BALANCE Interim Report No. 5

Evaluation of remote sensing methods as a tool to characterise shallow marine habitats

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0 PREFACE

This report is a BALANCE product and focuses on evaluation of remote sensing methods as a tool to characterise shallow marine habitats. The report has been compiled by:

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- Göran Sundblad, Alfred Sandström, Ulf Bergström and Peter Karås from Swedish Board of Fisheries, Institute of Coastal Research, P.O. Box 109, SE-74071, Öregrund, Sweden.

This working report is a status report from an ongoing study: "Remote sensing as a method to characterise shallow coastal habitats in the Baltic Sea". The study is a part of BALANCE is co-financed by the Swedish National Space Board, the Swedish Board of Fisheries (SBF) and the Swedish Environmental Protection Agency (SEPA). The majority of the evaluations, interpretations and analyses of remote sensing images are performed by Metria. The output from the study will form an important part of Work Package 2 by producing maps on environmental variables which are used for predicting the distribution of Baltic Sea habitats. The study will continue until the end of 2006. In a first stage, methods for interpreting satellite images are developed within two study areas in BALANCE pilot area 3. In the second and last stage these maps will be validated and used for modelling the distribution of fish habitats in the pilot area. A final report evaluating the usefulness of satellite imagery for characterising shallow coastal habitats is due December 2006.

More information about BALANCE can be found at http://www.balance-eu.org.

Alfred Sandström

Swedish Board of Fisheries, Institute of Coastal Research

1 INTRODUCTION

1.1 Background

The Baltic Sea coastal zone hosts a large variety of environments. In the near-shore shallow areas both production and diversity are usually high, which makes these habitats both ecologically and economically valuable and important for several organism groups. For several fish species these shallow areas function as spawning, feeding and recruitment habitats. The vast majority of both marine and freshwater fish species in the Baltic Sea utilise shallow coastal areas (depth 0-10 m) as nursery habitats. The threats to these environments are, however, many and there is a need to identify habitats with particularly high potential for fish recruitment in order to enable an efficient physical planning and thus a sustainable coastal zone management. Knowledge on the distribution of marine habitats is very fragmented today, mainly because of the high costs associated with conducting field surveys in marine areas. Remote sensing has the potential advantage of covering large areas and enabling a fast and resource-efficient method to map the characteristics of shallow habitats.

Mapping of fish nursery areas as well as the majority of other key biological habitats in BALANCE will mainly be conducted by combining statistical models describing the habitat requirements of the target organisms and using GIS to produce geographical predictions by combining several layers of habitat information. Since the access to high resolution maps that cover larger coastal areas currently is a significant bottleneck in all such efforts to model distribution of coastal habitats, the benefits from developing remote sensing techniques may be of fundamental importance for the long-term success of the project.

The evaluation of remote sensing possibilities was mainly concentrated on three environmental variables: (i) coverage and composition of submerged and emerged vegetation, (ii) water depth and to a smaller extent (iii) relative surface temperature variation. These parameters were chosen since they are important for characterising coastal habitats in general and fish nursery areas in particular.

(i) Vegetation is the main provider of structural complexity in marine and freshwater ecosystems and its importance in facilitating predator-prey interactions and sustaining species diversity in aquatic ecosystems has been demonstrated in numerous ecological studies (e.g. Orth et al., 1984; Pihl, 1986; Christensen & Persson, 1993; Mattila, 1995; Eklöv, 1997; Grenouillet & Pont, 2001). Vegetated areas may offer spawning substrate, refuge for larvae and juveniles during predation-sensitive stages and foraging possibilities for many coastal fishes. Current studies conducted by SBF in Pilot Area 3 indicate that fish species with littoral larvae may be particularly dependent on vegetation (Fig. 1). Studies within associated projects also show that loss of vegetated habitats and/or shifts in vegetation communities caused by physical disturbances and boating activities may affect the recruitment of near-shore fish species (Sandström et al., 2005).

