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Challenges of remote sensing for quantifying changes in large complex seagrass environments

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ABSTRACT

Managing seagrass environments and understanding and responding to coastal impacts such as floods or cyclones, requires assessment of seagrass distribution and its biophysical properties in time and space. Comparable assessments of seagrass distribution over time are often lacking as the information is present for separate dates, or created following different mapping approaches, and this makes it difficult to conduct quantitative comparisons. We provide an assessment of available data sets and approaches, and their suitability for monitoring and quantifying change in seagrass percentage cover and extent for a large coastal embayment (Moreton Bay, Australia, 1582 km^2). Seagrass percentage cover maps were created for 2011 and 2004 and compared to map and measure the extent of seagrass percentage cover change, and changes in the extent of seagrass environments. Total extent of seagrass was shown to be higher in 2011 compared to 2004. Potential sources of these differences may be: mapping inaccuracy; actual change in extent and cover; and, monthly to seasonal variations in seagrass cover. A qualitative comparison of the 2004 and 2011 maps was performed against maps of seagrass extent maps from 1975, 1986 and 1999, which were created using a range of different methods and data. The output maps show changes in seagrass extent, but a lack of detail arising from variable mapping methods and differing mapping extents prevented a reliable comparison. We conclude that robust mapping of seasonal and inter-annual variation in seagrass percentage cover distribution or extent, as well as impacts of episodic and stochastic disturbance events, requires a thorough understanding of the mapping approaches used so that data sets can be compared. Additional complimentary information is required to help understand the drivers of changes.

1. Introduction

Evidence of widespread impacts of human activities on marine ecosystems (Alongi, 2002; Pandolfi et al., 2003; Lotze et al., 2006; Waycott et al., 2009) has emphasised the value of obtaining time series data to map and monitor changes in the extent, composition and condition of marine habitats. However, the quantification of these qualities in marine ecosystems over appropriate spatial and temporal scales for monitoring, presents technical, logistic and financial challenges. Overcoming these challenges is key to providing the information for developing management strategies to mitigate potential stressors and disturbances.

Seagrass habitats provide important ecological services such as nursery grounds, fisheries resources, carbon storage and coastal protection (Waycott et al., 2009). These habitats are under threat from various natural and anthropogenic impacts (Grech et al., 2012). Natural disturbance events, such as flooding, can negatively impact the health and distribution of seagrass – the concomitant reduction of light (Longstaff et al., 1999; Collier et al., 2012), salinity changes (Sandoval-Gil et al., 2012), destabilisation of seagrasses through wave action (Waycott et al., 2009), and smothering of seagrass with sand (Schaffelke et al., 2002) are factors that negatively impact the health and distribution of seagrass.

Abbreviations: TM, Thematic Mapper.

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Management and monitoring agencies require spatial information collected systematically and regularly to describe the distribution and composition of seagrass to assess natural and anthropogenic impacts over time, and the effectiveness of implemented management practices (Waycott et al., 2009).

In terrestrial ecosystems, remote sensing techniques can rapidly and consistently provide moderate resolution (e.g. Landsat Thematic Mapper (TM) spatial scale, 30 m × 30 m pixel size) spatial data products for ecological attributes such as land cover or use and its trend over time (both subtle within months or strong within seasons), as well as disturbance events (Kennedy et al., 2012; Wulder et al., 2012). To provide useable information from remote sensing products in marine environments, additional considerations are required to understand the results in relation to biophysical properties of the water column and substrate/benthos, along with their spatial and temporal variations. Ecologically meaningful maps for coastal submerged habitats have been created successfully using a variety of optical remote sensing approaches and image types (Mumby et al., 2004; Dekker et al., 2006; Ferwerda et al., 2007; Andréfouët, 2008). The increase in accessibility of high spatial resolution imagery (Johansen et al., 2008) and free moderate resolution Landsat TM imagery (Wulder et al., 2012), has increased the capability to create comparable coral reef or seagrass habitat maps at various spatial scales and extents (Roelfsema et al., 2013). To conduct a reliable assessment of changes in seagrass extent and cover over time, the data sets compared should be based on specific requirements (Table 1).

The requirements outlined in Table 1 form guidelines to conduct change assessment and could be used to assess, explain and/or understand the difference visible between data sets due to natural changes or due to differences in mapping. In regards to assessing natural variability, intra vs. inter annual variation and algal presence, it is important that field sampling data and location, and date of remotely sensed data sets are considered.

