# Declines of seagrasses in a tropical harbour, North Queensland, Australia, are not the result of a single event

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A recent paper inferred that all seagrass in Cairns Harbour, tropical north-eastern Australia, had undergone 'complete and catastrophic loss' as a result of tropical cyclone Yasi in 2011. While we agree with the concern expressed, we would like to correct the suggestion that the declines were the result of a single climatic event and that all seagrass in Cairns Harbour were lost. Recent survey data and trend analysis from an on-ground monitoring program show that seagrasses in Cairns Harbour do remain, albeit at low levels, and the decline in seagrasses occurred over several years with cyclone Yasi having little additional impact. We have conducted annual on-ground surveys of seagrass distribution and the above-ground meadow biomass in Cairns Harbour and Trinity Inlet since 2001. This has shown a declining trend in biomass since a peak in 2004 and in area since it peaked in 2007. In 2012, seagrass area and above-ground biomass were significantly below the long-term (12 year) average but seagrass was still present. Declines were associated with regional impacts on coastal seagrasses from multiple years of above-average rainfall and severe storm and cyclone activity, similar to other nearby seagrass areas, and not as a result of a single event.

[McKenna S, Jarvis J, Sankey T, Reason C, Coles R and Rasheed M 2015 Declines of seagrasses in a tropical harbour, North Queensland, Australia, are not the result of a single event. *J. Biosci.* **40** 389–398] **DOI** 10.1007/s12038-015-9516-6

## 1. Introduction

The ecological importance of seagrasses as structural components of coastal ecosystems, and the need to protect them, is well recognized and documented (Larkum *et al*. 2006; Coles *et al*. 2015). The distribution and growth of these important habitats is largely influenced by environmental drivers such as depth, light, physical disturbance, nutrient availability, river flow and tidal exposure (Rasheed and Unsworth 2011; Chartrand *et al*. 2012; Petrou *et al*. 2013; Collier and Waycott 2014; Rasheed *et al*. 2014) and, more recently anthropogenic factors, such as coastal development and degraded water quality (Waycott *et al*. 2009; Taylor and Rasheed 2011; McKenzie *et al*. 2012).

Pollard and Greenway (2013) reported on 'complete and catastrophic loss' of seagrass in Cairns Harbour, tropical north-eastern Australia. Unfortunately, not all the information on changes in the seagrass meadows in Cairns Harbour would have been available to Pollard and Greenway (2013). This additional information leads to a different interpretation on the timing and causes of seagrass loss than that presented by Pollard and Greenway (2013). While we agree that there have been severe declines in the extent of seagrass in the harbour (Rasheed *et al*. 2013), we do not support the assertion that seagrasses were 'decimated overnight' as suggested in the title of their paper.

Cairns Harbour seagrasses have been widely and comprehensively studied as they are within a commercial port jurisdiction. Information is available on seagrass distribution from aerial photographs starting in the 1950s and from detailed field surveys since the early 1980s (Coles *et al*. 1985, 1987, 1989, 1990). Much of this information is primarily in the grey literature sponsored by the fishing industry, coastal development industries and port authorities. The values of Cairns Harbour seagrasses to the fishing industry

**Keywords.** Decline; management; ports; seagrass; tropical



Published online: 17 April 2015

have also been published in scientific literature (Coles *et al.* 1993; Watson *et al*. 1993) as has general seagrass distributional information (Lee Long *et al*. 1993; Coles *et al*. 2003).

UNESCO reports that excessive port development could threaten the status of the Great Barrier Reef World Heritage Area (UNESCO Decision 37 COM 7B.10., 2013) and ports and shipping are recognized as key threats to seagrasses in the region (Coles *et al.* 2010; Grech *et al*. 2012). This focus on ports and how they manage their environmental responsibilities in the Great Barrier Reef World Heritage Area (Grech *et al*. 2013) makes it important to publish the most recent information.

We contend that the losses of seagrass that have occurred in Cairns are not the result of a single event in 2011. The present paper focuses on updating data on seagrass meadow changes in the Cairns Harbour and their present status. We examine the changes in seagrass through a long-term monitoring program and demonstrate that declines commenced before 2011, and while tropical cyclone Yasi in 2011 was destructive, it was only a small part of a longer trend.

