Proposed Choice of Experimental Studies

New Technologies for Benthic Habitat Mapping

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Sammanfattning

I denna rapport föreslår vi experimentella studier som syftar mot framtida metoder för kartering av bottenvegetation och susbstrat. Målsättningen med de experimentella studierna är att indikera områden där ny teknik kan ge förbättringar för klassificering och kartering. Några exempel på sådan teknik är hyperspektrala system, multispektrala lasersystem och fluorescenssystem. Några av dessa tekniker har testats i pilotstudier men används ännu inte i större omfattning för kartering av bottenhabitat.

Vi förslår två experimentella aktiviteter varav den första är mätning och dokumentation av vegetation och substrats spektrala reflektans och fluorescens. Sådana data är relevanta för många fjärranalystekniker och det finns sedan tidigare endast få publicerade data som rör miljöer i Östersjön. Den andra aktiviteten är kartering av bottenmiljö från obemannat miniflygplan (UAV - unmanned aerial vehicle). Kartering med UAV kan vara av stort intresse, om den kan genomföras med tillräcklig noggrannhet, på grund av dess låga kostnad. UAV-studien kommer också inbegripa undersökning av inverkan från bildupplösingen på kartingsförmågan.

Rapporten är en del (akvatiskt arbetspaket 3, WPA3) av arbetet i EMMA-projektet som finansierias av Naturvårdsverket. Huvudfokus i projektet är kartering med data från flygburna operativa system (laserbatymetri och flygbilder). I denna rapport avser vi dock metoder och tekniker som kan vara av intresse på något längre sikt.

Nyckelord: Hyperspektral, flourescens, laser, lidar, UAV, vegetation, substrat

Summary

In this report is we propose experimental studies aiming at possible future methods for producing maps of underwater vegetation and substrates. The purpose of the experimental studies proposed in this report is to establish leverage with respect to possible future technologies and methods which could increase the potential for classification and mapping. Some examples are hyperspectral imaging, multispectral lasers and fluorescence remote sensing technologies. Some of these techniques have been tested in pilot studies but are not yet fully operational in a broader sense.

We propose two activities for the experimental studies. The first activity is to characterise spectral reflectance and fluorescence signatures of species and substrates. Such data are relevant for many types of remote sensors, and there are few such data published from Baltic environments. The second activity is a study of mapping capabilities from a small unmanned aerial platform (UAV). If accurate mapping could be done from UAV:s, this method would be of interest because of its low cost. The UAV-mapping study will also concern the influence from spatial resolution on the mapping capability.

This report is a part (Aquatic Work Package 3, WPA3) of the work within the EMMA project financed by the Swedish Environmental Protection Agency. The main focus of the EMMA-project is on remote sensing data from operational systems on airborne platforms. However, in this report we address new technologies and methods that are not fully operational today.

Keywords: Hyperspectral, flourescence, laser, lidar, UAV, vegetation, substrate

Contents

1 Introduction

The subject of this report is to propose experimental studies to be performed within the EMMA project (Environmental Mapping and Monitoring with laser And digital images). The proposed studies are aiming at possible future methods for producing maps of the biota under water that are based on actual observations.

This report is a part (Aquatic Work Package 3, WPA3) of the work within the EMMA project financed by the Swedish EPA (SEPA). The focus of the EMMA-project is on remote sensing data from *operational* systems on airborne platforms, but in WPA3 we also include new approaches which will be considered for experimental studies in field and in laboratory. This work will indicate how new technologies can be applied to aquatic ecology by mapping of submerged aquatic vegetation in estuarine environments. The work will stress the requirements and environmental monitoring needs and give useful information for future research. Examples of activities within this work package are focused studies of classification possibilities using state-of-the-art equipment available within the project group or data provided by cooperating projects.

The purpose of the experimental studies proposed in this report is to establish leverage with respect to possible technologies and methods which could increase the potential for classification and mapping. Some examples are hyperspectral imaging, multispectral lasers and fluorescence remote sensing technologies. With these studies we will address new, emerging methods that are not fully operational today. These methods may have been tested in pilot studies, with prototype instruments, or with commercial equipment not yet fully operational in a broader sense.

