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Using Earth Observation to update a Natura 2000 habitat map for a wetland in Greece

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Abstract

The European Habitats Directive 92/43/EEC has defined the need for the conservation of habitats and species with the adoption of appropriate measures. Within the Natura 2000 ecological network of special areas of conservation, natural habitats will be monitored to ensure the maintenance or restoration of their composition, structure and extent. The European Space Agency's GlobWetland project has provided remotely sensed products for several Ramsar wetlands worldwide, such as detailed land cover—land use, water cycle and inundated vegetation maps. This paper presents the development and testing of an operational methodology for updating a wetland's habitat map using the GlobWetland products, and the evaluation of the extent to which GlobWetland products have contributed to the habitat map updating. The developed methodology incorporated both automated and analyst-supervised techniques to photo-interpret, delineate, refine, and evaluate the updated habitat polygons. The developed methodology was proven successful in its application to the wetland complex of the Axios—Loudias—Aliakmon delta (Greece). The resulting habitat map met the European and Greek national requirements. Results revealed that GlobWetland products were a valuable contribution, but source data (enhanced satellite images) were necessary to discriminate spectrally similar habitats. Finally, the developed methodology can be modified for original habitat mapping.

Keywords: Habitat map; Remote sensing; Geographic analysis; Semi-automated methodology; Natura 2000

1. Introduction

Habitat fragmentation and destruction have major impacts on biodiversity, with severe economic, biological, societal and ethical consequences (Harris, 2004). In response, the European Union (EU) issued the Habitats Directive 92/43/EEC (EEC, 1992). The aim of this directive is the conservation of natural habitats, and of wild flora and fauna through the establishment of a network (Natura 2000) of special areas of conservation (SACs) and special protection areas (SPAs). Once designated, Natura 2000 sites are to be protected from deterioration and damage. Furthermore, any loss of protected habitats must be compensated for, by restoration or the creation of new ones, of at least the same surface area and equivalent ecological value. Monitoring the habitats' extent and quality is an essential tool towards this aim.

In accordance with EU legislation, monitoring and reporting on the state, trends and pressures on the habitats is required. A wide range of initiatives is being undertaken in this context by the European member states. Specifically, in 2001, member states reported their progress in legal transposition and implementation of the directive, and the establishment of the Natura 2000 network. A second report is expected from the member states, including the first assessment of conservation status of the habitats and species of community interest that are present in their territory (EC, 2005). Greece has responded to the Habitats Directive with the identification and mapping of habitats within the sites proposed to

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be included in Natura 2000 network (Hellenic Ministry of Environment, 2001).

Monitoring and mapping of the habitats are of importance not only in relation to the implementation of the Habitats Directive itself, but they are also essential for an overall biodiversity trend assessment in Europe. Moreover, they influence the management planning and the conservation priorities (EC, 2005). During the last decades, the scientific community has revealed a significant interest in mapping the natural and semi-natural habitats for the purpose of informing and developing wildlife conservation initiatives (Stevens et al., 2004). Monitoring and assessment has been conducted through a variety of methods, including ground-based and remotely sensed data collection methods.

To meet the requirements of continuous monitoring, the development of cost and time effective techniques is mandatory. Earth Observation (EO) has enormous potential as a source of information for species, habitats, landscape patterns and processes (Bock et al., 2005a; Nagendra, 2001; Nagendra and Gadgil, 1999; Poulin et al., 2002). The advantages offered by satellite EO are: the high resolution coverage of large areas at low cost, observation at several non-visible parts of the spectrum and homogeneous processing across the study area. Several remotely sensed datasets have been implemented in mapping the natural environment, ranging from medium (Debinski et al., 1999) and very high spatial resolution optical (Keramitsoglou et al., 2006), to microwave (Kasischke et al., 1997) and thermal infrared (Capolsini et al., 2003; Salisbury and Milton, 1988). Habitat mapping has been facilitated by the use of a range of techniques, such as: simple image processing techniques (Weber and Dunno, 2001), more advanced object-oriented techniques that classify homogenous areas rather than single pixels (Bock et al., 2005b), pixel window techniques that take into account the influence of their vicinity (Keramitsoglou et al., 2006), a contextual classifier (Hubert-Moy et al., 2001), a neural network classifier (Keramitsoglou et al., 2005), and more recently a neuro-fuzzy classifier (Mitrakis et al., 2007). Particularly within the Natura 2000 network, a number of studies have attempted to map habitat classes using EO (Bock et al., 2005b; Boyd et al., 2006; Keramitsoglou et al., 2005), providing results that contribute towards the implementation of the Habitats Directive.