## 2. Material and methods

### 2.1 *Cairns Harbour site*

The area described by Pollard and Greenway (2013) as Cairns Harbour includes the 'inner' harbour bounded by Ellie Point and the airport to the west, False Cape to the east and the entrance to Trinity Inlet to the south. This area is only part of a broader ecological system and only part of the Cairns Port managed area that extends both seawards and for several kilometres upstream into Trinity inlet (figure 1). Cairns is located in Queensland's tropical region and typically experiences a summer wet season (December to March) with an average annual rainfall of 2014.2 mm (BOM 2012). The Barron River drains the watershed that flows into the area just north of the study area (figure 1) and has a catchment area of approximately 2138 $km^2$. All climate data used in this study are publicly available from the Australian Bureau of Meteorology (BOM 2012) and the Department of Environment and Heritage Protection (DEHP 2012). Climate data were from the nearest weather station at Cairns (Station no. 31011) and the river monitoring station at the Barron River (Station. no. 916001B).

### 2.2 *Seagrass sampling*

Surveys of Cairns Harbour intertidal and subtidal seagrass meadows were conducted annually between October and January from 2001 to 2012 (figure 2). The monitoring program surveyed seagrass biomass (g DW $m^{-2}$), area (ha), distribution and species composition each spring/summer using methods developed by the James Cook University Seagrass Group for a network of established seagrass monitoring programs, including Townsville, Mourilyan Harbour, Gladstone, Karumba and Weipa.

2.2.1 *Seagrass meadow area mapping:* The boundary of seagrass meadows were mapped from aerial (helicopter) surveys conducted at low tide when the seagrass meadows were exposed, or by free diving and underwater camera techniques. All meadow boundaries were mapped using of global positioning system (GPS). Data were digitised on to a Geographic Information System (GIS) base map (McKenzie *et al.* 2001) with ArcGIS (Environmental Systems Research Institute). The GIS base map was constructed from a 1:25,000 vertical aerial photograph rectified and projected to Geodetic Datum of Australia (GDA 94) coordinates. The precision of the seagrass meadow boundary as mapped was determined using an estimate of mapping reliability (R)based on the distance between sampling sites used in mapping (McKenzie *et al.* 2001.). This resulted in a range of meadow size which is expressed as error bars in Fig. 4. Additional sources of mapping error associated with digitising aerial photographs onto base maps and with GPS fixes for survey sites were embedded within the meadow reliability estimates. Seagrass area was compiled across all species and meadows and reported as total area (ha) in Cairns Harbour.

2.2.2 *Seagrass above-ground biomass sampling:* Above-ground biomass data and seagrass species composition were estimated from between 239 (2006) and 572 (2012) ground truthedhabitat characterisation sites scattered haphazardly within the mapped seagrass meadows between 2001 and 2012. Above-ground seagrass biomass was determined at each of the sampling sites using a 'visual estimates of biomass' technique described by Mellors (1991). This method has been used in surveys throughout Queensland and many peer reviewed publications (Mumby *et al*. 1997; Rasheed *et al.* 2008; Rasheed and Unsworth 2011). The method involves an observer ranking above-ground seagrass biomass within three randomly placed 0.25 $m^2$ quadrats at each site. Measurements for each observer are later calibrated to previously obtained biomass values from seagrass harvested from quadrats and dried in the lab to determine mean above-ground biomass (g DW $m^{-2}$) at each site. Biomass area was compiled across all species and meadows and reported as mean biomass ± SE (g DW $m^{-2}$) in Cairns Harbour.

### 2.3 *Statistical analysis*

Seagrass above-ground biomass was compared between years with a one-way analysis of variance using R Core Team statistical package (2013). Biomass data was pooled