2 Background

The goal for mapping and monitoring is to differentiate between vegetation and non-vegetated bottoms and also to differentiate between species. This concerns not only obvious cases such as the distribution of *Zostera marina* on soft substrates but also, for example, hard substrates covered with filamentous algae that have very subtle differences in colour and geometrical shape. For example, if conventional laser depth sounding and conventional aerial photography with few-colour band cameras give poor classification and mapping results, new methods could be considered. One example is using hyperspectral imaging data, while another is laser techniques for active colour imaging or remote sensing of fluorescence. A third example would be to improve the spatial (pixel) resolution in the imagery. It should thus be noted that *resolution* can comprise all spatial, temporal and spectral resolution, which all have influence on the performance of the mapping and monitoring performance.

In a recent report (Kautsky *et al.* 2010) we conclude that several new technologies and methods are of interest for benthic habitat mapping. In the following subsections we briefly describe some of the conclusions on hyperspectral imaging, multispectral lasers, fluorescence sensing, unmanned platforms and methods.

2.1 Multi- or Hyperspectral Passive Imaging

For the first few metres below the sea surface, airborne and spaceborne passive *multi- or hyperspectral* imaging systems are of great interest for mapping as they offer increased possibilities to differentiate between habitat types. This is an important contribution in the near-shore and coastal zones. Passive sensors with high spatial resolution (metre-scale or better) are of largest interest for mapping, since the natural patchiness otherwise will blur the images and make classification less accurate. High spectral resolution or many "colour" bands in a passive sensor will result in better classification performance. Spectral reflectance data may additionally be used to monitor the health of the habitats. The required or optimal number of bands depends on which other data sources that are available, including their resolution.

2.2 Multispectral Lasers and Fluorescence Sensing

Airborne depth sounding laser is an interesting method for mapping of shallow underwater habitats. In general, the maximum depth range for airborne laser exceeds the possible depth range for passive sensors. Due to its high-resolution depth measurement capability, the lidar is able to capture different measures of bottom (or vegetation) roughness (rugosity, depth standard deviation, slopes etc), which have the potential to substantially improve classification and subsequent mapping of shallow benthic habitats (Brock *et al.* 2006; Méléder *et al.* 2007; Kuffner *et al.* 2007; Tulldahl *et al.* 2008). Laser sensing could be further developed from single-wavelength depth sounding systems to include fluorescence, Raman and other spectral techniques to increase the classification performance. So far, classification of bottom vegetation using e.g. fluorescence, polarisation and Raman scattering has only been tested with special prototype systems from underwater platforms. Fluorescence has several interesting features which might be useful in mapping of underwater habitats. One example is the laser induced fluorescence giving rise to the emission spectrum which could be used for classification together with e.g. the spectral reflectance signature. Another example is that in a time-resolved system, the fluorescence lifetime can indicate the health of plants. It should be noted that for underwater sensing, the excitation wavelengths are limited to the visual region as e.g. ultraviolet radiation is highly attenuated in water. A problem with airborne fluorosensing of the sea floor is that the signal is much weaker than the elastically reflected signal. Future laser systems with higher efficiency together with high-sensitivity receivers may partly solve this problem. Another possibility are utilising fluorosensors mounted on underwater platforms operating a few metres above the bottom.

Recent development of broadband lasers and advanced imaging 3D receivers has led to new opportunities for active multispectral and polarization imaging with high range resolution. The broad emission in supercontinuum white light lasers eliminates the problems with passive hyperspectral or multispectral imaging namely the conversion of the measured radiance to reflectance information. This conversion can be difficult for passive sensors, due to the changing geometry between the sun, target and sensor which can affect the reflectance, and also introduce shadows in the scene.

