High resolution multispectral satellite data for mapping benthic cover in turbid coastal waters

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The usefulness of high resolution satellite data for classification of shallow sea beds has been evaluated. The goal was to identify vegetation coverd areas and different species of bentich vegetation in the Gränsö-Singö archipelago. The results indicate that it could be possible to separate vegetation covered from unvegetated areas down to the maximum visible depth. The results also indicated that classification of specific species can be done in very shallow waters and/or if abundant in clean populations and in combination with field data collected as close as possible, both spatially and temporally. Even if the discrimination level is limited, the results are considered to be valuable by the end-users and the methodology could serve as an important/cost effective contribution in the ongoing environmental work along the coast of Sweden.

Keywords: Remote sensing, benthic cover, multispectral, Baltic Sea, shallow waters.

1. INTRODUCTION

1.1 Back ground

Industries and settlements, outlets and nutrification, ship and boat traffic and dredging threaten to destroy the environment in the archipelago and coastal zone. Shallow seabeds are often characterized by high biodiversity and variation, which need to be restored or maintained by continued prudent use. With respect to the Swedish environmental goals, consideration should be given, in connection with fishing and shipping, as well as construction and other development in coastal and archipelago areas, to the productive capacity, biological diversity, natural and cultural assets and outdoor recreation assets of the water areas. These considerations require knowledge about the status of the subsurface environment. During many years, information about these areas has been collected through costly field investigations. Today other techniques for monitoring are available and information derived from high resolution satellite data, which covers relatively large areas, could serve as a good basis and a complement to field investigations.

1.2 Geographic region

The Gräsö-Singö archipelago is highly variable and contains a large shallow marine area, thousands of small islands and a large number of protected bays. The largest value of the area is the low degree of human disturbance creating favourable conditions for both aquatic and terrestrial ecosystems and species. The area is at the border between the Bothnian Sea and Baltic Proper, which result in a marine flora and fauna that follows the salinity gradient from north to south. The shallow archipelago is of great value contains important reproduction areas for some species of fish and for breeding and migrating birds.

1.3 User needs

National, regional and local authorities need information about the subsurface environment in order to make decisions regarding preservation actions, developments and protected areas in the coastal zone. Sufficient knowledge to make those decisions does not exist for most areas today and it is necessary to develop new methods that can increase the information basis.

1.4 Project goals

The general goal was to investigate the possibility to develop methods, based on high resolution satellite data, to derive information about the subsurface environment. These methods could then contribute to the environmental work and decision making along the coast of Sweden, for the different municipalities, counties and SEPA. On a product level, the goal was to develop the following products if possible:

- A water mask, and a further refinement, showing shallow areas down to the maximum visible depth
- A map showing vegetation covered areas
- A map showing different species of vegetation

2. IMAGE DATA

The analysis is based on QuickBird and WorldView-1 images collected over the area of investigation during 2008. QuickBird has a spatial resolution of 0.6 m in panchromatic mode (450-900 nm) and 2.4 m in multispectral mode (Blue: 450-520 nm, green: 520-600 nm, red: 630-690 nm, near IR: 760-9000 nm). The QuickBird data was collected on the 22nd of August 2008 and WorldView-1 on the 29th of May 2008. The water level was 21 cm below mean at noon on the 29th of May and 10 cm above mean on the 22nd of August. On the 22nd of August the wind had been quite strong during the morning (8-9 m/s), which might be the reason for the visible wave action and also causing turbulence in the water column, with a lower Secchi depth as a result. The water level measurements were made in Forsmark and the wind speed at Örskär and reported by SMHI.

3. FIELD DATA

The field data set used in the analyses was collected by the County of Uppsala during 2006, in the area east of Gräsö. 13 shallow bays were visited and the abundance of vegetation and fish were investigated (Hjelm et al., 2007). Several transects were defined in each area and a squared sample area (0,25 m^2) was place on the bottom every 10th meter. Vegetation species and coverage were noted together with depth. This data was used in the classification and evaluation process.

