BIOTOPE MAPPING OF THE INTERTIDAL ZONE OF HELIGOLAND (NORTH SEA) USING HYERSPERCTRAL REMOTE SENSING IMAGES

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ABSTRACT

The marine nature reserve of the island of Heligoland is located in the German part of the southern North Sea and comprises a large amount of the species representative for Northern European rocky coasts. The recording of spatial changes of the major intertidal biotopes by remote sensing techniques provides a tool to assess biodiversity change and enables a synoptic view of the system. This complements detailed ground based biodiversity studies which are traditionally restricted in area and serves as basis for decisions, e.g. in coastal zone management, nature preservation, and monitoring of the water quality.

In July 2002 and September 2003, two data sets of Heligoland’s coast were acquired with the hyperspectral sensor ROSIS. The data were radiometrically, atmospherically, and geometrically corrected. Based on ground truth data and detailed spectral analysis, a supervised hierarchical classification scheme was developed to classify the different major biotopes of the intertidal zone. Comparison between the 2002 and 2003 data shows the potential and the limitations of this spectral approach and suggestions for improvement are presented. The difference in results between the hyperspectral classification of the biotopes and a recent ground based biotope mapping will be discussed.

1.0 INTRODUCTION

The comprehensive flora and fauna of the marine nature reserve “Heligoland’s Rock Socket” comprises a large amount of the species representative for Northern European coastal biotopes. The closely interlocked, characteristic biocoenoses are of supra-regional relevance. Due to the cleft structure of Heligoland’s rock socket, however, wide areas of the shore platform are not easily accessible and therefore regular in situ mapping is difficult. In order to be able to follow community changes on a spatial scale in future, remote sensing tools seem to be appropriate.

During the last century, the floristic species composition and community structure of the littoral rocky zone of Heligoland was documented in many studies (Kuckuck, 1897; Schmidt, 1928; Nienburg, 1930; Den Hartog, 1959; Lüning, 1970; Kornmann & Sahling, 1977, 1983, 1994; Brünger, 1989; Janke, 1986; Janke, 1990; Bartsch & Tittley, 2004). None of these studies were focussed on the spatial mapping of the biocoenoses.

Although a general stability of most perennial species and biotopes was documented (Bartsch & Kuhlenkamp, 2000; Bartsch & Tittley, 2004), seasonal species disappeared or were of non continuous occurrence, habitat change and especially the invasion of species partially produced considerable changes in the spatial distribution of biocoenoses. All these phenomena were, however, only documented qualitatively. To create a base line for future studies and to quantify the spatial extent of intertidal biotopes, a biotope map of Heligoland's intertidal was produced by in situ vegetation mapping (Bartsch et al., unpublished).

This mapping study was very time consuming and is too elaborate for a regular yearly or biennial inventory, besides the fact that it does not give a synoptic overview of the entire intertidal zone. Remote sensing methods ideally meet these requirements. The closely interlocked and partly small-scaled biotopes demand a sensor with high spatial and spectral resolution for species or genus separability. For these requirements DLR's airborne spectrometer ROSIS is especially suited.

2.0 TEST SITE

The test area is located in the North Sea at about 54°11'N and 7°53'E (Fig. 1). The small island extending about 0.9 km² was formed by an uplift of Mesozoic red sandstone (redsand in Table 1) above a salt dome during the Tertiary period. The upper island rises about 50 m above sea level showing a typical cliff coast. The shore is an abrasion platform also built of red sandstone, partly covered by man made hard substrate boulders (granite, basalt, concrete), especially near the sea- and harbour walls (map in Bartsch & Tittley, 2004). The intertidal platform is geomorphologically structured by distinct creeks (Fig. 2L). The difference between mean low and mean high water at Heligoland is 2.35 m (Lüning 1985), but most of the horizontal intertidal area comprises only a height difference of approximately 90 cm. The horizontal extent of the contiguous intertidal zone is only 10 ha. This paper focuses on the northern intertidal (Fig. 1), comprising approx. 350 m x 500 m.

