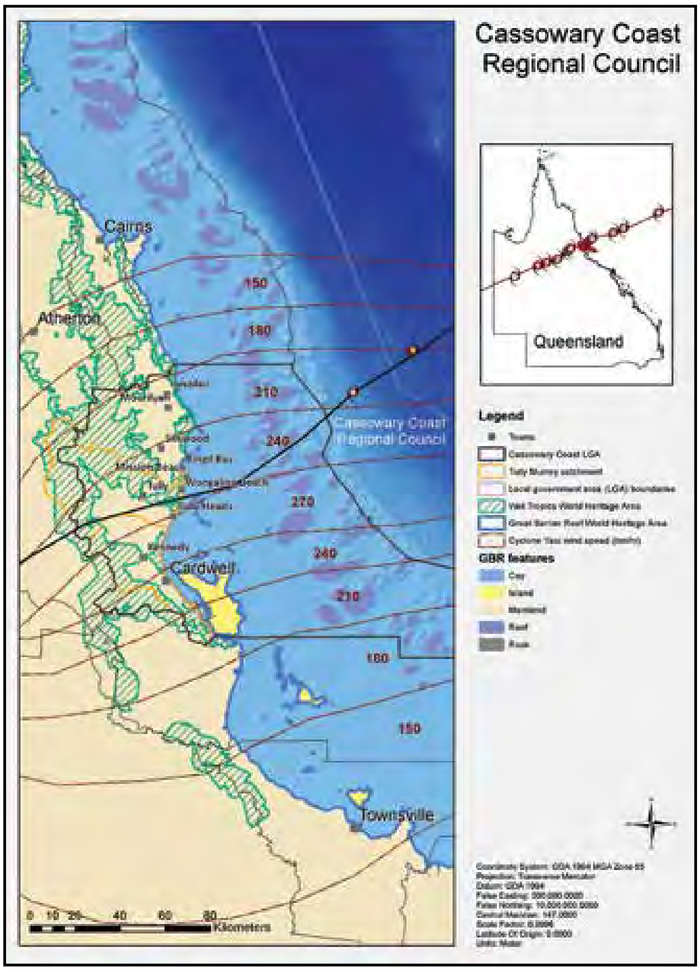
Figure 3: Secondary land use classes and IUCN protected areas affected by Cyclone Yasi, 2011.



Dunk Island Resort prior to TC Yasi.

Dunk Island Resort following the destructive waves, storm surge and winds caused by TC Yasi.

Figure 4: Great Barrier Reef features affected by Cyclone Yasi, 2011.



Damage and mass sand deposition at Dunk Island Resort caused by several metre storm surge during TC Yasi.

Table 5: Area (hectares) of primary land use affected by Cyclone Yasi at different wind speeds (km/hr).

Primary land use	Wind speed km/hr					Total	%
	150	180	210	240	270		
Conservation and natural environments	0	9,106.1	126,920.4	131,660.9	48,064.5	315,752.2	63.2
Intensive uses	0	234.7	3,006.9	3,699.3	480.3	7,421.2	1.5
Production from dryland agriculture and plantations	0	666.6	18,194.0	44,518.8	9,385.2	72,764.7	14.6
Production from irrigated agriculture and plantations	0	165.1	7,489.9	7,857.5	1,106.4	16,618.9	3.3
Production from relatively natural environments	0	280.9	16,775.9	15,137.5	5,510.8	37,705.2	7.5
Water	0	31.9	15,032.0	21,599.4	12,554.3	49,217.7	9.9
Total area	0	10,485.4	187,419.3	224,473.5	77,101.7	499,479.9	100.0

Table 6: Area (hectares) of secondary land use affected by Cyclone Yasi at different wind speeds (km/hr).