Results from automated methods generally report high performance, but accuracy may be very low in difficult classes (Bock et al., 2005b), which is insufficient for the requirements of a map related to European and national legislation. This low performance could be partially attributed to the indirect correspondence between spectral classes and habitat types. In fact, only a few habitats display a direct one-to-one relation with the spectral classes that can be defined on EO data, while the relation is usually many-to-many (Halada and Bugár, 2005; Nagendra and Gadgil, 1999; Poulin et al., 2002). Therefore, although the above-mentioned products from automated techniques have undeniably contributed towards the requirements of the Habitats Directive, they have yet to provide an operational solution.

Earth Observation for Natura 2000 (EON2000 project website, 2007) was a project that aimed to bridge these problems and facilitate the implementation of EO in monitoring protected areas. Recently, the SPIN project (Spatial Indicators for Nature Conservation, SPIN project website, 2007) examined the utility of a set of indicators derived using satellite images and GIS modelling for characterising the status of protected environments, including a wetland in northern Greece. Lately, the GlobWetland project (GlobWetland project website, 2007) has used EO for providing geographical products to meet the needs of Ramsar wetland managers, such as detailed land cover, water cycle extents and inundated vegetation maps. Through this project, five Natura 2000 wetlands were mapped in Greece, and thematic maps that described human pressures and ecosystem state were produced. Using these products, the existing habitat maps (Hellenic Ministry of Environment, 2001) of the sites were updated, in order to contribute to the requirement for a national report that arises from the Habitats Directive (article 17).

The aim of this work was to update a wetland's Natura 2000 habitat map using satellite EO products produced within the GlobWetland project. This was achieved through: (i) the development of an operational methodology that was tested on the GlobWetland sites, and (ii) the evaluation of the extent to which GlobWetland products contribute to the process of habitat map updating. The results from the selected prototype site only (delta of rivers Axios–Loudias–Aliakmonas) are presented in this paper.

1.1. Framework for habitat mapping

The main aim of the project ''Identification and description of habitat types in areas of interest for nature conservation'' was the identification, description and mapping of habitat types listed in Annex I of the Habitats Directive 92/43/EEC and of other habitat types present in Greek marine and terrestrial sites. The project was supervised by the Greek Ministry of Environment and was carried out during 1999–2001 covering 304 sites of the Natura 2000 network (Hellenic Ministry of Environment, 2001).

The determination of a habitat type's geographic limits was accomplished through in situ sampling, photo-interpretation of photomaps, and digitisation of topographic maps. The fieldwork included the identification of the site and selection of representative sampling areas. A first approach to the site's main vegetational and other characteristics was based on data captured from photomaps, topographic maps, and bibliographic data, whereas existing datasets were utilised when they had been collected by similar methods. The representative sampling areas for each vegetation type were selected during fieldwork, taking into consideration that: (i) they should be large enough to include all species of the plant community, (ii) the ecological circumstances are relatively constant within the sampling area, and (iii) the vegetation is homogeneous within the sampling area. The total dataset of sample plots was stored in a database managed by the Turboveg software package (Hennekens, 1995) and subjected to TWINSPAN, a method for polythetic divisive classification (Hill, 1979). TWINSPAN was used to classify the vegetation samples into phytocommunities, which represented the habitat types that were present in the study area.

Mapping employed standard interpretation techniques to identify homogeneous areas based on their differences in tone, texture and pattern, assisted by field verification. Each habitat polygon was considered to be uniform and homogeneous, and was connected with floristic composition per vegetation unit. The minimum mapping unit was 0.01 km^2, and the map production scale was 1:20,000. The final deliverable of the project was maps displaying the spatial distribution of habitat types (hereafter ‘‘habitat maps of 2001’’) and the location of the representative sampled areas.