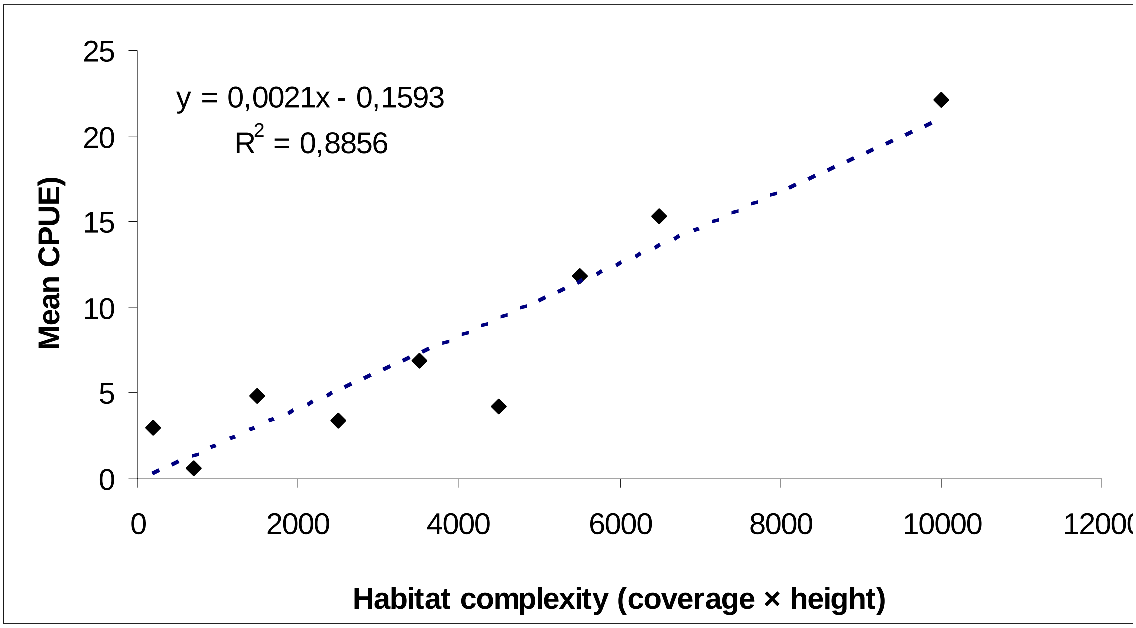


figure 1. Relationship between the catch per unit effort (CPUE) of juvenile fish and habitat complexity measured as the product of mean vegetation coverage (%) and height (cm). Data from the Interreg IIIa financed project "Fish production in shallow bays".

(ii) Water depth is also one of the key parameters in modelling marine habitat distribution both as a direct and as an indirect predictor variable. It is often highly correlated with other environmental variables such as vegetation, temperature, light climate and exposure to waves and ice-erosion. In order to use depth as a predictor variable for both fish recruitment potential and vegetation community composition there is a need for relatively detailed bathymetry maps, particularly for areas shallower than 5 m in depth (Fig. 2). Such maps are not available at the moment and thus a successful attempt to use remote sensing techniques will be necessary to use depth as a parameter in the modelling of these as well as other organism groups.

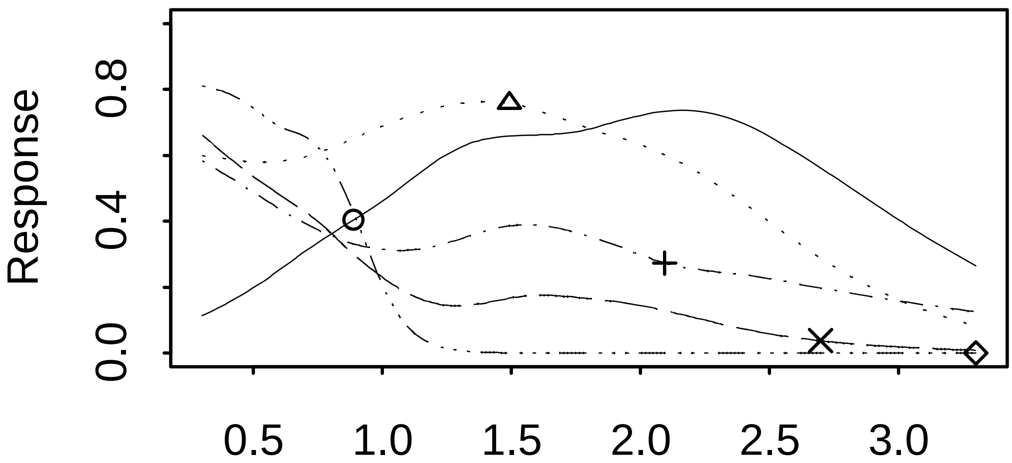


figure 2. Species model response curves in relation to a depth (m) gradient. Data from Sundblad, G., Sandström, A., Mattila, J., Snickars, M., unpublished data. O = pike, Δ = roach, + = rudd, x = tench, ◊ = goby.

(iii) Light attenuation or water turbidity may vary considerably within the archipelago areas in pilot area 3 partly due to natural causes but also to a large extent due to anthropogenic disturbances, e.g. eutrophication (Breukers et al., 1997), dredging (Gregory, 1990) and deforestation (Berube & Levesque, 1997). As a consequence water turbidity in many marine BS areas has been substantially elevated and the composition of suspended and particulate materials altered. Different substances absorb different parts of the light spectra, thus the intensity of remaining wave-lengths will vary with both depth and the composition and abundance of absorbing agents. Visual conditions also affect the depth distribution of submerged vegetation as well as the interactions between all organisms relying on visual cues for perceiving their ambient environment. In addition, water turbidity is a strong indicator for system productivity. Turbidity is particularly well correlated to the distribution of fish juveniles of species equipped with sensory physiological adaptations that enhance foraging and anti-predator behaviour in dim and turbid conditions and/or species that are favoured by increased productivity (Sandström, 2004).

(iv) Temperature is known to influence the recruitment of many temperate fish species (Neuman, 1976; Le Cren, 1987; Böhling et al., 1991; Buijse & Houthuijzen, 1992; Lappalainen & Lehtonen, 1995; Lehtonen & Lappalainen, 1995; Mehner et al., 1998). Temperature variations affect year-class-strength formation by its direct effect on mortality of embryos (Hokanson, 1977) and since it sets the physiological limits for fish growth and metabolism (Karås & Thoresson, 1992) it also has indirect effects on size-dependent predation and winter mortality (Post & Evans, 1989; Kirjasniemi & Valtonen, 1997; Lappalainen et al., 2000). The very earliest larval life-stages have been suggested to be the most vulnerable to unfavourable temperature conditions. These critical life-stages often occur in spring and in early summer when the relative temperature variations in the coastal zone is very pronounced. Subsequently, temperature variations during this period of time may be used as a subset for recruitment potential.

Although many of the analytical as well as technical approaches in remote sensing have been focused on terrestrial applications, the technique has also been used for determining a number of hydrological features. Examples of important applications are: separation of water from land, bathymetry, light attenuation, chl a levels, water surface roughness, level of evapotranspiration and surface temperatures. Several different technical as well as analytical approaches have been utilised, such as: radar equipped satellites, photogrammetry (using high quality photographs), multispectral analyses and radiation detectors.

