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Hybrid approach for mapping wetland habitats based on application of VHR satellite images

Zbigniew Bochenek
Institute of Geodesy and Cartography, 27 Modzelewskiego St., PL 02-679 Warsaw, Poland
Tel.: +48 22 3291977, Fax: +48 22 3291950, E-mail: zbigniew.bochenek@igik.edu.pl

Shailesh Shrestha
Institute of Geodesy and Cartography, 27 Modzelewskiego St., PL 02-679 Warsaw, Poland
Tel.: +48 22 3291949, Fax: +48 22 3291950, E-mail: shailesh.shrestha@igik.edu.pl

Iwona Malek
Institute of Geodesy and Cartography, 27 Modzelewskiego St., PL 02-679 Warsaw, Poland
Tel.: +48 22 3291992, Fax: +48 22 3291950, E-mail: iwona.malek@igik.edu.pl

Abstract. The article presents results of work aimed at developing methods for classifying wetland habitats, based on different types of satellite data and on various classification approaches. Very high resolution WorldView-2 satellite images were used for the research work as basic input data. An object-oriented, rule-based approach was applied to achieve high accuracy of classification of wetland vegetation classes. As a result of the research a semi-automatic classification method has been prepared within the eCognition environment, which enables high accuracy of the resultant map (ca. 90%) to be reached. At the final stage of the research, applicability of radar Terra SAR-X images for vegetation classification was studied.

Keywords: object-oriented classification, very high resolution images, wetland vegetation, radar imagery

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1. Introduction

Wetland environment is one of most complex ecosystems, due to variety of vegetation species and variability of environmental conditions, which affect habitat appearance. Hence, preparation of the remote sensing based method, which could be used for generating map of wetland habitats with high reliability, still remains a great challenge. Many research works were lately concentrated on this topic. The researchers applied various sets of remote sensing images and different approaches to image classification in order to obtain satisfactory results. Early approaches were based on Landsat-type data and supervised classifications of the study area (Benz et al., 2004; Dabrowska-Zielinska et al., 2009; Bwangoy et al., 2010; Davranche et al., 2010). In parallel, object-oriented approaches started to be examined, applying various algorithms of data classifications (Pekkarinen, 2002; Wei et al., 2005; Lucas et al., 2007; Frohn et al., 2009; Dronova et al., 2012). Recently, some studies on using high-resolution microwave images for analyzing wetland habitats have been also conducted (Dabrowska-Zielinska et al., 2012, 2013). But most of the research works were so far concentrated on single approach (pixel-based or object-based), exploiting one type of satellite data. In the presented work it was attempted to combine both basic approaches of data classification and to study complementarity of different remote sensing data sources for mapping wetland habitats.

2. Study area

A wetland area located in northwestern Poland (Biebrza Valley) was selected as a test site for the presented work. This area covering ca. 25 500 ha belongs to the Biebrza National Park – the largest national park in Poland. The selected test site is unique in Europe for its marshes and peatlands, being protected under the RAMSAR convention.

In general, three types of habitats exist within the study area: forest communities, shrub communities and non-forest land communities. Forest complexes consist mainly of mixed and deciduous forests, including alder, oak-hornbeam and birch communities. Shrub areas are mainly composed of willow; variations in water conditions and moving practices cause shrub encroachment within wetlands, thus changing plant composition and habitat type.

Non-forest communities are composed mainly of rushes and sedge (37.2% of the total Park area) and peatlands (31.5% of the total Park area). Peatlands are covered by moss-sedge communities, which include rare plant species. Water areas are accompanied partly by reed communities. The main NATURA 2000 habitats existing within the study area are as follows:

7230 – Alkaline fens,
7140 – Transition mires and quaking bogs,
6410 – *Molinia* meadows,
6510 – Lowland hay meadows,
9170 – Oak-hornbeam forests,
9150 – Bog woodland,
91T0 – Central European lichen pine forests.

The whole study area is characterized by occasional flooding (especially in springtime) and quite complex species compositions within particular meadow categories. In addition, part of the wetland area is managed by individual farmers, which through management practices (e.g. mowing, shrub removal) adds complexity to the situation, as observed with the use of satellite images.

