Remote Sensing of Environment 112 (2008) 3455–3467

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Regional-scale seagrass habitat mapping in the Wider Caribbean region using Landsat sensors: Applications to conservation and ecology

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ARTICLE INFO

Article history:
Received 7 April 2007
Received in revised form 22 December 2007
Accepted 12 January 2008

Keywords:
Seagrass
Coral reef
Thalassia testudinum
ETM+
IKONOS
Millennium Coral Reef Mapping Project
Conservation management
Habitat database
Biodiversity
Sea turtle
Chelonia mydas

ABSTRACT

Seagrass meadows occupy a large proportion of the world's coastal oceans and are some of the most productive systems on Earth. Direct and indirect human-derived impacts have led to significant seagrass declines worldwide and the alteration of services linked to their biodiversity. Effective conservation and the provision of sustainable recovery goals for ecologically significant species are limited by the absence of reliable information on seagrass extent. This is especially true for the Wider Caribbean region (WCR) where many conservation initiatives are under way, but are impaired by the lack of accurate baseline habitat maps. To assist with such a fundamental conservation need using high-resolution remote sensing data, both environmental and methodological challenges need to be tackled. First, the diversity of environments, the heterogeneity of habitats, and the vast extent of the targeted region mean that local expertise and field data of adequate quality and resolution are seldom available. Second, large-scale high-resolution mapping requires several hundred Landsat 5 and 7 images, which poses substantial processing problems.

The main goal of this study was to test the feasibility of achieving Landsat-based large-scale seagrass mapping with limited ground-truth data and acceptable accuracies. We used the following combination of methods to map seagrass throughout the WCR: geomorphological segmentation, contextual editing, and supervised classifications. A total of 40 Landsat scenes (path-row) were processed. Three major classes were derived ('dense seagrass', 'medium-sparse seagrass', and a generic 'other' class). Products' accuracies were assessed against (i) selected *in situ* data; (ii) patterns detectable with very high-resolution IKONOS images; and (iii) published habitat maps with documented accuracies. Despite variable overall classification accuracies (46–88%), following their critical evaluation, the resulting thematic maps were deemed acceptable to (i) regionally provide an adequate baseline for further large-scale conservation programs and research actions; and (ii) regionally re-assess carrying capacity estimates for green turtles. They certainly represent a drastic improvement relative to current regional databases.

1. Introduction

Seagrasses are submerged flowering plants (angiosperms) that can form dense beds in shallow subtidal, mostly clear and sheltered, soft-bottomed marine and estuarine environments (Phillips & Menez, 1988). These 'seagrass meadows' are important tropical, temperate, and subarctic coastal habitats (Hemminga & Duarte, 2000; den Hartog & Kuo, 2006), covering the equivalent of approximately 0.05–0.15% of the surface area of the oceans globally (Spalding et al., 2003). By providing substratum for epiphytic algae, shelter for invertebrates and fishes, and foraging areas for a variety of organisms, they significantly contribute to the biodiversity of coastal waters (Williams & Heck, 2001; Duffy, 2006). The combined productivity of seagrasses and epiphytic algae rank them among the most productive systems on Earth (Duarte & Cebrián, 1996; Duarte & Chiscano, 1999). These meadows also serve as critical breeding and nursery grounds for juvenile stages of many economically and ecologically important species (Beck et al., 2003; Heck et al., 2003; Dahlgren et al., 2006; Gillanders, 2006).

Established in coastal zones, seagrass beds are inherently dynamic systems prone to natural physical disturbance, particularly in temperate regions (Fonseca et al., 2002). However, changes or losses in abundance, species composition, structure, and extent have commonly resulted from activities such as eutrophication, overfishing, and habitat alteration or destruction (Short & Wyllie-Echeverria, 1996; Duarte, 2002). Until recently, relatively little attention has been paid to

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doi:10.1016/j.rse.2008.01.020

the impacts of human activities on seagrass food webs (Jackson, 2001; Duarte, 2002), with most studies focusing on how physical disturbance alters the structure and function of the 'seagrass habitats' themselves. The presence of green turtles (*Chelonia mydas*) may have had substantial ecological and evolutionary effects: increasing the productivity of seagrass in the same way as grazers in terrestrial grasslands (McNaughton, 1979; Pandolfi et al., 2003; Moran & Bjorndal, 2005; Moran & Bjorndal, 2007). Changes in temperature, nutrient levels, and salinity, as well as a 93–97% reduction in the Caribbean green turtle population compared to its size prior to human contact (Jackson et al., 2001), have been implicated in die-offs of seagrass throughout the region (Robblee et al., 1991; Jackson, 1997; Fourqurean & Robblee, 1999). Overall, anthropogenic impacts have contributed to seagrasses now ranking among the most threatened of marine habitats (Green & Short, 2003; Lotze et al., 2006; Orth et al., 2006).

