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Detection of deep water benthic macroalgae using image-based classification techniques on multibeam backscatter at Cashes Ledge, Gulf of Maine, USA

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ABSTRACT

Benthic macroalgae form an important part of temperate marine ecosystems, exhibiting a complex three-dimensional character which represents a vital foraging and spawning ground for many juvenile fish species. In this research, image-based techniques for classification of multibeam backscatter are explored for the detection of benthic macroalgae at Cashes Ledge in the Gulf of Maine, USA. Two classifications were performed using *QTC-Multiview*, differentiated by application of a threshold filter, and macroalgal signatures were independently extracted from the raw sonar datagrams in *Matlab*. All classifications were validated by comparison with video ground-truth data. The unfiltered classification shows a high degree of complexity in the shallowest areas within the study site; the filtered demonstrates markedly less variation by depth. The unfiltered classification shows a positive agreement with the video ground-truth data; 82.6% of observations recording *Laminaria* sp., 39.1% of *Agarum cribrosum* and 100.0% ($n = 3$) of mixed macroalgae occur within the same acoustically distinct group of classes. These are discrete from the 8.1% recorded agreement with absences and nulls (>40 m) of macrophytes ($n = 32$) from a total of 86 ground-truth locations. The results of the water column data extraction (*WCDE*) show similar success, accurately predicting 78.3% of *Laminaria* sp. and 30.4% of *A. cribrosum* observations.

The unfiltered classes which showed agreement with the ground-truth data were then compared to the *WCDE* results. Comparison of surface areas reveals the overall percentage agreement is relatively constant with depth (67.0–70.0%), with *Kappa* coefficient increasing from $k = 0.17–0.35$ as depth (and surface area) increases. The results have demonstrated that both methods were more effective at detecting the presence of *Laminaria* sp. (82.6–77.3%) than *Agarum cribrosum*, (66.6–30.4%), and that the efficiency of prediction decreased with depth. Canopy volume derived from the *WCDE* analysis was between 1.21×10^6 m^3 at <24 m water depth, 1.82×10^6 m^3 at <30 m and 2.45×10^6 m^3 at <40 m. These results suggest that the presence of benthic macrophytes has a significant capacity to affect image-based classification of acoustic data, and highlights the fact that multibeam backscatter and image-based classification have significant potential for benthic macroalgal research. This is beneficial to help refine segmentations of substrates, adding valuable contextual information about biological characteristics of infaunal and epifaunal benthic communities.

1. Introduction

Benthic macroalgae represent an important component of marine ecosystems, both in their own right and from the perspective of those organisms which utilise them for habitat at various stages in their life cycles. The complex three-dimensional structure of kelp canopies means that they provide a variety of niches which accommodate a wide range of species in temperate marine ecosystems (Dayton, 1985; Tegner and Dayton, 2000). Annual primary production for major marine macroalgae is higher than most comparable terrestrial biomass (Ross et al., 2008). Macroalgae have been shown to exhibit remarkable potential for CO_2 bioremediation (Gao and McKinley, 1994), in addition to presenting a potential alternative to fossil fuels (Yantovski, 2008). Commercial activities focus on the exploitation of macroalgae either directly

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(by extraction), or indirectly (by the extraction of resident species). Many species of commercial interest utilise macroalgae at various stages in their development; for example juvenile fish (Cote et al., 2003). The quality and availability of this habitat can have significant consequences for commercially significant species (e.g. *Gadus morhua*), although the relationship between individual species and use of habitat is not yet well understood. However, the lack of habitat availability will undoubtedly have profound implications for the sustainable exploitation of commercial stocks (e.g. Tegner and Dayton, 2000; Steneck et al., 2002).

1.1. Temperate kelp forest habitats

Kelp forests dominate the rocky subtidal habitats of the vast majority of temperate marine ecosystems, with global their distribution controlled by the function of a suite of environmental factors including; light, substrata, sedimentation, nutrient availability, water motion, salinity and temperature (Dayton, 1985). Steneck et al. (2002) describe three distinct morphological forms, differentiated by the canopy height of their fronds. The groups are described as being either ‘canopy’, ‘stipate’ or ‘prostrate’. These differing adult morphologies can coexist, and this serves to increase the structural diversity of the system. This typically involves the presence of the three morphologies with an understory of corticated macrophyte turf with encrusting coralline algae (Dayton, 1985). It is with the third morphological group, the ‘prostrate’ kelps which cover the benthos with their fronds (Steneck et al., 2002), and the concept of canopy structure that this research is primarily concerned. This morphological group includes several common species of *Laminaria* which co-occur in depth banded zonations, common in the Gulf of Maine region in the North Atlantic coast of the USA.