The project's results were valuable for the implementation of Habitats Directive in Greece and they can be used as baseline data for issuing environmental permits, as well as for management plans, future monitoring and early detection of environmental changes, etc.

2. Materials and methods

2.1. Study area

The delta of the rivers Axios–Loudias–Aliakmonas is situated in northern Greece (Fig. 1). It is a wetland of international importance according to the Ramsar Convention (site code 59, area 118 km^2). A number of important habitats for rare and endangered species are located in this area. It is, therefore, part of a special protected area designated by the implementation of European Directive 79/409/EEC (EEC, 1979) (site code GR1220010, area 295 km^2) and a site of community importance following the implementation of the Habitats Directive (site code GR1220002, area 336 km^2). Moreover, the study area is designated as being part of an ecologically important area, protected under a national joint ministerial decision.

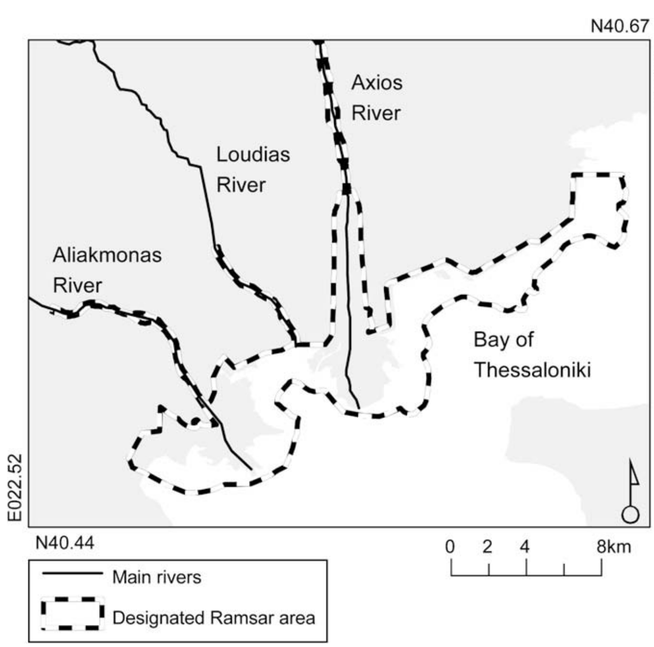

Fig. 1. Location map.

From a geo-morphological point of view it is a complicated deltaic system with numerous ramifications on the rivers' watercourse. As a result, the habitats consist of small interwoven patches of high biodiversity. The biological value of the area is high: aquatic flora, fish species (some considered vulnerable and are protected by fisheries legislation), reptiles, amphibians, mammals (some included in the various vulnerability categories in the Red Data Book on Threatened Vertebrates of Greece) and avifauna (approximately 215 bird species have been recorded, some of which nest in the area and the rest stop by or winter there). Most of these bird species are protected by legislation.

The Axios–Loudias–Aliakmonas delta constitutes one of the most ecologically and economically important wetlands in Greece with multiple services, such as provisioning, regulating, supporting and cultural (MA, 2005). The floodplain upstream of the delta is one of the most productive agricultural areas of Greece, in which extended reclamation and irrigation projects have been carried out since the 1930s. In addition, aquaculture is one of the most important economic activities in the bay, currently accounting for 88% of the national mussel production (Askew, 1987; NCRM, 2001). Furthermore, economic growth has lead to industrial development; this has resulted in the expansion of the industrial zone of Thessaloniki up to the north-eastern boundary of the study area (Poulos et al., 1994).

The majority of environmental problems affecting the study area arise from human activity: dams and irrigation networks, drainage works, pollution of surface waters, over-fishing, extensive aquacultures and in particular mussel farming, hunting, overgrazing, illegal sand extraction, construction of illegal settlements on the coastline and poor management of water resources (Zalidis et al., 1997).

The habitat types of Annex I of the Habitats Directive that were identified in the habitat maps of 2001 in the study area are displayed in Table 1.

