Regional Studies in Marine Science 7 (2016) 100–110

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Geomorphic classification of coral reefs in the north western Australian shelf

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HIGHLIGHTS

- Reef distribution shows significant geomorphological complexity.
- Fringing reefs are the dominant reef type and are widely distributed.
- Planar reefs are isolated and located some distance from the mainland coast.
- High intertidal reefs are remarkable features of the Kimberley Bioregion.
- The resulting data provides a reliable, spatially constrained dataset for coastal management.

ARTICLE INFO

Article history:
Received 20 April 2016
Received in revised form
24 May 2016
Accepted 31 May 2016
Available online 9 June 2016

Keywords:
Kimberley Bioregion
Coastal management
Continental shelf
Reef mapping
Remote sensing
GIS

ABSTRACT

Coral reefs occur extensively along the northwest Australian continental shelf in the Kimberley Bioregion (KIM), forming major geomorphic features along and just off the coast. These reefs have not been studied in as much detail as the offshore reefs and are poorly known due to the coastal conditions, including extremely high tide regimes, high turbidity and complex coastline morphology. This study aims to establish a regional-scale distribution map of exposed and intertidal reefs of the KIM and to classify the Kimberley reefs into types, adopting widely recognised reef classification and typology schemes. Remote sensing and Geographic Information Systems (GIS) were used in this study to process and produce digital maps as well as to provide some of the first detailed spatial analysis of reef distribution. Outcomes of this study showed that the Kimberley reefs possess strong morphological complexity and clear regional patterns. The study revealed that the number of Kimberley reefs and their area are considerably (60%) greater than previously thought; the total combined reefal area is approximately 1,950 km^2. Fringing reefs have been identified as the dominant reef type and are widely distributed throughout the KIM. It was also found that tidal range affected the distribution of reef geomorphologies. The outcomes of this study will contribute to a better understanding of the Kimberley reefs, and provide marine park managers with essential and quality scientific information so that better management decisions can be made in this area.

1. Introduction

1.1. Reef mapping and classification

Coral reefs are widely distributed through the world's tropical oceans and commonly rise abruptly from relatively deep water creating a major navigational hazard, but can also provide a safe anchorage. There are many famous examples of ships running aground on coral reefs, the wrecks of the VOC ship Batavia in 1629 and the HMS Pandora in 1779 being just two notable Australian examples (Green, 1975; Edwards et al., 2003). The increase in international shipping during the 18th and 19th century saw maritime nations and international trading companies seek ways to reduce shipping losses through improved charting, but also sought a scientific understanding of where reefs are likely to be encountered and how they form. In fact few questions in 19th century science aroused more controversy than the origin of coral reefs. So when

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http://dx.doi.org/10.1016/j.rsma.2016.05.012
2352-4855/

HMS Beagle departed in 1831 on its 5-year journey of discovery around the world, it not only carried a young Charles Darwin but also secret instructions from the Admiralty requiring a detailed geological investigation on how coral reefs formed.

The result was that in 1842 Darwin published *The Structure and Distribution of Coral Reefs*, the first of three major monographs arising from observations and data he collected during his voyage on the Beagle. This monograph put forth the theory of atoll formation through island subsidence and included the first detailed map of the distribution of different kinds of coral reefs through the Indo-Pacific and Caribbean region. This map represents the first global census of coral reefs and presented the first geomorphic reef classification scheme which is still in use today. Joubin (1912) expanded Darwin's original reef census by producing a series of five 1:10,000,000 scale reef maps covering the entire globe. His work combined existing survey charts as well as observations and voyage reports from a range of sources.

Following Joubin's work, there was almost no other attempt to systematically map coral reefs on a global scale until the launch of the Landsat series of satellites in the 1970's, which for the first time allowed the detection of coral reefs using moderate-resolution satellite imagery (Jupp et al., 1985), and the opportunity to map reefs globally. Most recently, the United Nations Environment Program (UNEP) funded the Global Reef Monitoring Network (GRMN) and the International Coral Reef Action Network (ICRAN) to build and maintain a global reef GIS database *ReefBase*, which provides a repository for available knowledge about coral reefs. The Millennium Coral Reef Mapping Project is using a suite of high-resolution spaceborne remotely sensed imagery systematically map and classify coral reefs worldwide (IMaRS-USF and IRD, 2005; ReefBase, 2015).