4. PREPROCESSING

Both images were geometrically corrected using 0.5 meter orthophotos as base reference and the derived RMSE was below pixel size. The images were then radiometrically calibrated, i.e. the raw numbers (DNs) have been converted to the top-of-atmosphere radiation, and atmospherically corrected using 6S (Vermote et al., 1997).

5. METHODS & RESULTS

5.1 Water mask

A water mask was produced for each image and used in the analysis. The generation of a water mask and sub sequent divisions was mainly used to focus the classification effort to the right areas. This step is not as straightforward as it may seem, as there are spectral similarities and overlaps between many land and water objects, e.g. shaded ground areas and vegetated bottoms, and we are mostly interested of the difficult areas along the shores. The water mask derived from QB data was created using Spectral Angle Mapper (SAM) classification and a number of spectral signatures that were selected from the image. These signatures represented all different characteristics of water pixels and were identified with guides of the field data. Good classification results could be achieved and used to build a water mask.

5.2 Shallow areas

To evaluate the potential of the QB data collected in August for classification of shallow sea beds, different unsupervised classification methods (e.g. IsoData or Kmeans) where tested within the water mask. After the classification, all classes that were visually identified as shallow water was merged to one class and possibilities and limitations regarding separation of shallow and deep water were analyzed. In general the results were promising, but there were still some erroneous pixels. This analysis is based on the atmospherically corrected image and a problem with wave glint became evident in the data and inferred errors in the result. However, a classification attempt based on a sea surface corrected data did not generate any improvement of the results. Instead, a depth map based on the panchromatic data from May was used to identify the shallow areas (Philipson and Eriksson, 2010). The maximum visible depth was around 1.7 meters in August, and a mask corresponding to the depth interval 0-2 meters were produced and used in the further analysis of the QB data. From this mask, small clusters (<10 pixels) were filtered out to remove pixels that almost completely corresponded to waves.

5.3 Vegetation covered shallow seabeds

Looking at the panchromatic data collected in May, a majority of the bottoms showed no signs of vegetation. It was possible to manually identify several smaller areas that most likely were covered with vegetation or at least accumulations of last year's vegetation, but it is not possible to automatically separate dark vegetation from deep water. However, it was possible to separate bottoms with vegetation from bare ones based on the four available bands in the multispectral image. Spectral signatures corresponding to different types of vegetations and bottoms, on different depths, were defined and used to classify the whole image. Supervised Maximum Likelihood classification was applied and realistic maps could be derived. In Figures 1a-d two examples are showing the aggregations of the classes that correspond to vegetation (green) and bare bottoms (cyan).

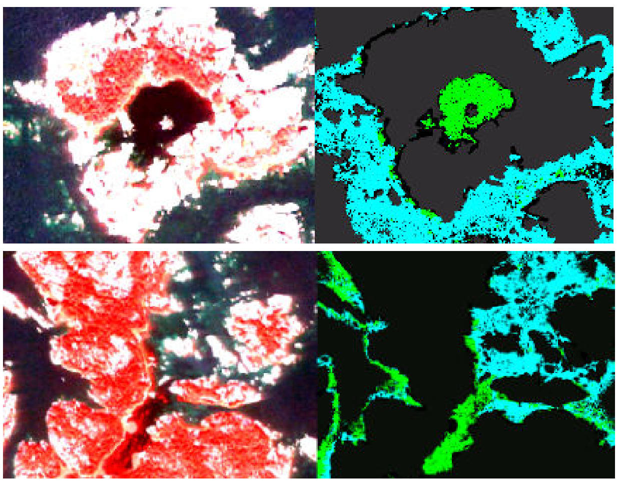

Figure 1a-d. QB data with the IR band displayed in red (to the left) and the classification (to the right).

We have not focused on the pixels in the shoreline in the analysis, but have concentrated on finding larger vegetation covered areas a few meters away from the shore. We will also miss areas when depths are approaching, or are below, the maximum visible depth for this image and point of time. However, it is important to point out that this type of product, even if it is limited, can be derived without field data and be valuable to the end users community.