Unlike terrestrial areas the spectral properties registered via remote sensing in aquatic environments is more influenced by light transmittance than on surface characteristics alone. The water colour monitored by the different wave bands of the satellites is largely determined by the processes of reflection, refraction and diffraction that scatters light and by absorption by the water in itself and by dissolved and particulate substances in the water. Different substances absorb different parts of the light spectra and thus influence the transmittance of different wave-lengths, thus potentially altering the peak in reflectance compared to pure water. Distilled water absorbs much of the light in the red and the infrared (>575 nm), the violet and the ultraviolet (UV) region (<400 nm) of the spectra and very little in the middle regions, especially in the blue section (400-450 nm).

In conclusion, remote sensing as a tool to assess the characteristics and status of aquatic habitats has not yet been fully developed and tested but it may have great potential, particularly in order to attain perspectives on broader scales and to analyse phenomena that occur over large areas. This analysis is one of the first to test the potential of high resolution satellite images to target the unique characteristics of Baltic shallow habitats.

1.2 Objectives

The objectives of the ongoing project is to A) evaluate the possibility of using remote sensing (satellite imagery) for characterisation and identification of shallow marine coastal habitats in the Baltic Sea and B) to evaluate if satellite based information can complement existing information and hence be incorporated in the strategies developed to protect the marine environment and to achieve a sustainable management of the fish resource. A) above, will be done in two steps, 1) development of methods and 2) validation/evaluation of accuracy. Presented in this status report are current results from method development for habitat classification using satellite imagery (A1), and preliminary evaluation analyses of the classifications usability for fish habitat modelling (A2).

1.3 Expected results

The results from the project are expected to provide a thorough evaluation of the usefulness of satellite imagery in identifying and characterizing important shallow marine habitats in the coastal zone of the Baltic Sea and based on a cost-benefit analysis describe its operational potential. Project results will be presented in the final report due December 2006.

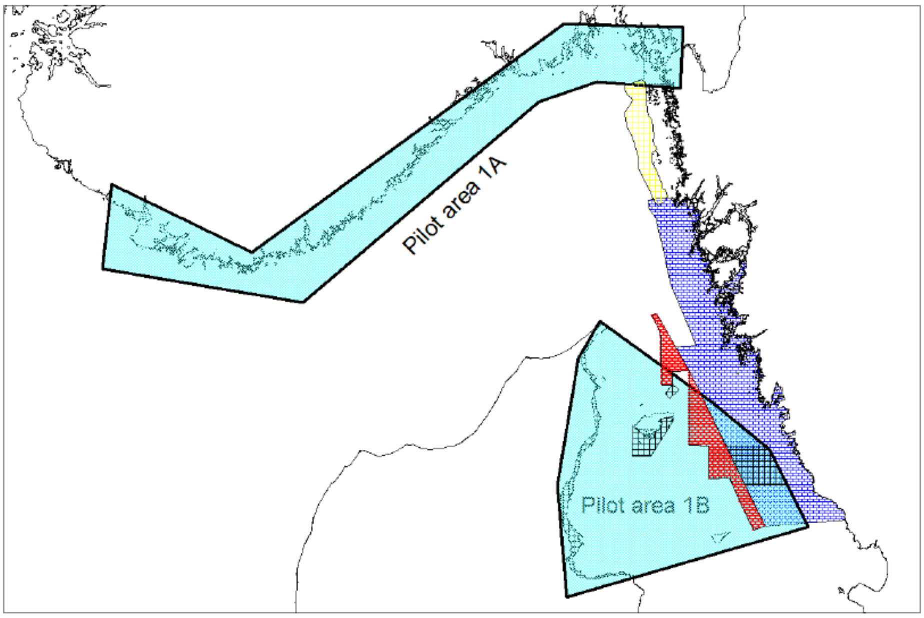


Figure 3. Location of pilot area 1A and 1B in the Skagerrak and Northern Kattegat.

2 METHODS AND MATERIALS

The analysed scenes are situated within BALANCE pilot area 3 (Fig. 3). Imagery from two satellites have been used, SPOT 5 and Landsat ETM+. The analysed images have been selected from a larger set of images mainly based on existing cloud conditions and the availability of reference data. The selection of scenes has also been based on season, resulting in late summer scenes for SPOT 5 when the vegetation is fully developed and spring scenes for Landsat, when temperature variation is most evident.