2.3 Unmanned Platforms

Platforms will continue to be developed for autonomous operation with the long term aim to reduce cost of operation and limit manpower involvement. Both underwater, surface and airborne platforms are included in this development. There are several examples of existing airborne platforms with different size and payload capability. The smallest ones are cheap and can today carry passive camera equipment that may readily be useful for benthic habitat mapping in the most shallow areas.

2.4 Methodology

For existing and new sensors, the methods will be developed by better and more automated algorithms for data exploration and for fusing different data sets together. This includes both fusion of data from different remote sensors (e.g. laser and passive) and remote sensing data with in situ sampling. Also, fusion of remote sensing data e.g. with existing depth data digitised from hydrographic maps is a method that increase the value of passive remote sensing data compared to when it is used as single data source.

3 Proposed Choice of Experimental Studies

We propose two activities for the experimental studies in EMMA, aiming at possible future methods for producing maps benthic habitats. The first activity will be to characterise spectral reflectance and fluorescence signatures of species and substrates. To our knowledge, there are few such data published from Baltic environments. One example of reflectance data from the Baltic is published by Kutser and co-workers (Kutser *et al.* 2006). They presented a library of algae and different substrates from Estonian coastal waters of the Baltic. The inherent reflectance spectrum is one of the key measures for classification. Knowledge of the fluorescence intensity is useful for feasbility studies and performance calculations for real systems. The second activity will be to study mapping capabilities from a small unmanned aerial platform (UAV). If accurate mapping could be done from UAV:s, this method would be of interest because of its low cost. Both the studies will be made with equipment or data already available to the EMMA-project.

3.1 Hyperspectral Passive and Fluorescence Signatures of Species and Substrates

The aim of this study will be to document the reflectance and fluorescence spectral characteristics of vegetation and substrate samples. The results can be used for studies of separability between individual or groups of species or substrates. The spectral range between 450 nm and 700 nm is of highest importance as this is the range where the optical attenuation in typical Baltic waters is the smallest (an example is shown in Figure 1). The purpose of the work is to find wavelength regions (passive and fluorescence) where groups of species or substrates have large differences. This information is essential for the choice of spectral bands for mapping with multi-, hyperspectral or fluorescence instruments. The work will include studies of the fluorescence absolute intensity related to the reflectance at one or several specific wavelengths of the same species or substrate.

The vegetation and substrate samples will be collected and subsequently measured in laboratory. The spectral reflectance of the samples will be measured with a Cary Spectrometer (Figure 2). Sample results from such measurements are shown in Figure 3 (a) with samples shown in Figure 3 (b). The spectral fluorescence will be measured with a setup schematically shown in Figure 4. A laser wavelength of 532 nm will be used for excitation of the samples via an optical fiber and a probe. The choice of 532 nm as excitation wavelength is motivated by the fact that this wavelength is commonly used in bathymetric laser scanners. The reflected and fluorescencent signals are led from the probe through an optical fiber to a spectrometer and the signals are recorded in the computer. A filter with cutoff wavelength of 550 nm is mounted between the probe and the spectrometer. This reduces the saturation effects in the spectrometer from the (in-band) reflected signal at 532 nm. An example of results from a test measurement with this setup in shown in Figure 5.