5.4 Classification of different species of vegetation

The final goal was to investigate if different species of vegetation could be separated in the multispectral data. Our previous attempts based on images collected over the Arkö-Gränsö archipelago have not been very promising, other than in very shallow areas, and these results are also supported by several research articles (Kutser et al., 2006, Kutser et al. 2006b, Vahtmäe, et al., 2006). The sensors (e.g. number of bands and the bandwidths) are limiting factors along with the relatively limited Secchi depth of Baltic waters. The field data collected in 2006 have been used to evaluate the possibility to identify different species of vegetation. It is two years between the image and field data collection, which of course infers some uncertainty in the analysis. However, the field data shows that the area east of Gräsö either is very sparsely vegetated or densely vegetated with one or two dominating species. It seems likely that pure and dense stand could be annually recurring. We have extracted image data/spectral signatures that correspond to all (53) squares containing one single species with a coverage between 80-100%, from the atmospherically corrected QB image. An average of the centre pixel and the four closest neighbours were used to calculate the signature. Three of the investigated areas (Bryggebåddalen, Kullaskäret and Stapelbådan) were located inside the images, see Figure 2 and data from these areas has been extracted and used in the analyse.

Figure 2a-c. Bryggebådan, East Kullaskäret and Stapelbådan.

Several classification methods were tested to see if similar patterns could be identified. The classification was made for all pixels included in the earlier defined mask of vegetated shallow areas. One of the obvious agreements was *Myriophyllum sibiricum Kom.* that was identified by all methods southeast of Kullaskäret, but in general, it was difficult to observe any common patterns for all methods. A comparison with the field observations indicated that the Spectral Angle Mapper (SAM) classification generated the best result, and a few examples are given in Figure 3 below. It is reasonable that this method works best as the shape of the spectra (theoretically) should be the same for all pixels corresponding to the same species, but that the intensity of the reflected light could be different depending on the depth. However, in reality, depth will also affect the shape to some extent and this statement is therefore more likely true for a limited depth interval depending on the depth of the training data spectra. This suggest that it is necessary to have depth stratified training data for all classes. The maps in Figure 3 have been made more readable through a majority analysis, i.e. the class of the centre pixel in a 3x3 window is replaced by the class of the majority of the nine pixels. It is encouraging to see that the different classes do not form "depth classes" and that the dominating classes that falls out corresponds relatively well with the observations made in field. The species *Zannichellia palustris L. (32%), Callitriche hermaphroditica (17%)* and *Chara aspera (15%)* constitute app. 65 % of the training data sites corresponding to 80-100% coverage, which indicates that these three species are the dominating species in the investigated area. In the classification the distribution is as follows: *Zannichellia palustris L. 24%, Callitriche hermaphroditica 19%* and *Chara aspera 15%.* The main difference in the classified image is *Potamogeton pectinatus L.* that only stands for 8% of the field data, but which constitutes 28% of the classified pixels. These four species corresponds to 85% of the classified pixels. In a normal work procedure, the available field data are divided into two sets, one for training and one for evaluation. This data set was not big enough for a statistical evaluation of that kind. It is difficult to further numerically evaluate these results, as the two data sets (image and field) are from different years and as the field data set is limited, and be able to make any well-founded conclusions. Looking at the spectral signatures corresponding to the training data, it is obvious that the variability within one class sometimes is larger than between classes. Different depth is of course one factor contributing to this variation. Still, an attempt was made to perform an evaluation of the result exemplified in Figure 3. What could be done was to compare the field data class, which also was used to calculate the training signature, with the classification result. This is not desirable, but possible in this case as the defined training signatures were an average of five pixels. This means that the signature corresponding to the exact field location (1 pixel), will not be identical to the signature calculated (5 pixels) for the classification. The result is as follows: 29 of the 53 points had been masked out by the earlier defined mask corresponding to vegetated shallow areas. 17 of 24 remaining points were correctly classified (71%), 3 of 24 (13%) changed class after the majority operation, but were correctly classified initially. 4 of 24 (17%) did not end up in the correct class. If this evaluation would have shown a complete randomness in the numbers, we could have concluded that

