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# Biophysical Parameters Assessed from Microwave and Optical Data

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***Abstract*—The study has been carried out at Biebrza Wetlands situated in the N-E part of Poland, a NATURA 2000 and Ramsar Convention test site in 2003-2009. It is one of the largest in Europe natural rich biotope with the large amount of unique species of flora and important zone for nesting and wintering for fauna. Data from microwave and optical satellite images and soil-vegetation ground measurements were analyzed to develop methods for monitoring and mapping biophysical parameters. Satellite data applied for the study included: ENVISAT.ASAR, ENVISAT.MERIS, ALOS.PALSAR, ALOS.AVNIR-2, and NOAA.AVHRR data. Optical images were used for classification of wetlands communities and calculation of vegetation index NDVI. Also, latent heat flux has been calculated using NOAA.AVHRR data and meteorological data. Microwave images acquired in different modes (ASAR IS2 and IS6, ALPSR.FBD) and polarizations (HH, HV, VV) were used for assessment and mapping of Leaf Area Index (LAI) and soil moisture (SM) for every habitat classified from optical images. Backscattering coefficient calculated from ALOS.PALSAR HV and ENVISAT.ASAR IS6 VV was applied for assessment of vegetation bio-parameters. Backscattering coefficient calculated from ALOS.PALSAR.FBD HH and ENVISAT.ASAR HH IS2 was used for SM assessment. The study was conducted in the framework of ESA PECS project No 98101 and ESA PI projects: C1P.7389 and AOALO.3742.**

***Keywords*—ENVISAT, ALOS, NOAA, LAI, biomass, heat fluxes, H/LE, soil moisture.**

## I. Introduction

WETLAND ecosystems hold an important part of Europe's biodiversity and act as carbon repository important to reduce levels of greenhouse gases in the atmosphere. There is a need for repetitive inventory and monitoring of the wetlands for the sake of change detection. This is possible to accomplish through remote sensing techniques. This paper focused on developing methods for monitoring and mapping various wetlands variables using microwave and optical satellite data. Satellite data applied for the study included: ENVISAT.ASAR, ENVISAT.MERIS, ALOS.PALSAR, ALOS.AVNIR-2, and NOAA.AVHRR, Tab. 1. Optical images were used for classification of wetlands communities and calculation of vegetation index NDVI. Also, heat fluxes have been calculated using NOAA.AVHRR data and meteorological data. Vegetation index was analyzed along with Leaf Area Index (LAI) measured in-situ. It was considered that NDVI characterizes vegetation biomass and vegetation surface roughness. Microwave images acquired in different modes and polarizations were used for assessment and mapping of biophysical parameters [1] for every habitat classified from optical images. The advantage of using satellite observations is to deliver repetitive information about temporal and spatial changes of biophysical variables in the wetlands area, very often impenetrable. Knowledge about biophysical properties of wetlands retrieved from satellite images will improve management and protection of the sensitive wetlands ecosystems, which influence various factors of carbon and water cycles. The methodology developed is suitable for applications to the system of monitoring wetlands in Europe.

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TABLE I
Details of Satellite Data Applied for the Study

| Satellite Sensor | Acquisition Date | Resolution (m) | Polarization | Incidence Angle |
|---|---|---|---|---|
| ENVISAT ASAR | 2003-05-08 | 12.5 | HH, HV | 23.0 (IS2) |
| | 2003-06-12 | | HH, HV | 23.0 (IS2) |
| | 2003-07-17 | | HH, HV | 23.0 (IS2) |
| | 2003-09-25 | | HH, HV | 23.0 (IS2) |
| | 2004-05-11 | | HH, HV | 23.0 (IS2) |
| | 2008-04-28 | | HH, VV | 41.0 (IS6) |
| | 2008-05-08 | | HH, VV | 23.0 (IS2) |
| | 2008-06-15 | | HH, VV | 41.0 (IS6) |
| | 2009-04-26 | | HH, VV | 41.0 (IS6) |
| | 2009-05-28 | | HH, VV | 23.0 (IS2) |
| | 2009-05-31 | | HH, VV | 41.0 (IS6) |
| ALOS PALSAR | 2008-05-12 | 12.5 | HH, HV | 38.7 |
| | 2008-07-26 | | | |
| | 2009-06-13 | | | |
| ENVISAT MERIS | 2003-04-21 | 300 | - | - |
| | 2004-04-15 | | | |
| | 2006-07-19 | | | |
| | 2008-04-24 | | | |
| | 2008-05-06 | | | |
| | 2008-07-25 | | | |
| | 2008-05-06 | | | |
| | 2009-04-28 | | | |
| ALOS AVNIR-2 | 2007-07-17 | 10 | - | - |
| NOAA AVHRR | 2003-05-08 | 1000 | - | - |
| | 2008-05-06 | | - | - |