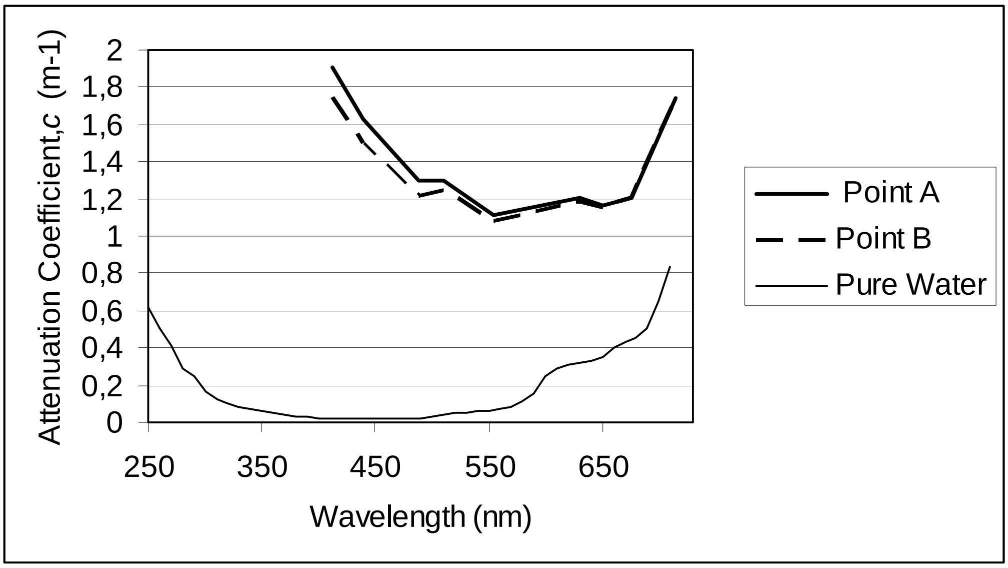
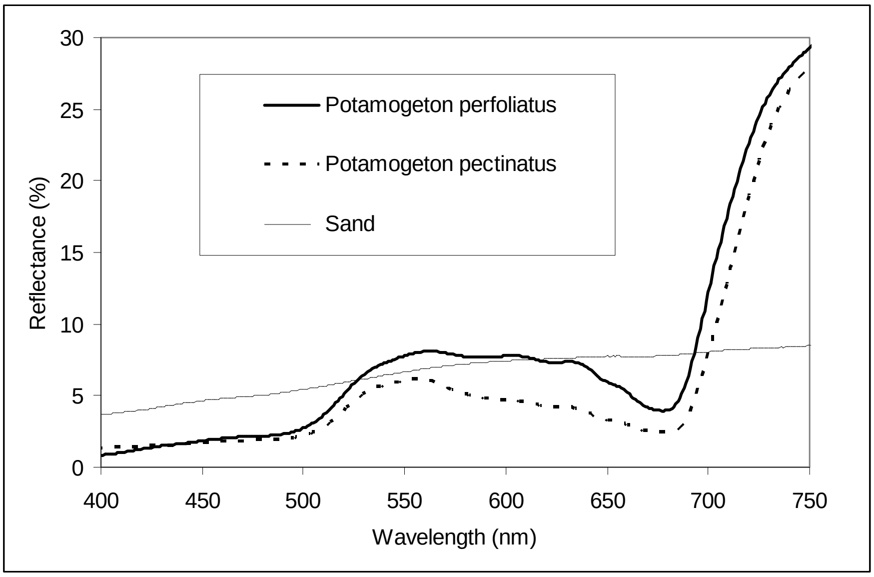


Figure 1. Example of measured spectral attenuation coefficient at nine wavelengths (instrument: AC-9 WET Labs Inc.) compared to attenuation coefficient of pure water (Mobley 1994). The measurements were made in Arkösund, Sweden on September 12, 2007 at two positions (Points "A" and "B") in the Arkö archipelago situated close to the outlet of Motala Ström (Kautsky *et al.* 2010) .

Figure 2. CARY UV-VIS-NIR Spectrophotometer.



(a)

(b) (c) (d)

Figure 3. Example of results from test measurements of spectral reflectance (a). The tests were made on *Potamogeton perfoliatus* (b), *Potamogeton pectinatus* (c), and coarse sand (d). The samples were collected on August 3-4, 2009 in Sävarfjärden, Umeå for the ULTRA-project (EU Interreg IV Botnia-Atlantica programme, http://www.kvarken.fi/Pa_svenska/Projekt/Ultra).