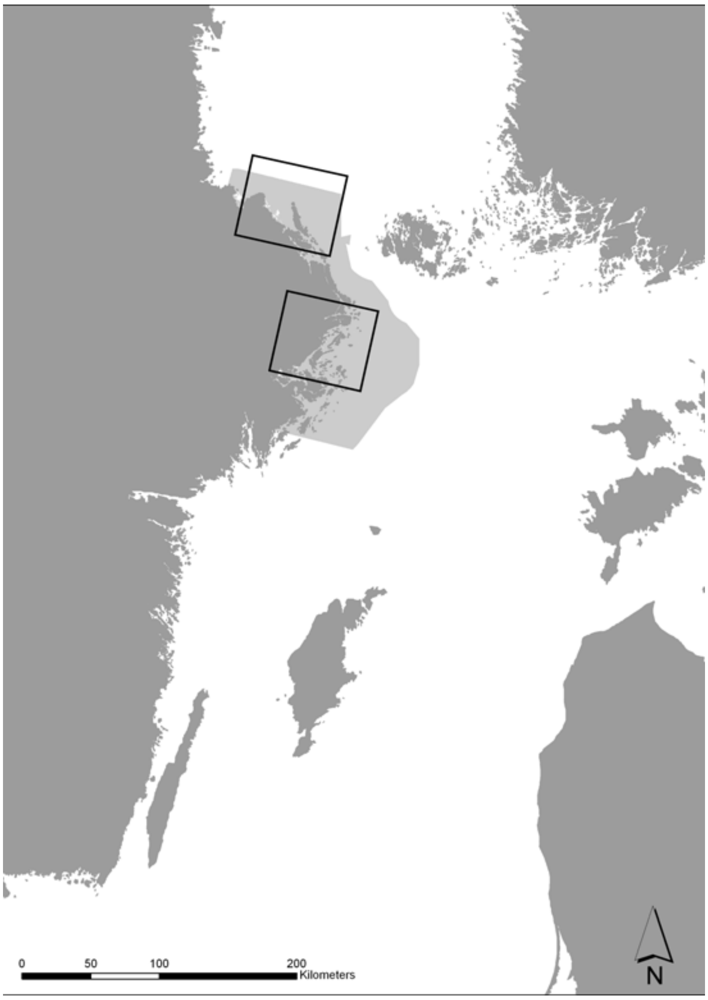


figure 4. Satellites extent, cover of satellite imagery within BALANCE pilot area 3, dark squares are SPOT 5 and light gray is Landsat 7 ETM+.

2.1 SPOT 5

The satellite SPOT 5 was launched in 2002 and circles the earth in 26 days. Four bands have been used for the analyses presented in this status report, where band 1 is green (0.50-0.59 µm), band 2 is red (0.61-0.68 µm), band 3 is near infra-red (0.78-0.89 µm) and band 4 is shortwave infrared (1.58 to 1.75 µm). The scenes have a spatial resolution of 10 metres, except for band 4 (SWIR) with 20 m resolution. The images are shown in Fig. 4.

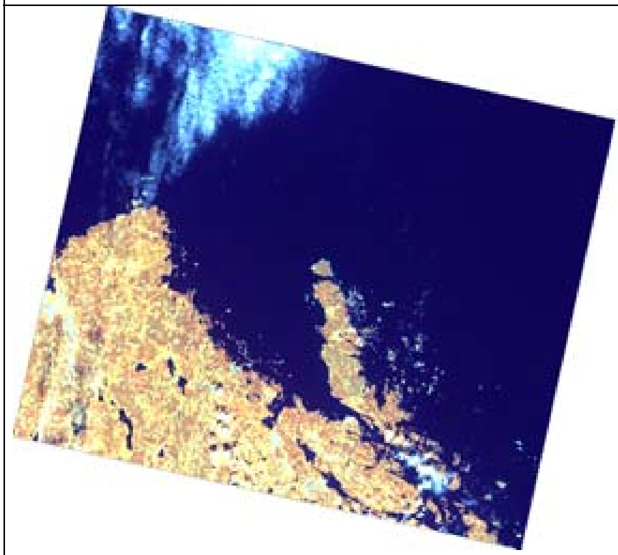
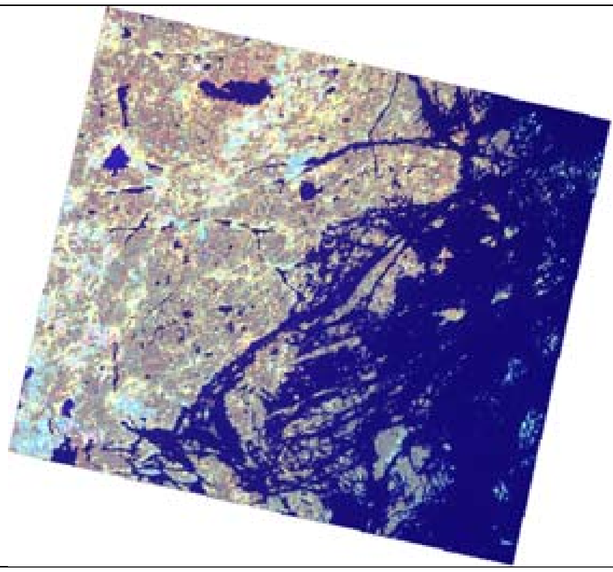
SPOT 5	
	
County of Uppland *September 5^{th} 2003* *SPOT 5, ID58/226, 10m resolution*	*County of Stockholm* *August 8^{th} 2004* *SPOT 5, ID61/228, 10m resolution*

figure 5. Original scenes from SPOT-5 used in the analyses.

2.1.1 Emergent vegetation

In the study areas emergent vegetation mainly consists of common reed belts (*Phragmites australis*) although other species form local stands, i.e. Bulrushes (Typha sp.) and Clubrushes (*Schoenoplectus sp*.). The delineation of emergent vegetation using satellite images described in this report is focused on common reed. Common reed is the largest grass in the region and normally forms large stands, making them relatively easy to separate from water using remote sensing. Reed belts are an important habitat providing food and shelter for different fishes and life-stages (Urho, 2002).

