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AN OBJECT-BASED APPROACH FOR WETLAND HABITATS INVENTORY AND ASSESSMENT USING ALOS AVNIR-2 AND FIELD DATA

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ABSTRACT

A hierarchical process for a Mediterranean wetland habitats inventory and assessment using object-based image analysis applied to medium spatial resolution satellite is discussed. The method is based on spectral, contextual and spatial criteria, coupled with knowledge of ecological conditions of the wetland. The main objective of this research was to evaluate object-based methodology performance to assess wetland condition and discriminate wetland vegetation species and habitats as defined by Natura 2000 framework. A medium spatial resolution ALOS AVNIR-2 image, captured in July 2007, and coincident field data covering the wetland area of lakes Koronia-Volvi in Greece, was used in this analysis. An innovative sampling design is presented and a 4-level hierarchical structure classification scheme is introduced. Issues regarding shape and size of sampling units, configuration and their spatial random distribution by stratum are addressed. The preliminary results show excellent discrimination among most vegetation species, while habitat mapping has proved a time-consuming task. Thematic accuracy of habitats mapping will be assessed using field data acquired during intensive field survey. We believe that integration between hierarchical levels will further improve classification performance. The work presented was supported by the WETMUST project (Integrated multiple level wetlands monitoring system using innovative technologies, INTERREG IIIB ARCHIMED) and European Space Agency (ESA).

1. INTRODUCTION

In response of European Union (EU) Habitats Directive 92/43/EEC [1], Greece proceeded to the identification and mapping of habitats within the sites proposed to be included in Natura 2000 network [2]. The project employed standard aerial photointerpretation techniques to identify homogeneous areas assisted by field verification. The resulting maps displayed the spatial distribution of habitat types.

However, continuous monitoring of habitats is required in Natura 2000 sites. A sound statistical strategy to collect basic information and measure specific variables is fundamental to the design of scientifically credible inventory [3]. The lakes-wetland ecosystem was conceived as an ideal application area due its complexity and heterogeneity, for developing an integrated geospatial framework at the site level to provide detailed information on the current condition of the wetland's species and habitats and establish a mechanism to monitor the condition of species and habitats.

Growing demands for geospatially explicit information over time are emerging as a result of complex sustainability challenges. Earth Observation (EO) has enormous potential as a source of relevant information. Several studies can be found in literature that use remote sensing data for mapping and monitoring of wetlands and their habitats ([4], [5], [6] and [7]).

Further to the type of EO data employed, methodology is equally important especially if a complex environment has to be mapped; in this direction, various methods and measures have been developed ([8], [9]). Traditional pixel based supervised classification methods (e.g. maximum likelihood, etc.) assign a particular pixel to a class without taking into account the neighbourhood of the pixel. Recently, the object-based approach opens new opportunities for describing the complexity of wetland ecosystem resource attributes at multiple resolution levels and for advancing the design of current inventory and monitoring programs ([10], [11] and [12]).

Object-based analysis is a relative new methodological approach in digital image analysis. This approach is closer to human cognitive process than the analysis based on individual pixels; the Cognitive Science describes information treatment in human brain as a conceptual and ablative process directed to objects. With regard to the perception of the environment, objects with meaning and importance resulting from analysis of image data represent very efficiently structures of the real world [13]. Image classification based on object-based analysis is a form of supervised classification, as it allows the user to educate the system either by sampling objects or by setting and combining rules. Object-based classification is particularly suitable for high textured images, where individual pixels are not considered to represent reasonable units for classification [13]. This approach has proven to be able to provide better classification results than per-pixel classification approaches, especially for fine spatial resolution data [14]. Object-based classification is inherently linked to the hierarchy theory; hierarchical is a system organized in levels as monotonically increasing series of temporal and spatial scales [15]. In other words, observations on a specific temporal or spatial scale will result in certain functions being expressed more intensely or effectively than other [16]. Lower levels in hierarchy are characterized by coarser spatial and temporal scales and reversely. From a technological point of view, hierarchy theory and multi-scale approach can be combined in object-based image analysis (OBIA) algorithms and software. OBIA comprises the step of image segmentation, where meaningful (to each targeted scale) objects are obtained and image classification (supervised or rule-based), where these object are classified on their specific scale according to a hierarchically structured nomenclature.

