

## **DERIVING INDICATORS FOR MONITORING EUROPEAN RAMSAR WETLANDS USING EARTH OBSERVATION: THE CASE STUDY OF DELTA AXIOS-LOUDIAS-ALIAKMONAS, GREECE**

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### **EXTENDED ABSTRACT**

The aim of this work was to design and implement indicators for wetland monitoring, using Earth Observation (EO) techniques in the framework of the European Space Agency's GlobWetland project. Specific objectives included: (i) evaluation of monitoring requirements, (ii) design of a monitoring protocol and a geodatabase, and (iii) application and evaluation of the methodology in the study area (wetland of Axios-Loudias-Aliakmonas rivers delta), which was one of the prototype sites of the GlobWetland project. Analysis of data needs involved evaluation of the international, European, and national legislation that required monitoring and reporting. The resulting data requirements have been defined to describe the active pressures, their impact on the natural ecosystem and eventually the environmental state as a result of the pressures. To meet the requirements, existing datasets were evaluated for their usefulness, new satellite images were acquired, and historical archived images were obtained to use as the main source of data. Visual field observations were also conducted in time close to image acquisition. The monitoring protocol was designed, which contributed towards efficient monitoring of European Ramsar wetlands using a set of indicators. Also, a universal geodatabase was designed, which facilitated data storage, retrieval, analysis, and ensured standardized reporting. EO and GIS methods used during monitoring of the study area involved preprocessing of the satellite images, enhancement of information, information extraction, and derivation of indicators. Resulting thematic maps revealed and quantified the intensity of pressures in the vicinity of the protected wetland: intensive agriculture covered almost 50% of the study area, and several hundreds mussel farms were recorded. The state of the wetland was described with the seasonal change in the spatial extents of the water bodies (only 8%), and the spatial distribution of habitats (Annex I of Habitat Directive). Study of the changes that occurred during the last decade (1994-2004), revealed that irrigated agriculture did not increase significantly, but settlements and road network have expanded. The most notable change in the state of the wetland was a reduction in the delta extent, mainly due to detention of suspended material in diversion dams and decrease of water supply.

**Keywords:** monitoring, environmental indicators, remote sensing, GIS, geographic analysis, wetland

## **1. INTRODUCTION**

Wetlands are transient ecosystems that are facing the impacts of human activities. Despite their value in hydro-ecologic functions and recreational activities, they have been facing threats in their water quality, depletion of resources, loss of area, and alterations in hydrologic regime.

Monitoring, being an integral tool for the management of natural ecosystems, is the means of assessment of the level of the active pressures, the conservation status, as well as a method to evaluate the effectiveness of the applied conservation measures. Moreover, European directives, international and national legislation pose the need for monitoring directly (European Directives 92/43/EEC, 2000/60/EC), or indirectly through the process of reporting (Ramsar Convention). However, monitoring actions and programs have so far been limited, sporadic, and inconsistent due to high costs, inaccessibility of wetland areas, and variability of adopted methods.

Recent advances in satellite Earth Observation (EO) have led to increased interest for environmental application. EO data have a number of advantages relative to other data sources: they are a consistent way of data collection, broadly cover the entire study area, allow easy multi-temporal comparison, are cost effective in medium to large study areas, and offer a unique way to study inaccessible or highly protected areas. Subsequent analysis of remotely sensed data in a Geographic Information System (GIS) can provide useful environmental information. The European Space Agency's GlobWetland project has focused on the needs of wetlands of international importance according to the Ramsar Convention, providing EO information products for several wetlands, such as detailed land cover - land use, water cycle and inundated vegetation maps.

The aim of this work was to design and implement indicators for wetland monitoring, using EO techniques in the framework of the GlobWetland project. Specific objectives included: (i) evaluation of monitoring requirements, (ii) design of a monitoring protocol and a geodatabase, and (iii) application and evaluation of the methodology in the study area (delta of rivers Axios-Loudias-Aliakmonas), which was one of the prototype sites of the GlobWetland project. The methods and results presented in this paper are part of the GlobWetland methodology developed by the GlobWetland team [1] and the implementation of GlobWetland project in Greece [2].