The delineation of emergent vegetation (reed habitats) was based on a classification process called segmentation, i.e. merging pixels with similar spectral characteristics into segments (www.definiens-imaging.com/: eCognition manual – Concepts & Methods). As input, SPOT bands XS2 – XS4 (red, near infrared and shortwave infrared) were considered in the classification. Segments which have known reference points, from ground-thruthing and aerial photos, are then turned into training areas. One advantage of segmentation compared to other methods is the decreased bias compared to manual delineation of training areas. Segments that share the spectral characteristics of the training areas are then reclassified accordingly. Also other segment feature characteristics, such as shape, texture, neighbourhood relations etc., can be considered. The accuracy of the resulting habitat map is to a large extent dependent on the precision and similarity with which the training areas have been classified. Reed habitat output is provided both as GIS grid and shape layers, showing reed on land, reed in water, water covered by other, unknown surface features (e.g. bridges, boats, rocks etc.) and lastly, other open land less than 5 m above sea level.

2.1.2 Submerged vegetation

Submerged vegetation classification has been done using Artificial Neural Networks (ANN). Artificial neural networks are a powerful non-linear mapping structure suitable for models where underlying data relationships are unknown (e.g. Lek & Guegan, 1999). They have proven useful for pattern-recognition problems with non-linear responses to environmental variables (Lek & Guegan, 1999; Olden & Jackson, 2000). Ground-truth data consisted of surveys carried out between 2001 and 2005 by SBF. In these surveys several parameters have been collated, e.g. depth, vegetation coverage, temperature, turbidity, salinity and fish abundance. Further, the dispersal and characteristics of different wave lengths in water has been utilized when creating an indexed image from the satellites green and red band, band 1 and 2 respectively, using the following formula;

(Band1 - Band2)/(Band2 +Band1) → Stretched to values between 0-255

The network was trained on data from the SBF's surveys, band 1-3 and the index image. Vegetation coverage was divided into two classes, 0-50 % and 50-100% total vegetation cover. The output consists of GIS grid layers ranging from -1 to 1 for each class, with an approximate break at about 0.5 for class 0-50 % total vegetation cover. Values above 0.5 are likely to show vegetation free areas and values below are likely to have vegetation cover. These preliminary vegetation grids were mainly used in an attempt to disentangle the interaction between submerged vegetation and depth, and were used as input in the depth classification.

2.1.3 Depth classification

Depth is a key parameter structuring marine communities but there is still a lack of comprehensive high resolution bathymetry maps for near-shore coastal areas. Hence, obtaining bathymetry maps using satellite imagery would be of great value, not only for the predictive habitat modelling within BALANCE but potential usage can also be found in commercial areas, e.g. the production of nautical sea charts. However, when using satellite data for characterisation of depth, it is necessary to remove noise caused by other variables, e.g. vegetation, turbidity and bottom substrate. The ability of different wave lengths to penetrate into the water and actually reach the bottom is affected by these other variables, and thus the same depth may produce different spectral images depending on complex interactions between the variables. Hence, ANN's were also used in the depth classification. The network was based on the same large ground-truth data set as the vegetation analysis. The network consisted of satellite data from bands 1 and 2 (green and red), the indexed image as well as the submerged vegetation outputs. Also, depth curves from existing sea charts have been used to limit the area of classification to waters between 0-6 meters. Outputs from the classification are depth GIS-grid layers with depth values in decimetres for each pixel (Fig. 5).

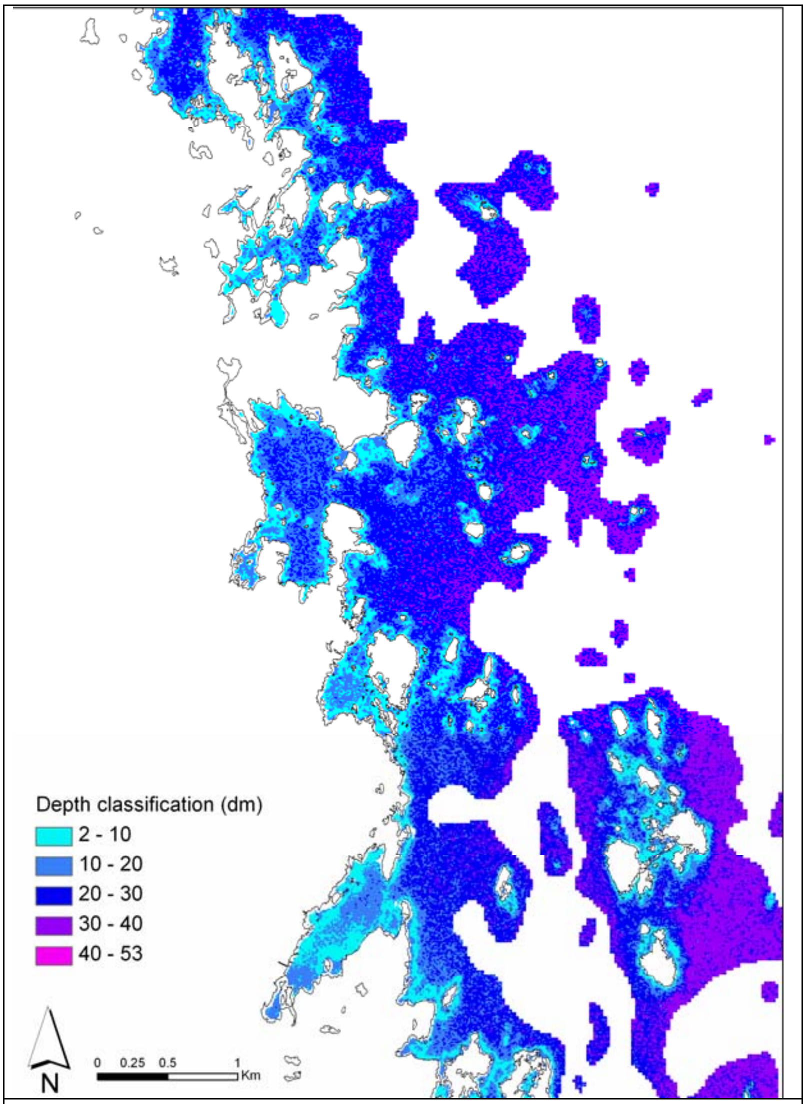


figure 6. Output example from depth reclassification of satellite images, see text for analyses description.