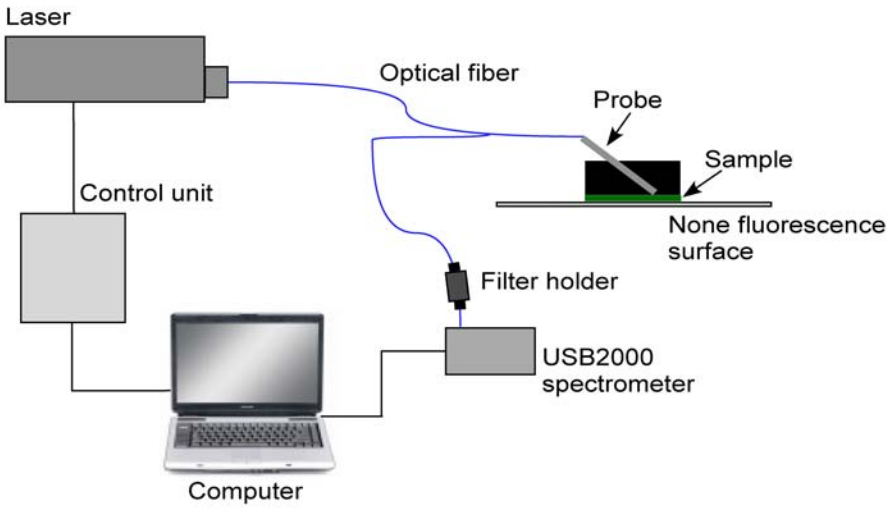


Figure 4. Schematic description of the fluorescence measurement setup. The measurements are made at an angle of 0° or 45° to the normal of the sample surface.

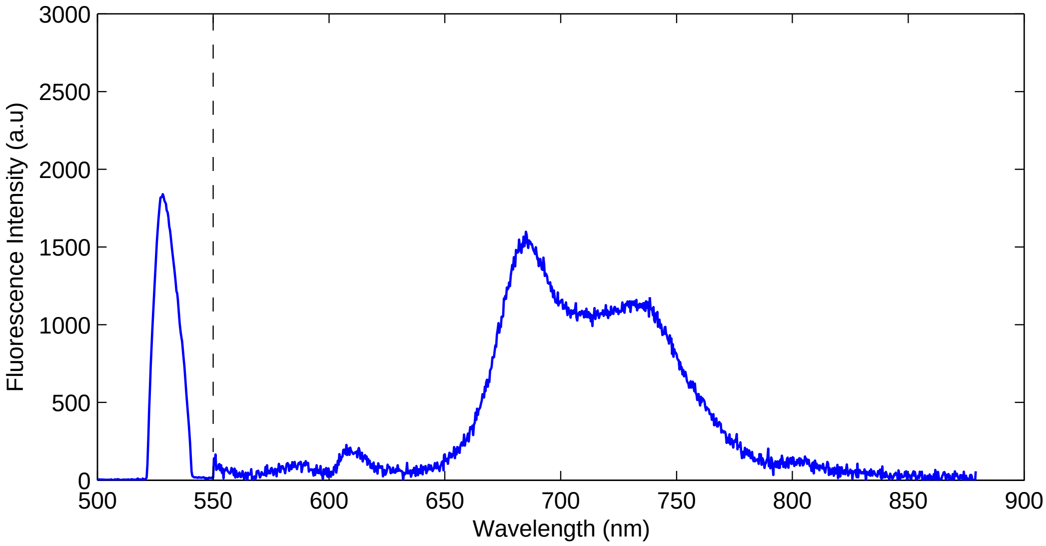


Figure 5. Spectral fluorescence results from a test measurement on dandelion leaf containing a fluorescence peak at an appoximate wavelength λ of 690 nm for chlorophyll. The measurements are made at an angle of 45° to the normal of the sample surface. In the figure, the signals at λ > 550 nm are multiplied by a factor of 10, relative to the signals at λ < 550 nm. At λ =532 nm the reflected (elastic) laser signal is shown.

3.2 Mapping from Small Unmanned Aerial Platform

Aerial images from small UAV:s can be low-cost data for mapping of shallow waters. There are several advantages of using UAV-images. For example, high spatial resolution can be achieved with inexpensive cameras due to the low flight altitudes. Also, as the platforms are low-cost, the operation can be delayed e.g. due to bad weather without significant increase of the overall cost of the mapping project. Images can thus be captured at times when conditions are favourable. Such conditions includes high solar angle, low water turbidity, and low wind and surface waves. A disadvantage with the use of small UAV:s are that they can only carry low-weight sensors which, today, are less advanced.