2.2. Datasets and methods

A set of GlobWetland products has been used as input in this work. These are digital thematic maps, which were produced by the GlobWetland project team and were designed to meet wetland managers' needs (Jones et al., 2006).

- Land use–land cover map (LULC). The study area was categorised following the CRAMSAR nomenclature (STRP, 2005), which is a modified CORINE land cover classification scheme to incorporate the detailed Ramsar wetland classification (Table 2). According to CRAMSAR nomenclature, the LULC of the study area consisted of 12 classes. Automated object-oriented classification was incorporated in order to segment a multispectral SPOT 5 image (acquired on 19/08/2004) into objects, based on their spectral and shape characteristics. Following

Table 1
Habitats of Annex I of the habitats directive identified in the study area

Habitat code	Habitat description
1061[a]	Unvegetated sandy substrates
1130	Estuaries
1150[b]	Lagoons
119B[a]	Vegetated soft substrates
1310	*Salicornia* and other annuals colonising mud and sand
1410	Mediterranean salt meadows (*Juncetalia maritimi*)
1420	Mediterranean and thermo-Atlantic halophilous scrubs (*Arthrocnemetalia fructicosae*)
3150	Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation
3280	Constantly flowing Mediterranean rivers: *Paspalo-Agrostidion* and hanging curtains of *Salix* and *Populus alba*
32B0[a]	Muddy banks of Euro-Siberian rivers with annual vegetation
6290[a]	Mediterranean subnitrophilus grasslands
651A[a]	Mesophile pastures
72A0[a]	Reed beds
92A0	*Salix alba* and *Populus alba* galleries
92D0	Thermo-Mediterranean riparian galleries (*Nerio-Tamariceteae*) and south-west Iberian Peninsula riparian galleries (*Securinegion tinctoriae*)

[a] Habitats not included in Annex I.
[b] Priority habitat type according to Annex I.

segmentation, features such as reflectance, shape, hierarchy or thematic attributes were used to assign the objects into the corresponding classes (Baatz et al., 2002). The result was further improved with manual analyst classification based on fieldwork knowledge. The resulting LULC map was validated against field observations using a confusion matrix, reaching an overall accuracy of 85%.

- Water cycle map. Radar imagery, with its advantageous ability to accurately detect specular reflectors such as water bodies, was utilised. RADARSAT fine beam images (acquired on 04/08/2004, 09/11/2004 and 02/04/2005) were low pass filtered to remove speckle. The radar images were processed to produce a separation index image, the normalized difference radar index (NDRI):

$$\mathrm{NDRI} = \frac{(R_{\min}+R_{\max})}{(R_{\min}+R_{\max})}$$

where $R_{\min}$ was the minimum and $R_{\min}$ the maximum backscatter of the input radar images for each pixel (De Moraes Novo et al., 1998; Gimeno et al., 2004). Segmentation algorithms were applied to the NDRI image, and objects of low backscatter were assigned to the classes of interest: high seasonal water extent and low seasonal water extent. The resulting water cycle map was validated against field observations collected during high (spring) and low (autumn) water levels, reaching an overall accuracy of 90%.

Table 2
LULC classes in the study area following the CRAMSAR classification system

CRAMSAR code	LULC description
3112	Wet forests including riparian
321	Natural grassland
324	Transitional woodland shrub
333	Sparsely vegetated areas
411	Inland marshes
421	Salt marshes
4215	Halophytes and tamarisks
4232	Intertidal forested wetlands
511	Water courses
512	Water bodies
521	Coastal lagoons
523	Sea and ocean

- Inundated vegetation map. The effect of 'double bounce', which is a double reflection from standing vegetation in water, was utilised. In a process similar to the water cycle map, inundated vegetation was mapped as areas of high backscatter on the filtered radar images.

The mapping accuracy of these GlobWetland products was equivalent to a scale of 1:10,000, and the minimum mapping unit was 0.01 km^2.

