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Multiple methods, maps, and management applications: Purpose made seafloor maps in support of ocean management

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ABSTRACT

The establishment of multibeam echosounders (MBES) as a mainstream tool in ocean mapping has facilitated integrative approaches toward nautical charting, benthic habitat mapping, and seafloor geotechnical surveys. The inherent bathymetric and backscatter information generated by MBES enables marine scientists to present highly accurate bathymetric data with a spatial resolution closely matching that of terrestrial mapping. Furthermore, developments in data collection and processing of MBES backscatter, combined with the quality of the co-registered depth information, have resulted in the increasing preferential use of multibeam technology over conventional sidescan sonar for the production of benthic habitat maps. A range of post-processing approaches can generate customized map products to meet multiple ocean management needs, thus extracting maximum value from a single survey data set. Based on recent studies over German Bank off SW Nova Scotia, Canada, we show how primary MBES bathymetric and backscatter data, along with supplementary data (i.e. in situ video and stills), were processed using a variety of methods to generate a series of maps. Methods conventionally used for classification of multi-spectral data were tested for classification of the MBES data set to produce a map summarizing broad bio-physical characteristics of the seafloor (i.e. a benthoscape map), which is of value for use in many aspects of marine spatial planning. A species-specific habitat map for the sea scallop *Placopecten magellanicus* was also generated from the MBES data by applying a Species Distribution Modeling (SDM) method to spatially predict habitat suitability, which offers tremendous promise for use in fisheries management. In addition, we explore the challenges of incorporating benthic community data into maps based on species information derived from a large number of seafloor photographs. Through the process of applying multiple methods to generate multiple maps for management applications, we demonstrate the efficient use of survey data sets to maximize the benefit to a wide number of potential end users, and to facilitate the move toward an ecosystem-based approach to management.

1. Introduction

There is general acceptance that to effectively manage the oceans' resources, an ecosystem-based approach to management must be adopted (Castilla and Defeo, 2005; Douvere, 2008; Garcia et al., 2003). As on land, successful management and conservation of the environment requires knowledge of the extent, geographical range, and ecological characteristics of the resource of interest — and maps are the pre-eminent means of recording and communicating this information. These maps, in combination with spatial information on human activities, can then be used to assess conflicts or compatibilities between human uses and the environment (Cogan et al., 2009; Ehler and Douvere, 2009). To create these maps, spatially explicit data must first be collected. However, compared to mapping on land, map production of the marine environment can be technologically challenging and relatively expensive to undertake.

In the terrestrial environment, development of aerial and satellite remote sensing over the past few decades has increased the accessibility and affordability of optical remote sensed data for broad-scale ecological studies, which in turn has dramatically improved our understanding of the spatial patterns and complexities of terrestrial ecosystems (Franklin, 2009; Guisan and Zimmermann, 2000). Unfortunately, the application of aerial and satellite remote sensing techniques for mapping marine benthic environments is restricted to shallow, coastal waters due to the limited penetration of light through seawater, leaving the vast majority of the seabed beyond the scope of these methods. As a result, the field of benthic habitat mapping lags somewhat behind its terrestrial counterpart. However, through developments in acoustic survey techniques, (such as single-beam acoustic ground discrimination systems, sidescan sonar systems, and more recently multi-beam echo sounders (MBES)), marine mapping efforts

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have begun to match the quality and resolution of those in the terrestrial realm. Moreover, many analysis techniques developed for terrestrial (optical) remotely sensed data are transferable for use in analyzing marine (acoustic) remotely sensed data sets.

Based on optical remote sensing, established techniques and approaches have been developed to classify multi-spectral data and segment images into categories which capture patterns in landscape characteristics (Turner et al., 2001). Primary data collected from MBES (e.g. bathymetry, backscatter) and associated secondary data (i.e. derived data such as slope, aspect, curvature, etc.), can be processed in an analogous way to multi-spectral data sets collected by aerial or satellite systems. A recent review by Brown et al. (2011a) examined benthic habitat mapping studies which have utilized acoustic survey methods over the past decade and found that recent studies are starting to explore the direct application of multi-spectral classification methods for mapping benthic ecosystems using acoustic remotely sensed data layers.

The process of segmenting multi-spectral data involves grouping or generalizing data into spectral classes which relate to distinctive landscape features (map classes) measured in situ (a process commonly referred to as ground-truthing). There are two main strategies by which multi-spectral data can be segmented; unsupervised and supervised. Unsupervised classification takes a top-down approach where the environmental data is organized into units before it is combined with in situ data. This segmentation process often involves unsupervised classification algorithms which identify spectral classes based on spectral similarities. This approach usually generates a large number of spectral classes, and while there may be a 1:1 relationship between some of the spectral classes and map classes, in general this relationship is unlikely to hold for all classes. To generate useful maps from this approach, the process usually involves combining spectral classes until the best match is reached between the spectral and in situ measured map classes (Lu and Weng, 2007). The ultimate end product is a classified image (landscape map) where the final classes are defined based on a best-fit of biological data to segmented spectral data.