## II. Test Site and In-Situ Measurements

The Biebrza Wetlands are situated in Northeast Poland (UL: N54o E22o10' and LR: N53o10' E23o30'). It is one of the largest areas of marshes and swamps in Europe, and is considered as wild and minimally affected by human impact. There are more than 70 natural and semi-natural plant communities. The most dominant and ecologically valuable are: sedge, sedge-moss, reeds, rush and scrubs (birch, willow, alder, aspen). The scrub encroachment, the lowering of the water table, and changes of farming activity cause ecological problems in these areas, [2].

It is a vast complex of peatlands (45,000 ha) with peat up to 3 m deep. Sands underlie the peat deposit with gravel series at the bottom of the northern part and silts and clays in the southern part, [3]. The canals constructed in the first half of the 19th century and later in the 60th have changed hydrological regimes of the valley, leading to a permanent drop in the water table and drainage of the peatlands. This decrease of the ground level gave way to many semi-natural communities the most common being meadow type associations. One of the greatest threats to the Park is artificial drainage, which results in the invasion of marshes by shrubs and trees. This loss of sedge and moss communities is accelerated as farmers (landowners) cease mowing for hay production.

Generally, Biebrza Valley is a flat area, the coolest one in Poland, with the length of the growing season less than 200 days and mean precipitation less than 500 mm. Summer is warm but short. Winter is cold and long. The main river is Biebrza whose recipient is Narew River. The Biebrza drainage basin area is 7051 km2. The river length is 155 km; mean flow amounts to 35.3 m3/s.

This study was carried out during 2003-2009. These years comprise different moisture conditions from dry (2003) to wet (2008). Fig. 1 presents the area of the test site (black curve) and measurement plots (red dots) located on ALOS.AVNIR-2 (RGB 3,2,1 composition) acquired on 17.07.2007.

Ground truth data applied for the study included various biophysical parameters measured at test site during satellite overpasses. These were: volumetric soil moisture (SM, [%]) measured using TRIME FM, Leaf Area Index (LAI) measured using LAI-2000 Plant Canopy Analyzer, wet and dry biomass, height and type of vegetation habitat. Measurements were carried out at the areas of different wetlands communities. At the same time, meteorological parameters such as air temperature, wind speed, solar and net radiation were measured with ENERCO Portable Met Station. All these ground measurements were used along with satellite data in statistical analyses.

## III. Application of Optical Data

Optical images were used for classification of wetlands communities and calculation of vegetation index NDVI.

Wetlands communities' classification, which is essential for the calculation of biophysical parameters using satellite data, was performed for the layer of wetlands vegetation derived from CORINE Land Cover database, [4]. To distinguish different vegetation communities, the pixel-based supervised maximum likelihood classification method was applied to ENVISAT.MERIS satellite image registered on 21st April 2003. The following channels were chosen: 2, 5, 7, 8, 10, and 13. The validation was performed using ground truth observations and the accuracy of the classifications was evaluated. Fig. 2 presents results of this classification.

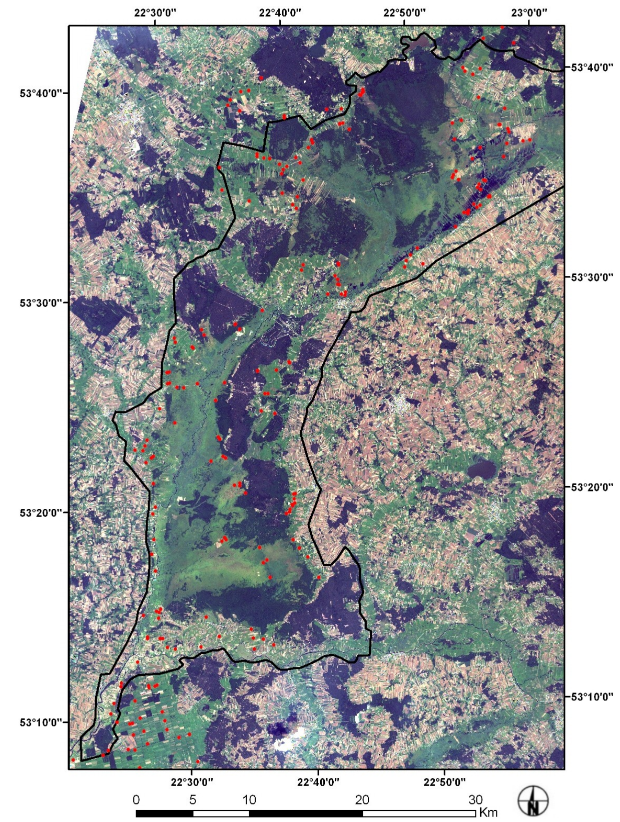


Fig. 1. ALOS.AVNIR-2 RGB (3,2,1) composition with measurement points (red) and boundary of the test site (black).