Our study region encompasses Moreton Bay, Southeast Queensland, Australia. Seagrasses in Moreton Bay have long been studied at various spatial scales (Abal and Dennison, 1996; Grice et al., 1996; Udy and Dennison, 1997; Longstaff et al., 1999; Prange and Dennison, 2000) from patch scale (~10–100 m), to meadow and ecosystem scales (>1 km e.g. Moreton Bay, Australia; 1582 km^2) (Young and Kirkman, 1975; Hyland et al., 1989; Dennison and Abal, 1999; Stevens and Connelly, 2005; Zharikov et al., 2005; Phinn et al., 2008; Roelfsema et al., 2009; Lyons et al., 2012). At the patch scale, several approaches have been applied to map properties of seagrass in the eastern part of Moreton Bay. To date, no peer-reviewed publications have assessed changes over time in seagrass cover for the whole of Moreton Bay. The main hindrance to such a comparison is the variability between the mapping methods used as well as the limited spatial extent of previous mapping approaches (Roelfsema et al., 2009).

The overall aim of this study was to provide assessment of available data sets and approaches, and their suitability for monitoring and quantifying change in seagrass percentage cover and extent for a large coastal embayment (Moreton Bay, Australia; 1582 km^2). We initially determined an assessment of change in seagrass percentage cover for 2004 to 2011 from maps produced using consistent data sets and methodology. As comparable methods were used for the analyses, the advantages and limitations afforded by this approach could be determined. Additionally, this study provides a description of observed changes, the reliability, and the limitation of the comparison of seagrass area or percentage cover over time for seagrass maps generated for 1975, 1987, 1999, 2004 and 2011. The conclusion discusses the observed changes, taking into consideration the limitations of the methods used to map the seagrass properties, and the guidelines proposed for marine ecologists and managers seeking to use time series of remotely sensed data for monitoring (Table 1).

2. Materials and methods

2.1. Study site

Moreton Bay is located in South East Queensland, Australia (27°15′ S, 153°15′ E), and covers an area of 1582 km^2. It is a partially enclosed, relatively shallow embayment, bounded to the east by Moreton and Stradbroke Islands (Fig. 1).

The Brisbane metropolitan area has a population of two million and is located on the western shores of the Bay. The Bay receives terrestrial runoff from the South East Queensland (SEQ) catchment area via five large rivers. The associated runoff regime has been significantly altered over the last several decades due to water impoundment, changes in vegetation cover, decreases in agricultural land use and extensive urbanisation (Dennison and Abal, 1999; Mcalpine et al., 2007). Many of these changes are likely to have influenced seagrass growth and decline, particularly in the western part of the Bay, although we do not explicitly discuss links to these drivers in this study. Additionally, large scale flooding events occurred in SEQ in 1974, 2011 and 2013, although their impact on seagrass distribution is unclear at present. Introduction of management policy specific to seagrass habitat (e.g. reduction in nutrient and sediment loads, specific mooring types, protected areas, go slow zones) has aided in reducing stress and impact on seagrass habitats (Dennison et al., 2004; Waycott et al., 2009;

Table 1
Ideal requirements to conduct a reliable assessment of changes in seagrass extent and horizontal projected percentage seagrass cover over time. *The error that could occur when requirement is not adhered to.

Ideal data set requirements	Error type*	Example of impact of error (DS1 = data set 1, DS2 = Data set 2)
Georeferenced	Position shift	Changes detected (false positives)
Near identical spatial extent	Missing data	If an area is not mapped for DS1 compared to DS2 due to missing data it could be detected as a change
Identical mapping categories	Incomparable mapping categories	Qualitative versus quantitative categories
Identical mapping scale	Variation in level of detail	Small patches of seagrass are mapped in one and not in the other
Reproducible mapping method	Methodological error	DS1 based on manual digitisation, DS2 based on pixel based image classification
Seasonal sampling	Natural variation	DS1 in winter versus DS2 in summer
Similar tidal stage and water clarity	Affects ability to detect seagrass	Satellite image for DS1 was derived at high tide with turbid water, and for DS2 with low tide and clear water. Seagrass could be mapped in deeper water for DS2.
Replicate field sampling	Variation in calibration or validation	DS1 field data based on limited point based sampling, DS2 based on detailed transect sampling for same area.
Sampling accuracy	Decreased map quality	DS1 has high accuracy, versus DS2 with low accuracy resulting in low reliability