Secondary land use	Wind speed km/hr					Total	%
	150	180	210	240	270		
Cropping	0	17,213.3	63,640.3	40,034.5	6,423.6	64,215.5	12.9
Estuary/coastal waters	0	51.3	32,896.3	0	0	121.1	0.03
Grazing modified pastures	0	147.6	51.3	52.4	35.2	244.7	0.05
Intensive animal production	0	7,342.3	692.0	7,805.1	1,040.8	16,343.8	3.3
Intensive horticulture	0	16,283.8	26.9	12,781.9	3,835.3	33,181.9	6.6
Irrigated cropping	0	7,436.0	235.1	3,912.4	1,214.9	12,576.2	2.5
Irrigated perennial horticulture	0	106,806.6	16,180.9	112,178.5	42,620.7	270,435.9	54.1
Irrigated seasonal horticulture	0	19,103.8	30.4	19,048.8	5,423.8	43,852.4	8.8
Land in transition	0	889.9	145.2	4,366.1	2,961.5	8,270.3	1.7
Livestock grazing	0	2,026.6	32,885.7	2,450.6	449.7	5,159.1	1.0
Managed resource production	0	2,284.7	1,463.4	1,273.8	70.3	3,647.9	0.7
Manufacturing and industrial	0	371.2	318.4	460.1	5.3	839.1	0.2
Marsh/wetland	0	5,302.2	12,556.3	16,356.3	11,256.8	32,915.4	6.6
Mining	0	247.3	169.4	445.1	0	692.4	0.1
Nature conservation	0	18.5	261,484.6	8.4	0	26.9	0.01
Other minimal use	0	36.9	43,555.1	108.4	0	145.3	0.03
Perennial horticulture	0	1,010.0	12.5	433.6	20.3	1,463.9	0.3
Plantation forestry	0	181.5	8,213.6	135.9	1.1	318.6	0.1
Production forestry	0	71.3	4,520.9	98.2	0	169.5	0.04
Reservoir/dam	0	2.7	78.2	9.8	0	12.5	0.01
Residential	0	492.1	4,924.3	2,355.6	1,675.5	4,523.2	0.9
River	0	9.0	3,627.0	56.9	12.2	78.3	0.02
Services	0	85.7	836.1	78.8	24.2	188.7	0.04
Transport and communication	0	4.6	188.6	5.9	0	10.6	0.01
Utilities	0	0	10.6	16.2	0	16.2	0.01
Waste treatment and disposal	0	0	16.2	0	30.4	30.4	0.01
Total area	0	187,419.3	488,759.6	224,473.5	77,101.7	499479.9	100.0

Table 7: Value of freehold properties within the Cassowary Coast Regional Council area affected by Cyclone Yasi, and after in 2012 and 2013.

Wind speed km/hr	Total area (ha) of localities within wind speed track	Area (ha) that includes property value	Total property value $AUD of localities
150	0	0	0
180	11,048.79	3,797.83	24,764,288
210	205,543.58	133,079.41	889,545,438
240	285,020.27	242,566.98	1,436,237,660
270	91,558.22	91,558.22	114,968,009
Total	593,170.85	471,002.44	2,465,515,396
2012	593,170.85	471,002.44	2,147,154,703
2013	593,170.85	471,002.44	2,014,325,544

Figure 5: Cassowary Coast Regional Council – demographics showing children (dependents 0-19 years old) and population aged above 65 years affected by Cyclone Yasi, 2011.