1.2. Remote sensing of benthic habitats

Benthic habitat mapping is a rapidly expanding multidisciplinary science; its origins in surficial geology have broadened to include subsurface geology, hydrodynamics, biological and ecological elements of the seafloor environment (Brown et al., 2002; Beaman et al., 2005; Anderson et al., 2008; Brown and Blondel, 2009). This discipline is evolving largely in tandem with advances in acquisition hardware and software, with each generation of sensors increasing in sensitivity and resolvability (Mayer, 2006a). The sensor technology and processing units have developed rapidly in a relatively short period of time leading to a wide variety of instruments including; single and multibeam echosounders, side-scan sonar and synthetic aperture sonar. The relative merits are discussed at length in several seminal texts (Medwin and Clay, 1998; Lurton, 2002). Increasingly, multibeam echosounders (MBES) are becoming the tool of choice for seabed habitat mapping efforts (Hughes Clarke et al., 1996; Kostylev et al., 2001; Lathrop et al., 2006; McGonigle et al., 2009; Brown et al., in press), and the question arises as to which is the most effective way to process and interpret these data to maximum effect.

Techniques for the classification of remotely sensed data have developed in concert with the technology (Anderson et al., 2008). One of the main commercial packages in the marine sector is *QTC-Multiview*, which is designed to perform objective segmentations of MBES backscatter data (Preston et al., 2001; QTC, 2005). This software has previously been demonstrated to have performed effective, ecologically meaningful segmentations of backscatter data (e.g. Robidoux et al., 2008; Preston, 2009; McGonigle et al., 2009, 2010a, 2010b; Brown et al., in press). The overwhelming majority of previous examples of classification procedures for MBES data have been based around substrate classification (e.g. Collins and Preston, 2002; Fonseca and Mayer, 2007), or the detection of habitats which exhibit a strong geophysical signature e.g. biogenic reefs (Roberts et al., 2005) or scallop beds (Kostylev et al., 2001, 2003). However, the effectiveness of *QTC-Multiview* has not yet been fully examined, particularly with the anticipated presence of biogenic material in the water column. It has yet to be established whether this methodology can provide an acceptable technique for the differentiation of more subtle variations, such as that between gradational substrates or the presence/absence of benthic macrophytes.

1.3. Remote sensing of algal habitats

Remote sensing of benthic macroalgae is broadly divisible into either electromagnetic (EM) or acoustic approaches to detection. The theory and application of optical techniques for the remote sensing of aquatic vegetation are well summarised by Silva et al. (2008). However, irrespective of the mode of acquisition, the use of optical techniques for remote sensing in coastal and marine waters is fundamentally limited to shallow, clear coastal waters due to the attenuation of EM radiation by the water column (Lehmann and Lachavanne, 1997) and the inability to directly measure the depths at which algae occur.

The use of acoustic techniques resolves these issues, facilitating the detection of the vertical height of the macrophyte canopy relative to the seabed. The transmission and reception of sound of an appropriately high frequency with sufficient vertical resolution would theoretically allow for the differentiation of the vertical structure of a macrophyte canopy from the seabed interface. Acoustics have been used extensively in the detection of underwater vegetation, although the vast majority have done so using single beam echosounder technology (Anderson et al., 2002; Sabol et al., 2002; Quintino et al., 2010) and side-scan sonar (Kruss et al., 2006; Tegowski et al., 2007). Multibeam technology is gaining widespread adoption within the scientific community for a wide range of applications, although this potential has yet to be fully exploited. Potential reasons for this may include the relative infancy of the hardware and processing and the relatively costs associated with data acquisition.

Increasingly, attention is being drawn to using water column to better understanding the processes which control the distribution of benthic organisms and the communities to which they belong. Focusing on objects in the water column and directly above the benthos using MBES is a relatively recent phenomenon in seabed science, and is most commonly implemented for the detection of fish (e.g. Mayer et al., 2002; Cutter and Demer, 2007; Gurshin et al., 2009; Weber et al., 2009). Similar approaches have also been applied to the detection of benthic macrophytes using MBES bathymetric soundings (Komatsu et al., 2003; Mayer, 2006b; Kruss et al., 2008).

1.4. Study area

Cashes Ledge, a shallow offshore bank in the central Gulf of Maine off the US Coast of New England (Fig. 1) was the selected as the study area. The geology of the region has been described previously (Uchupi, 1968; Ballard and Uchupi, 1975; Uchupi and Bolmer, 2008), comprising a series of basins intermittently capped by irregularly crested ridges and banks. The Ammen Rock Pinnacle (Figs. 1 and 4a) is the shallowest part of the 8.88 km^2 study area (>10 m water depth) and is the focus of this investigation. The Pinnacle was the subject of previous scientific investigations into the distribution of deep water algae in the late 1980s (Vadas and Steneck, 1988).

Cashes Ledge has been historically noted for its productivity as a fishing ground (Collins and Rathbun, 1887; Rich, 1929). The area is