3. Satellite images and ancillary data

Two types of satellite images have been applied in the presented study – optical very high resolution images and radar HR images.

The optical data were collected by a sensor installed on the World View 2 satellite. The sensor is characterized by the following features:

- 2 m resolution in multispectral mode.
- 8 spectral bands (coastal, blue, green, yellow, red, red edge, NIR1, NIR 2).
- 11-bit dynamic range.

The WorldView-2 image for the Biebrza test site was collected on 11 August 2011; it covered area of 146 km^2 (9 km × 16 km), comprising the Lower Basin of the Biebrza Valley. A colour composite formed from three WorldView-2 channels (7, 5, 3), covering the study area, is presented in Figure 1.

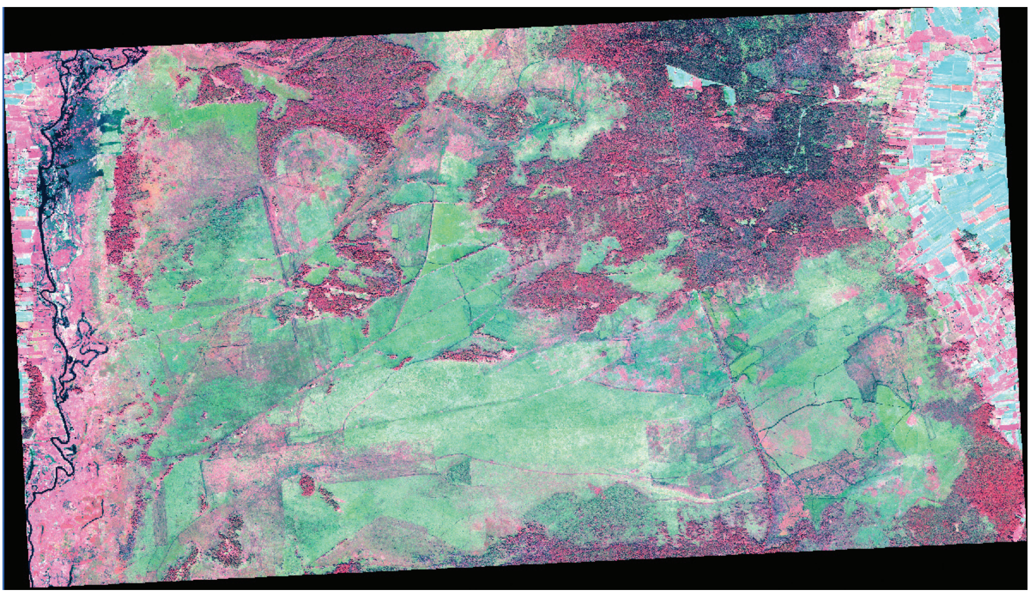

Fig. 1. Colour composite covering the study area based on World View channels

Terra SAR-X radar images were the second type of satellite data applied for the study area. The data were collected in SCANSAR mode (VV polarization) on five dates during the 2012 growing season (22 June, 3 July, 17 July, 10 September, and 13 October). The nominal resolution of the RE product delivered for research works was 18 m. The colour composite formed from three Terra SAR-X images is presented in Figure 2.

In order to be able to carry out the classification process properly, reference information was collected for the study area. The reference data consisted of vegetation maps, prepared as a result of fieldwork performed by ecologists from the Biebrza National Park. Moreover, point information on plant species and the state of wetland vegetation has been gathered in the course of ground campaigns.

4. Methodological approach

4.1. General assumptions

The main idea of this work was to elaborate a semi-automatic method for classification of wetland habitats. The initial study was aimed at determining which vegetation classes existing within the wetland study area can be effectively distinguishable. Separability analysis based on WorldView-2 data was performed, taking into account numerous categories existing on vegetation maps prepared during ground campaigns. As a result of the preliminary analyses 8 vegetation categories, appearing within the study area have been classified:

- deciduous forests,
- coniferous forests,
- shrub communities,
- sedge communities,
- moss-sedge communities,
- wet grasslands,
- rushes,
- reeds.