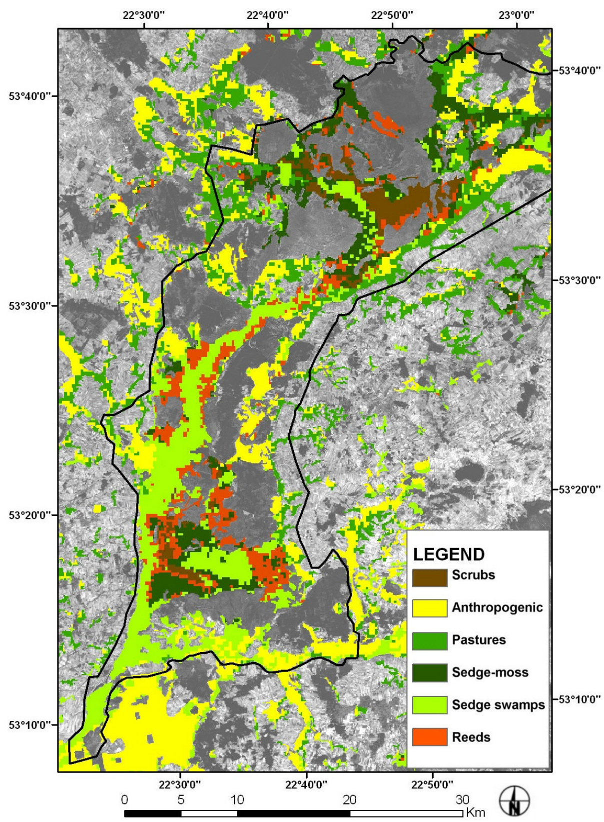


Fig. 2. Map of wetlands communities derived from ENVISAT.MERIS image acquired on 21st April 2003.

As can be seen on the map (Fig. 2) six vegetation classes, which represent the most dominant wetland vegetation communities: scrubs, anthropogenic meadows, pastures, sedge-moss, sedge swamps, and reeds, have been distinguished. The overall accuracy equals to 93 %. For further analyses concerning ground truth measurements and satellite data the class named scrubs was not included due to insufficient numbers of in-situ observations.

Vegetation index NDVI was calculated from ENVISAT.MERIS satellite data taking into account jointly the features of vegetation responsible for reflection in various bands and combining this information from several spectral bands [5]. Taking into account differences in spectral response of various vegetation communities the following MERIS channels were applied for calculation of NDVI: 2 (blue), 7 (red), 13 (near infrared). Fig. 3 and 4 present maps of NDVI index calculated from MERIS images registered for the test site at the time period of the years 2003 (Fig. 3) and 2008 (Fig. 4). It can be noticed that the year 2003 was dry year; the values of NDVI were much lower than for the year 2008, which was considered as wet year. Thus, vegetation indices can be used for monitoring of biomass changes over wetland areas.

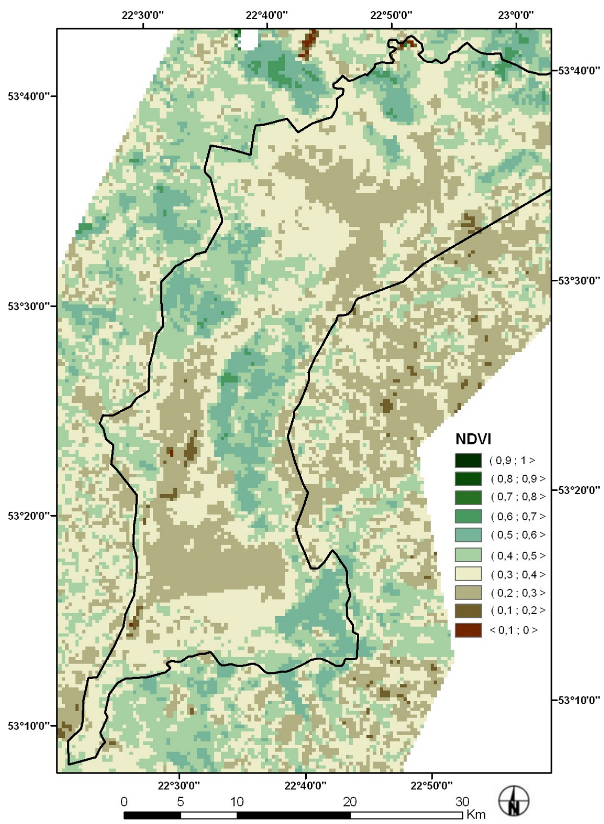


Fig. 3. Map of NDVI index calculated from MERIS images acquired on 21.04.2003.

