Towards a standardised methodology for inventorying and monitoring Mediterranean wetlands using Earth observation

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ABSTRACT

Knowledge and expertise on using Earth observation (EO) technology are being exchanged in the framework of several projects in order to establish a standardized methodology aiming at inventorying and monitoring Mediterranean wetlands at site, catchment, national, and regional levels. The strong points of EO include the enhanced spatial, geometric and spectral characteristics of the new satellite sensors, the possibility to choose from a variety of sensors in respect to mapping scales and nomenclatures, and the cost effectiveness of the approach. The aim of this paper is to demonstrate how EO can assist the establishment of a comprehensive methodological approach to achieve a multilevel inventory and monitoring of Mediterranean wetlands. ISARS/NOA Remote Sensing Group is employing hybrid data processing methodologies, combining visual and computer assisted photointerpretation, as well as advanced computer methods using spectral/textural/ contextural classifications and change detection to define the status and trends in wetland ecosystems.

1. BACKGROUND

The Mediterranean Wetlands Initiative (MedWet) was founded in 1991 as a long-term regional collaboration initiative among Mediterranean countries, specialised wetland centres and international NGOs active in protecting wetlands.

Mediterranean wetlands, typically made up of river deltas, lagoons and temporary marshes, are valuable natural resources that have provided essential services (clean water, protection from floods, stabilising of the sea shore, fisheries and agriculture) to people for thousands of years. Many Mediterranean wetlands are lost compared to 100 years ago, and the remaining valuable ones are still under threat of loss and degradation.

In May 1999, MedWet was placed under the aegis of the Ramsar Convention on Wetlands by the seventh Conference of the Contracting Parties (COP7, Costa Rica), which officially endorsed this structure as a model of regional collaboration for the Convention. At the heart of the MedWet Initiative lies the aim of promoting the wise use of wetlands, access to wetland resources, poverty alleviation, food and water security and the maintenance of biodiversity of wetlands.

From its inception, the Mediterranean Wetlands Initiative with its multi-actor approach, has focused on the development and testing of tools and methodologies adapted to the specifics of the Mediterranean. With the realisation that a clear understanding of the distribution, size and types of wetlands as well as the assessment of their change over time are crucial to securing their wise use and conservation, MedWet has focused its activities on the development of methods and tools on wetland inventories, assessment and monitoring.

These methods and tools were developed during the MedWet 1 (ACNAT) project and presented in 1996 at its closure in a Conference on Mediterranean Wetlands in Venice. They consist of a series of manuals [1, 2, 3, 4] complemented by a database software package [5] and a methodological guide for planning monitoring programmes [6].

Over the last decade the partners in the MedWet Initiative have been further developing their inventory toolkit and the related data support structures and have thereby addressed the part of the request for information under the Ramsar Convention dealing with the need for a regional wetland inventory. To this direction, the MedWet inventory methodology and the successive versions of the MedWet Database have been used in some ten countries for inventorying wetlands [7]. In most cases, it has been used directly (in Portugal, in Greece, in Albania, in Slovenia, in FYROM, in Morocco, in Croatia, in Italy, in Spain, etc.), while in one case it has been further adapted (by the "Agence de l'Eau" RMC in France).

Nonetheless, the previous attempts have not been undertaken with a specific view to create a common knowledge base on Mediterranean water-related ecosystems. As a result so far there has not been an attempt to link together these efforts. At the same time MedWet has put increased effort to promote the inventory methods and tools through big or small projects led by MedWet partners (MedWet 2, MedWetCoast, Albanian Wetland Inventory, MedWet/Regions and MedWet/SUDOE projects, etc). During these projects it became obvious that the MedWet inventory method should be updated in order to integrate information in line with the European legislation (Water Framework Directive) and to incorporate state-of-the-art technologies on inventorying, monitoring and data management and processing in order to be successful in responding to future targets and related requirements of an international or even the EU 2010 biodiversity target.