Next, the appropriate method of image classification has been chosen. As VHR WorldView-2 image, due to its 2 m ground resolution, delivers fine textural information about land cover classes, it was decided to apply an object-oriented approach for developing the method of classification of wetland habitats. Several options within that approach

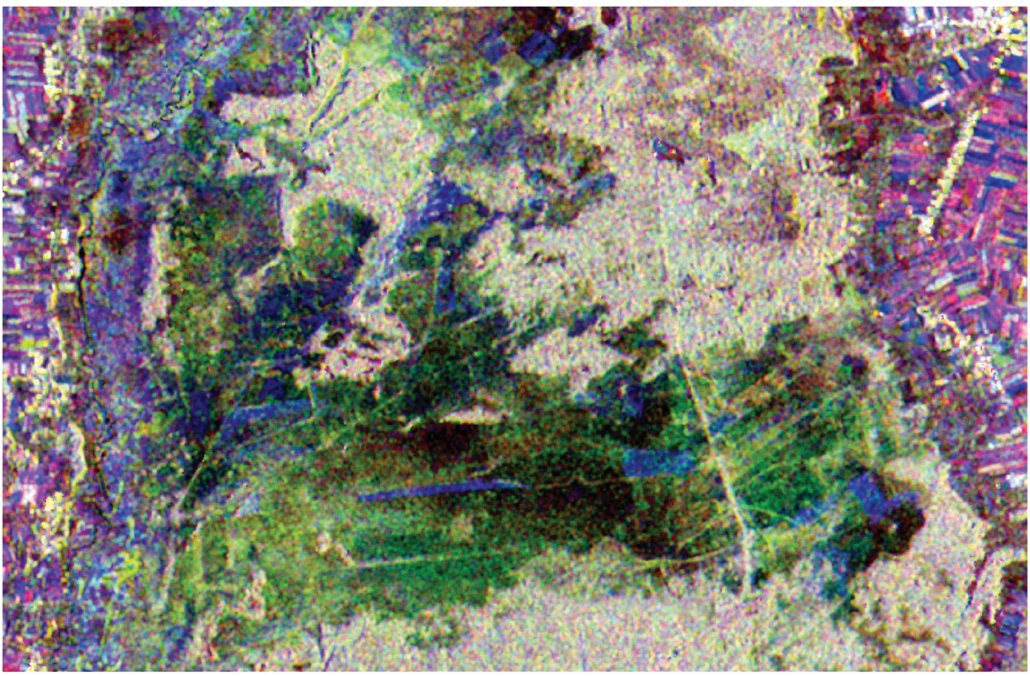

Fig. 2. Colour composite covering the study area based on Terra SAR-X data

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were examined in order to find the optimum solution for producing a classification map with high accuracy. They are presented in the next section.

4.2. Object-based classification method of wetland habitats

In the first part of the work an 8-band WorldView-2 image of the Biebrza test site was imported to the eCognition environment. Next, multi-resolution segmentation of the image was performed, applying an iterative approach to determine optimum segmentation parameters. The aim of this iterative procedure was to find such a solution which could keep quite large objects, still preserving their spectral/textural homogeneity. Once objects were determined, samples representing eight vegetation classes and water class were selected, using reference maps produced in the course of fieldwork. Based on the samples for particular vegetation classes separability analysis was performed in order to find those classes which are similar, as far as spectral response, solely, is concerned. As a result of this analysis some wetland categories, e.g. sedge communities and wet grasslands, proved to have quite low spectral separability, even taking into account all eight bands of the World View sensor. Hence, it was decided to search for other features which could be helpful in discriminating the classes of interest. Texture proved to be the most important feature for this purpose. At the initial stage of this part of the work texture measures developed by Haralick – contrast, mean, homogeneity, dissimilarity – were studied. Finally a filtering procedure which utilizes edge extraction Lee sigma filters was applied. Two sigma filters were used for this purpose, which emphasize the inner and outer object boundaries, respectively. The sum of two filtered images formed the resultant image, which was used at the next stages of analysis for deriving texture information.