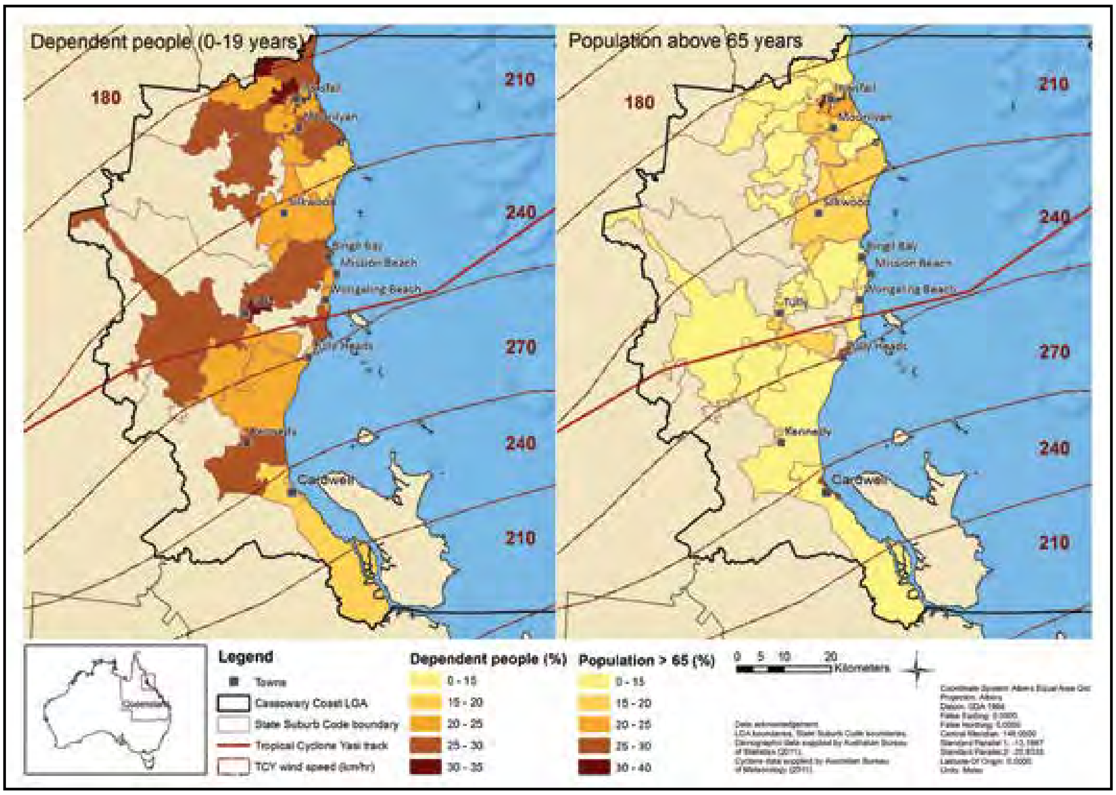
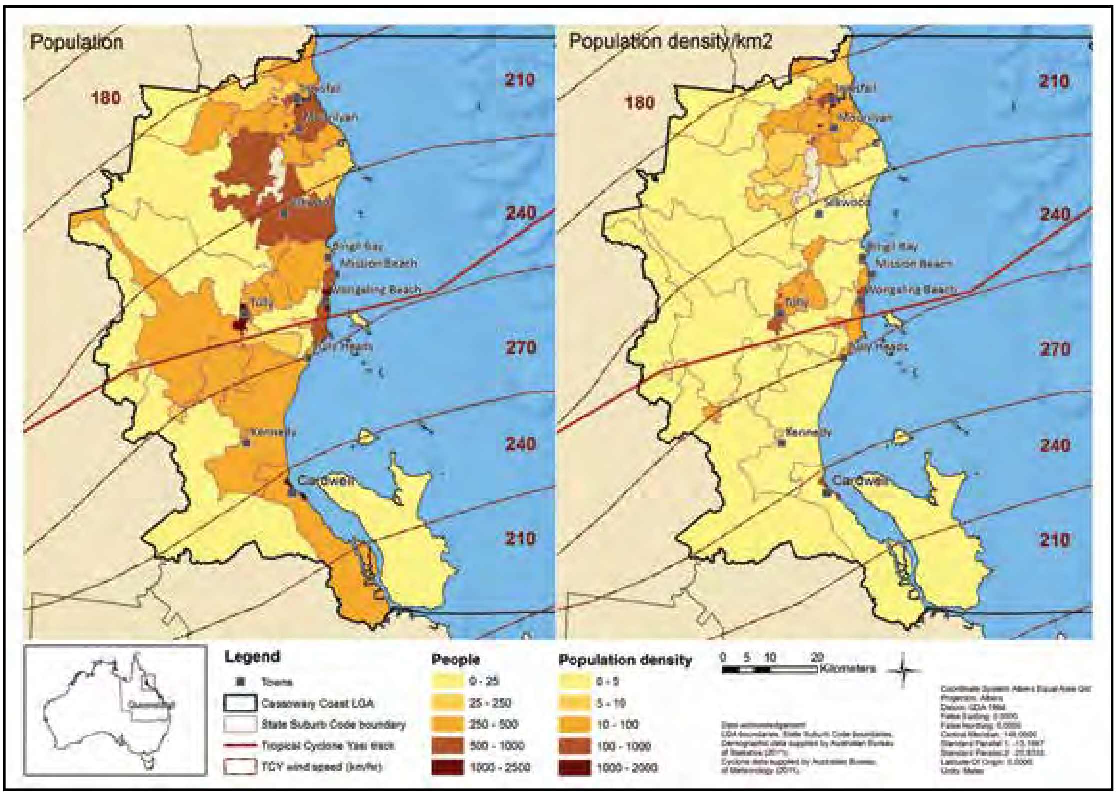


