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Evaluation of WorldView-2 and acoustic remote sensing for mapping benthic habitats in temperate coastal Pacific waters

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ABSTRACT

Maps of nearshore marine habitat are fundamental tools for the management and conservation of coastal ecosystems. While traditional field mapping techniques, such as towed video and diver surveys, are still commonly employed for generating highly detailed maps of seafloor habitat, acoustic and satellite remote sensing have proven to be efficient alternatives for generating habitat maps. To date remote sensing using satellite imagery has dominated mapping efforts over coral reefs and other tropical ecosystems with fewer studies applied in temperate marine regions where acoustic studies are more common. Few studies exist that have assessed the performance of high resolution satellite imagery in mapping seafloor habitat in temperate regions. This paper compares the efficacy of high resolution satellite imagery (WorldView-2) and a single-beam acoustic ground discrimination system (QTC View V) for mapping the distribution of submerged aquatic vegetation at a site within the Gwaii Haanas National Marine Conservation Area (GHNMCA) off the north coast of British Columbia, Canada. Ground-truth data for training and validation were collected using a towed underwater video camera. Prior to classification the WorldView-2 image (8 bands, 2 m resolution) was processed following orthorectification, atmospheric correction, glint correction, land and optically deep water masking. An acoustic survey was conducted using a 200 kHz echosounder and data were processed and interpolated using QTC IMPACT software. The WorldView-2 imagery performed best in mapping habitat in regions shallower than 3 m, obtaining a total accuracy 75%, where it could identify the distribution of green algae (*Ulva* spp.), brown algae (*Fucus* spp.) and eelgrass (*Zostera marina*). The 200 kHz data were unable to detect the distribution of brown and green algae but were able to map the distribution of eelgrass as well as a subtidal red algae (*Chondrocanthus exasperatus*) (total accuracy 80%). A final habitat map containing all habitat types present at the study site was produced using the output from both datasets. The study resulted in recommendations for remote mapping of submerged vegetation in temperate coastal area.

1. Introduction

Submerged aquatic vegetation (e.g. seagrasses) and algae (seaweeds) are vital to coastal ecosystem health and resilience. For example, eelgrass (*Zostera marina*) and other seagrass species provide crucial ecosystem services including sediment retention (Mateo, Sanchez-Lizaso, & Romero, 2003), carbon cycling (Hemming & Duarte, 2000) and providing physical stability to coastlines by baffling against wave and current action (Hemming & Duarte, 2000). Furthermore, seagrasses provide important habitat for a variety of fish and invertebrate species including juvenile salmon (*Onchorhynchus* sp.) and Pacific herring (*Clupea harengus*) (Borg, Rowden, Atrill, Schembri, & Jones, 2006; Chittaro, Finley, & Levin, 2009; Robinson, Yakimishyn, & Dearden, 2011). In Canada, eelgrass has been identified as an ecologically significant species under the Canada Oceans Act, which recognises the vital role that eelgrass plays in maintaining coastal ecosystem health (DFO, 2009). However, as coastal ecosystems continue to decline in health and in coverage (Lotze et al., 2006) documenting the distribution and spatial extent of nearshore marine habitats is vital to their conservation and management (Horning, Robinson, Sterling, Turner, & Spector, 2010).

Delineation of the spatial extent of inter- and subtidal habitats has typically been conducted using field-based techniques, which provide a high level of detail but can be prohibitively time- and labour-intensive for mapping large tracts of coastline (Environment Canada and Precision identification, 2002; Roelfsema et al., 2009). A proposed alternative is the creation of habitat maps based on remotely-sensed data that can summarise ecologically meaningful information in remote geographic regions (Mumby & Harborne, 1999). Further benefits of remote sensing include the potential for automation and repeatability, which could improve the spatial and temporal coverage for monitoring coastal ecosystems.

Remote sensing methods for mapping marine habitats include passive optical sensors and active acoustic sensors. Both techniques and

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their associated methods of data collection vary with regards to their spatial, temporal and, in the case of optical sensors, spectral resolution, and these properties will affect the scale and accuracy of the final habitat map.

Passive optical sensors are now common tools for mapping shallow ($<$30 m) benthic habitat. In particular, multispectral sensors (e.g. IKONOS, Quickbird) have been used to map nearshore benthic habitat (Fornes et al., 2006; O'Neill & Costa, 2013; Urbański, Mazur, & Janas, 2009) with newer sensors continuing to enter the market. Among those sensors recently launched, the WorldView-2 multispectral sensor provides the highest spatial and spectral resolution of any multispectral satellite imagery currently available (DigitalGlobe, 2009). The sensor has an 8 band multispectral resolution with 6 bands in the visible spectrum and 2 near-infrared bands at a 2 m spatial resolution (Table 1). This increased spectral resolution (8 bands), as compared to other sensors such as QuickBird and IKONOS (4 bands), improves the accuracy of bathymetric mapping applications (Collin & Hench, 2012; Kerr, 2011) and the discrimination of marine habitats such as corals (Botha, Brando, Anstee, Dekker, & Sagar, 2013). However, the ability to map benthic habitat using satellite imagery is also dependent on the depth of the habitat, the light attenuation characteristics of the overlying water column, and the reflectance contrast between the target habitat and the surrounding substrate (Green, Mumby, Edwards, & Clark, 2000). These issues are particularly relevant for mapping nearshore habitats in temperate marine regions where benthic habitat occur outside of the resolution of passive optical sensors.