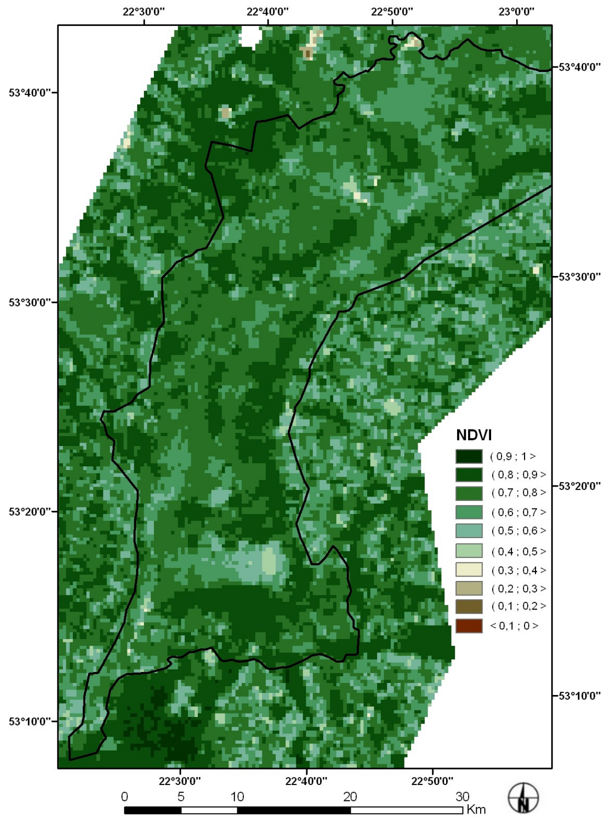


Fig. 4. Map of NDVI index calculated from MERIS images acquired on 06.05.2008.

Vegetation index NDVI calculated from optical images acquired by ENVISAT.MERIS spectrometer was applied for calculation of LAI values. The relationships between LAI values measured at the test site and NDVI index calculated from MERIS satellite images for distinguished vegetation classes (Fig. 2) were analyzed. Tab. 2 presents the equations, which were used for LAI mapping and monitoring using ENVISAT.MERIS images.

TABLE II
RESULTS OF STATISTICAL ANALYZES BETWEEN LAI AND NDVI FROM MERIS AT THE 95% CONFIDENCE LEVEL

| Class | r | No of observations | St. Error of Estimation | Equation |
|---|---|---|---|---|
| reeds | 0.77 | 9 | 1.04 | LAI= -0.69+7.23*NDVI |
| sedge swamps | 0.78 | 30 | 0.81 | LAI= -3.0+8.54*NDVI |
| sedge-moss | 0.80 | 21 | 0.69 | LAI= -2.38+6.59*NDVI |
| anthro-pogenic | 0.81 | 72 | 1.06 | LAI= -7.46+14.0*NDVI |
| pastures | 0.76 | 32 | 0.54 | LAI= -2.28+6.01*NDVI |

NOAA.AVHRR data and meteorological data have been used for calculation of latent heat flux (LE) as a residual of the energy budget equation, [6]:

$$LE = R_n - H - G. \quad (1)$$

In this equation the soil heat flux (G) was considered as a portion of net radiation (Rn). Sensible heat flux (H) was