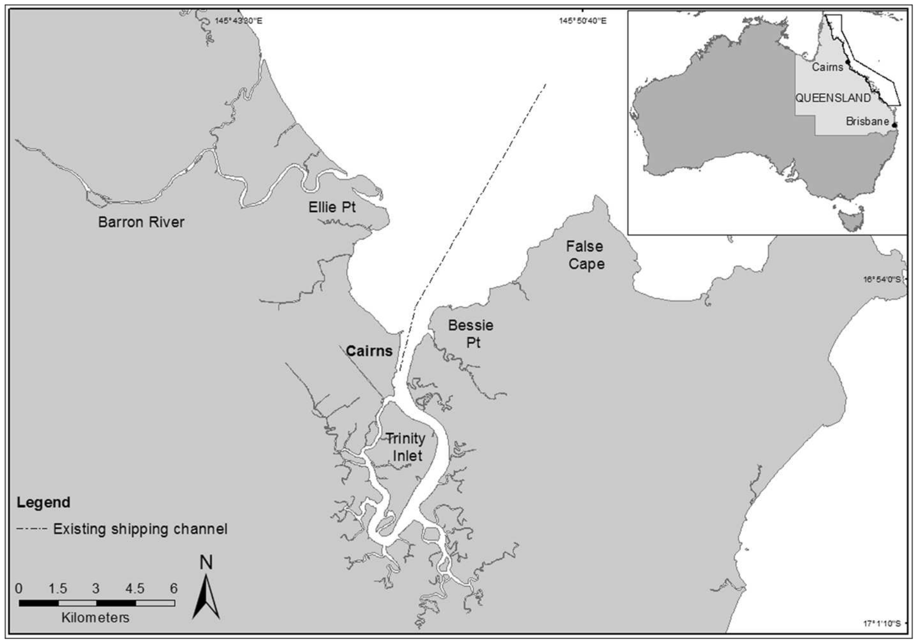


**Figure 1.** Cairns Harbour and port managed area.

across all meadows and species, and analysed for the effects of time. Model residuals were examined for normality and homogeneity (Quinn and Keough 2002). Tukey's *post hoc* analysis with a bonferroni correction factor was used to test for significant differences in biomass between years (multcomp package, Hothorn *et al*. 2008).

## 3. Results

### 3.1 *Seagrass meadow area*

In 2012 four species of seagrass were present in Cairns Harbour, *Halodule uninervis, Zosteramuelleri, Halophila ovalis* and *Halophila decipiens* (Rasheed *et al*. 2013).*Halophila decipiens* was the dominant species in sub-tidal water and *H. uninervis* and *Z. muelleri* were dominant in the intertidal meadows. Seagrass in Cairns Harbour and Trinity Inlet, increased in area between 2001 (662.5 ±145.6 ha) to the maximum extent recorded in 2007 (1487.5±98.9 ha; figure 4). Seagrass area stabilised in 2007 and 2008 before declining by 81% between 2008 and 2009 (figure 4). Seagrass area continued to decline through 2012 when seagrass area was reduced to 30.9±2.5 ha, of which 28.1±0.9 ha was found in the same study area as Pollard and Greenway (2013). In the broader subtidal areas of the Cairns region (within 10 nautical miles of the harbour from Ellie Point and False Cape) 151.8±70.6 ha of seagrass were recorded and mapped in 2012. Small *H. ovalis* and *H. decipiens* meadows (13.2±5 ha) were also mapped several kilometres upstream of the Trinity Inlet entrance (figure 3).

### 3.2 *Seagrass meadow biomass*

Above-ground seagrass biomass showed a significant decline over time (F (11, 1899) = 20.4, MSE = 21273, $p$<0.001; figure 5). However, maximum seagrass biomass (39.48±3.79 g DW $m^{-2}$) was recorded in 2004, three years earlier than maximum seagrass area (figures 4 and 5). Significant declines in seagrass biomass following the 2004 peak began in 2006 (2004, 2006; $p$=0.008) and continued through 2010 (2004, 2010; $p$<0.001). Between 2010 and 2012 seagrass biomass remained at reduced levels. Minimum biomass values were recorded in 2012 of 1.01±0.17g DW $m^{-2}$, 94% below the 12-year long-term average (2001–2012) of 17.89±3.67g DW $m^{-2}$ (figure 5).

### 3.3 *Rainfall and river flow*

Prior to 2012, the Cairns region had multiple years of above average wet seasons and severe storm and cyclone activity. Annual rainfall was above the long-term average in 2004, 2006 and from 2008 to 2011 (figure 6). In addition, river flow just north of the entrance of the harbour was above the long-term average of 781,128 megalitres per year in 2001, 2004, 2006, 2008, 2009 and 2011 (figure 6).