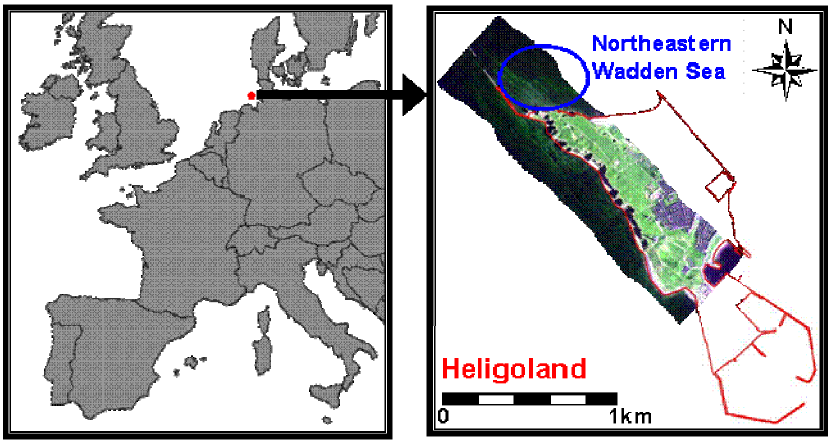

Figure 1. Location of the test site

Most of the intertidal platform is characterised by algal dominated communities, but also animal dominated areas are present. Besides these sites there are other visually distinct areas present that are either characterised by the substrate type or by the water body. All relevant expected classes are listed in Table 1 and examples of communities are given in Fig. 2.

Table 1. Description of communities, substrate types and their visual appearance

Code	Community or substrate	Zone
Fser dense	Dense fucoids mainly of the dark brown alga Fucus serratus	Lower intertidal
Fser degraded	Cover of fucoids reduced, thereby showing a variety of crustose, red and green algal species	Lower intertidal
Mas	dense cover of the visually dark red algae Mastocarpus stellatus and/or Chondrus crispus	Middle to lower intertidal
FserR	Brown fucoids and red Mastocarpus/Chondrus in variable amount	Middle to lower intertidal
Ent/Ulva	Band of dense tubular or bladelike light-green algae	Middle intertidal near cliffs
Rho	Rhodothamniella biotope; small patches within the dense fucoids covered by light-green algae (Ulva sp.)	Lower intertidal
Cor	mixed flora characterised by calcareous red algae often overgrown with seasonal green and brown algae; covered with water during low tide	Intertidal channels
Myt	sparsely vegetated areas dominated by the mussel Mytilus edulis and limpets; crustose algae and few red and brown algae present	Middle intertidal
SemLitX	sparsely vegetated areas dominated by barnacles and limpets; crustose algae and few fucoids and red algae present	Middle intertidal
Ldig	Dense belt of laminarian kelps (Laminaria digitata) with a light-brown colour; mostly water covered during low tide	Sublittoral fringe
Sar	Dense cover of the light-brown invasive species Sargassum muticum, floating in part on water surface and invading channels	Sublittoral fringe and intertidal channels
redsand	nonvegetated red sandstone areas	land
rock	nonvegetated areas other than red sandstone	land
sandy bottom	Water covered inlets covered by sand or defractured shells	sublittoral
Sub-littoral	Vegetated sub-littoral areas	sublittoral
water	nonvegetated pure water	sublittoral

The communities were described in detail by Bartsch & Tittley (2004) and create a small-scaled mosaic within the horizontally orientated areas of the intertidal. They are mostly visually discernable by the naked eye. A detailed yet unpublished biotope map of the intertidal of Heligoland and other georeferenced field information was used for comparison between hyperspectral classification and the field situation.