Figure 6: Cassowary Coast Regional Council – demographics showing population density and number of people affected by Cyclone Yasi, 2011.



4. Discussion

During the early development of many Australian coastal regions, a lack of planning and development restrictions, combined with a clear disregard for coastal hazards, has resulted in significant numbers of people and infrastructure placed at risk from hazards such as storm surges and inundations (King *et al*., 2012) which are often secondary effects from tropical cyclones. With the onset of climate change, coupled with development pressures associated with coastal population growth, levels of vulnerability and risk in storm surge prone areas will only increase. In response to this projected increase, this case study investigated the remaining area of natural coastal features and protected areas in the wake of Australia's second largest cyclone in the Cassowary Coast Local Government Area (LGA) in protecting communities from cyclones and associated storm surge and damage.

Cyclone Yasi made landfall near Mission Beach and continued inland for over 500 kilometres before it weakened near Mt Isa. Serious storm tide inundation was narrowly avoided as tropical Cyclone Yasi crossed 4 hours post high tide. However, it still caused extensive wind/rain damage and resulted in storm tide inundation in several locations along Queensland's tropical coast. The high wave energy generated by Cyclone Yasi resulted in beach erosion between Cairns and Townsville, and damage to infrastructure along the coastline between these two cities. Our analysis interrogates further the effects of Yasi on the natural environment within the Tully-Murray catchment where wind speeds between 200-275 km/hr were recorded by looking at both primary and secondary land uses, regional ecosystems and features of the Great Barrier Reef.

In Australia more than 92% of the population is already concentrated in six State capital cities and additionally unprecedented urban growth is also taking place along the Australian coastline, a phenomenon termed 'sea-change'[11] (Bohnet & Pert, 2010; Burnley & Murphy, 2004). By steering particular land uses away from vulnerable areas and encouraging their development in less hazard-prone locations, a community can reduce the risk to individuals and livelihoods. In the Queensland Coastal Plan (2011) there has been an increased focus on coastal hazard zones, based on a static increase in mean sea level and changes to the intensity of mid latitudinal storms and tropical cyclones[12]. Future land use planning and zoning will be imperative to the hazard adaptation process, for instance by reducing development in hazard prone areas. In North Queensland where the probability of severe cyclone-induced storm surges is relatively high in future decades, the strategy encouraged by the Queensland Reconstruction Authority is to build residences better able to withstand severe cyclonic winds and associated storm surges (Queensland Reconstruction Authority, 2011).

Historically, in many communities a 'land use plan' may be nothing more than a common understanding of where particular land uses should occur. Effective land use management systems need to have plans that are supported by policies, that prevent particular land uses from occurring in specific areas and encourage their development in more desirable locations. As shown the property values within the study area have decreased since Cyclone Yasi, and the economic impact has been estimated at close to AUS$ 3.6 billion dollars (according to forecasting service Tropical Storm Risk (TSR)). Some say its overall damage as measured by insurers puts it as the second worst cyclone to ever hit Australia, after Cyclone Tracy, which struck Darwin in 1974. It has been estimated that Cyclone Yasi destroyed about 15% of all sugar crops in Australia[13], and 50% of the productive potential in the region. Estimates of close to AUS$ 504 million dollars[14] in lost sugar cane generated revenue were also described.