Other auxiliary datasets that have been used and the adopted methods of digital processing were:

- Original habitat map of 2001 produced with the methodology outlined in Section 1.1, and the results of the detailed vegetation survey.
- Field visits during image acquisition. The locations visited were documented using a handheld PC connected to a GPS and a digital camera. A habitat class was associated by visual identification.
- Black and white photomaps, scale 1:5000, acquired in 1996.
- Source data: subsets of the satellite images (SPOT 5 and RADARSAT) that had been used in the GlobWetland products.
- A Digital Elevation Model (DEM), which was produced with interpolation of elevation contours and points using the ANUDEM method (Hutchinson, 1989).

Digital image processing was performed in ERDAS Imagine 8.7 (Leica Geosystems GIS & Mapping LLC) and eCognition v.4 (Definiens Inc.). Geographic analysis, digitising and cartographic production was performed in ArcGIS 9.1 (Environmental Systems Research Institute, Inc.). Field locations were taken with a standard 12 channel GPS receiver.

3. Results and discussion

3.1. Methodology for updating a wetland's habitat map

The proposed methodology involves a combination of both automated and analyst-supervised techniques. It consists of the following steps (Fig. 2):

- *Step 1: image enhancement and processing*. Satellite images were enhanced to increase the level of provided information. RADARSAT image was filtered using a Lee-sigma spatial filter (Lee, 1986) to remove noise, which appeared in the form of speckle and would hinder information extraction. A radiometric piecewise stretch was applied to the individual bands' histograms of the

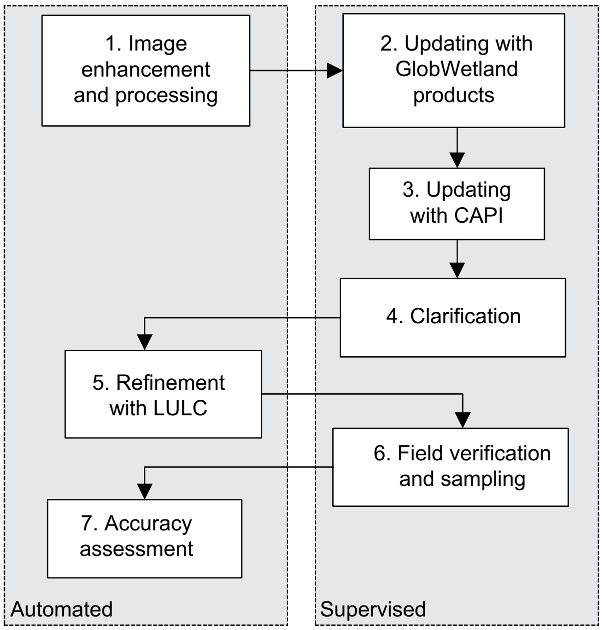

Fig. 2. Flowchart of proposed methodology.

SPOT 5 image, to enhance the appearance of the wetland parts of the image. Finally, texture analysis was performed on the bands of the SPOT 5 image, which increased the contrast between areas of uniform and variable pattern. Several sizes of moving window were examined to reveal changes in the scale of the pattern.