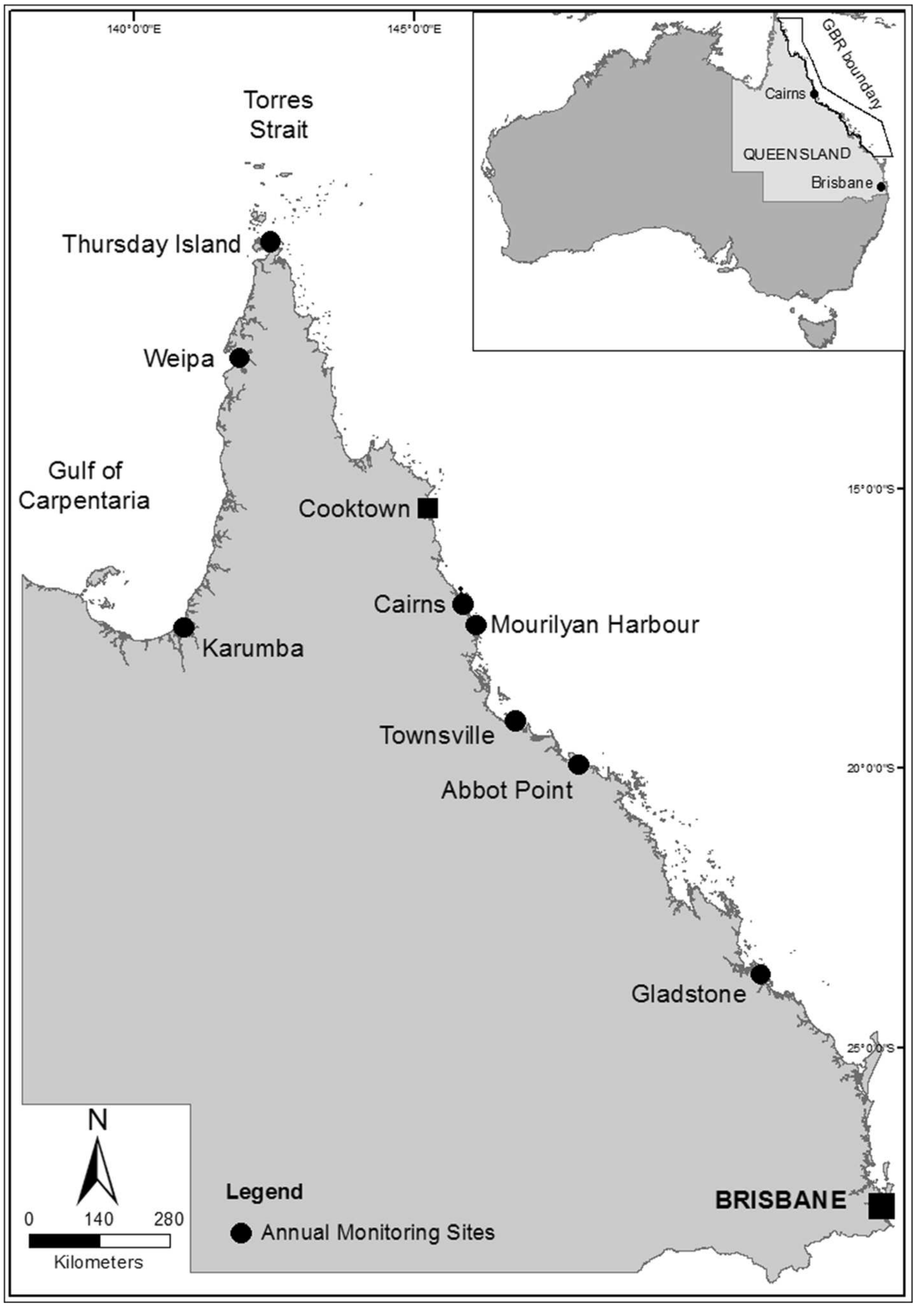


**Figure 2.** Queensland Ports where seagrass is monitored annually.

## 4. Discussion

Tropical seagrass meadow area and biomass can be highly variable particularly under estuarine influence (Coles *et al.* 2007: McKenzie *et al.* 2010; Rasheed and Unsworth 2011; Unsworth *et al.* 2012). However, seagrass meadows were relatively stable in area throughout the north-eastern Australian coast until 2009. After this time a series of tropical storms and floods led to declines in area and abundance in many coastal meadows (Petus *et al.* 2014; Rasheed *et al.* 2014) .Although these changes included a dramatic reduction in meadow area and biomass in the Cairns Harbour, nearly 200 ha of seagrass remained in 2012. While there were significant declines in seagrass, there was certainly not a 'loss of all seagrass' (Pollard and Greenway 2013) in the area referred to as 'Cairns Harbour'.