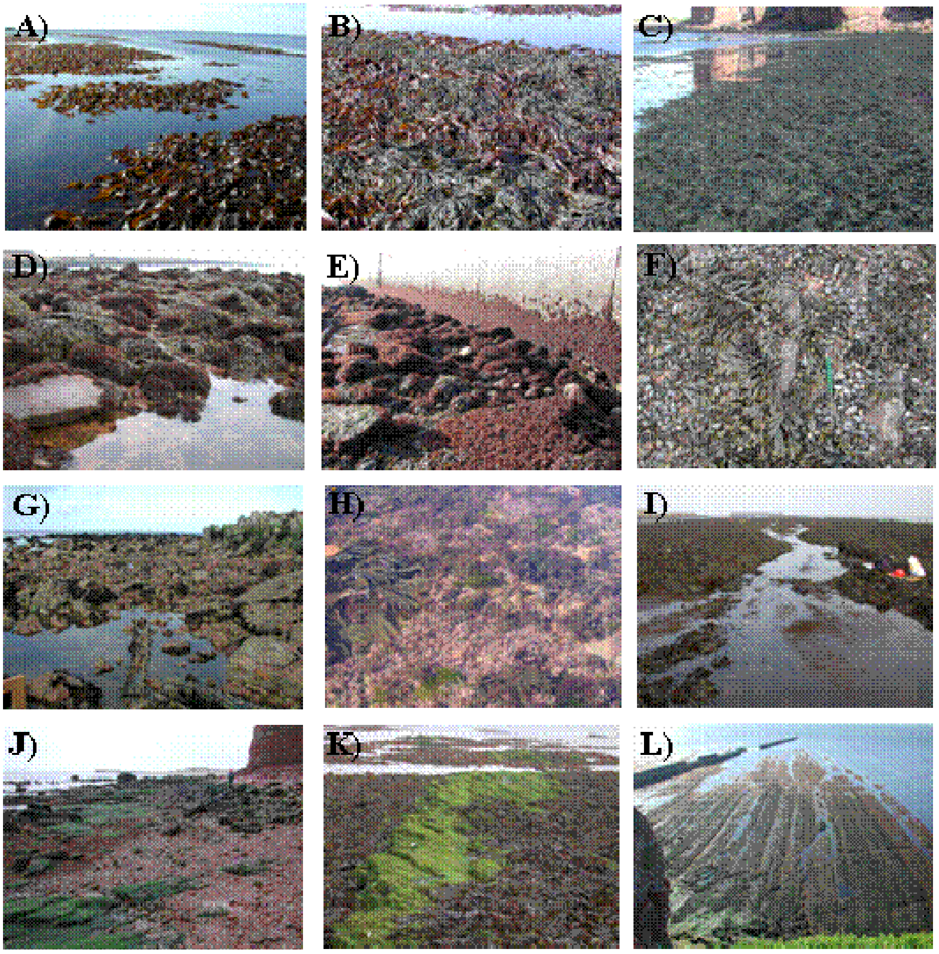

Figure 2. Main communities of Heligoland's intertidal area and overview of northern intertidal. A: 'Ldig' girdle of kelps; B: mixture of kelps and fucoids; C: dense fucoids 'Fser dense'; D: mixture of fucoids and red algae 'FserR'; E: dense red algae 'Mas'; F: sparsely vegetated mussel field 'Myt'; G: sparsely vegetated barnacles and limpets area 'SemLitX'; H: intertidal channel with coralline algae 'Cor'; I: intertidal channel with invasive *Sargassum muticum* 'Sar'; .J: green algal band 'Ent/Ulva'; K: *Ulva* covered *Rhodothamniella* biotope 'Rho'; L: overview of northern intertidal with fractured geomorphology. Photos: I. Bartsch

3.0 HYPERSPECTRAL DATA AND PROCESSING

The Reflective Optics System Imaging Spectroradiometer (ROSIS) was developed since 1986 in cooperation between DLR, GKSS, and MBB (now Astrium) (Kunkel et al. 1991, van der Piepen 1995, Gege et al. 1998). It is a push broom scanner with 512 spatial and 115 spectral pixels recording in the wavelength range between 430 nm and 860 nm. The spectral sampling interval amounts 4 nm and the full width at half maximum is about 7.5 nm. Technical details are given in Tab. 2.

