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Mapping seagrass and colonized hard bottom in Springs Coast, Florida using WorldView-2 satellite imagery

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A B S T R A C T

The offshore extent of seagrass habitat along the West Florida (USA) coast represents an important corridor for inshore-offshore migration of economically important fish and shellfish. Surviving at the fringe of light requirements, offshore seagrass beds are sensitive to changes in water clarity. Beyond and intermingled with the offshore seagrass areas are large swaths of colonized hard bottom. These offshore habitats of the West Florida coast have lacked mapping efforts needed for status and trends monitoring. The objective of this study was to propose an object-based classification method for mapping offshore habitats and to compare results to traditional photo-interpreted maps. Benthic maps were created from WorldView-2 satellite imagery using an Object Based Image Analysis (OBIA) method and a visual photo-interpretation method. A logistic regression analysis identified depth and distance from shore as significant parameters for discriminating spectrally similar seagrass and colonized hard bottom features. Seagrass, colonized hard bottom and unconsolidated sediment (sand) were mapped with 78% overall accuracy using the OBIA method compared to 71% overall accuracy using the photo-interpretation method. This study suggests an alternative for mapping deeper, offshore habitats capable of producing higher thematic and spatial resolution maps compared to those created with the traditional photo-interpretation method.

1. Introduction

Florida's estuaries and marine waters contain the United States' largest seagrass beds. Conservation of this priority marine habitat is listed as one of the goals of Florida's Wildlife Legacy Initiative (Florida Fish and Wildlife Conservation Commission, 2005). Offshore seagrass beds and hard bottom provide a vital corridor for inshore-offshore migration of economically important fish and shellfish such as shrimp, grouper, and snapper species (Jackson et al., 2001; Gillanders, 2006). Hard bottom also provides an important habitat for fisheries. There are well recognized relationships between fish species richness and bathymetric complexity provided by hard bottom (Luckhurst and Luckhurst, 1978). Detailed maps of these offshore areas are needed to inform management on the distribution of important fish habitats. It is estimated that 13% of the west Florida shelf could potentially be occupied by coral-sponge hard bottom communities (Jaap, 2015), little of which has been mapped (Rohmann et al., 2005). Mapping of seagrass is also important, particularly in this offshore region at depths on the fringe of seagrass light requirements (4.5–7.5 m) where seagrass is likely to be more sensitive to declines in water clarity (Kenworthy and Fonseca, 1996).

Nearshore benthic mapping efforts have documented the largest tracts of seagrass in Florida along the Big Bend region of Florida ranging from Tarpon Springs north to Apalachicola Bay. While inshore seagrass habitats are regularly mapped and monitored by the Southwest Florida Water Management District (SWFWMD), areas beyond 15 miles from shore have not been mapped in decades. The last known offshore mapping effort was conducted by Continental Shelf Associates Inc. (1986), who mapped approximately 1000 km^2 of continuous seagrass in the offshore areas. These offshore areas have been identified by several resource management agencies as a considerable data gap (SWFWMD, 2001;

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SWFWMD and Avineon, 2007).

A major challenge to seafloor mapping in these offshore areas is the cost of extending current mapping efforts to include offshore areas where seagrass may occur (Yarbro and Carlson, 2013). Inshore seagrass in the Gulf Coast waters of Levy, Citrus, Hernando, and Pasco counties (Springs Coast) is currently mapped by the SWFWMD from aerial imagery acquired during targeted airborne missions. Extending the SWFWMD's aircraft collected photo-interpretation mapping program into offshore areas, which could double the currently mapped inshore area, has been cost prohibitive.

Over the last several decades, advances in remote sensing technology and data analysis techniques have substantially improved benthic habitat mapping capabilities (Purkis and Roelfsema, 2015). For example, in the Springs Coast, IKONOS satellite imagery has been proven a more cost effective data source than conventional aerial photography acquisition for seagrass mapping (Baumstark et al., 2013a). Mapping seagrass distributions using satellite imagery has been improved by image processing techniques such as pixel-based classifications and object-based image analysis (OBIA; Louchard et al., 2003; Mishra et al., 2005; Fornes et al., 2006; Peneva et al., 2008; Knudby and Nordlund, 2011; Meyer and Pu, 2012; Phinn et al., 2012; Baumstark et al., 2013a). Benthic classification accuracy is further improved by using preprocessing procedures such as sun glint corrections (Hedley et al., 2005; Hochberg et al., 2003) and light attenuation corrections (Pu et al., 2014).