To meet the above mentioned considerations, a new project was conceptualised and was funded by INTERREG IIIC, named MedWet/CODDE. The project is executed by six partners – MedWet Secretariat (project leader), Greek Biotope / Wetland Centre (EKBY), Station Biologique de la Tour du Valat (TdV), Instituto da Conservação da Natureza (ICN), Agenzia Regionale per la Protezione Ambientale della Toscana (ARPAT) and Geography Institute of Tartu University in Estonia (IGUT). The partnership aims at bringing together a strong technical and scientific capacity, while putting to full use the outreach potential of the broad and long established MedWet network.

The main objectives of the MedWet / CODDE project are to: (1) exchange existing knowledge and expertise on inventorying ecosystems through the revision of the MedWet inventory method for meeting new EU obligations and adapting new technologies (Earth Observation products), (2) establish mechanisms for data exchange focusing on ensuring the participation of states, produce exchange protocols, and develop a web based information system, and (3) encourage decision makers to force and support actions such as, inventory and monitoring wetlands following the MedWet method and provision of existing inventory data for storing them in the MedWet web-information.

Overall, the MedWet/CODDE project is considered as a fundamental step towards the establishment of a dynamic schema of collaboration for evaluating the status and trends of wetlands in the Mediterranean region. An important part of this effort is the integration of remote sensing methods and tools to the MedWet inventory method. To this direction, a group of experts is collaborating with MedWet to standardize the method for inventorying and monitoring Mediterranean wetlands using EO.

2. FRAMEWORK FOR INVENTORING AND MONITORING MEDITERRANEAN WETLANDS USING EO DATA

The conservation of Mediterranean wetlands requires a good knowledge on the location, extent, conservation status and trends of these areas. The analysis of the wetland resources, their status and trends, and the dissemination of the results are fundamental for mobilising the decision-makers about the need to conserve, manage and use aquatic ecosystems in a sustainable way. This should be reflected through the adoption and implementation of national wetland policies and action plans. In addition, data exist for many countries, regions and individual sites or taxonomic groups, but often they are not easily accessible and they are under different formats.

Aware of the great problems facing wetlands in the Mediterranean region, the biological station of Tour du Valat is promoting a partnership to create an "Observatory of Mediterranean wetlands" that aims to assess the conservation status and the trends, and to disseminate the results in order to mobilize decision-makers.

In this line, the Greek Biotope Wetland Centre (EKBY) is proposing a framework for inventorying and monitoring Mediterranean wetlands using EO data. It is important to note that, so far, no specific project, dealing with the use of EO data, has faced the mapping of wetland resources in a multilevel approach; there is, however, a plethora of EO data sources and relevant methodologies. The present paper sets up the framework into which this effort will be gradually further developed. More specifically, this framework is constituted by two broad components: (a) wetland mapping and (b) monitoring of sentinel wetland sites, which are described next. The second component is being developed in collaboration with the Coastal Global Terrestrial Observing System (C-GTOS). ISARS/NOA Remote Sensing Group is responsible for the development and / or integration of certain EO applications to implement the inventory and monitoring framework.

Component (a): Wetland mapping

Answering the challenge of mapping wetlands in a multilevel approach, the present component is further analysed in three levels, namely national or regional, catchment and site following a top-down process. Each level has its own main objective and a different methodological approach is consequently applied. The outputs of each level are, however, complementary and can be used as resource data for the others. The objective of each level is: (i) national or regional level: to register the country's or region's wetland areas and map their approximate cover; (ii) catchment level: to map the land cover of the catchment's wetland areas; (iii) site level: to map the resources of a wetland site.

- At first and second levels, field work is restricted only to verification of the classification results based on EO data. At the third level, field work is further extended for the purpose of the delineation process of the wetland site boundaries, during which more accurate and long period data on vegetation, soil, and water regime are required.
- The outputs of each level are produced at different scales: (1) National or regional 1:1 000 000 – 1:300 000 (depending on the size of the country/region) (2) Catchment: 1:200 000 - 1:50 000 (3) Site: 1:25 000 – 1:5 000 (for small sites a larger scale may be needed)
- Classification Systems. At first level wetland areas are classified according to Ramsar wetland types. At second level CORINE land cover is used with the extensions proposed during the Globewetland project or according to the MedWet Habitat Description System. At third level, wetland habitats are classified according to Ramsar wetland types and to the MedWet Habitat Description System.
- The outputs of each level are digital thematic maps depicting wetland areas classified according to the pre mentioned classification systems. Appropriate background information is depicted such as hydrographic network, cities and towns etc.
- Main uses of the outputs are: (1) Establishment of national wetland lists to support wetland inventories at national or regional level, (2) Assist wetland status and trends assessment in Mediterranean, (3) Assist planning, accounting, assessment etc. for nature conservation purposes in conjunction with outputs and tools of the EU Directives (i.e., Habitats, WFD) or strategies like ICZM or with the Land and Ecosystem Accounting method (LEAC) of EEA, and (4) Provide input to the "Observatory of Mediterranean wetlands", a tool for assessing the status and trends of Mediterranean Wetlands.