Table 2. Rosis technical data

Spectral range	430 - 860 nm
Sampling interval	4.0 nm
Number of spectral bands	115
Pixel per scan line	512
Radiometric quantisation	14 bit
Field of view	± 8,7°
Instantaneous field of view	0.59 mrad
Pixel size at 1600 m altitude	1 m x 1 m
Possible mirror tilt in flight direction	± 20°

On July 16th, 2002 and September 5th, 2003, ROSIS data were acquired during low tide over the test area in Heligoland. Both data sets were radiometrically corrected using laboratory measurements to convert counts into radiance values. Both ROSIS scenes were atmospherically corrected to surface reflectance using the software package ATCOR-A for airborne data (Richter 1996). This parametric program accounts for the irradiance characteristics of the sun, rayleigh and aerosol scattering in the atmosphere, the scan angle effect, and the adjacency effect. It includes information about the sun-sensor-geometry, the flight altitude, and the ground altitude above sea level. All parameters used are listed in Tab. 3.

Table 3. Input parameters for atmospheric correction

Flight parameters	ROSIS flight 2002	ROSIS flight 2003
Date	July 16th	September 5th
Time [MESZ]	10:30	13:30
Number of flight lines	1	2
Flight altitude [m]	1750	1500
Pixel size [m²]	1.2 x 1.2	0.84 x 0.84
Ground altitute above sea level [m]	0.1	0.1
Solar zenith angle [°]	47.7	47.4
Solar azimuth angle [°]	114.8	181.0
Solar elevation [°]	42.3	42.6
Flight heading [°] (0° = North)	325	314
Water vapour content [gcm^{-2}]	10	10
Aerosol type	maritime	maritime
Visibility [km]	70	70
Adjacency box [pixel]	500	500

Geometric correction was conducted with a parametric calculation of the flight angles roll, pitch, and heading (yaw) registered by the airplane's inertial system including additional information of the flight velocity, the altitude above ground, and the focal length of the telescope (Müller et al. 2002). Remaining distortions due to subliminal gusts of wind or residual errors in the determination of the boresight angles between the on board mounted instruments were corrected with adjustment via 130 to 170 ground control points close to sea level to an existing orthophoto. This procedure left local distortions below 3 m.

4.0 HIERARCHICAL CLASSIFICATION METHOD

Compared to the existing in situ biotope map and other field informations, the results by standard classification methods remained unsatisfactory. Therefore, a stepwise (here called: hierarchical) classification scheme was developed based on ROSIS spectra from the spectral library after extended spectral inspections of all present characteristic biotopes or substrates (see Table 1). The most representative spectrum for each class (Fig. 3) was determined heuristically and used as endmember for the further classification (Fig. 4).

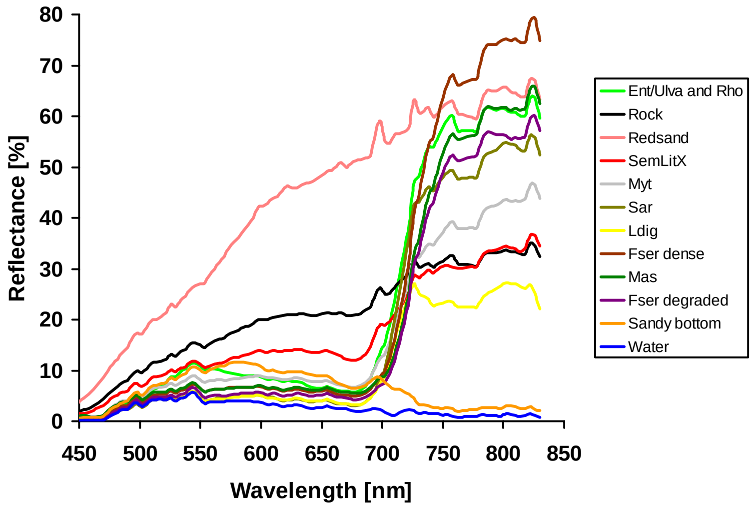

Figure 3. Representative reflectance spectra for Heligoland's biotope and substrate classes

The result of each step was masked out from the rest of the scene. Higher, dry areas (intertidal zone) were separated from lower areas characterised by variable levels of water cover (sublittoral) in the first place. This was carried out via the threshold of 20 % reflectance at 802 nm (ROSIS band 94) where the water absorption is high thereby reducing the reflected light considerably and delimitating it from the high reflectance by vegetation or open rock.