2.2 LANDSAT 7 ETM+

The LANDSAT 7 was launched in 1999 with 5 bands covering the range from blue – green – red – near infrared and shortwave infrared, and a thermal IR channel. The 5 bands have a spatial resolution of 30 metres and the thermal IR channel has 60 metres spatial resolution. The original scene used in these analyses was taken during spring (2003-04-26) when spatial variation in water temperature is at its maximum. The scene covers large parts of BALANCE pilot area 3 in Sweden, including both of SBF's case study areas. The LANDSAT data was resampled to a resolution of 25 metres during the geo-correction and orthorectification of the images.

Water spring temperature displays large spatial variation, with enclosed sheltered inlets and bays being warmer than more exposed areas. The thermal IR channel does not record actual water temperature but rather relative differences in temperature between pixels (in values between 0 and 255). An unsupervised classification was used to divide the thermal spectral channel into 10 clusters describing thermal variation (Fig. 6). Further, shallower areas were divided in the same amount of clusters for thermal variation in the near-shore shallow areas (Fig. 7). Thermal variation is described from warm (red) to cold (blue).

Landsat 7 ETM+ classified into 10 clusters, whole area

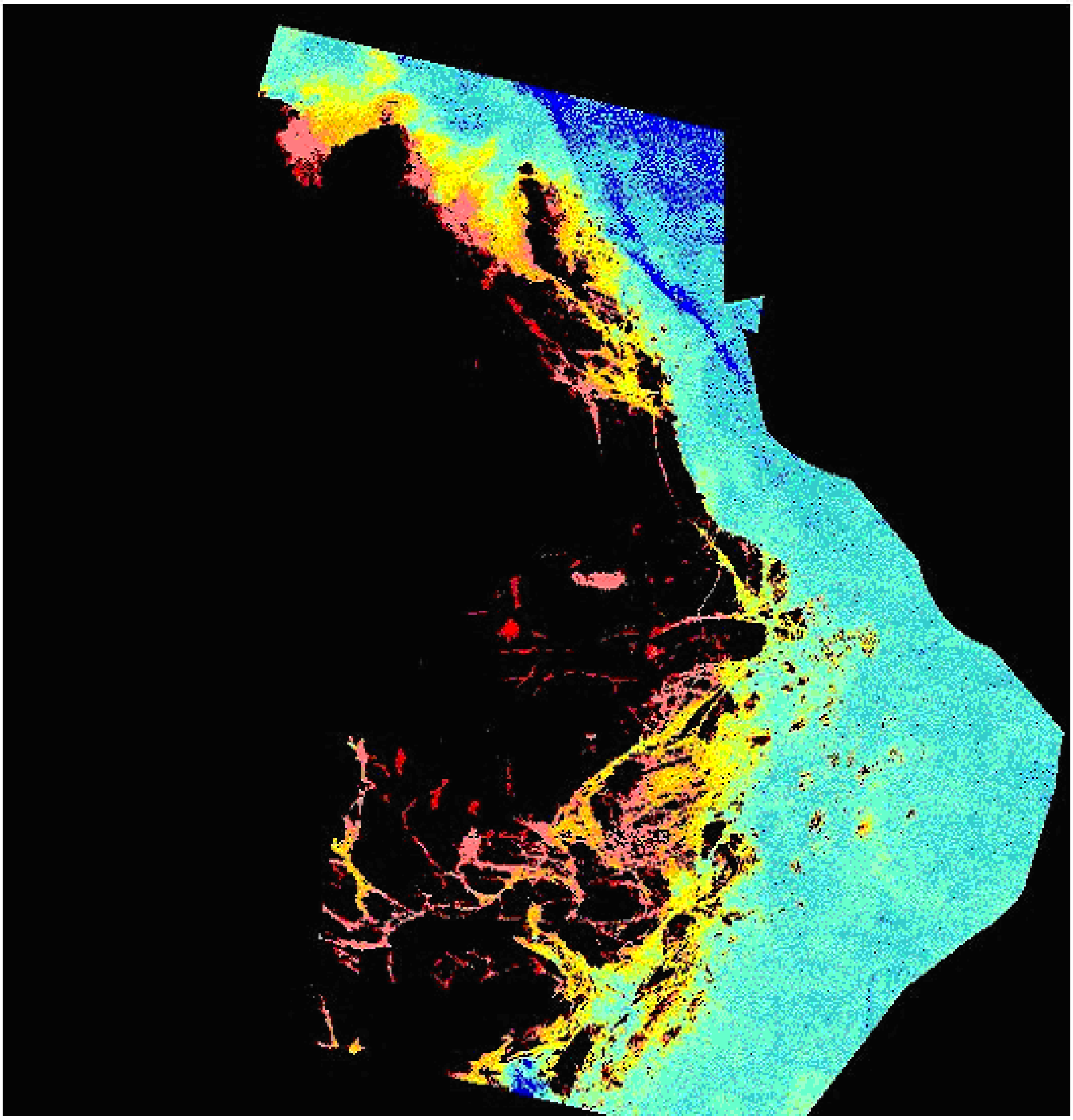


figure 7. Temperature variation in water 2003-04-26, Uppsala and Stockholm county. Thermal variation is described from warm (red) to cold (blue). See text for description of classification.