Component (b): Monitoring of sentinel wetland sites

The concept of sentinel ecosystems was developed by Jassby [8] and further adopted for observing systems [9]. For observing systems sentinel ecosystems represent a limited number of sites within international programs, such as MedWet, Ramsar, Man and the Biosphere, etc. These systems should be relatively well understood with substantial datasets. Society should value them such that management and protection are fostered. Further, there should be commitment for sustained observations – past, present and future. The network of sites can then form an early warning and core system for assessment of boarder regional and global change.

Establishing a network of sentinel wetland ecosystems within the Mediterranean depends on information available from MedWet, Ramsar and GTOS. The information includes (1) an appropriate classification of wetlands, (2) locations of different wetland sites by class, (3) assessment of condition of selected sites, and (4) determination of accessibility to site data and sustainability of measurements within the sites.

As an initial effort, a GIS tool from the Food and Agriculture Organization of the United Nations (FAO) has been used to summarize information on Ramsar sites of countries from the region of the Mediterranean Sea. A GIS database from the original site descriptions was created. Subsequently, the database was used to assess (1) the number of sites and types of wetlands and (2) the recognized values of and threats to the sites.

Within the Mediterranean region, the project will next involve MedWet and its wetlands that are beyond Ramsar sites. Efforts to enhance the classification schemes of wetlands and include hydrogeomorphic classifications can be included. Then using the expertise of MedWet and Ramsar, the final steps will be conducted to establish a network of sentinel wetlands within the Mediterranean.

3. ADVANCES IN EO - THE ROLE OF ISARS

In the context of the above mentioned purposes, there is a large assortment of EO data available that can be used. These data currently provide the users with a variety of temporal, spatial and spectral information. The choice of EO data types as well as of methods applied to process these data depends on the specific application and of the level of detail and accuracy required.

Traditional supervised classification methods using EO data are “pixel based”. These originate from simple statistical models. For instance, maximum likelihood (MLH) decision rule is based on the probability that a pixel belongs to a particular class, assuming a Gaussian model for the distribution of pixels from each class. Such classifications are pixel based in the sense that the algorithm attributes a specific class label to one particular pixel without taking into account the vicinity of this pixel. The classification accuracy achieved with MLH varies considerably from 60 to 90%, depending on the number of classes and the complexity of the area covered by the satellite scene.
Since very high spatial resolution satellite data (with ground sampling distance < 10m) became available, the performance of the previous “traditional” classification schemes has relatively decreased. This becomes apparent with the following example: let us assume the same complex wetland scene acquired by multispectral sensors onboard Landsat and IKONOS-2 satellites with ground sampling distances of 30 m and 4 m respectively. The 30x30 m^2 pixels of Landsat will give the spectral signature resulting from the contribution of several land cover types (mixed pixel or “mixel"), for example trees, water, bushes etc. In the case of an IKONOS-2 multispectral 4x4 m^2 pixel, the situation is somewhat different as each individual object (e.g., a forested habitat) consists of a number of pixels. Therefore, when applying a pixel based classification scheme, the output will be quite homogeneous in the first case and rather noisy in the second, a since in a typical Mediterranean wetland many different spectral classes may be present.