Acoustic remote sensing technologies are typically used for mapping subtidal habitats that are not discernible by passive optical sensors due to increased depth. Generally, acoustic ground-discrimination systems (AGDS) such as multi-beam sonar (Collins & Galloway, 1998), side-scan sonar (Brown et al., 2005), and single-beam echosounders (SBES) (Greenstreet, 1997) are employed. SBES present an inexpensive, mobile and non-invasive means of mapping shallow seafloor habitat in coastal areas inaccessible to larger vessels (Mumby et al., 2004). The QTC VIEW Series V (QTC5) is one such system which is effective at mapping both sedimentary habitats of the seafloor (e.g. Freitas, Rodrigues, & Quintino, 2003; Freitas, Sampaio, Oliveira, Rodrigues, & Quintino, 2006) and submerged vegetation (e.g. Quintino et al., 2009). In comparison to passive optical sensors, acoustic sensors such as QTC5 can measure seabed structures that are biologically relevant at greater depths and are unconstrained by optical water properties. However, acoustic sensors are restricted to mapping very shallow substrate ($<$0.5 m) or exposed seafloor, are limited in their spatial resolution and require interpolation between transects. Several studies have shown that it is be possible to overcome the disadvantages present within optical and acoustic remote sensing systems by combining these remote sensing technologies to produce benthic habitat maps (Bejarano, Mumby, Hedley, & Sotheran, 2010; Riegl & Purkis, 2005), however, these studies were conducted in tropical marine regions which present significantly different optical characteristics compared to temperate marine areas.

The purpose of this study was to (1) evaluate habitat discrimination from passive optical and single-beam active acoustic methods, with particular reference to detecting aquatic vegetation (seagrass and algae); and, (2) examine the applicability of these individual systems in supporting habitat mapping for conservation management. The study site, on the west coast of British Columbia, Canada, was selected because it is a monitoring site with known presence of eelgrass within the Gwaii Haanas National Marine Conservation Area and Haida Heritage Site. The primary sources of data were WorldView-2 satellite imagery, a QTC View V acoustics unit operated at 200 kHz, and *in situ* videography of the substrate and epiflora.

Table 1
Number of sites visited in the survey of benthic substrates and division of sites into classification training and testing sites. EG = eelgrass, AG = green algae, BA = brown algae, UV = unvegetated, d = deep, s = shallow. Brown or green algae training did not occur in deep regions and red algae did not occur in shallow regions of the study site.

Substrate class	Substrate abbrev.	Training/validation sites
Deep eelgrass	(dEG)	95/307
Shallow eelgrass	(sEG)	105/297
Green algae	(sGA)	60/134
Brown algae	(sBA)	26/86
Red algae	(dRA)	81/91
Deep unvegetated substrate	(dUV)	108/296
Shallow unvegetated substrate	(sUV)	90/282

2. Methods

2.1. Study area

The research took place at Bag Harbour, a small estuary south of Burnaby Narrows in Haida Gwaii, British Columbia, Canada, located within the Gwaii Haanas National Marine Conservation Area Reserve and Haida Heritage Site (GHNMCA) (Fig. 1). Bag Harbour is roughly 600 m long and 300 m wide and is largely protected from predominant south-easterly winds by surrounding land masses and mountains. The maximum depth at Bag Harbour is approximately 12 m.

According to the British Columbia ShoreZone coastal resource information system there are patches of continuous green algae (*Ulva* spp.) and brown algae (*Fucus* spp.) as well as eelgrass present at the site (Howes, Harper, & Owens, 1994). As a part of the GHNMCA eelgrass monitoring survey program, data on the water quality, biological characteristics of eelgrass meadows and fish sampling have been collected since 2004 (Robinson & Yakimishyn, 2013; Robinson et al., 2011). In 2008, an eelgrass assessment by Parks Canada reported the following average metrics for eelgrass: density = 800 shoot m^{-2}, biomass = 937 g m^{-2}, leaf area index = 1.76 (Robinson & Yakimyshyn, 2008). The areal extent of inter- and subtidal eelgrass meadows has never been mapped at Bag Harbour.

2.2. Field survey and data processing

A benthic habitat ground-truthing survey was conducted at Bag Harbour on June 1st and 2nd, 2012 (weather was sunny and calm) via a towed underwater video transects using a small colour video camera (Deep Blue Pro, Ocean Systems Inc.) mounted on a custom-made aluminum wing. Live feed was visible via a field computer and allowed the camera operator to maintain the camera 1–2 m above the seafloor using an electrical downrigger which provided an imagery swath width of approximately 2 m. Video transects were run both parallel to shore (approximately 5–10 m apart) and orthogonal to shore (approximately 50 m apart) (Fig. 2a). Transect location began from the north side of the mouth of Bag Harbour where steep rocky shore transitioned to shallow slope beach. The transect interval was chosen to balance transect distance (as close as possible) and field time for video data collection (2 days). Sampling was concentrated in the nearshore environment to ensure adequate sampling of habitats that would be discernible by both the optical and acoustic sensor. Vessel speed was maintained between 1 and 2 kn during video surveys to guarantee video quality (image blurring was significant at speeds over 2 kn). A depth logger (Sensus Ultra U-04133, Reefnet Inc.) was attached to the camera and recorded depth every second during deployment. A dGPS was mounted next to the downrigger to maximise positional accuracy and logged positional data and local time every second. Video and dGPS data were recorded directly to a laptop computer hard drive. On June 2nd, 2012 a Secchi depth measurement (4.5 m) was taken at the mouth of Bag Harbour and the perimeter of exposed intertidal eelgrass meadows were mapped using a handheld dGPS at low tide (+0.9 m).