Landsat 7 ETM+ classified into 10 clusters, shallow area

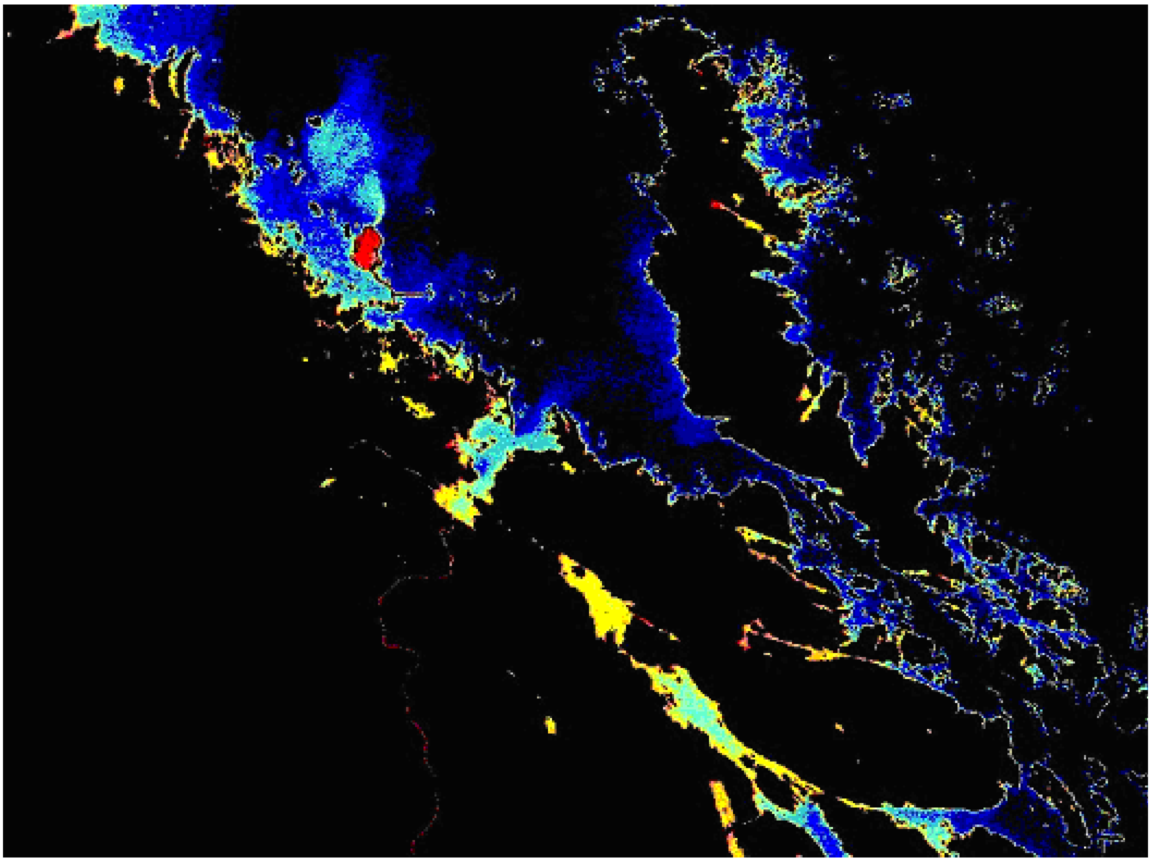


figure 8. Temperature variation in shallow coastal waters 2003-04-26, close up of Forsmark, Uppsala county. Thermal variation is described from warm (red) to cold (blue). See text for description of classification. Note the cooling water outlet from the Biotest basin at the Forsmark nuclear plant (top left).

3 EVALUATION AND RECOMMENDATIONS

In the marine environment, many physical parameters exhibit some form of interaction and correlation with each other. The satellites used in these analyses records different wave lengths ability to penetrate into the water and these differences have then been used to assess and disentangle different variables, such as depth and vegetation that are of importance for the BALANCE habitat modelling. These interactions, where the relationships often are unknown, make the separation of one satellite scene into different parameters difficult. Artificial neural networks (ANN) have been shown to be useful where underlying data relationships are unknown (e.g. Lek & Guegan, 1999) and have been used in the classification of depth and submerged vegetation. During 2006 the project will look further into the possibility to include the parameters turbidity and bottom substrate and the possibility to classify light attenuation. Emergent vegetation is less difficult to distinguish using remote sensing and its delineation was performed using segmentation procedures. The evaluation presented in this status report has been focused on the results, difficulties and future development possibilities.

3.1 Vegetation

Emergent vegetation

Current results indicate that the spectral signature of emergent vegetation is distinct and thus identified with a relatively high precision using the methods described in this status report. There may be some difficulties to separate reed belts from other emerged vegetation and also to get a good separation of the reed belts towards other vegetation classes on land (meadows, grasslands and wetlands). During 2006 further analysis will include different types of emerged vegetation.

Submerged vegetation

The interactions between depth, turbidity/phytoplankton and submerged vegetation are necessary to consider in the classification of submerged vegetation. Vegetation classification so far has only been produced as an input layer to enhance the precision of the depth classification, whereby no evaluation of the vegetation output has been performed. However, presently it is evident that incorporating turbidity in the classification and delineation of depth and vegetation is of importance and would be beneficial for the future modelling of submerged vegetation.