- *Step 2: updating with GlobWetland products*. Input datasets were overlaid in the Geographic Information System (GIS) using variable levels of transparency. The selected dominant information layers were the habitat map of 2001, and the LULC map. Where appropriate, inundated vegetation and water cycle maps were also included. A first level of mapping was performed with these datasets, using on-screen digitising. The habitat polygons of 2001 were corrected in cases where LULC changes had occurred.
- *Step 3: updating with computer assisted photo-interpretation (CAPI)*. The preliminary updated habitat polygons were overlaid on the enhanced satellite images to detect within and between polygon variability in tone, colour, pattern, and composition. Through careful CAPI, the preliminary updated habitat polygons were corrected, divided or merged as appropriately, to match patterns visible on the enhanced satellite images. This second level of mapping was essential in order to detect the subtle differences between habitats that had not been depicted during the production of GlobWetland products.
- *Step 4: clarification*. Areas of confusion were clarified using 3-dimensionl viewing of high-resolution photomaps. Perspective pseudo-3D viewing has been used to differentiate vegetation based on the terrain of their usual location (Weber and Dunno, 2001). Also, the detailed information offered by the photomaps was proven useful where the spatial resolution of the satellite image was insufficient.
- *Step 5: refinement with LULC map*. A wall-to-wall (i.e. covering the entire map and not a sample) comparison was performed between the LULC map and the preliminary updated habitat map to reveal consistent errors that have occurred. Using overlay analysis a cross table was produced that contained the area coverage of each combination of classes of the two input datasets. Considering that there is no one-to-one link between the classes of the two datasets, the cases of agreement were spread throughout the table, and not only in the diagonal. The resulting table is similar to an error matrix and estimates errors of omission, which is an indication of how well a certain area on the ground can be classified, and errors of commission, which is the probability that an area assigned to a class actually represents that class on the ground (Congalton, 1991). In this case, errors of commission were only evaluated in order to verify if the habitat class attributed to each polygon corresponded to the appropriate LULC class determined in the equivalent map. The disagreements that were identified in this step were examined in the GIS using CAPI, and corrections were performed on the updated habitat map.
- *Step 6: field verification and additional sampling*. Habitat ambiguities that could not be identified in the laboratory were noted and were examined during field verification. Field clarifications were incorporated to produce the final updated habitat map. Additional sampling was conducted to document changes in vegetation's structure and type of habitat.
- *Step 7: accuracy assessment*. The accuracy of the map was evaluated using a sample of field observations that had not been used in the updating procedure. To assess the accuracy of the updated habitat map, the habitat classes identified on the field were compared with the classes of the updated habitat map on each observation point. The calculated overall accuracy was an indication of the quality of the map. The k hat statistic was also estimated, which gives the probability that the result is significantly better than a random result achieved by chance (Congalton, 1991).

3.2. Application to the delta of Axios–Loudias–Aliakmon

The developed methodology was used to update the habitat map of 2001 in the study area. The GlobWetland products, together with the enhanced satellite images were used in the updating procedure. In addition to these, the detailed information offered by the photomaps was proven useful in cases of low features differentiation, such as forest from shrub dominated habitats, habitats that were composed of patches smaller than the spatial resolution of the satellite images, and cultivated fields that did not have a regular shape but their cultivation lines where visible on the photomaps. Perspective 3D viewing was not useful in the study area, as the landscape was predominantly flat.

After the preliminary habitat map was produced with on-screen digitising, it was refined with the use of the LULC map. In the resulting cross table, all the cases of disagreement were examined with careful photo-interpretation. Most of these were cases of ambiguity in the classification scheme, e.g. habitat type 3150 (Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation) could partially be LULC class 411 (inland marshes) and 421 (salt marshes), when dominated by wetland vegetation. A consistent error was noted in habitat type 6290 (Mediterranean subnitrophilus grasslands), where certain salt marshes had been photo-interpreted erroneously, and was corrected.

The results were displayed in the form of a map that described the spatial distribution of the updated habitat polygons, and a table that provided statistics about the frequency of appearance and total area of each habitat type. A sample of the updated habitat map is presented in Fig. 3, together with the habitat map of 2001, and the LULC map for purpose of visual comparison. It is evident that some habitat polygons have undergone severe changes in their extents (Fig. 3a,b), while others did not change (Fig. 3c). Part of the geographic mismatch of the habitat map of 2001 could be attributed to the low scale of production.

The accuracy of the updated habitat map was assessed using a set of 162 points selected by stratified random sampling on the updated habitat map. A habitat class had been associated to these points by visual identification during fieldwork. After comparison of the habitat classes identified on the field with the classes of the updated habitat map on each point, the overall accuracy (93%) and the k hat statistic (0.91) were estimated.

3.3. Evaluation of methodology and contribution of GlobWetland products

The overall accuracy and reliability of the results were very high and met the requirements set (Hellenic Ministry of Environment, 2001), which was expected from a semi-automated methodology in which the analysts had a close supervision and the possibility for manual error correction throughout the procedure. Nevertheless, this high level of quality was required for a map related to European and national legislation. The time and effort involved for this methodology was relatively high, as on-screen digitising and simultaneous photo-interpretation of several information layers was a laborious task.