The aim of this work was to evaluate object-based image analysis techniques for species and habitat mapping. An ALOS AVNIR-2 image was used, while training and testing data sampling was designed to fit a 10-m pixel size (ALOS spatial resolution) and the needs of a hierarchically structured nomenclature. The study results at three different mapping scales (e.g. species scale, habitats scale, and vegetation scale) will be used as baseline data for future monitoring and detection of environmental changes.

2. MATERIALS AND METHODS

2.1 Study area

Lakes Koronia and Volvi are located in a tectonic depression in northern Greece (40^o 41'N, 23^o 20'E). Their watershed covers an area of 2.000 km^2, and is drained eastwards into the sea (Fig. 1). The lakes-wetland ecosystem is characterized by high rates of biodiversity since there have been reported 336 vegetation species, 34 mammals, 14 reptiles, 5 amphibians and 29 fish species [17]. The climate of the region is transitional between Mediterranean and temperate. The lakes–wetland ecosystem is surrounded by an intensively cultivated agricultural area. The dominant agricultural crops are maize, alfalfa and cereals. There is no exploitation of surface water, and the only source of fresh water for irrigation, industrial and urban use is through groundwater resources. The recent development of numerous pump wells in the surrounding area has resulted in depletion of the aquifer, and a subsequent decrease in the water level of lake Koronia. The industrial sector has also increased in the past decade, discharging untreated effluents in the lake from fabric dyeing, food and dairy processing activities.

Because of the above-mentioned pressures, Lake Koronia became progressively more eutrophic, especially after the early 1990s, and is currently hypertrophic [18]. Along with the drastic alteration in the water level, which reached a decrease of 100% this year, the natural ecosystem has suffered severe degradation. There has been a significant loss of volume and habitat heterogeneity in the lake and wetland. The emergent macrophyte community (dominated by Phragmites australis) has shifted lakewards and expanded on a recently exposed lake bed [7]. In recognition of its ecological importance, and to prevent further degradation, the lake–wetland system of Lakes Koronia and Volvi is protected by a number of legal and binding actions: it is a Wetland of International Importance according to the Ramsar Convention (site code 57, area 163.88 km^2), a Special Protected Area designated by the implementation of European Directive 79/409/ EEC (site code GR1220009, area 156.71 km^2), and a Site of Community Importance following the implementation of the European Habitat Directive 92/43/EEC (site code GR1220001, area 269.47 km^2). The relevant national and local authorities have responded with the identification and mapping of habitats (Hellenic Ministry of Environment 2001), the compilation of the Master Plan for the restoration of Lake Koronia, and the Revised Restoration Plan for Lake Koronia [19]. According to the proposed management actions, continuous monitoring of the above wetland is required to fulfil the obligations to the international and European legislation.

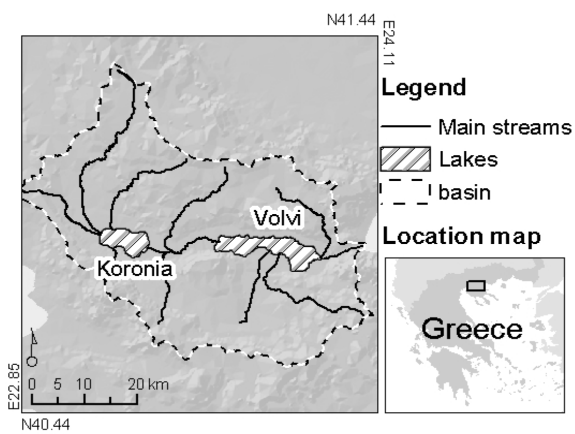

Figure 1. Location map

2.2 Datasets and Methods

The main data source was a planned single satellite image acquisition. A medium-resolution (10m pixel size) multispectral (blue, green, red, and near-infrared bands) image was acquired on 15/06/07 by ALOS AVNIR-2 sensor. The acquisition date was carefully selected in a period where natural vegetation was at full growth and the lakes were flooded.