Then, each spectrally distinct biotope or substrate class was separated stepwise from the rest. Green and brown algae have a very similar reflectance in the blue, red, and near infrared and could not be discriminated via the spectral angle mapper which gives a strong focus on the entire spectral course. Therefore, the height of the green peak at 554 nm (band 32) was calculated in relation to a constructed base line from 518 nm (band 23) to 594 nm (band 42). This is a reversed version of the absorption depth introduced by Goetz (1991). The threshold to classify green algae was set to 1.5 % for the height of the green peak in congruence with the biotope map. To separate the vegetation from open rock or sparsely vegetated areas like 'Myt' or 'SemLitX', another threshold of 8 % at 686 nm was introduced. It makes use of the red spectral range with high chlorophyll absorption by vegetation and further increasing reflectance of unvegetated areas. Within the nonvegetated or sparsely vegetated areas, the four different classes 'rock', 'redsand', 'SemLitX' and 'Myt'(see Table 1 and Fig. 2) were SAM classified in the next step (Kruse et al. 1993). The reflectance of the *Mytilus* field 'Myt' was scattering around the threshold value for nonvegetated areas. Therefore, the not yet considered spectra were now detected by SAM mapping with a narrow spectral angle. The class 'Sar' dominated by *Sargassum muticum*, an invasive brown algal species, was critical as no georeferenced ground truth data were available for this class; only the approximate distribution in the field is known. Since the species occurs in floating patches on the water surface and thus does not occur on higher dry locations, the SAM angle was kept reasonably low. The sublittoral fringe brown kelp *Laminaria digitata* (class 'Ldig') inhabits a different habitat compared to all intertidal brown fucoid sites and was therefore also classified separately. In a final step the intertidal fucoids were separated into two classes representing a dense *Fucus serratus* cover 'Fser dense' and areas were the *Fucus* cover was reduced 'Fser degraded' and coralline crusts became visible or replaced by other red algae 'FserR' (*Mastocarpus*).

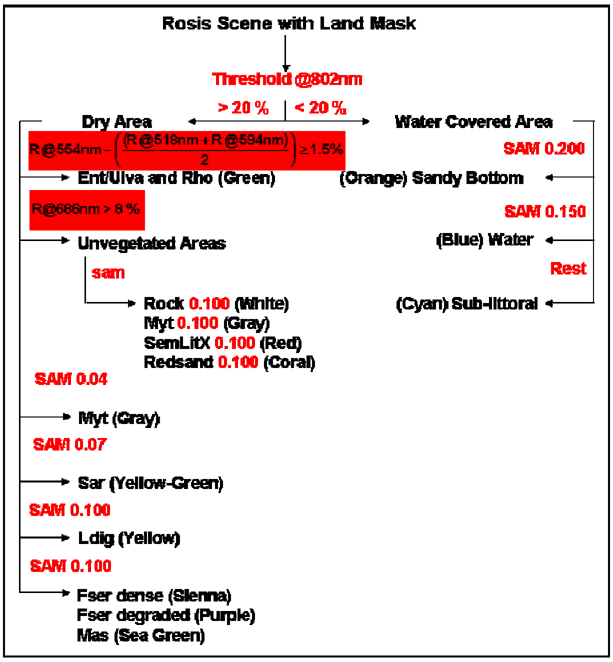

Figure 4. Hierarchical classification scheme

In the sublittoral zone only three different classes were considered, all of them not verified by exact ground truth data, but by general observations and knowledge of the sites. The sandy tidal inlets are known from diving excursions and can be distinguished by the higher reflectance in the visible, especially green and red spectral range. The class 'water' was taken as pure deep water without submersed vegetation and can mainly be discriminated by the high absorption and therefore low reflectance around 700 nm. The rest of the sublittoral zone was combined in one class 'sublittoral' being a mixture of submerged vegetation – in most cases kelp beds are assumed assumed - with a different water column above.

The Rosis scene of 2003 was analysed with exactly the same classification scheme and endmember spectra.