Water depth

The potentially strong correlations between depth and other water parameters makes, as discussed previously, extracting detailed bathymetry maps difficult without consideration to underlying interactions influencing the recorded scene. Presented in this status report are the first attempts to use ANN's to disentangle these interactions. A first output map is shown in Fig. 5, where depth is given in decimetres for each pixel. Preliminary evaluations suggest that future modelling, as for submerged vegetation, should include turbidity and bottom substrate in the network and that the maximum classifiable depth is down to four meters. In general, there seems to be an underestimation of depth, resulting in an overestimation of the distribution of shallow habitats.

Temperature

The importance of temperature on fish growth, reproduction and spatial distribution has been shown in several studies. For several fish species in the Baltic Sea shallow, sheltered inlets that warm early in spring are an important spawning habitat (Urho, 2002). Further, these habitats also play important roles as nursery areas for juveniles (Urho, 2002). Temperature can thus be considered as a proximal direct gradient of large importance determining recruitment habitats in the Baltic Sea region. A first attempt to construct spatial predictive models using wave exposure and the satellite spring temperature variation presented here, pointed at the importance of access to these types of data (Fig. 8).

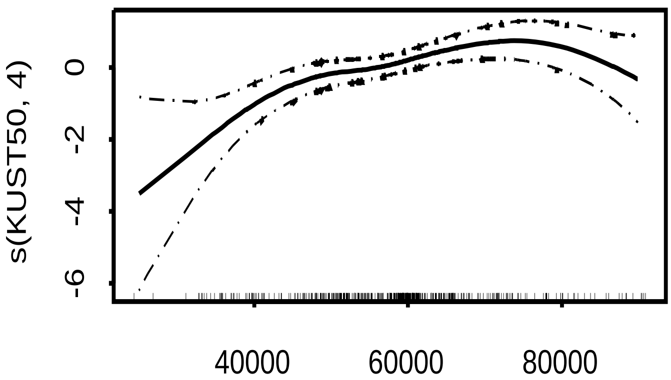


figure 9. The relationship between spring thermal variation measured with Landsat ETM+ (X-axis, higher values indicate warmer water) and model response for roach probability of presence. Data from Sundblad, G., Sandström, A., Mattila, J., Snickars, M., unpublished data.

4 CONCLUSIONS

Within BALANCE, predictive spatial modelling will be used to produce habitat maps for juvenile fish. The modelling procedure is divided in two steps, firstly building explanatory statistical models describing the relationships between abiota-biota and secondly using these explanatory models to produce habitat maps over large geographic areas. Preliminary analyses indicate that high-precision explanation models can be built using existing field data. The potential bottleneck in producing the habitat maps lies in access to necessary predictor GIS-layers with sufficient spatial coverage. This status report shows that remote sensing techniques, in this case derived from SPOT 5 and Landsat ETM+ images, can provide some of these essential habitat GIS-layers that are not currently available. Some of the parameters are well delineated using relatively simple techniques, while others will require further modelling efforts to increase the accuracy of the spatial layers.

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About the BALANCE project:

This report is a product of the BSR INTERREG IIIB project "BALANCE".

The BALANCE project aims to provide a transnational marine management template based on zoning, which can assist stakeholders in planning and implementing effective management solutions for sustainable use and protection of our valuable marine landscapes and unique natural heritage. The template will be based on data sharing, mapping of marine landscapes and habitats, development of the blue corridor concept, information on key stakeholder interests and development of a cross-sectoral and transnational Baltic zoning approach. BALANCE thus provides a transnational solution to a transnational problem.

The BALANCE partnership is composed of the following institutions based in 10 countries: The Danish Forest and Nature Agency (Lead), The Geological Survey of Denmark and Greenland, The National Environmental Research Institute, The Danish Institute for Fisheries Research, WWF Denmark, WWF Germany, Institute of Aquatic Ecology at University of Latvia, Estonian Marine Institute at University of Tartu, Coastal Research and Planning Institute at Klaipeda University, Metsähallitus Natural Heritage Service, The Finnish Environment Institute, The Geological Survey of Finland, WWF Finland, The Swedish Environmental Protection Agency, The National Board of Fisheries – Department of Research and Development, The Geological Survey of Sweden, County Administrative Board of Stockholm, Department of Marine Ecology at Gothenburg University and WWF Sweden.

The following institutes contribute as consultants to the partnership: The Geological Survey of Norway, Norwegian Institute for Water Research, DHI Water and Environment, The Leibniz Institute of Marine Sciences, The Sea Fisheries Institute, The Finnish Game and Fisheries Research Institute, Metria Miljöanalys and The Nature Conservancy.

The **BALANCE Report Series** included at the 1st of July 2006:

BALANCE Interim Report No. 1 "Delineation of the BALANCE Pilot Areas".
BALANCE Interim Report No. 2 "Development of a methodology for selection and assessment of a representative MPA network in the Baltic Sea – An interim strategy".
BALANCE Interim Report No. 3 "Feasibility of hyperspectral remote sensing for mapping benthic macroalgal cover in turbid coastal waters of the Baltic Sea".
BALANCE Interim Report No. 4 "Literature review of the "Blue Corridors" concept and its applicability to the Baltic Sea".
BALANCE Interim Report No. 5 "Evaluation of remote sensing methods as a tool to characterise shallow marine habitats".
BALANCE Interim Report No. 6 "BALANCE Cruise Report – The Archipelago Sea".

For more information please see www.balance-eu.org and http://maps.sgu.se/Portal