Because of the ecological importance of the lake-wetland ecosystem, it is essential to initiate large-scale, site and species specific inventory. Detailed fieldwork was necessary for land cover/land use, vegetation species and habitats inventory, and for accuracy assessment of the results. Therefore, 137 field plots were stratified at random across wetland habitats, using handheld GPS (Global Positioning System) receiver, describing various land cover types and habitats according to the CRAMSAR classification system, at dates concurrent with the satellite image (July 2007). Existing vector habitat maps of the Natura 2000 were used to stratify field plots (Fig. 2).

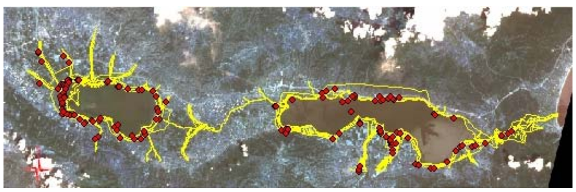

Figure 2. Plot distribution.

The basic sampling unit (su) used to inventory the wetland resources in the study area was a 10 *m* x 10 *m* (Fig. 3) on a side, corresponding to the spatial resolution of satellite imagery [3]. A cluster of nine 10 *m* x 10 *m* su's were selected at each plot to capture the spatial variability observed on the ground [20]. Each plot was centered on the coordinates assigned to it and laid out in a north-south, east-west manner. Because su's will be permanent plots, every plot right down corner was documented on the ground. Five (1, 3, 5, 7 and 9) of the nine *su*'s were selected for detailed measurement, using circular plots of 3 and 5 meters radius. *Su*-5 was located at the plot center. The other four *su*'s were located at fixed angle directions and constant distance with respect to the su-5 center (Figure 3). Large trees (>12.5 *cm* DBH) falling inside the 5 meter radius circular plot were measured on each of the five *su*'s. Trees and shrubs (2.5 *cm* < DBH < 12.5 *cm*) falling inside the 3 meter radius circular plot were measured on a circular plot (3 *m* radius) co-located at the centre of the five *su*'s. Herbs and seedlings (height > 30 *cm* and DBH < 2.5 *cm*) were sampled on three subplots (1 *m* x 1*m*) located diagonally across the three (1, 5 and 9) *su's* on a 14.14 *m* transect. Two of the subplots, were located at the end of transect, while the third subplot was located at the center of the 5th *su*.

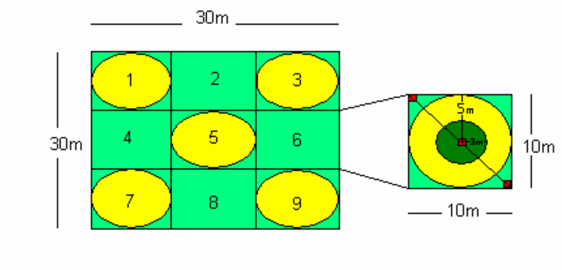

Figure 3. Plot layout for sampling units [20].

Essential features and key elements observed on the sample plots, included:

- Land cover/land use types as well as their percent cover,
- Number, diameter (DBH) and height, as well as features of the cover of all trees and shrubs above a specified diameter to characterize the structure of the forested wetland,
- Ground vegetation (species and percent cover),
- Wildlife indicators (bird calls, scat, tracts, nests, etc.), and
- Environmental disturbances indicators (pollution, fire, clearings, vegetation damages, etc.).

The nomenclature used in the present study was the CRAMSAR division (level 4) to categorize land cover and land use. For wetland habitat classification, Annex I of directive 92/43/EC was used to have a meaningful comparison between the two different dates (2001 and present) of wetland habitats assessment, for monitoring. To simplify the classification task (considering this work as a preliminary phase) we focused on the wetland of lake Koronia (Fig. 4).