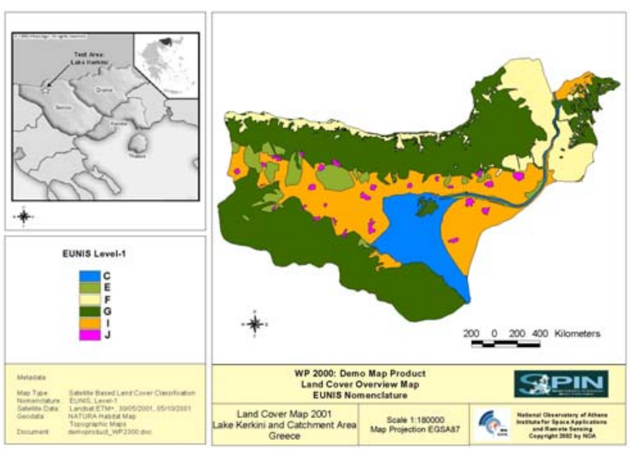

Figure 1: Demo Map Product of Lake Kerkini (catchment level) in Northern Greece [SPIN Project]

From the above it has become clear that the requirements in spatial resolution and the corresponding possibilities from extracting information from a single satellite image are linked not only to the object size and type but also to the actual task and information requirements of the user. It is nonetheless clear that traditional pixel based automatic classification methods are not flexible in integrating satellite images of different resolutions, and they do not take into account the context and shape of an area. Object-oriented classification approaches use, in general, flexible software packages allowing the integration of ancillary data and the combination of images with various resolutions. They also use the shape and context of an area in the classification process but they are demanding in hardware requirements. Finally, semi-automatic Computer Assisted Photointerpretation (CAP) enables the user to have full control on the classification result, which is in vector format, and has low hardware requirements. CAP is, however, a time consuming and labour intensive method. An example of CAP methodology applied to classify Kerkini catchment area (in Northern Greece) in EUNIS first level nomenclature can be seen in Figure 1.

ISARS/NOA Remote Sensing Group has employed advanced computer methods using spectral/texture/contexture classifications so as to define the status and trends in ecosystems. In particular, new techniques that take into account not only the spectral signature of an individual pixel but also the spatial features extracted from the vicinity of the pixel, within a specified pixel window [10] are examined. Three different pixel window classifiers are briefly presented next.

- The first method is **kernel based re-classification (KRC)** software developed by Barnsley and Barr [11]. Originally the concept of land use classification using a cover frequency method was introduced by Gong and Howarth [12] who appreciated the weaknesses of pixel based classification of high spatial resolution images and applied it to SPOT-HRV images. The overall classification accuracy reported until now in the literature varies from 74% [13] to 96% [11] using a two-date multispectral set of IRS-1C LISS-III and Pan, and a single multispectral SPOT-1 HRV image, respectively. It is important to note that both studies address the urban environment. KRC examines labels of adjacent pixels within the square kernel and calculates the so-called adjacency-event matrix, accounting for the spatial arrangement and frequency of the labels. Criterion for pixel re-labelling is the degree of matching between the adjacency event matrix and the Template Matrices produced during training. Thus, the algorithm accounts for texture and spectral components of the information classes. ISARS/NOA has applied the method specifically for the classification of natural biotopes including wetlands [14].

- The second approach is based on the **radial basis function neural network (RBF-NN)** architecture [15]. RBFs constitute a special type of artificial neural networks, which has certain advantages over other network types such as the Feedforward Neural Networks (FNNs), including simpler network configurations and faster training procedures. Neural networks have been utilized extensively in solving image classification problems, e.g. [16, 17]. Surprisingly, the applications of the RBF architecture in solving this type of problems are very few. Keramitsoglou et al. [18] have compared RBF-NN classifier with maximum likelihood classifier (MLH). In all experiments the neural network classifiers performed better overall than MLH, in some cases by as much as 17%. For the training of the neural network classifiers, a method based on the fuzzy means algorithm [19] was used.

- **Support Vector Machines (SVM)** is the third classification method that is presented here. It is a supervised learning technique rooted in the Statistical Learning Theory developed by Vladimir Vapnik and co-workers at AT&T Bell Laboratories [20, 21], which is gaining popularity due to many attractive features and promising empirical performance [22]. Originally the SVM method was worked out for linear two-class classification with margin, where margin means the minimal distance from the separating hyperplane to the closest data points. SVM learning machine seeks for an optimal separating hyperplane, where the margin is maximal. An important and unique feature of this approach is that the solution is based only on those marginal data points, called support vectors. The linear SVM can be extended to nonlinear one using a set of nonlinear basis functions. Several successful application of SVMs in image classification have been reported in the literature [23, 24, 25].