The aim of this study is to find the maximum depth range for mapping and explore the possibility to separate individual or groups of species and substrates from the image data. Using the high spatial resolution in the data we will be able to study the mapping capability with several different spatial resolutions, starting with the highest resolution and by gradually downsampling the spatial data. We will also address the quality and accuracy in sensor data and identify possible improvements for the data collection.

The method will be based on using information both from the UAV-images and high-resolution depth data from laser scanning of the same site. The depth data and estimates of water turbidity will be used for correction of the colour information in the image data. Subsequently, the corrected pixel colour information will be used togheter with *in-situ* sea floor data for classification tests. Using both depth data and image data have been shown to give significantly better classification results (e.g. Malthus and Karpouzli 2003; Tuell *et al.* 2005) than using image data only (e.g. Phinn *et al.* 2008).

We will use data from the Rönnskär archipelago outside Vaasa, Finland. The data were collected in the ULTRA project (http://www.kvarken.fi/Pa_svenska/Projekt/Ultra) with laser data from surveys with the Hawk Eye II system in September 13 and 15, 2009, and UAV imagery from surveys in August 5-6, 2009. The UAV imagery was collected by the company PIEneering (http://www.pieneering.fi/) using a conventional, compact camera on the SmartOne platform (http://www.smartplanes.se/). PIEneering produced othophotos from the collected images (see Figure 6). The orthophotos will be the input data for our study. The orthophotos were delivered in two versions, where one has unadjusted color information. The second version was radiometrically adjusted to obtain color corrected images although the bottom depth was not used in these corrections.

Currently, preparations are made for a possible follow-on activity to the ULTRA project - "ULTRA 2". If such a project is realised, we will perform this study in cooperation with ULTRA 2.

(a)

(b)

Figure 6. Example of an orthophoto from the Rönnsskär archipelago, Finland. The photo is produced from individual images taken from a UAV. The orthophoto contains approximately 350 Mpixels (a). In (b) a detail of 100m * 100m from the red square in (a) is shown. The Ground Sample Distance (GSD) is about 0.1 m. The image data were collected on August 6, 2009 by the ULTRA-project (EU Interreg IV Botnia-Atlantica programme, http://www.kvarken.fi/Pa_svenska/Projekt/Ultra).

4 Discussion

Both of the proposed experimental studies, spectral reflectance/fluorescence signatures and mapping capabilities from small UAV, will address several of the items identified in the literature study of new methods for benthic habitat mapping (Kautsky *et al.* 2010). The Spectral reflectance and fluorescence mesaurements are relevant for:

- multi- and hyperspectral passive cameras,
- multispectral active (laser) sensors,
- laser (in-band) reflectance signatures for conventional laser scanners,
- laser induced fluorescence sensors.

The UAV mapping study is of interest for examining:

- mapping results with different spatial resolutions,
- the capability for low cost mapping,
- methods for combination of different data sets (depth from laser scanning together with images from UAV).

The spectral signature measurements will give information of wavelength regions (passive and fluorescence) where groups of species or substrates have large differences. These results will be data of a specific part of the sample (e.g. the leaves of *Potamogeton perfoliatus*). In a real remote sensing situation, the signal in a single sensor pixel will mostly be from a combination of different substrates, species geometries and species parts. Thus a separability between samples in the laboratory spectral measurements can not be conclusive for the separability in a real remote sensing case. The information will rather serve as an indication for potential areas (wavelength regions etc) for further analysis and future work. For example, in remote sensing, the fluorescent signal from a species will cover only parts of the sensor field-of-view (footprint). Thus, only distinct fluorescent signatures should be considered for real systems and mapping methods.