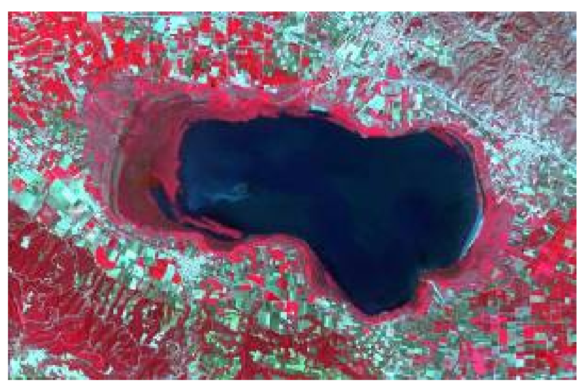

Figure 4. The subset of ALOS image covering the wetland of lake Koronia (experimental study site).

In this study, we assumed that a hierarchical network of image objects results in a better representation of lake-wetland ecosystem complexity [10]. This hierarchy is constructed at four different levels in terms of scale and at three levels in terms of nomenclature (Fig. 5). More specifically, at the lowest scale, the targeted objects are species patches, while at the second lower scale the targeted objects are patches of habitats. The third level has rather technical objective, i.e. discrimination of agricultural fields from natural patches, while the highest scale represents the vegetation and land conditions. In terms of nomenclature, the highest level is that of vegetation conditions (existence of vegetation or water), the second level is that of habitat category (trees, shrubs and herbs), and the lowest level is that of species category (e.g. high reeds, tamarix, etc.)

Figure 5. The schemes of inheritance (left) and groups hierarchy (right).

Multi-scale segmentation was applied on the ALOS image using eCognition 4.0 Professional software (Definiens Imaging, Munich). The process of segmentation divides the image into spatially continuous and homogenous regions called image objects. With this approach adjacent pixels were aggregated in image objects by considering spectral and shape characteristics. According to the hierarchy four different segmentation scales were defined (Tab. 1).

The 1st level (lower level) of segmentation targeted possible single-pixel objects (the minimum possible object size) in order to fit with the sampling scheme (i.e. the 10m su); therefore, the scale parameter was set to 1. Here the objective was the discrimination of the different species found in the study area. At the 2nd level, segmentation targeted at the habitat formation, thus the scale parameter was set to 2 as derived from statistics of the 1st level objects.

Table 1. Parameters opted for segmentation of ALOS image.

Parameter/ Level	Scale factor	Spectral factor	Shape factor	Compact-ness
1st (Species)	1	0.9	0.1	0.5
2nd (Habitats)	2	0.9	0.1	0.5
3rd (Fields)	15	0.7	0.3	0.5
4th (Vegetation)	25	0.9	0.1	0.3

At the 3rd level, after several trial segmentations, the scale parameter was set to 15, where the agricultural fields showed (by visual interpretation) to be segmented properly. This level will be used in the phase of classification in order to filter agricultural fields classified incorrectly as natural species. Finally, the 4th level is a broad (though accurate) discrimination between vegetated land, non-vegetated land, and water bodies (Fig. 6).

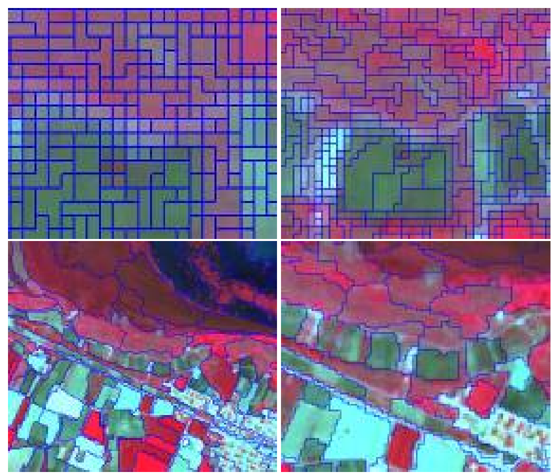

Figure 6. Image subsets from the same area, where the different segmentation levels are shown (UL=1, UR=2, BL=3, BR=4).