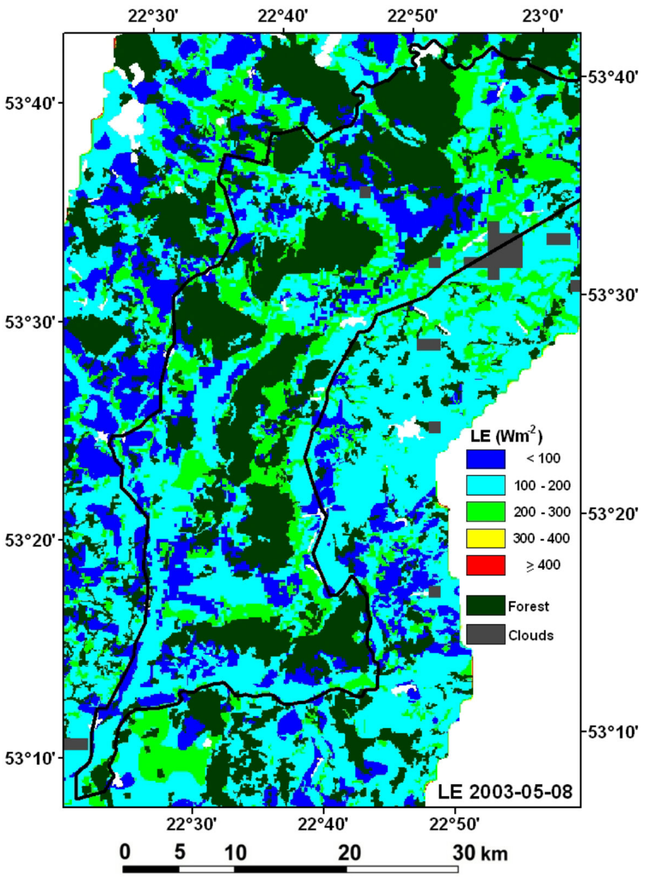


Fig. 5. Map of LE derived from NOAA.AVHRR and meteorological data for 08.05.2003.

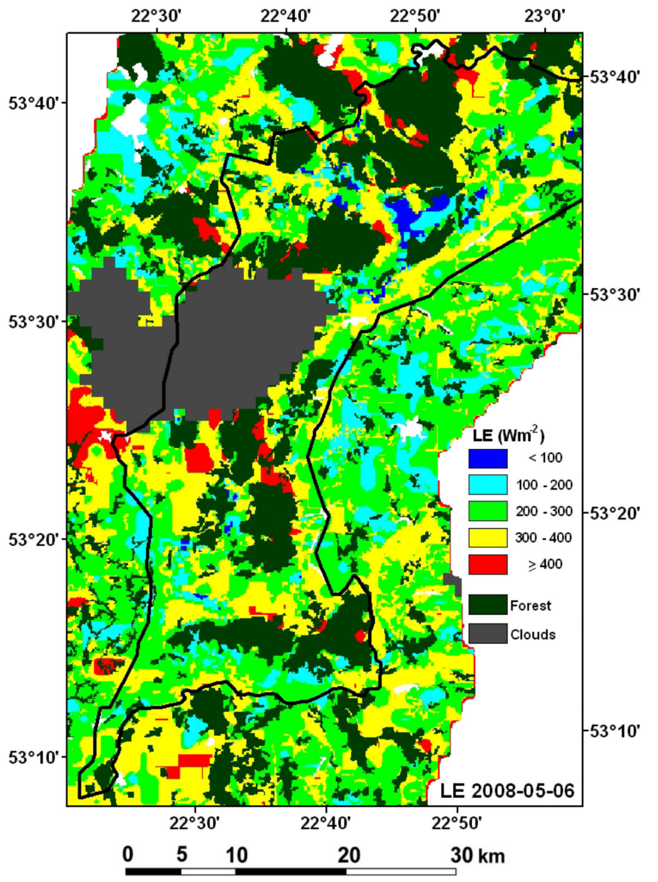


Fig. 7. Map of LE derived from NOAA.AVHRR and meteorological data for 06.05.2008.

calculated using surface temperature derived from thermal channels 4 and 5 of NOAA.AVHRR images, corrected for atmospheric influence, [7]. The air temperature, net radiation, and wind speed were measured at the study area. Aerodynamic resistance (ra), which depends on such parameters as: wind speed, and canopy height, was corrected for atmosphere stability, [8].

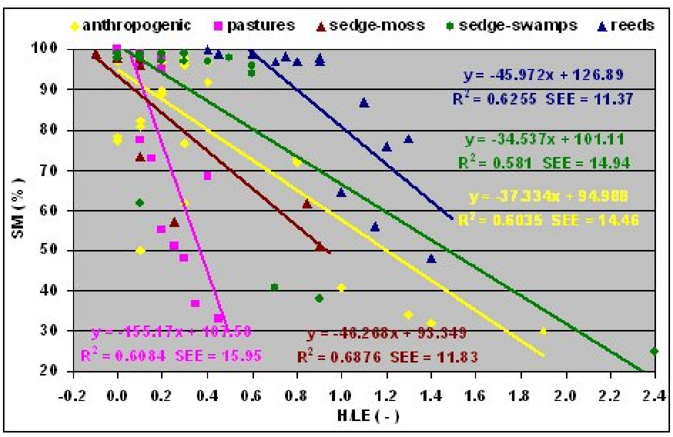


Fig. 6. Relationship between measured SM and H/LE index, for distinguished vegetation classes.