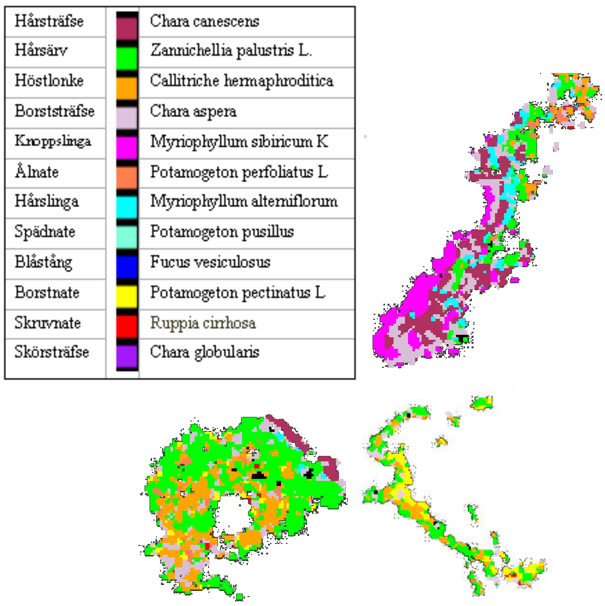

Figure 3a-d. Map legend with both the Swedish and the Latin name of the species, and a example of the classification result in East Kullaskäret Bryggebådan, and Stapelbådan

either species discrimination is NOT possible at all, and/or, that it is possible that the field data is not representative two years after collection. Instead, these results indicate that species discrimination could be possible if a relatively large amount of field data is available and if the stands are somewhat pure as they seem to be in Gräsö archipelago. An attempt was made to, if possible, find (or defined) differences and similarities between spectra representing; 1, the same species on similar depth, 2, same species on different depth and 3, different species on similar depth. Theoretically the shape of the spectral should be the same for all locations corresponding to the same species, but vary in intensity depending on the depth [4]. This was true for some of the species in the field data, but the same species could also show intensity differences even if they had been collected on the same depth, see example with *Zannichellia palustris L.* in figure 4.

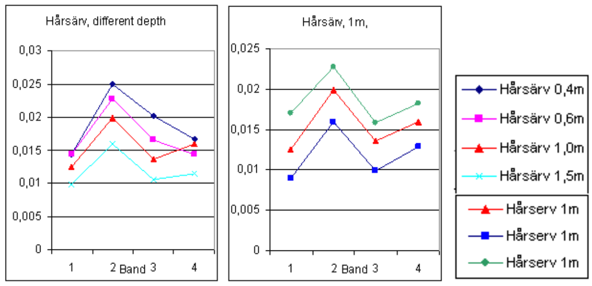

Figure 4a-b, Spectral signature for *Zannichellia palustris L.* at different depth (0,4, 0,6, 1,0 and 1,5 m) and spectral signature from location at the same depth (1m).

We could also see that the same species could differ in reflectance. Figure 5 shows an example of two stands of *Myriophyllum sibiricum Kom.* in the same bay and at the same depth with different intensity in NIR, i.e. training data from both these location was needed to detect both stands of *Myriophyllum sibiricum Kom.* in this bay. The reason for this difference in NIR reflectance can not be explained based on the available filed data.

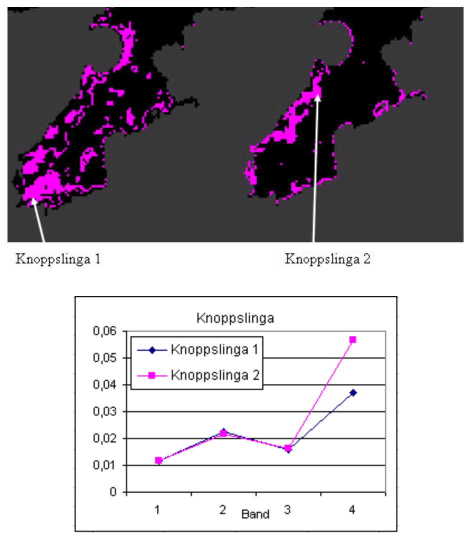

Figure 5a-b. The classification outcome from two stands of *Myriophyllum sibiricum Kom.* located in the same bay, at the same depth, and their spectral reflectance.