The most important decision at this stage of the work concerned the type of classification algorithm to be used for image classification. Several options of algorithms were examined:

- *k*-Nearest Neighbours algorithm (KNN), where an object is classified by a majority vote of its neighbours, with the object being assigned to the class most common among its *k* nearest neighbours;
- Support Vector Machine (SVM) algorithm, where a model is built that assigns new examples to one category or the other, making it a non-probabilistic binary linear classifier;
- Bayes classifier (ML), which minimizes the probability of misclassification, applied intensively in supervised classification.

After generating classification images with the use of these algorithms, it was found that none of them can produce results with high accuracy. Therefore it was decided to look for another solution – a rule-based approach supported by expert knowledge and utilizing a stepwise procedure of classification.

Classification in this approach begins with discrimination of water category. This is done on the basis of assigning a threshold for the spectral reflectance of water in the near infrared band (NIR1: 760-860 nm). In order to obtain large water objects, merge procedures are performed, as well as cleaning procedures concerning small artifacts classified as water.

At the next step the joint forest and shrub category is distinguished. That is done by applying a threshold to a Lee sigma filtered image, which enables the researcher to discriminate between high texture (forests and shrubs) and low texture (remaining vegetation classes). Next, the shrub category is extracted from the joint forest plus shrub group by using the Haralick texture measure – contrast. This measure enables the researcher to separate both classes by applying the proper threshold value. Furthermore, two forest types are discriminated; in this case a single spectral feature – reflectance in the NIR2 band (860-1040 nm) – is utilized.

In the next step the rushes category is distinguished. This class can be separated from the remaining wetland classes through application of two spectral features: reflectance in the Red Edge band and the NDVI index derived from the red and NIR1 bands. In order to classify the reeds category four spectral features should be used: reflectance in the yellow, red, Red Edge and NIR1 bands.

Two large wetland categories existing within the study area are sedge and moss-sedge communities. In order to distinguish moss-sedge plant formation two spectral features are applied: the NDVI index and reflectance in the green band. The contextual information is also applied to improve classification of this wetland category. The sedge category remains as a residual of the process of classifying the moss-sedge community.

Applying this scheme, a classification image for the Biebrza test was produced. It includes eight vegetation categories. The classification limited to the boundaries of the national park is presented in Figure 3.

At the next stage accuracy assessment of the classification map was carried out. A set of test areas was prepared for this purpose. The test areas were selected using the detailed vegetation maps prepared in the course of fieldwork by experts from the Biebrza National Park. Next, a standard accuracy assessment procedure was applied, resulting in a contingency table and information on producer's and user's accuracy. Information on accuracy assessment is included in Table 1.

Results of the accuracy assessment generally confirm high overall accuracy of distinguishing the main vegetation classes existing within the wetland ecosystem. Most of the wetland habitats within the Biebrza National Park test site were classified with ca. 90% producer's accuracy, with the exception of wet grasslands, which are quite a complex habitat, composed of different plant species. The shrub category was classified with accuracy exceeding 85%, which creates possibilities to fulfill the information needs of the end-user – Biebrza National Park – related to monitoring shrub/tree

Table 1. Accuracy assessment of the classification image for the wetland test site

Class name	Producer's accuracy [%]	User's accuracy [%]
rushes	93.6	89.1
sedge	92.9	88.8
moss-sedge	92.4	99.2
shrubs	86.6	89.2
forest – deciduous	99.9	95.0
water	99.0	100.0
wet grassland	81.0	100.0
reeds	90.5	56.9
forest – coniferous	76.4	100.0
overall accuracy = 92.8 %		
kappa coefficient = 0.9047		