Figures 2 (a), (b) and (c) show the output of the three previously introduced pixel window classifiers, for the classification of a 4-m spatial resolution multispectral IKONOS-2 image. Fig. 2 (d) is the reference (ground-truth) map. The test area is the international importance wetland of Lake Kerkini in Macedonia (Northern Greece) and the objective is to classify it into five classes as determined by the European Nature Information System (EUNIS) developed by the European Environment Agency. After a series of experiments [26], the best overall accuracy for each one of the classifiers is 57%, 69% and 72% for KRC, RBF-NN and SVM, respectively.

An integral component of the launching of this effort is to take advantage of the existing state-of-the-art in the domain and make use if necessary of the prototype products produced in the frame of recent EU and ESA relevant projects. For instance, the GlobWetland Project (www.globwetland.org; funded by ESA Data User Element), aims at developing demonstration products (such as land use-land cover and change detection maps) based on EO to improve the ability of wetland managers from 17 national focal points around the globe to better monitor and assess the condition of wetlands within their respective countries. Another example is GEOLAND (www.gmes-geoland.info; FP6, IP in collaboration with ESA) which aims to demonstrate that EO-based products and services can fundamentally support professional end-users with a legal monitoring or reporting mandate on regional, national and international level. Finally, within the framework of the SPIN project (Spatial Indicators for European Nature Conservation), specifically developed for NATURA 2000 site management and monitoring, the feasibility of advanced classification methods for the EO-based mapping of European habitats according to certain mapping keys was in depth investigated. These results will be included in the present effort (www.spin-project.org).

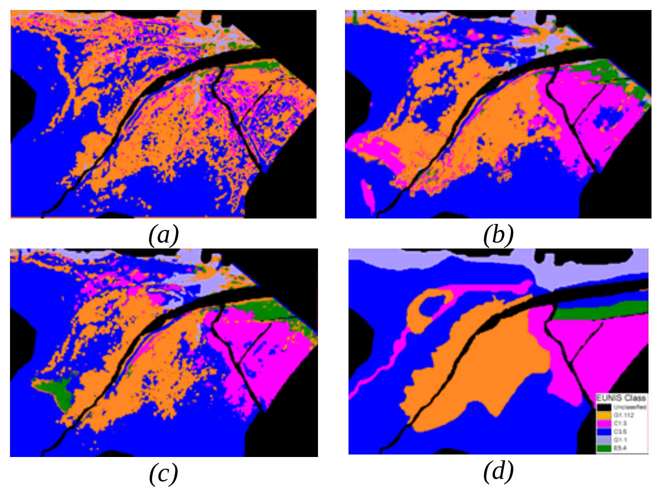

Figure 2: Lake Kerkini (site level). The output of (a) KRC, (b) RBF-NN and (c) SVM classifiers. The reference map is shown in (d).

4. CONCLUDING REMARKS

Based on the experience and expertise of the collaborating organisations, the initial steps for the realisation of the framework are now finalised and include:

(1) Reviewing the ways in which existing EO technology, sensors and image processing methodologies can contribute to the inventory and monitoring framework,
(2) Specifying how current and upcoming technologies and information from EO sensors may enhance this contribution, and
(3) Developing and testing novel methods using EO data and integrating auxiliary information for

wetland inventory, assessment, and monitoring at different levels (regional and national, catchment and site).

With the present collaboration it is intended to gain a better understanding of information products and services to be derived for the profit of the MedWet Initiative, as well as other relevant international Conventions such as Ramsar, so as to prepare and assist future user-driven activities and EO missions. The outcome of this collaboration will be reported in a specific manual document, suggesting clear user-oriented guidelines for the use of EO data.

The analysis performed up to now in the frame of MedWet/CODDE demonstrates that there is a considerable potential in EO to fulfil the objectives of the MedWet Initiative. In order to convert, however, this potential capability into operational applications, it is necessary to foster the collaboration, and increase the mutual understanding and knowledge with the Wetland and EO communities at international level. It is also important that the satellite and sensor manufacturers are provided with clear specifications and requirements regarding the characteristics of future missions, as well as the data cost policy and data access issues.

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