Fig. 5 and 7 present the maps of LE values distribution at the test site area in the beginning of May 2003 and 2008. In May 2008 the LE was the highest of all the given cases: for sedge-moss and pastures exceeded 400 Wm-2, for anthropogenic meadows equaled to 300-400 Wm-2, (Fig. 7). It has to be noted that in May 2008 SM conditions were wet. In the same period of the year in 2003 the SM conditions were much dryer resulting in lower values of LE: the lowest were obtained for shrubs and agricultural areas (100 – 200 Wm-2), (Fig. 5). In view of the vegetation habitats, LE values were the highest for pastures and anthropogenic meadows and the lowest for shrubs, which occupied dryer sites.

SM can be assessed from the ratio of H/LE. High values of SM are related to low values of H/LE, as most of the incoming energy is used to evaporate water (Fig. 6).

The best relationship between soil moisture (SM)measured in-situ and H/LE index calculated from NOAA.AVHRR and meteorological observation can be reported for pastures and anthropogenic grassland (rather low moisture content), but also for sedge-moss and reeds. The lowest is for sedge-swamps. It proves that with high evapotranspiration of sedge swamps, the variation in moisture could not be very well monitored.

## IV. Application of Microwave Data

Backscattering coefficient $\sigma$ calculated from microwave images acquired by ENVISAT and ALOS radar sensors was analyzed along with ground truth measurements of LAI and soil moisture (SM) carried out for vegetation classes distinguished from MERIS image. ALOS.PALSAR HV and ENVISAT.ASAR IS6 VV gave the best results for LAI estimation. The relationship between LAI and $\sigma$ was negative – the higher values of LAI the lower values of $\sigma$ were. It is explained that the vegetation attenuates the wave while penetrating vegetation through the way to soil. LAI is important index as there is the relationship between LAI and biomass. Thus, in case of cloudy weather it is possible to use microwave data for calculation of LAI. Fig. 8 presents results of statistical analyses between LAI and $\sigma$, which was calculated from ALOS.PALSAR HV images. The highest correlation has been obtained for reeds, the lowest for pastures – the class not typical in wetlands communities. There is high correlation between LAI and biomass for particular vegetation classes, which has been examined, Fig. 9. It is important to include LAI data to assess biomass. Most of the models for biomass assessment include the value of LAI.

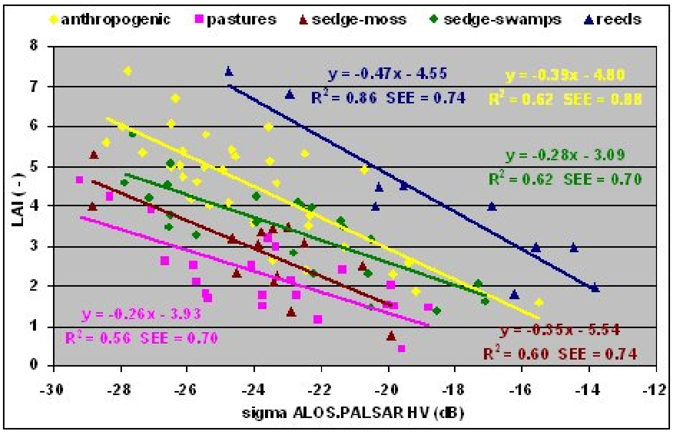


Fig. 8. Relationship between measured LAI and $\sigma^{\circ}$ calculated from ALOS.PALSAR., for separate vegetation classes.

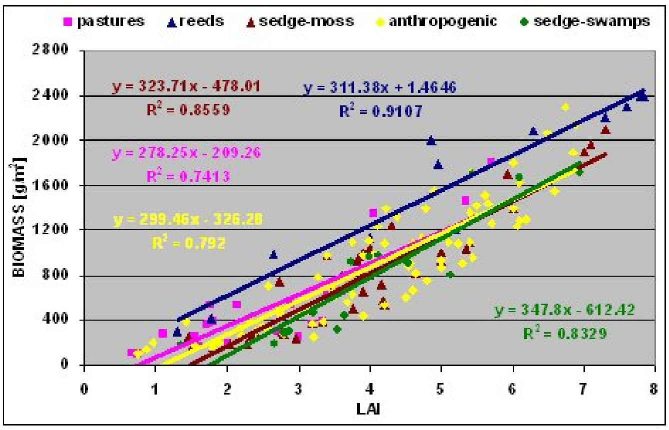


Fig. 9. Relationship between biomass and LAI from in-situ measurements.