## **2. STUDY AREA**

The study area, delta of rivers Axios-Loudias-Aliakmonas (N40.5° E022.7°), Greece, is a wetland of international importance according to the Ramsar Convention. In this area, a number of important habitats for rare and endangered species exist, thus it is part of a Special Protected Area designated by the implementation of European Directive 79/409/EEC and a Site of Community Importance following the implementation of European Habitat Directive 92/43/EEC. Main economic activity in the study area is agriculture and aquaculture. The presence of an extensive irrigation and drainage system has led to the intensification of agriculture, with main crops being rice, cotton, and maize. Main source of irrigation water is from diversion dams built on the main rivers. Reported problems include interruption in water discharge at Axios river mouth in the summer, increasing water and land salinity, high concentration of agrochemicals, and pollution from nitrogen fertilizers. As a result, the wetland complex is facing severe degradation.

## **3. MATERIALS AND METHODS**

### **3.1. Data needs, data availability and new acquisitions**

Analysis of data needs involved communication with national and local users and stakeholders. A questionnaire was designed in order to record the data requirements of

the local and national authorities: the Natural Environment Management Section of the Hellenic Ministry of Environment, Physical Planning and Public Works, the Management Body for monitoring and protection of the wetland and the wider area, the Organisation for the Master Plan and Environmental Protection of Thessaloniki, and the Region of Central Macedonia. The questionnaire acted also as a standardized channel of communication with the local users.

Reports of several projects, studies and works, and relevant publications were examined to define the availability of existing datasets. These were located in digital on-line libraries, as well as the libraries of national and local authorities. Available Earth Observation products and datasets were also downloaded from the on-line archives of the Joint Research Centre (JRC), the European Space Agency (ESA), and the United States Geological Survey (USGS).

Additional satellite images were also obtained from ESA through the GlobWetland project in order to cover the need for up to date information. Historical satellite images acquired in the 90's were also obtained to describe the past status of the wetland and the surrounding area, and identify changes that have occurred. The satellite images used were acquired by the SPOT 4 (24/08/1994), the SPOT 5 (19/08/2004), and Radarsat satellite (05/08/2004, 02/04/2005, and 09/11/2004).

Visual field observations were also conducted in time close to new image acquisition. These covered the natural habitats of the wetland and the human activities of the wider area. The equipment used was a palmtop PC with a GPS receiver attached, maps of the area, and a digital camera.

### **3.2. Designing a monitoring protocol and a geodatabase**

Designing a monitoring protocol for a European Ramsar wetland involved analysis of monitoring and reporting requirements and guidelines defined in the international, European, and national legislation. These were the Ramsar Convention on Wetlands of International Importance, the European Water Framework Directive (2000/60/EC) and its relevant guidance documents [3], the European Habitats Directive (92/43/EEC), and the Greek Joint Ministerial Decision 14874/3291/98 regarding its protection measures.

Additional reference documents that describe the process of designing a monitoring protocol were taken into account [4, 5]. These define the primary concerns when designing a monitoring project: (i) clear definition of the objectives according to the extent of the changes in spatial and temporal scale, (ii) availability of resources, and (iii) restrictions in the selection of indicators and measurement techniques. Also, the DPSIR frame (Driving forces-Pressures-State-Impact-Response) of the European Environment Agency was taken into account in the selection of indicators, as well as the observations and recommendations of related work [6, 7]. A detailed description of the design process of the monitoring protocol is described in [8].

Aim of the geodatabase was to facilitate data storage, retrieval, analysis, and ensure standardized reporting. Its designing was in line with the Guidance Document on GIS of the WFD [9], which has implemented the strategy and principles of the European INSPIRE initiative (Infrastructure for Spatial Information in Europe). It was further customised according to the analysis of data needs, which incorporated the local conditions. The geodatabase incorporated the Ramsar Inventory metadata system ([http://www.ramsar.org/key\\_res\\_viii\\_06\\_e.doc](http://www.ramsar.org/key_res_viii_06_e.doc)), as the system suggested by the WFD (ISO 19115) was not available at the time of writing.

### **3.3. Wetlands monitoring using EO techniques**

The satellite images were ortho-rectified using available photomaps as accurate geographic reference. The horizontal accuracy accomplished was  $\pm 8\text{m}$ , which was accepted, as it was less than the pixel size. No atmospheric correction was necessary for

the optical images, as long as they would be used in separate processes of information extraction, before any multi-temporal comparisons would be made [10]. A sigma lee spatial filter [11] was applied in the radar images to remove noise, which appeared in the form of speckle and would hinder information extraction. Also, a radiometric piecewise stretch was applied to the individual bands' histograms of the optical images, to enhance the appearance of the wetland parts of the image.