Alternatively, supervised classification approaches can be adopted whereby the in situ data is used to "guide" the classification of the spectral data. The spectral data at the locations of the in situ class information is used as training information, and the chosen supervised classification algorithm then classifies each pixel in the rest of the image based on comparison with the training data, or more commonly, summary properties of the training data (Lu and Weng, 2007). Recently, supervised approaches aimed at mapping single species or community patterns have been the focus of a great deal of research attention (Elith and Leathwick, 2009; Ferrier and Guisan, 2006). This is commonly referred to as Species Distribution Modeling (SDM) and a large number of methods have been developed, each with strengths and weaknesses depending on the life traits of the focal species and the availability of spatial environmental data sets with which to run the model (Franklin, 2009).

The end results of both unsupervised and supervised techniques are maps which capture patterns in bio-physical characteristics of the environment at a resolution of value for the management of natural resources. The various thematic maps can be used for numerous aspects of spatial planning; from biodiversity and conservation management, through sustainable mineral and natural resource exploitation, to socio-economic applications (Elith and Leathwick, 2009; Ferrier and Guisan, 2006; Franklin, 2009).

The review by Brown et al. (2011a) identified three main approaches to benthic habitat mapping: 1) abiotic habitat mapping; 2) benthic community mapping; and 3) single species habitat mapping. The first approach, abiotic habitat mapping, is comparable in many ways to the unsupervised segmentation of optical remote sensing data sets for the production of landscape maps. The second approach, benthic community mapping, attempts to map predictable community types on the seafloor. Although a large number of studies have attempted to do this over the past decade (see Brown et al., 2011a, and examples presented therein), community patterns can be difficult to capture since species composition often shifts gradually along environmental gradients (Brown et al., 2011a). The third approach, single species habitat mapping, attempts to generate benthic maps displaying suitable habitat for a focal species. SDM methods fall under this category, and the underlying rationale of the approach is often based on ecological niche concepts. Single species mapping utilizing SDM methods have recently been demonstrated to work effectively in marine applications, especially where the focal species is sessile and has a strong association with seafloor physical/geological characteristics (Davies et al., 2008; Galparsoro et al., 2009; Iampietro et al., 2008; Monk et al., 2010).

It is often time-intensive and expensive to collect and compile biological and environmental data from the marine environment to produce a map to address a particular management need. However, using a variety of analysis tools and the same basic data sets, multiple maps can be derived for multiple management needs thus maximizing the value returned for the given investment. In this study, we demonstrate how the same basic MBES and in situ ground-truthing data sets can be processed using different methods to generate products that capture patterns of abiotic, community, and single species characteristics, and which offer benefits for ocean management. We apply an unsupervised classification approach (CLUSTER) to segment MBES data from German Bank off SW Nova Scotia in order to produce a bio-physical classification of the area, which we call a "benthoscape map" (Zajac, 2008; Zajac et al., 2003) due to the analogies with generating terrestrial landscape maps from optical data sets in a similar way. We go on to explore benthic community patterns derived from an extensive underwater photographic data set from the area, and relate these to the map products. Finally, we use the same data layers to generate a species specific habitat map for sea scallop (*Placopecten magellanicus*). This SDM is compared with the benthoscape map and with the spatial distribution of fishing-effort from commercial scallop draggers providing information for fisheries management decisions.

2. Materials and methods

2.1. Bathymetric data

The area chosen for the study was German Bank and Scallop Fishing Area 29 (SFA 29) located off south-west Nova Scotia on the Scotian Shelf in the eastern Gulf of Maine (Fig. 1). Multibeam bathymetric data were collected over the study area covering 3650 km^2 of seafloor by the Canadian Hydrographic Service using the Canadian Coast Guard Ship "Frederick G. Creed"; a SWATH (Small Waterplane Area Twin Hull) vessel (DFO, 2006). The ship was equipped with a Simrad Subsea EM1000 multibeam bathymetric survey system (95 kHz) with the transducer mounted on the starboard pontoon. This system produces 60 beams arrayed over an arc of 150° and operates by ensonifying a narrow strip of sea floor across track and detecting the bottom echoes. The width of the sea floor imaged on each survey line was five to six times the water depth. Line spacing was about three to four times water depth to provide ensonification overlap between adjacent lines. The differential global positioning system was used for navigation, providing positional accuracy of +/−3 m. Survey speeds averaged 14 kn resulting in an average data collection rate of approximately 5.0 km^2 h^{-1} in water depths of 20–70 m. The sound velocity of the ocean was periodically measured during data acquisition and was used to correct for effects of sonar beam refraction caused by changes in water density.

The data were examined following collection and erroneous values were removed using CARIS/HIPS software (www.caris.com). Within HIPS the data were adjusted for tidal variation using tidal predictions from the Canadian Hydrographic Service. The data were archived in the form of raw datagrams (raw.all files), and these were subsequently