A few sites corresponding to *Zannichellia palustris L.* and *Callitriche hermaphroditica* were investigated closer because these two species were often confused in the classification evaluation. When comparing their spectral properties from locations in the depth range 0,8 -1,4 m (see Figure 6) the two species were different in the angels and also in intensity. However, classification attempts to improve the result was not successful. This could perhaps be explained by the fact that the field data collection and the image registration were made during different years or that these classes are spectrally to close to be able do separate in turbid waters like these with only 4 spectral bands.

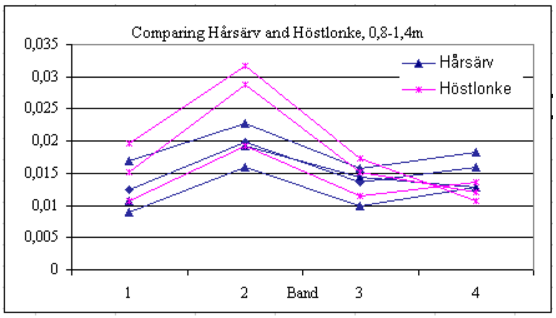

Figure 6. Comparing the spectral signature for location with *Zannichellia palustris L.* and *Callitriche hermaphroditica*.

In our efforts to produce a vegetation map, many different classification attempts were made. The best method generated a map with eight species (some species represented with two trainings areas) in the depth range 0,8 to 1,2 meters, classified under a depth mask covering the same range, see Figure 7. The eight different species fell out in specific patterns explored during the classification attempts we previous did on individual class, but a complete evaluation was not possible with respect to the sparse amount field data. To perform the classification in a small depth range gave a more accurate classification, which is reasonable with respect to the effect of the water column on the spectra. Through interpretation we could see that the northern part of the image had less accuracy, something perhaps explained by the few field data point in this area.

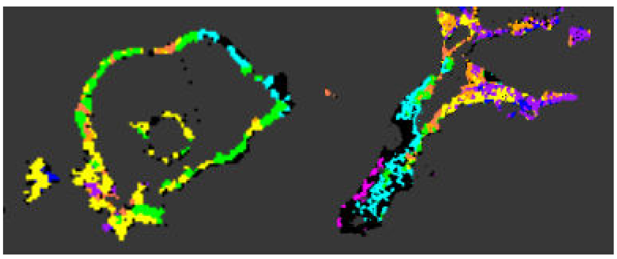

Figure 7a-b. Classification output in Bryggebådan and East Kullaskäret, with same legend as fig 20.

During all these classification attempts we have come to understand that the spectral information can be used for classification and that useful results can be produced, but that extensive field data is necessary.

6. CONCLUSIONS

- In the panchromatic data from May the maximum visible depth was around 3 meters and in the multi spectral data from August appr. 1.7 meters. The possible depth will be limited by the transparency of the water and the properties of the sensor.
- The multispectral data is useful for production of maps showing bottoms with vegetation as separated from unvegetated ones, down to the maximum visible depth. It is not possible to separate dark vegetation from deep areas based on just one band, which indicates that panchromatic data is insufficient for this purpose.
- Different vegetation species could be possible to separate in shallow areas if it occurs in larger relatively pure populations.
- A map of vegetation species were produced over the shallow vegetation covered areas east of Gräsö. A satisfactory evaluation of the map could not be made due to lack of field data.
- It is unlikely that a spectral signature identified for one species, in one area, could be applicable to another area without considering and correcting for a number of factors like water quality conditions, depth etc.
- Extensive field data collected in the imaged area, and preferably as close as possible to the image collection seems to be necessary in order to cover the variation of each species, the variation in mixture of species and the influence of different depths.
- The spectral properties of the available sensors are definitely limiting the discrimination possibilities for vegetation on species level.

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