Compared to fully automated methodologies, the developed methodology was relatively slower and more resource demanding. However, the reported accuracy of the automated methods is considerably lower (Bock et al., 2005b; Keramitsoglou et al., 2006; Keramitsoglou et al., 2005). Compared to the result produced by the original methodology (Hellenic Ministry of Environment, 2001), the developed methodology provided a higher mapping accuracy due to datasets of higher spatial resolution, better discrimination of objects due to the wider variety of image bands, and required less fieldwork.

The input GlobWetland products were proven useful in the application of the methodology. The accuracy of the LULC map was high even in the complex ecosystem of the study area and classes corresponded well to the actual habitats on the ground. This was valuable in the updating procedure, as it reduced the effort for photo-interpretation of source data. LULC objects created with object-oriented classification were more uniform than traditional raster based results, and thus easier to manipulate in a map updating procedure. In a similar way, the water cycle and inundated vegetation products provided ready-to-use information and facilitated the updating of certain habitat types, such as 1310 (*Salicornia* and other annuals colonising mud and sand). However, LULC

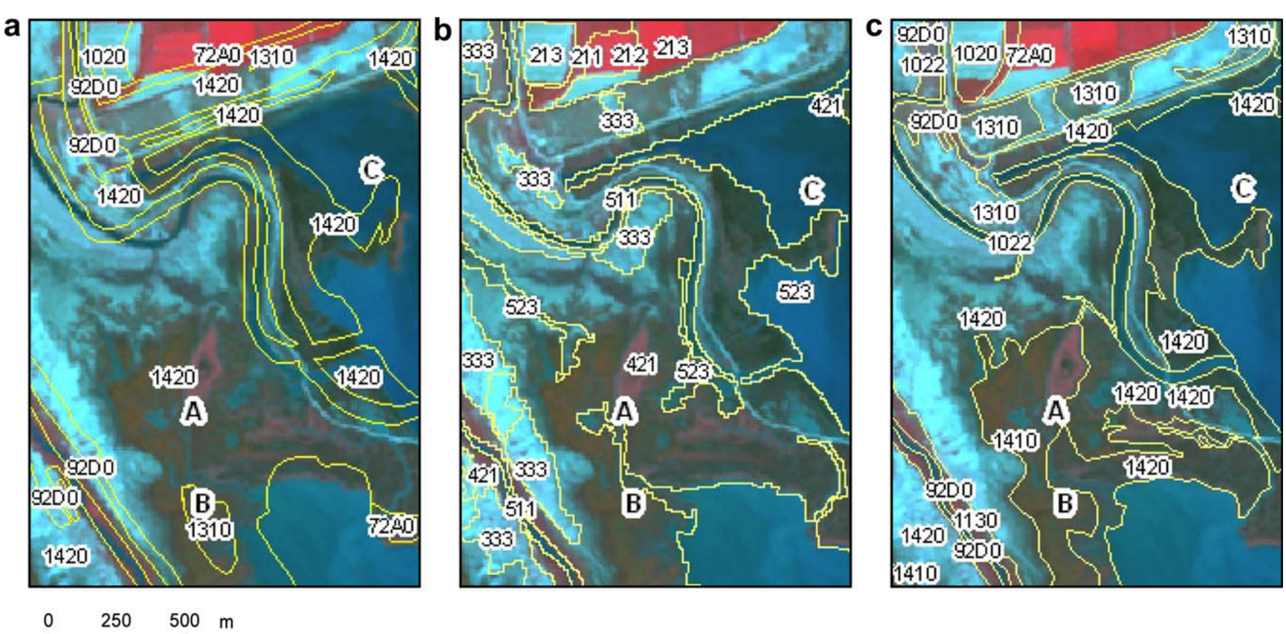

Fig. 3. The habitat map of 2001 using the original methodology (a), the LULC map (b), and the updated habitat map using the proposed methodology (c), focusing in Axios delta. Habitat codes and LULC codes displayed in each polygon are listed in Tables 1 and 2, respectively. Background reference is SPOT 5 image (RGB = 3, 2, 1).

classes were broad and not designed to detect subtle differences between spectrally similar habitat types. This was an expected weakness that originated from the adopted classification system and could not be attributed to the method of LULC map production. Nevertheless, this was overcome within the context of the developed methodology with CAPI (step 3).