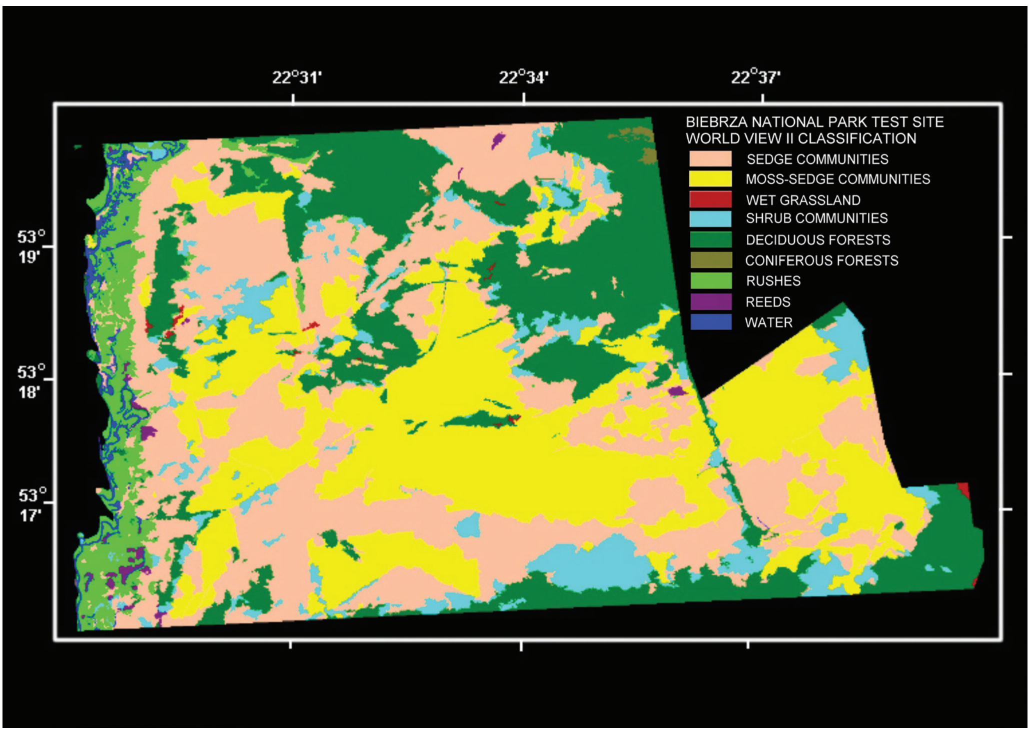

Fig. 3. Classification map of the wetland test site – Biebrza National Park (Lower Basin)

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encroachment. Nevertheless, it must be mentioned that the final level of classification accuracy greatly depends both on field information concerning habitat distribution and on the time of image acquisition, as well as on the type of satellite data.

In order to examine whether the usage of another type of satellite data adds new information to that obtained while applying VHR optical images, radar Terra SAR-X imagery was used. In this case a pixel-based approach was utilized for the classification process. As the basis of classification, a multi-temporal image, collected at five dates within the growing season, was applied. Supervised classification applying the Bayesian algorithm was carried out within the ERDAS environment, utilizing samples collected for 8 vegetation classes. The resultant classification map is presented in Figure 4.

Comparison of classifications based on VHR optical images and on radar images reveals similarities in classifying some vegetation categories (forests, moss-sedge community). Nevertheless, the two classifications are not easily comparable, due to different ground resolutions, various classification approaches (object-based vs. pixel-based) and different dates of image acquisition. For some vegetation classes (e.g. shrubs, reeds) a backscattering coefficient derived from radar images seems more sensitive to the structure of these plant formations than spectral reflectance derived from optical images. Also some management practices changing the vegetation environment can be more easily distinguishable while applying radar data. In order to make a quantitative comparison of both classifications, accuracy assessment based on test areas is planned for radar classification in the near future.

Conclusions

The research works presented in this article proved that very high resolution satellite images with ground resolution of 2 metres in multispectral mode are the optimum remote sensing data for producing detailed vegetation maps, as the prepared method utilizes both spectral and textural information for