5.0 RESULTS AND DISCUSSION

The hierarchical classification applied to the 2002 data (Fig. 5a) discriminated well the open rock zone at the cliff base as well as the green algal belt (Ent/Ulva) seawards of the open rock near the cliff base. The spectral library showed that different green algal dominated communities like 'Ent/Ulva' and 'Rho' could not be differentiated from each other spectrally, but due to their location. Those areas dominated by the mussel *Mytilus* (class 'Myt') and the distribution of the dense *Fucus serratus* fields (class 'dense Fser') fits the in situ biotope map very well. However, the discrimination of areas with a reduced brown algal *Fucus* cover (class 'Fser degraded'), areas with a mixed *Fucus* and red algal (*Mastocarpus*) vegetation (class 'FserR') and areas densely covered by the red algae *Mastocarpus stellatus* (class'Mas') was problematic and did not coincide with the situation in the field. Only if taken together theses classes formed a major group fitting the ground truth. The distribution of *Sargassum* patches as generated by this classification is uncertain due to lacking field information, but separation of the two major sublittoral fringe communities 'Sar' and 'Ldig' is expected in future as spectra characteristics are different (see Fig. 3). The appearance of *Sargassum* in the channel regions could not be proved by the classification. The distribution of the brown kelp *Laminaria digitata* (class 'Ldig') is congruent with the field experience, but probably only shows those areas with a specific water level above their blades. This is nicely seen if comparing this class in scene 2002 and 2003. The latter scene does not show the *L. digitata* fields although they were present. The absence of this class in the 2003 scene may be due to the higher water level in the 2003 scene. Therefore, much of the *L. digitata* was classified as sublittoral. Generally, the knowledge of the sublittoral vegetation by in situ inventory is very sparse and could therefore not be split up further. However, the sandy tidal inlets are well known and fit reality.

The preconditions for the 2003 scene differed to 2002 with respect to the exceptionally hot preceding summer, the concurrent weather conditions during the flight with high wind speeds, a slightly higher water level, and different illumination geometry. The first aspect led to a degradation in vegetation cover. This is especially valid for the brown *Fucus* fields and the upper green algal belt (class 'Ent/Ulva'). Due to bumpy winds a lacking overlap of the flight lines generated a big unclassified area in the middle of the intertidal (Fig 5B). The class 'sandy inlet' was much enlarged probably due to sun glint in the outer bounds (classified as disconnected sand pixels), and maybe a dissemination and shift of the sublittoral bottom sand cover had taken place. The slightly higher water level mainly resulted in a smaller 'Ldig' class and a greater vegetated sublittoral class (Fig. 5b). Mainly due to the lower sun angle in fall the shadow was greater partly covering the rock, the *Enteromorpha* green algal belt and the mixed *Fucus* zones at the cliff base. Very striking in the 2003 scene are the two patches close to the cliff classified as 'SemLitX' (shadow area in 2002) which do not represent reality as this community is only present in the southwestern intertidal of Heligoland. The *Mytilus* distribution is also difficult to duplicate. This suggests that the classification of the different sparsely vegetated areas needsimprovement and a better separation from degraded *Fucus* sites. After the hot summer bigger areas were sparsely vegetated than in the year before but nevertheless consisted of separable communities. Areas with a dense *Fucus* vegetation, however, covered about the same area as in 2002 which also is validated by ground truth data.