Another advantage of image processing based benthic mapping is the ability to quantify metrics of greater ecological significance compared to the discrete benthic classes derived from traditional photo-interpretation (e.g., continuous v. discontinuous seagrass). For example, spatial configuration derived from OBIA may provide landscape configuration information which can influence the distribution and community dynamics of seagrass-associated fauna (Bell et al., 2001, 2006; Hovel and Fonseca, 2005; Boström et al., 2006). Seagrass cover percentage is an ecologically important parameter as it influences surrounding species (Boström and Bonsdorff, 2000), impacts water clarity (Newell and Koch, 2004) and provides an important indicator of seagrass health (Wood and Lavery, 2000; Martínez-Crego et al., 2008). Quantification of seagrass percent cover is now possible via methods that utilize the additional spectral information offered by satellite imagery (Sleeman et al., 2005; Urbański et al., 2009; Baumstark et al., 2013a; Roelfsema et al., 2014).

While cost-effective satellite imagery and emerging image processing techniques have improved mapping of seagrass habitats, there has been little application of these methods in mapping offshore colonized hard bottoms. A limitation of mapping colonized hard bottom is in distinguishing it from seagrass which tends to be spectrally similar (Mishra et al., 2005). Successful differentiation of spectrally similar seagrass and colonized hard bottom features usually requires image preprocessing and the consideration of both spectral and spatial information extracted from high resolution satellite imagery (e.g., IKONOS with 4 multispectral bands at approximately 4 m resolution).

Therefore, a general goal of this effort is to further evaluate the utility of modern, high resolution satellite imagery and image processing techniques for producing a map of offshore colonized hard bottom distribution along with the western extent of seagrass in the Springs Coast area, Florida, USA. The resulting map is expected to serve as baseline information for monitoring of status and trends of these ecologically important and sensitive habitats. A secondary objective of this work is to evaluate and compare the capability of visual photo-interpretation and object-based image analysis (OBIA) methods for mapping benthic habitat from WorldView-2 (WV2) satellite imagery. It is expected that the spatial location of image features can be used to differentiate spectrally similar seagrass and colonized hard bottom features in this study area to improve the accuracy of results for mapping offshore seagrass and colonized hard bottom benthic features. It is also expected that WV2 imagery and OBIA methods will provide accurate, repeatable and informative results that can be used for long term monitoring.

2. Study area and data sets

The Springs Coast is located along Florida's Gulf Coast and includes the nearshore waters of Levy, Citrus, Hernando, and Pasco counties. The study area in Springs Coast measures approximately 570 km^2 and is located approximately 10 km offshore between depths of 1.5–12 m (Fig. 1). The study area is characterized by a shallow gently sloping seafloor where predominantly unconsolidated sediment (sand) substrate slowly transitions to large swaths of hard bottom areas offshore. Along this transition, the dominant biological cover changes from seagrass rooted in sand to soft coral, sponges and macroalgae attached to hard bottom (colonized hard bottom, Schroeder et al., 1988). These low-relief, carbonate rock hard bottom areas can be densely colonized or, in less colonized areas, rock may be covered by a thin sand veneer. The Coastal Marine Ecological Classification System (CMECS) categorizes this type of colonized hard bottom as Pavement (FGDC, 2012).

The WorldView-2 (WV2) sensor provides 8 multispectral bands at approximately 2 m pixel resolution (Table 1). WV2 was selected for this study due to its high spatial resolution (2 m for multispectral) and spectral resolution compared to similar satellites such as IKONOS, WorldView-1, QuickBird and GeoEye. Reaching over 10 m depth, this study area is just within the limit of what can be mapped using passive remote sensing systems (optically shallow water; Van Der Meer and de Jong, 2006). WV2 provides additional spectral bands that better penetrate water (bands that are not attenuated as quickly by water, Bands 1 and 3). The tasking capabilities of the WV2 sensor can also improve image quality by targeting optimum environmental conditions for acquisition (e.g., water clarity, sea state, sun angle, and cloud cover, etc.). A WV2 image of the study area was acquired on June 17, 2012 via satellite tasking.

3. Methods

In this study, we compared two methods for mapping offshore benthic habitats in the study area from WV2 imagery: 1) traditional photo-interpretation and 2) object-based image analysis (OBIA). Image processing and classification methods are outlined in Fig. 2. Methods were designed to maximize consistency with ongoing mapping programs in the Springs Coast study area.

Tasking acquisition was restricted to low wind conditions to minimize sun glint from waves and a minimum of 5 days after a major rain event to avoid turbidity from terrestrial run off. In order to avoid glare on the surface of the water, collection specifications were set to be between 5 and 20 degrees off-nadir with a sensor azimuth opposite that of the sun azimuth. Sensor azimuth was set to be greater than 300 and less than 60° azimuth where the sun was due South (180° azimuth).

The WV2 scene was provided with radiometric corrections for atmospheric and sensor related interferences and conversion of pixel values to absolute spectral radiance (DigitalGlobe, 2010). For preprocessing, a depth-variant light attenuation correction was applied to the image. Correction factors were estimated and applied to each band in the scene by comparing blue and green band radiance ratios of sand bottom type at different depths following