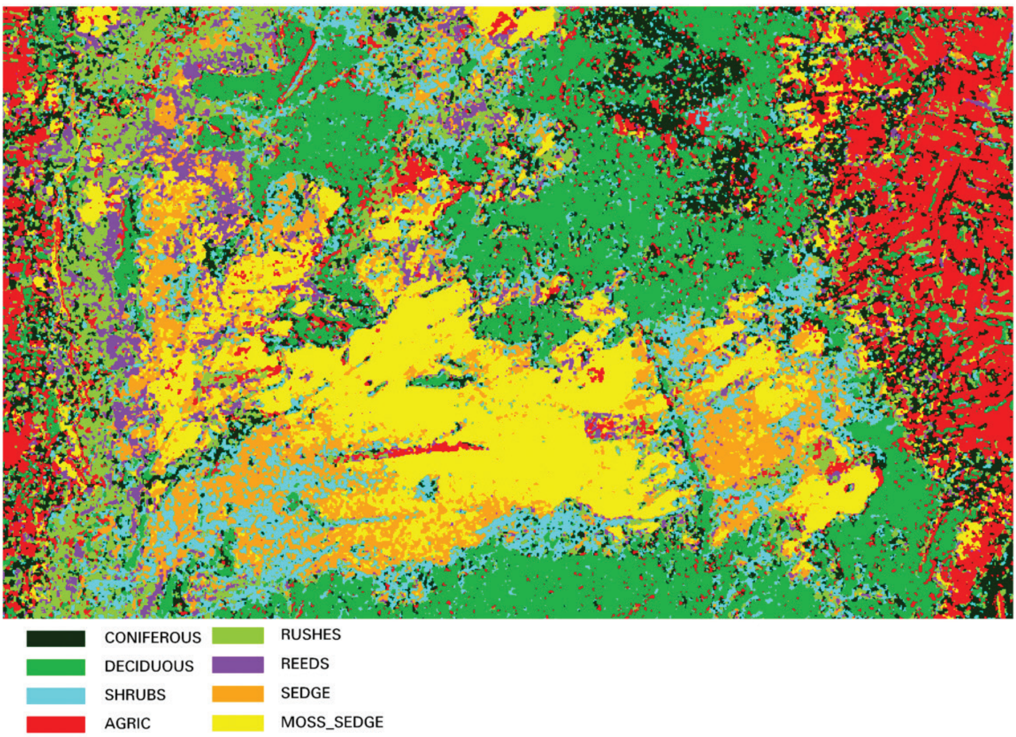

Fig. 4. Classification map of the wetland test site based on radar Terra SAR-X data

classifying vegetation communities. Date of acquisition of satellite images for mapping wetland areas is one of the crucial points. Due to periodical floods appearing in the spring season, summer seems to be the best time window for data collection. When transferring the method to other wetland ecosystems, possible management practices applied to some parts of the area (mowing, shrub cutting) must be taken into account. Adequate ground truth information, needed for selecting classification parameters and for accuracy assessment, spread across the study area, should also be available to achieve high reliability of the final mapping products. Application of high-resolution radar imagery can add complementary information to that achieved while using solely optical satellite data.

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Hybrydowa metoda kartowania obszarów podmokłych z wykorzystaniem wysokorozdzielczych obrazów satelitarnych

Zbigniew Bochenek
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, PL-02-679 Warszawa
Tel.: +48 22 3291977, Fax: +48 22 3291950, E-mail: zbigniew.bochenek@igik.edu.pl

Shailesh Shrestha
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, PL-02-679 Warszawa
Tel.: +48 22 3291949, Fax: +48 22 3291950, E-mail: shailesh.shrestha@igik.edu.pl

Iwona Małek
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, PL-02-679 Warszawa
Tel.: +48 22 3291992, Fax: +48 22 3291950, E-mail: iwona.malek@igik.edu.pl

Streszczenie W artykule zostały przedstawione wyniki prac ukierunkowanych na opracowanie metod klasyfikacji obszarów podmokłych, bazujących na różnych typach danych satelitarnych oraz na różnych podejściach klasyfikacyjnych. Do prac badawczych jako podstawowe materiały wykorzystano wysokorozdzielcze obrazy satelitarne WorldView-2. Zastosowano metodę klasyfikacji obiektowej do osiągnięcia wysokiej dokładności klasyfikacji zbiorowisk roślinnych na obszarach podmokłych. W wyniku prac utworzono półautomatyczną metodę klasyfikacji w środowisku eCognition, która umożliwia osiągnięcie wysokiej dokładności (rzędu 90%). W końcowej części prac badawczych przeprowadzono analizę stosowalności obrazów radarowych Terra SAR-X dla celów klasyfikacji typów roślinności.

Słowa kluczowe: klasyfikacja obiektowa, wysokorozdzielcze obrazy satelitarne, kartowanie obszarów podmokłych, obrazy radarowe