The decline in biomass in Cairns Harbour was evident by 2006 (figure 5) and meadow area declined dramatically after

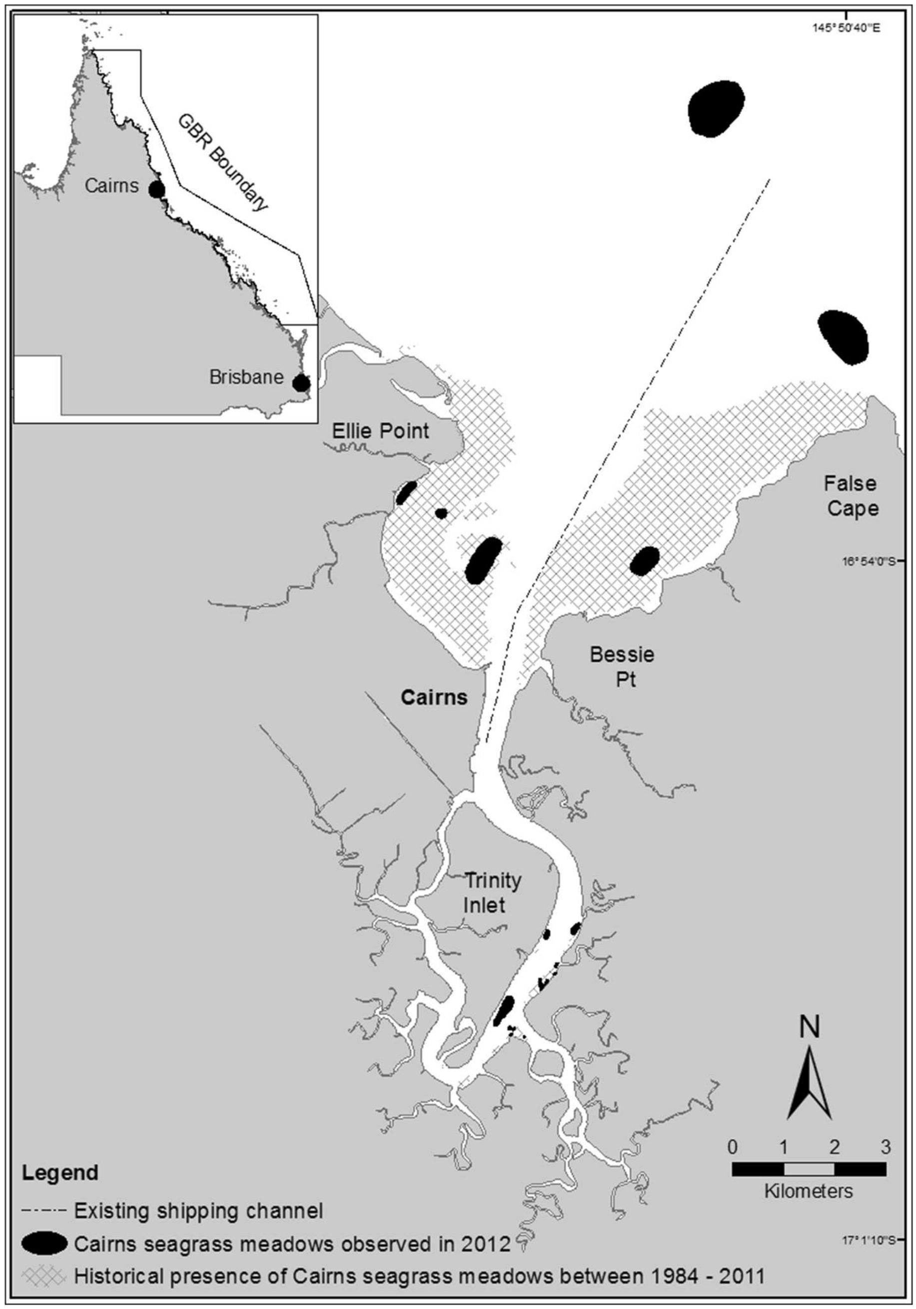


**Figure 3.** Location of Cairns seagrass meadows in the 2012 baseline survey, and the historical presence of seagrass between 2001 and 2012.

2009 (figure 4). The declines are not recent, and while tropical cyclone Yasi in 2011 was destructive, it was only a small part of a longer trend. The Cairns Harbour and the coast of Queensland south of Cooktown have had an unprecedented series of wet seasons and tropical storms. This sequence commenced in 2006 with severe tropical cyclone Larry and was followed by cyclone Hamish in 2009, Olga and Tasha in 2010, Anthony and the severe tropical cyclone Yasi in 2011, and cyclone Jasmine in 2012. In addition the region was subjected to a strong La Niña weather system in 2010/11 with elevated rainfall and strong winds (Rasheed *et al*. 2014). The effect of these conditions on seagrasses was not confined to the Cairns region with declines also reported nearby from Mourilyan Harbour, Townsville and Bowen, and some level of impact extended south to include the entire tropical eastern coast south of Cairns (Davies *et al*. 2013a; McKenna and Rasheed 2013a; Rasheed *et al*. 2014; Petus *et al*. 2014). In contrast, recent monitoring north of