Given the ongoing coastal zone development around the globe, it is imperative to design and implement effective ways to protect coastal resources. Specifically, at the Fifth World Parks Congress in 2003, the recommendation was made to develop extensive networks of Marine Protected Areas (MPAs) that "include strictly protected areas [amounting] to at least 20–30% of each habitat" by 2012. However, exact predictions of the potential status of seagrasses in the future and best ways to protect them are hampered—chiefly by the absence of consistent and reliable information concerning the present extent of this habitat. Similarly, current carrying capacity estimates of green turtles for the Caribbean (16–586 million individuals), are based on only a very rough idea of seagrass extent thought of as available for foraging (Jackson et al., 2001).

A literature review conducted for this study suggests that there are many site specific studies and records of seagrass bed extent and distribution for the WCR. However, with few exceptions (e.g., Puerto Rico and the U.S. Virgin Islands), relevant documents are difficult to access and rarely, or poorly, document mapping methods or accuracies. Digital maps in GIS formats are often unavailable, or their use restricted. The only existing database generating a global overview was developed by the United Nations Environment Program-World Conservation Monitoring Centre (UNEP-WCMC) in 2003. The resulting "World Atlas of Seagrasses" was the first synthesis of the distribution and status of seagrass habitat at that scale (Green & Short, 2003). However, direct habitat maps (i.e., chiefly derived from remotely sensed data), which provide the most accurate data on habitat distribution, were only available for a very limited subset of the world. The majority of geographic information thus falls into two main categories: (i) interpolation of expert knowledge and observations; and (ii) point-based samples, which are useful in providing information regarding species presence, but give no information as to actual seagrass extent (Spalding et al., 2003). As a result, the worldwide UNEP-WCMC database, including the Caribbean section, suffers from substantial inaccuracy (vast commission or omission errors (i.e., including a seagrass pixel in a non-seagrass area and vice versa)), poor spatial representation, and limited spatial resolution.

Satellite remote sensing provides a tool to develop a reliable, methodologically consistent database of seagrass extent over large regions, in a cost effective, objective, and timely fashion (Mumby et al., 1999; Krause-Jensen et al., 2004; Balmford et al., 2005). Habitat mapping on the scale of a region poses new environmental and methodological challenges rarely addressed in tropical initiatives to date (but see the Millennium Coral Reef Mapping Project (Andréfouët & Guzmán, 2005; Andréfouët et al., 2005)). First, the diversity of environments (estuaries, cross-shelf areas, banks, atolls, and narrow

Table 1
List of sites for which thematic seagrass habitat maps were derived in this paper

Focal area	Landsat path-row	Accuracy assessment data	IKONOS data	References
Bahamas	13–41, 14–41, 14–42, 13–42, 12–42, 15–43, 14–43, 13–43, 12–43, 11–43, 15–44, 14–44, 13–44, 12–44, 11–44, 10–44, 12–45, 11–45, 10–45, 9–45	IKONOS and *in situ*	Lee Stocking Island Andros Island. (AUTEC)	Armstrong (1993); Andréfouët et al. (2003); Call et al. (2003), and Louchard et al. (2003)
Belize	19–48, 18–48, 19–49, 18–49	IKONOS	Lighthouse Atoll Glovers Atoll Barrier Reef section Patch Reef section	Andréfouët et al. (2003)
Mexico (Yucatán coast)	20–45, 19–45, 18–45, 19–46, 18–46, 19–47, 18–47	IKONOS	Akumal Boca Paila Mahahual	Andréfouët et al. (2003); Garza-Perez et al. (2004)
Roatán (Honduras)	17–49	IKONOS	Roatán	Maeder et al. (2002)
St Croix (US Virgin Island)	4–48	NOAA		NOAA (2001)
Puerto Rico (south coast)	5–48	NOAA		NOAA (2001)
San Blas offshore banks and islands (Panama)	11–53	*in situ*		Andréfouët and Guzmán (2005)
Los Roques (Venezuela)	4–52	*in situ*		Schweizer et al. (2005)
Alacranes Bank (Mexico)	20–45	N/A (published value: 77%)		Bello-Pineda et al. (2005)
Guadeloupe	1–49	N/A (published value: 95.7%)		Chauvaud et al. (2001)
Bay du Robert (Martinique)	1–50	N/A (published value: 94%)		Chauvaud et al. (1998)
Providence Island (Colombia)	14–51	N/A		Díaz et al. (2003)
San Andrés (Colombia)	14–51	N/A		Díaz et al. (2003)

Available ancillary data and references on previous remote sensing and habitat mapping work at these same sites are also presented. Where applicable, the type of data used to assess accuracy of our products is indicated.