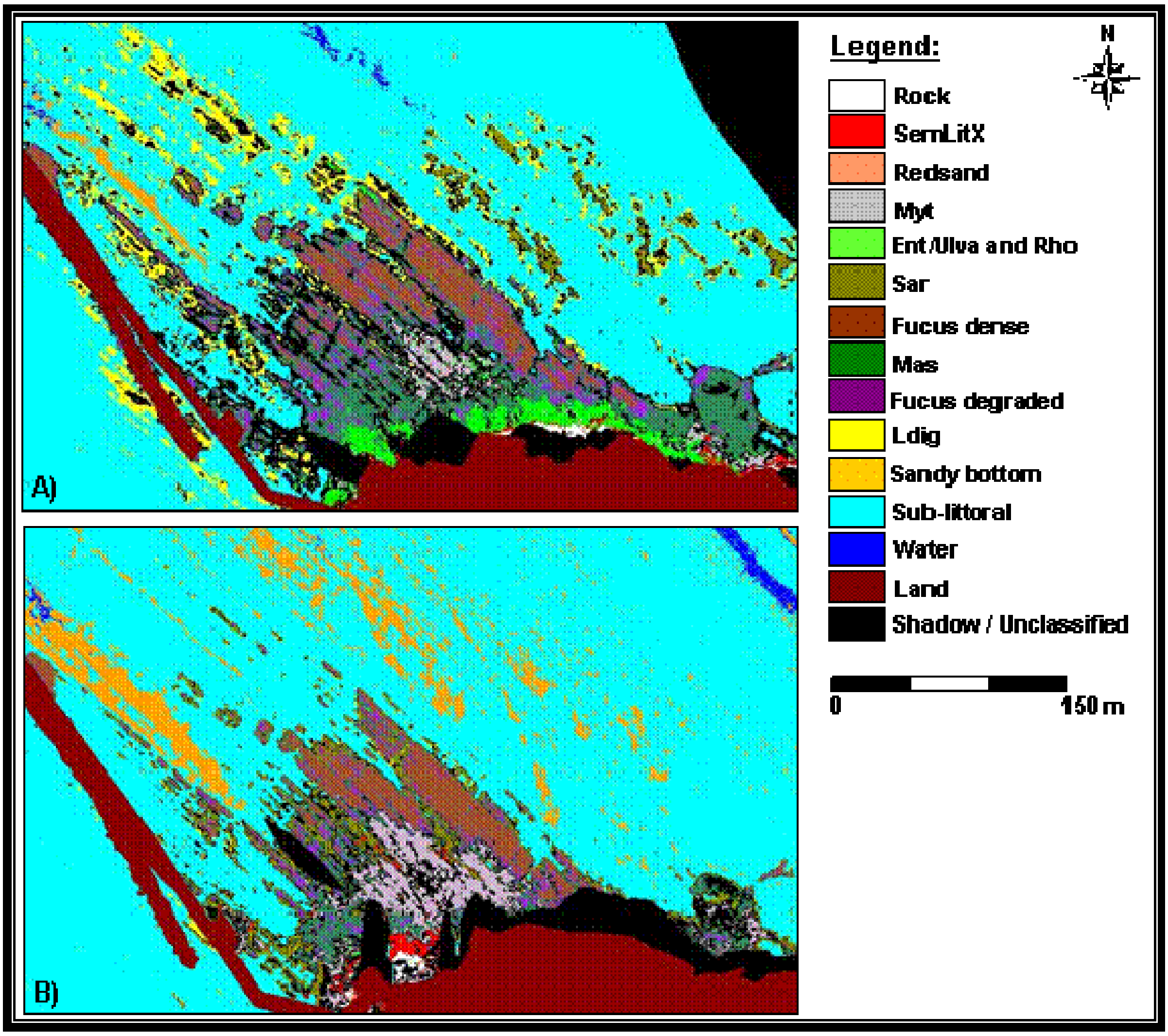

Figure 5. Resulting biotope maps from the two ROSIS flights in 2002 and 2003

6.0 CONCLUSION AND OUTLOOK

It was shown that hyperspectral airborne data may be used to support mapping of major small-scaled intertidal communities and/or status of the vegetation and to provide a synoptic view, a major prerequisite for the generation of time series. However, the classes of the remote sensing approach which are based on their spectral differentiability are not the same as those mapped in situ generated from the knowledge of species and their abundances. Green algal dominated sites generally had to be aggregated in one class although they comprise several biotopes. Some biotopes like *Corallina* tidal inlets could not be spectrally detected at all, probably due to their variable species content and water cover. For these and several other biotopes more knowledge of the spectral characteristics of the different visually dominating species within biotopes is needed. For this task, field work with a portable spectrometer will be necessary in the future. Also the validation of the in situ campaign has to concentrate on different aspects: besides typical sites with uniform cover of single species, especially the transmission zones have to be focused upon. This was e.g. revealed for the *Fucus* cover in fall 2003 where the main focus of the ground truth data were in the registration of the extent of the dense *Fucus* areas whereas the remote sensing uncertainties appeared to be in those sites with a reduced *Fucus* cover after the hot summer.

7.0 ACKNOWLEDGEMENT

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