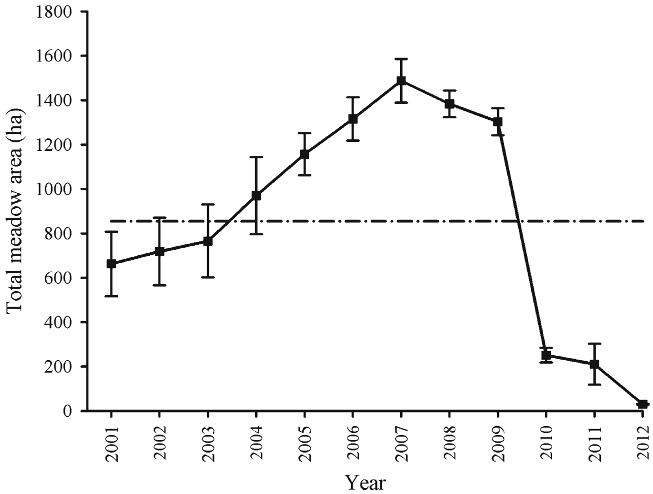


**Figure 4.** Total area (ha) of Cairns Harbour monitoring meadows from 2001–2012 (error bars indicate potential range of meadow size - "R"). Dashed line represents long-term mean above-ground biomass from 2001 to 2012.

Cooktown suggests little change in northern meadows (McKenzie *et al*. 2014) and monitoring elsewhere in Queensland waters; Torres Strait, Weipa and Karumba (figure 2) show no significant long-term downward trends in seagrass area and biomass (Mellors *et al*. 2008; McKenna and Rasheed 2013b).

Coastal habitats along the Queensland coast are regularly exposed to flooding and cyclones; however, the cumulative impacts of multiple years of above average wet seasons associated with La Niña conditions were unprecedented.

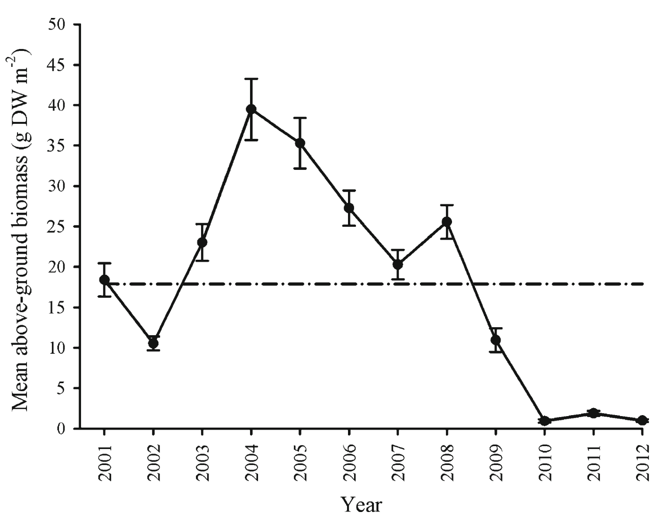


**Figure 5.** Mean above-ground biomass (g DW $m^{-2}$) of Cairns Harbour monitoring meadows from 2001–2012 (error bars - standard error). Dashed line represents long-term mean above-ground biomass from 2001 to 2012.

The combination of high rainfall, high river flow and cyclones can negatively impact seagrass either rphysically (burial, scouring, direct removal of plants and seed-banks) (Preen *et al*. 1995; Bach *et al*. 1998; Campbell and McKenzie 2004) or physiologically (light limitation, excess nutrients and herbicides, and changes in salinity) (Björk *et al*. 1999; Ralph *et al*. 2007; Chartrand *et al*. 2012; Collier *et al*. 2014). The quality and quantity of light is a critical determinant of seagrass growth and abundance (Ralph *et al*. 2007; Chartrand *et al*. 2012; Petrou *et al*. 2013) and low light levels are thought to be the primary factor limiting the growth of many coastal seagrasses (Waycott *et al*. 2005; Petrou *et al*. 2013). When low light conditions are prolonged, growth rates slow and plants drop leaves and shoots, thus reducing their abundance (Ralph *et al*. 2007; Collier *et al*. 2012). Studies of seagrasses in tropical regions have indicated that genera such as *Zostera* and *Halodule* have significantly greater light requirements (Grice *et al*. 1996; Bach *et al*. 1998; Longstaff and Dennison 1999; Longstaff 2003; Collier and Waycott 2009; Collier *et al*. 2009; Chartrand *et al*. 2012) than other genera such as *Halophila* species (Udy and Levy 2002; Fourqurean *et al*. 2003; Freeman *et al*. 2008). In Cairns it has been the higher light requiring species, *Zostera muelleri* and *Halodule uninervis*, that have significantly declined in recent years.