Fig. 10 presents map of LAI assessed from ALOS.PALSAR HV image using derived equations, which shows Fig. 8. Amount of biomass can be assessed using LAI calculated from optical or microwave images.

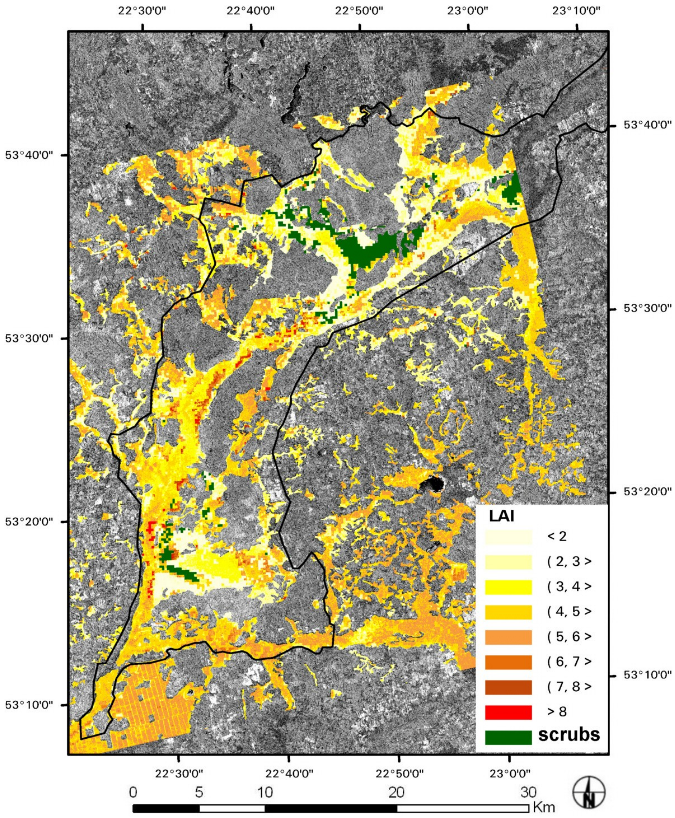


Fig. 10. Map of LAI calculated from ALOS.PALSAR HV acquired on 12.05.2008.

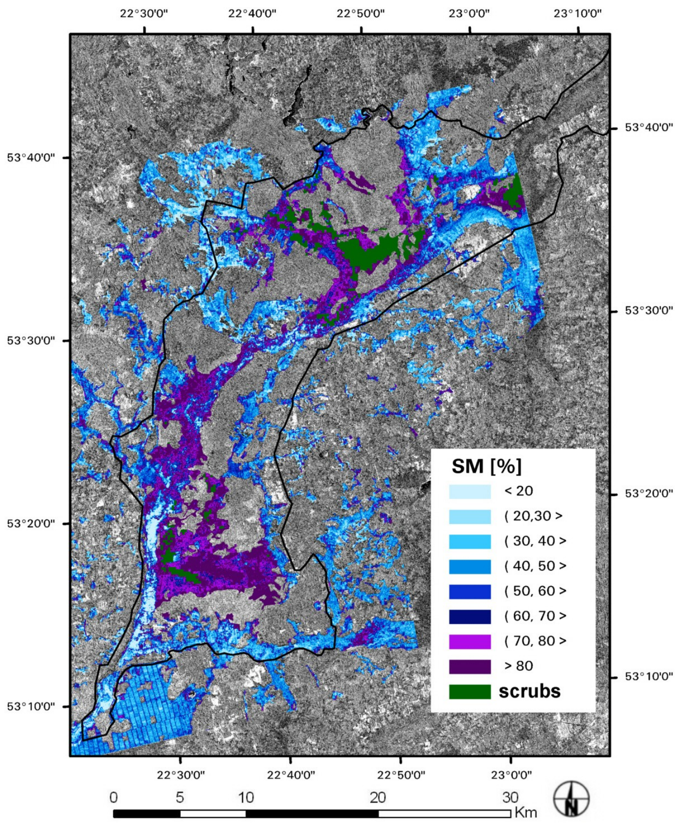


Fig. 11. Map of soil moisture calculated from ALOS.PALSAR HH acquired on 12.05.2008.