The development of a geomorphic classification of coral reefs has been closely linked to the improvement of reef mapping techniques (Kordi et al., 2016). For instance, the three basic classes of reef include fringing, barrier, and atoll were identified by Darwin (1842) and formed the basis for his global map of coral reefs. In the 1920s, the advent of aerial photography allowed coral reefs to be viewed in plan view, allowing for a more detailed analysis of spatial characteristics of reefs and mapping their features in greater detail. The pioneering geoscientific work on Australian reef classification was conducted by Fairbridge (1950, 1967), who recognised the role of antecedent topography, eustasy, and physical processes in generating reef morphology, first working on the Great Barrier Reef (GBR) and later on the reefs of northern Australia, including the Kimberley coast (Finkl, 2011). Subsequently, as knowledge of reefal processes increased, Hopley (1982) was able to develop an evolutionary reef classification scheme for the GBR. Accordingly, reef classification and reef typology at the global, regional and reefal scales have been dramatically improved (Andréfouët et al., 2006; Hopley et al., 2007; Leon and Woodroffe, 2013; Madden et al., 2013; Roelfsema et al., 2013; Rowlands et al., 2014).

There are still many reef regions of the world where the accurate numbers and extent of coral reefs are underestimated or unknown. One such area is the Kimberley bioregion of north-west Australia where there have only been a limited number of global scale mapping efforts that have advanced our understanding of reef formation and growth, as well as providing information for monitoring of coral reef health and to support informed decisions about coral reef use and management in this region (Spalding et al., 2001; Wilkinson, 2008), but they still lack the resolution required to provide realistic reef census data at regional and local scales. Despite efforts that have been made to fill this gap, no significant spatial map detailing the size and distribution of the Kimberley reefs and their attributes exists.

1.2. North west Australian reef systems

The Reefs of North West Australia occur within two distinct bioregions, the shelf edge Oceanic Shoals bioregion (OSS) and the inner shelf Kimberley bioregion (KIM) (Fig. 1). The OSS, which includes the Rowley Shoals and Scott Reef have seen significant scientific investigations, due in part to their proximity to the Browse Gas Fields. In particular, the morphology and growth history of these reefs have been examined using a number of methodologies such as coring, U-series dating and vertical seismic profiling (Collins, 2011; Collins et al., 2011).

The inner shelf reefs of the Kimberley have seen limited scientific study due in part to the geographic remoteness of the region and limited infrastructure. Early investigations by Teichert and Fairbridge (1948) noted that fringing reefs exist around the margins of many islands in the region, despite the normally unsuitable environment for coral build-up, including high sediment input, macrotidal regimes, highly turbid water and raised sea surface temperatures. Wilson (1972) and O'Connor (1989) observed reefs in the intertidal zone between shallow rocky shoals, along muddy shores, and in some bays. Geographic and geomorphic estimation of reef location, thickness, and reef area was provided by Brooke (1997), who demonstrated that fringing reefs were widespread along the Kimberley coast and could be classified into three reef forms: fringing reefs adjacent to a cliffed shore; reefs developing on bedrock edges; and large reef complexes. Latest studies of Montgomery Reef and Talbot Bay by Wilson (2013) and Wilson et al. (2011) revealed the unique nature of these reefs and their habitats and substrates and documented the relationship between the unique physical processes and reef geomorphology. Despite these studies, there are still many unknowns in our understanding of the Kimberley reefs.

This study intends to provide a spatial analysis of fringing and nearshore reefs along the Kimberley coast. The spatial approach is expected to lead to an analysis of the reefs' geomorphologic patterns, new information about reef statistics, and to a description of reef classification and distribution by type. The resulting data will provide a reliable, spatially constrained dataset for biodiversity assessment and reef structure comparisons. It will also provide stakeholders and beneficiaries, such as marine park authorities, universities, Traditional Owners, and non-governmental organisation (NGOs) with quality information relevant to the monitoring, conservation, and management of these vital natural resources. Furthermore, it will pave the way for future studies in various disciplines beyond the scope of this study.

2. Methodology

2.1. Study area

The KIM covers a massive area 60,000 km^2, stretching from Cape Londonderry (13°S) in the north to Cape Leveque in the south (16°S). The KIM coast is characterised by deep inlets, capes and archipelagos forming a very complex coastline (Fig. 1). It has extensive fringing coral reefs that exceed the Ningaloo Reef in their biological diversity and it supports a huge range of marine habitats (DEC, 2011). In some parts of the Kimberley coast the spring tide reaches more than 11 m, making it the highest tidal range of any coral reef system in the world and the second largest tide after Fundy Bay in Canada (Purcell, 2002; Wolanski and Spagnol, 2003). Kimberley coral reefs are the main geomorphic feature along the continental shelf between the latitudes of 12°S and 18°S (Collins, 2011). Currently, activities such as oil and gas extraction, mining, and tourism are increasing in this region, necessitating timely management to protect the marine environment (Wood and Mills, 2008).