Of particular concern is the potentially limited capacity for the large *Zostera* and *Halodule* meadows, which were once in Cairns Harbour, to recover following the sustained declines. Where seagrass area and abundance have been reduced in other east coast locations, recovery has been mixed, with some coastal meadows having limited recovery similar to Cairns including those around Bowen/Abbot Point (Rasheed *et al*. 2014), but others showing good signs of recovery including around Townsville and Gladstone (figure 2) (Davies *et al*. 2013a, 2013b).

The recovery of tropical seagrasses from prolonged and large-scale disturbances is dependent on the seagrass species present and the life history traits of those species at the impacted location (Rasheed 1999, 2004; Rasheed *et al*. 2014). Seagrasses are clonal plants and meadows can recover by vegetative means (asexual reproduction) through the extension of rhizomes, as well through recruitment from propagules (seeds/sexual reproduction) (Rasheed 1999, 2004; Inglis 2000; Jarvis and Moore 2010; Macreadie *et al*. 2014; Rasheed *et al*. 2014). Studies on *Zostera muelleri*at Ellie Point in Cairns Harbour (Rasheed 1999) and *Halodule uninervis* at Bowen (Rasheed *et al*. 2014) have found that the recovery of these meadows is highly reliant on asexual colonisation through rhizome extension from nearby plants. With the significant loss of adult *Zostera* and *Halodule* plants in Cairns Harbour, the seagrass meadows will be highly reliant on seeds stored in the sediment, or recruitment of seeds or propagules through dispersal, to re-establish and