When assessing the socio-economic position of the Cassowary Coast Regional area, a few disturbing patterns appear (when compared to other regions in the Wet Tropics), namely: incomes and employment are relatively low, unemployment is relatively high, and more than three quarters of the population have been assessed as falling within the bottom two quintiles of the Australian Bureau of Statistics', Socio-Economic Indexes for Areas (SEIFA)[15] index of socioeconomic disadvantage (Office of Economic and Statistical Research, 2011).

Protected areas have a high capacity to supply regulating ecosystem services (e.g. storm protection, flood control, erosion regulation) due to the low level of human intervention. The larger the protective buffer (especially along the coastline) the greater the damage reduction. In our study, a large area of the coastline has been cleared and was exposed to greater damage. Historically, much of the region was covered by tropical rainforest with local variations in type. Although our study did not look specifically at mangroves, they have been recognized as an important buffer between land and sea, filtering terrestrial discharge, decreasing the sediment loading of coastal waters and maintaining the integrity of coastlines (Lovelock & Ellison, 2007). The role of mangroves as a natural protective belt against cyclone and storm surges is however under threat, at the very time when storm damage is predicted to increase through climate change. The major impact from Tropical Cyclone Yasi occurred to the coast on the southern side of its track (in the vicinity of the radius of maximum winds) for beaches facing an east to south-east direction (e.g. Tully/Hull Heads, Mission Beach, Bingil Bay), which had the greatest exposure to onshore winds. It is suggested that future studies compare areas with and without mangroves along this coast at a more local scale, and investigate and quantify the role of mangroves in ameliorating effects such as wave surges post cyclone. It is recommended that vegetation characteristics such as vegetation density, stiffness, and width be measured, as

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[11] Sea-change is a popular Australian expression for what has been termed 'amenity migration' in the United States, Canada and Europe (Esparza & Carruthers, 2000; Marcouiller, Clendenning, & Kedzior, 2002; Moss, 2006).

[12] see Queensland Coastal Plan, s2.1 – Defining Coastal Hazard Areas

[13] http://www.news.com.au/finance/sugar-price-soars-on-us-markets-as-cyclone-yasi-hits-queensland/story-e6frfm1i-1225999207987

[14] http://www.reuters.com/article/2011/02/03/us-cyclone-australia-losses-idUSTRE7121K620110203

[15] http://www.abs.gov.au/websitedbs/censushome.nsf/home/seifa

vegetation width and height have been shown to have a positive effect on wave attenuation and shoreline stabilization (Shepard *et al*., 2011). Furthermore, a recent study of the links between the oceans and human health noted a critical need for epidemiological research to address the public health consequences of coastal flooding and the anticipated amplification of this human health hazard due to climate change (Kite-Powell *et al*. , 2008).

5. Conclusion

Damage from cyclones is caused by high wind velocities and additionally through storm surges inundating coastal areas. Measures to reduce the impact of cyclones in the past have included: using expensive structural and non-structural approaches to attenuate storm surges; the design of buildings and infrastructure to withstand high wind speeds; strengthening community and ecosystem resilience so that systems recover more quickly; and providing a buffer zone between the coastline and infrastructure.

The insight provided from this study builds on these measures by examining protected areas and natural features as barriers and their cyclone buffering capacity. This study strengthens the view that management of natural areas should be integrated into coastal zone hazard mitigation and climate change adaptation policies. Natural Resource Management (NRM) managers and communities need to be more aware of the value natural ecosystems play in protection of shores from storm surges and waves resulting from cyclones.

In the wake of Tropical Cyclone Yasi, the Cassowary Coast Regional Council, in association with James Cook University and the Queensland Reconstruction Authority released a set of non-statutory guidelines related specifically to communities affected by Yasi and destructive surges (King *et al*., 2012). Although the report and guidelines were based on a specific assessment of the Tully/Hull Heads townships, the recommendations included are currently applicable to all low lying coastal communities throughout Queensland. How we choose to respond to coastal hazards from cyclones and sea level rise has further significant implications for sustaining our coastal livelihoods and ecosystems. It is clear that coastal management decisions should consider the dynamics of natural coastal systems previous to human modifications and be cautious about any actions that erode the natural benefits and ecosystem services provided by natural resources and protected areas.

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