A possible extension of currently operational laser scanners would be the use of one or several flurorescence receiver channels. The fusion of the fluorescence, in-band laser, and passive reflectance data may improve the discrimination between species and substrates. The chlorophyll fluorescence peak is within a wavelength region (about 650 nm - 700 nm) where the attenuation in water increases from its minimum attenuation (see Figure 1). The minimum attenuation is approximately in the region 470 nm - 660 nm for typical Baltic waters (CDOM dominated (coloured dissolved organic matter)). It is thus expected that the lower parts of the chlorophyll fluorescence band (e.g. < 690 nm) is more useful for remote mapping than the longer wavelengths. The relatively high attenuation at fluorescence wavelengths combined with the low fluorescence signal (compared to the in-band reflectance) will thus result in a smaller maximum depth range if the systems otherwise are unchanged with respect to laser power and receiver sensitivity.

The operational use of a UAV-mapping method could be to use depth data collected at one occasion, e.g. by laser scanning, together with image data captured with UAV:s at several different times for monitoring of changes in the environment. The more expensive laser scanning data could thus be used over at long time period while the low cost UAV image data could be captured more often. A future possibility would be to equip UAV:s with multiple wavelength cameras, which are able to capture more spectral information than the conventional RGB-channels and thus give better information for classification. It should be noted that the maximum depth range for mapping with passive remote sensing image data normally is smaller than the maximum range for laser scanning and limited to depths smaller than the Secchi depth. Thus, the shallowest areas (down to about 3-5 m depth) are the main interest for passive cameras. However, data from high quality cameras with high sensitivity may allow mapping down to somewhat larger maximum depths.

References

Brock, J. C., Wright, C. W., Kuffner, I. B., Hernandez, R., and Thompson, P. 2006. Airborne lidar sensing of massive stony coral colonies on patch reefs in the northern Florida reef tract. *Remote Sensing of Environment* 104, 31-42.

Kautsky, H., Tulldahl, H. M., Steinvall, O., Strömbeck, N., and Wikström, S. A. 2010. *New technologies for benthic habitat mapping - literature study*. FOI-R--3013--SE. Linköping, Sweden: Swedish Defence Research Agency.

Kuffner, I. B., Brock, J. C., Grober-Dunsmore, R., Bonito, V. E., Donald, H. T., and Wayne, W. C. 2007. Relationships between reef fish communities and remotely sensed rugosity measurements in Biscayne National Park, Florida, USA. *Environmental Biology of Fishes* 78, 71-82.

Kutser, T., Vahtmäe, E., and Metsamaa, L. 2006. Spectral library of macro algae and benthic substrates in Estonian coastal waters. *Proceedings of Estonian Academy of Science* 55, 329-340.

Malthus, T. J. and Karpouzli, E. 2003. Integrating field and high spatial resolution satellite-based methods for monitoring shallow submersed aquatic habitats in the Sound of Eriskay, Scotland, UK. *Int. J. Remote Sensing* 24, 2585-2593.

Méléder, V., Populus, J., and Rollet, C. 2007. *Mapping seabed substrata using Lidar remote sensing*. Action 4. MESH. http://www.searchmesh.org/default.aspx

Mobley, C. D. 1994. *Light and Water*. San Diego: Academic Press.

Phinn, S., Roelfsema, C., Dekker, A., Brando, V., and Anstee, J. 2008. Mapping seagrass species, cover and biomass in shallow waters: An assessment of satellite and airborne multispectral and airborne hyper-spectral imaging systems in Moreton Bay (Australia). *Remote Sensing of Environment* 112, 3413-3425.

Tuell, G., Park, J. Y., Aitken, J., Ramnath, V., Feygels, V., Guenther, G., and Kopilevich, Y. 2005. SHOALS-enabled 3-d benthic mapping. In *Proceedings of Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XI,* Orlando, FL, 28 March–1 April 2005, SPIE Vol. 5806, 816-826.

Tulldahl, H. M., Vahlberg, C., Axelsson, A., and Janeke, H. 2008. Sea floor characterization from airborne lidar data. In *Proceedings of International Lidar Mapping Forum 08,* Denver, USA, Februari 21-22 2008, Vol.