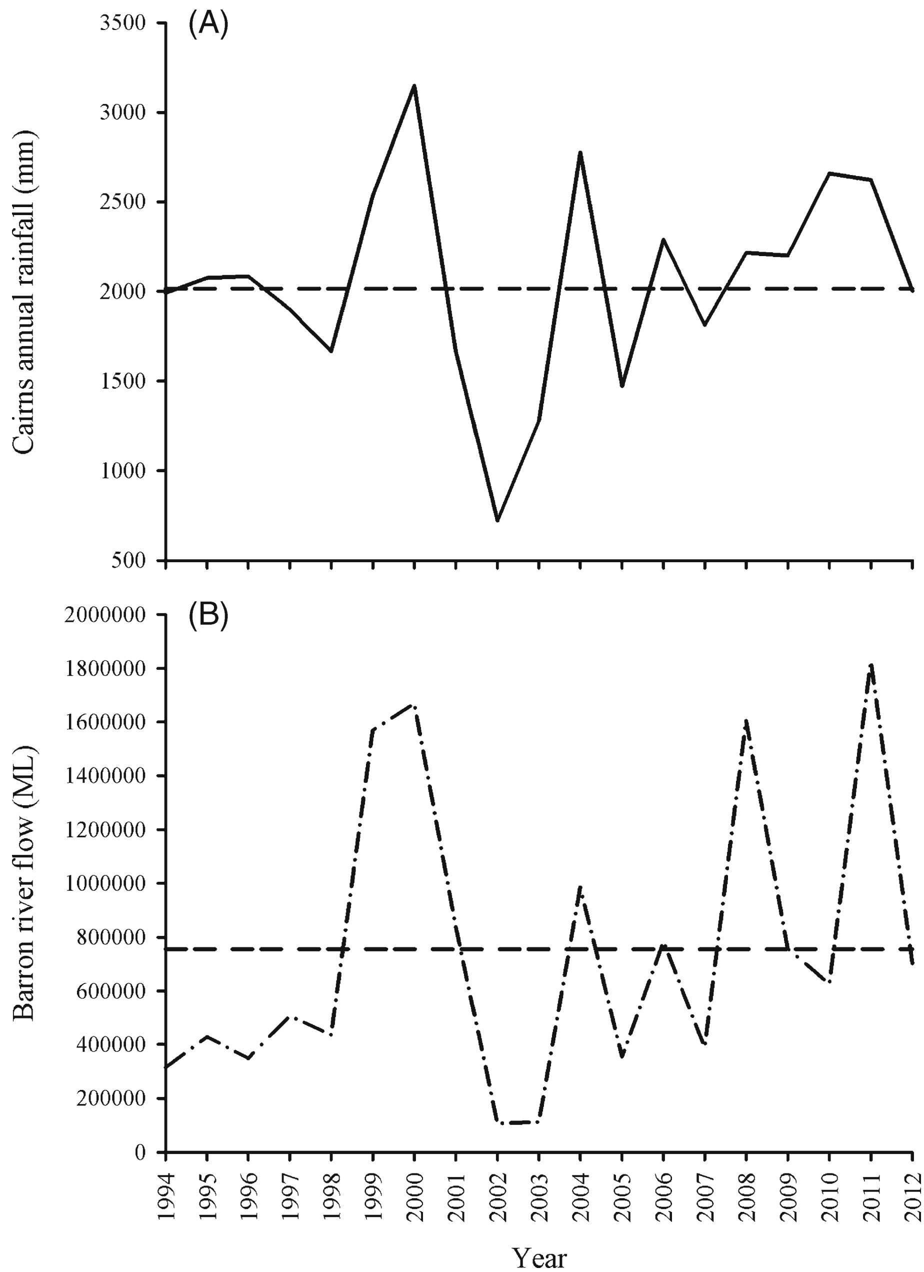


**Figure 6.** Mean (A) annual rainfall (mm) in Cairns and (B) Barron river flow from 2001–2012. The dashed lines represent the respective mean rainfall (1942–2012) and river flow conditions (1994–2012). Rainfall data courtesy of the Australian Bureau of Meteorology, Station 31011. River flow data courtesy of the Department of Environment and Heritage Protection, Station 916001B.

in these experimental studies there was limited success from seed-based recovery in Cairns.

Multiple years of seagrass decline are likely to leave a legacy of reduced resilience of seagrasses to further impacts. As a result seagrasses may now be more susceptible to wet season conditions and additional major impact events compared to previous years. In other north Queensland seagrass monitoring locations such as Mourilyan Harbour and Abbot Point/Bowen, repeated impacts have led to sustained losses of seagrasses (McKenna and Rasheed 2014; Rasheed *et al*. 2014; York *et al*. 2014). In Mourilyan Harbour recovery is unlikely to occur for key meadows, as there is now no obvious source of propagules, without some form of assisted restoration (York *et al*. 2014).

Cairns Harbour is considered a high-risk area for seagrass due to the accumulation of anthropogenic threats (Grech *et al*. 2011) and it would be expected that seagrass resilience to increased stress would be low. However, in 1993 the Trinity Inlet Management Plan was developed to halt deterioration in the harbour environment. As a result of this plan, most marine vegetation was protected in a marine park, urban waste disposal sites were removed from mangrove areas, sewage treatment plants were upgraded and urban and agricultural water way management plans were implemented (Margerum 1999; Derbyshire *et al*. 2002). Development near waterways in the Cairns Harbour catchment is subject to planning requirements (Lucas 2008) and is closely regulated. Because of these initiatives, there is little evidence that the Cairns Harbour environment and management of the catchment/watershed has changed since 1993 in a way that would result in the loss of seagrass. Although anthropogenic influences and impacts cannot be ruled out, the most likely explanation for the decline of seagrass in Cairns Harbour is the series of weather impacts spaced across time resulting in unfavourable conditions for seagrasses and a downward spiral in resilience and concomitant reduction in recovery after each event.

We are in agreement to a large extent with the observations of Pollard and Greenway (2013) other than to note the extended timing of the changes, the likely reasons for them, and that residual seagrass meadows remain. Of more concern is that where other seagrass meadows in similar environments and ports have shown signs of recovery, seagrass area and abundance in Cairns Harbour has not.

There are ongoing pressures to develop Cairns Harbour with plans under consideration for shipping channel dredging. Cairns is a tourist hub for the Great Barrier Reef World Heritage Area and the management of this area and the region's port management has been criticized by UNESCO (UNESCO 2013) for its impact on habitats such as seagrass. With a background of potential pressures from climate change and the need to ensure the reef environments remain healthy for the tourist industry, we feel it is essential to ensure the record of changes in Cairns Harbour is correct.

## Acknowledgements

This project receives funding from Ports North and previously through the Trinity Inlet Waterways and Trinity Inlet Management Program. We would like to thank the many James Cook University and Fisheries Queensland staff who have contributed to the monitoring program over the years.

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*MS received 14 April 2014; accepted 25 February 2015*

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