Source data (enhanced satellite images) provided useful information in the second level of mapping. Energy reflected on the near-infrared and middle-infrared parts of the spectrum were particularly sensitive to chlorophyll and moisture content, and helped differentiate between several types of wetland vegetation. Variation in the reflected microwave signal was used to detect differences of roughness of vegetation cover, and in certain cases, distinguish wetland forest areas from shrubs. High-resolution photomaps were not essential, considering the detail required and map production scale, but were proven useful to keep the list of ambiguities that required field verification to a minimum.

3.4. Applicability and limitations of methodology

The developed methodology has been applied to update the habitat map of four other Greek Ramsar wetlands within the implementation of GlobWetland project in Greece, which are included in the Natura 2000 network: artificial lake Kerkini (site code 58, area 109 km^2), Amvrakikos gulf (site code 61, area 236 km^2), Kotychi lagoons (site code 63, area 63 km^2), and lakes Koronia–Volvi (site code 57, area 163 km^2). Compared to the application in the delta of Axios–Loudias–Aliakmonas, no modifications were necessary to cover the specific conditions of these other sites, and results revealed similar accuracy (Zalidis et al., 2006). The high complexity and detailed habitat pattern of the study area was the reason for its selection in this work.

The developed methodology could also be used for original habitat mapping, after some modifications. First, the LULC map would be used directly as a preliminary habitat map, which would subsequently be refined using the enhanced satellite images. Second, a larger number of vegetation samples would be required to verify and document each habitat type. In general, satellite images and fieldwork would substitute the existing habitat map of 2001.

Regarding its applicability on a European level, the scale specifications set by national legislation, and local landscape complexity and vegetation variability would have to be addressed. A variable sample of European Ramsar wetlands has been examined within the GlobWetland project, providing acceptable results (Jones et al., 2006). Considering the significant contribution of the GlobWetland products, there is a strong indication that the proposed methodology can perform under these conditions. However, further testing is necessary to assess the methodology in different scales and environments.

The most notable limitation of the proposed methodology is the wave effect on the interpretation of surface water bodies from radar images. Waves caused by wind and rain increase surface roughness of water bodies. As a result, radar backscatter of water surfaces is increased and information is obscured. Use of an alternate date image has been suggested, as low pass filtering was not successful to reveal patterns in the wave affected area (Topaloglou et al., 2006).

Using the proposed methodology, the habitat map was updated regarding habitat polygon extents. This information, together with an analysis of pressures is essential to indicate a decrease in the conservation status, which would provide guidance for intensive monitoring and analysis of habitat structure and composition (EC, 2004).

The usefulness of results could be enhanced, if certain GlobWetland products (water cycle and inundated vegetation maps) were used to describe the spatial correlation of habitat types with hydroperiod types (Cowardin and Golet, 1995). This could contribute towards understanding the structure and condition of the riparian or intertidal zone that is needed to support the biological quality elements (WFD CIS Guidance Document No. 12, 2003).

4. Conclusions

The developed methodology was proven successful in its application to the wetland complex of the Axios–Loudias–Aliakmon delta, as the resulting habitat map met the European and national requirements. Compared with the original methodology and with the reported fully automated methods, the developed methodology provided higher accuracy and reliability and was faster than the original, but could not compete with the speed of the automated methods.

GlobWetland products were a valuable contribution to the proposed methodology, and were used extensively during the updating and refinement steps. The main benefit gained from the use of information products, as compared to source data, was to reduce the effort of photo-interpretation. Some of the auxiliary datasets were not essential to the implementation of the methodology in the study area, but may be required in applying the methodology to other Natura 2000 wetlands.

The implementation of the developed methodology and consequently the update of habitat maps in protected areas constitute an efficient tool in planning, management, and assessing the effectiveness of measures. Moreover, it can provide guidance for setting priorities in conservation policy and influence land use planning.

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