Classification followed different techniques on each scale (level). At the 1st level, we applied supervised classification using the training samples selected by the field survey. At the 2nd level, we followed a rule-based approach in order to classify the objects; habitat classes were determined using mainly the rule of relative area of contained species, while additional rules are under elaboration for further enhancement. At the 3rd level, classification also used rules; mainly the shape parameters differentiating fields from natural patches were incorporated in class descriptions. At the 4th level, a rule-based approach used the NDVI value (as a sigmoid fuzzy function around 0.175) to separate vegetation from non-vegetation; water was classified using the brightness value of 30 in the NIR band as a fuzzy threshold as well.

3. RESULTS AND DISCUSSION

The classification resulted in thematic mapping at two different scales (corresponding to the 1st and 4th level respectively); as the results of levels 2 and 3 are not convincing yet, they are still being elaborated. All mapping results have a fuzzy character, i.e. objects are classified to many classes with probability values. For instance, an object can be classified for 0.80 as high reed and for 0.35 as tamarix; the viewing result though will put this object in its primary class (i.e. high reed in this case). At the 1st classification level, results were reliable only along a narrow zone around the lake, i.e. where the wetland is located. This happens because the 1st level targeted the species, thus no other classes were included in the nomenclature. The effect of the higher levels (e.g. 3rd level where agricultural fields are contained) on the 1st level will improve the result and make it acceptable for the entire experimental subset (Fig. 7). At the 4th level the classification separated vegetated from non-vegetated land and water bodies (Fig. 8).

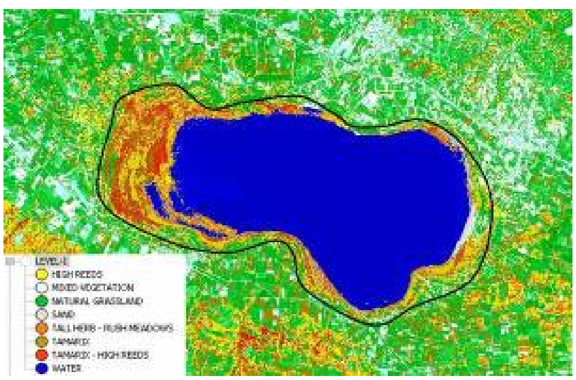

Figure 7. The classified image at the 1st level (species); the black line shows the area of interest, where the results are expected to be reliable.

All mapping results will be evaluated in a twofold way: a) In terms of classification stability, which is defined as the difference of the primary and secondary fuzzy classification values of an object at a specific level on an average and 2) in terms of error matrix, i.e. by checking the truth of the primary classification values with reference data (existing samples from the field survey).

Figure 8. The 4th classification level distinguished vegetated from non-vegetated land and water bodies using rule-based fuzzy algorithms.

4. CONCLUSIONS

The study demonstrates the use of object-based methods for classifying multispectral medium spatial resolution data along with a sampling strategy. Object-based analysis of ALOS imagery achieved to distinguish ecological patches of interest by segmenting the image at the lower possible level and thus express the classification nomenclature for species and habitats in the wetland of Koronia. Use of shape parameters and contextual information was found necessary for discriminating either classes of interest directly or in an intermediate phase. The analysis of ALOS for the purposes of detailed habitat mapping proved a time consuming task, given the fact that the use of heuristics is major part of the approach.

The performance of the developed methodology is still under evaluation. More research is needed to validate our preliminary results and against to traditional pixel-based classification methods. So far, qualitative assessment based on visual interpretation and our familiarity with the study site showed excellent discrimination of the most of the participating species; sources of error included differentiating between phragmites or tamarix-dominated types and sclerophyllous (Q. Ilex)-dominated types founded in the surrounding area. Vegetation existence mapping was obviously excellent as well. Statistical accuracy assessment will be implemented to test classification accuracy. The detailed inventory data will be used to develop spatial statistical models of variables selected to describe wetland habitat structure.

We believe our research study, designed to be independent of high or medium satellite spatial resolution, will be a valuable contribution to our proposed integrated geospatial framework for wetlands under the WETMUST project.

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