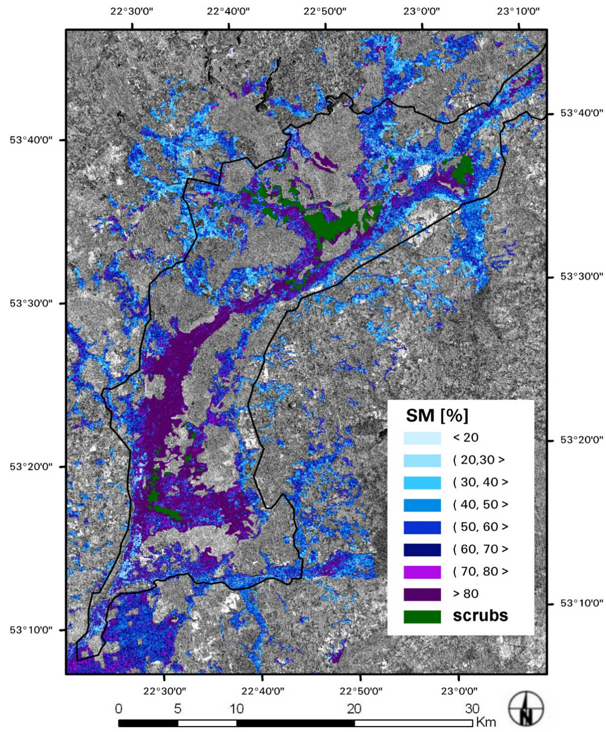


Fig. 12. Map of soil moisture calculated from ENVISAT.ASAR. HH IS2 acquired on 08.05.2008.

Statistical analyses between ground truth and microwave satellite data indicated that ?° calculated from ALOS.PALSAR HH and ENVISAT.ASAR HH IS2 images gave the best results for soil moisture estimation. The wave in HH penetrates more effectively vegetation reaching the soil, and rather steep angles have been found to be more useful for examination of soil moisture by diminishing roughness effects and vegetation attenuation. Fig. 11 and 12 present maps of SM derived from ALOS.PALSAR HH and ENVISAT.ASAR IS2 HH images registered for the test site at similar period of the year 2008. It can be noticed that SM from ALOS.PALSAR HH is lower of about 10% then SM from ENVISAT.ASAR HH IS2, especially for anthropogenic meadows. Taking into account in-situ data it can be noticed that equations derived from ASAR HH IS2 data overestimate observations.

## V. Conclusions

The objective of this study was to elaborate the method for the assessment of various biophysical parameters in a wetlands ecosystem using numerous satellite images acquired in optical and microwave spectrum. Existing models of soil moisture conditions deducing drought effects incorporate mostly meteorological parameters as precipitation and air temperature. Calculated potential evapotranspiration very often does not reflect soil ground conditions especially in wetlands. Therefore incorporate actual evapotranspiration and soil moisture derived from satellite data give the opportunity of actual wetlands conditions. This information could be included into every day observations of the sensitive ecosystem, which stable conditions, are the guarantee for existing balance of the area. Such input may be included into the “Decision Support System” for Biebrza National Park, which is being developed in order to quantify environmental changes, [9].

The ENVISAT.MERIS images registered in optical spectrum can be used for classification of wetlands communities what is essential for assessment of various vegetation biophysical parameters from satellite data. To obtain LAI for the particular wetlands classes NDVI index calculated from optical images such as ENVISAT.MERIS can be applied. Also, LAI can be assessed using backscattering coefficient calculated from ALOS.PALSAR HV and ENVISAT.ASAR HH IS6 microwave images, especially during cloudy conditions.

The backscattering coefficient calculated from microwave images such as ALOS.PALSAR HH and ENVISAT.ASAR HH IS2 can be used for soil moisture prediction for each of the vegetation class. Also, soil moisture can be assessed from the ratio of sensible heat flux to latent heat flux (H/LE) calculated using surface temperature derived from thermal channels of NOAA.AVHRR images in conjunction with meteorological data. Great similarity was noticed between values of soil moisture obtained from microwave data and the soil moisture index H/LE derived from optical data. Assessed latent heat flux (LE) from NOAA.AVHRR data and meteorological observations could be used as the regular input to the water balance models for wetlands ecosystems.

Equations, derived from statistical analyses between satellite and in-situ observation can be used for mapping and monitoring wetland biophysical properties not only for Biebrza Valley, but also for other marshland areas in Europe. The launch of Sentinels satellites (1 and 2) within the GMES Programme will give the continuity of the research, which is presented in this article.

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