The process of information extraction involved the visualization, overlay and analysis of described datasets in a GIS. Conversion from raster to vector format was used as a method to facilitate further analysis of certain features. These were the road network, settlement boundaries, and elevation contours, which were converted to vector format from the topographic maps, using on-screen digitising. The Digital Elevation Model (DEM) of the study area, which is a continuous raster that shows the elevation in each point, was interpolated from the elevation contours using the ANUDEM method [12]. From the DEM, a series of information were derived (slope, flow direction and flow accumulation) as intermediate steps for the extraction of the natural drainage network of the area. After overlaying the latter on the optical image, numerous human interventions were identified, which were corrected in a secondary phase.

Computer-assisted photo-interpretation of available datasets was used to update the existing outdated habitat map. Enhanced images and location of field observations were displayed together with the existing map in order to identify and accurately re-map the extents of habitat types [13].

Radar images' characteristic to detect changes in earth surface roughness was employed to identify and map the waterline. Water appeared smooth in the image, contrasting with mud or vegetation that displayed significantly higher roughness. Inundated vegetation had also a different appearance because of double backscatter of radar signal, which is dominant in cases of quasi-perfect reflectors at a right angle, such as water and emergent plants' hard stems. The same principles were useful in the identification and delineation of the aquacultures that operated in the bay [14].

The multi-spectral characteristics of optical sensors were employed to produce a land cover map of the study area. The study area was categorised following the CRAMSAR nomenclature, which is a modified CORINE Land Cover classification scheme to incorporate the detailed Ramsar wetland classification. Automated object-oriented classification was incorporated in order to segment the SPOT images into objects, based on their spectral and shape characteristics. After segmentation, features such as reflectance, shape, hierarchy or thematic attributes were used to assign the objects into the corresponding classes. The result was further improved with manual analyst classification based on fieldwork knowledge [1].

Change detection was performed with simple overlay analysis [15] of the produced information layers for years 1994 and 2004.

## **4. RESULTS AND DISCUSSION**

### **4.1. Evaluation of monitoring requirements**

Analysis of legislation and questionnaires provided the monitoring requirements. These have been defined to describe the active pressures, their impact on the natural ecosystem, the ecological character and changes in the ecological character as a result of the pressures. The required information products were grouped in the following categories:

(i) Base maps and landscape information. Includes accurate geo-referenced base maps, land use / land cover maps, elevation information, location of infrastructure and human activities, covering the wetland and the surrounding area.

(ii) Human activities and pressures. Includes indicators describing the main human activities in the wetland and the wider area, which act as pressures on the natural ecosystem.

(iii) Wetland and water parameters. Includes indicators required to characterise the wetland and the surrounding area, useful for monitoring wetland conditions.

(iv) Long term changes of human activities and wetland characteristics. Includes change detection indicators for major land cover types, water extents and human activities.

To meet these requirements, existing datasets were evaluated for their usefulness, new satellite images were acquired, and historical archived images were obtained to use as the main source of data. Table 1 summarises the datasets used in relation to the required information products.

**Table 1:** Datasets used in relation to the required EO information products and indicators

Information product	Indicator	Extents (space / time)	Datasets used
Base maps and landscape information	Land cover	Basin / 1994, 2004	Satellite images and field work
	Hydrological network	Basin / 2004	DEM and satellite images
	DEM	Basin / 2004	Topographic maps
Human activities and pressures	Settlements	Basin / 1994, 2004	Topographic maps and satellite images
	Road network	Basin / 1994, 2004	Topographic maps and satellite images
	Irrigated agriculture	Basin / 1994, 2004	Satellite images and field work
	Mussel farms	Bay / 2004	Satellite images
Wetland and water parameters	Natura 2000 habitat types	Ramsar area / 2004	Satellite images and field work
	Water bodies and seasonal changes	Ramsar area / 2004	Satellite images and field work
	Wetland vegetation	Ramsar area / 2004	Satellite images and field work
Long term changes of human activities and wetland characteristics	Changes in irrigation pattern	Basin / 1994, 2004	Satellite images and field work
	Changes in infrastructures	Basin / 1994, 2004	Topographic maps and satellite images
	Changes of water extents	Ramsar area / 1994, 2004	Satellite images and field work
	Changes in major land cover	Basin / 1994, 2004	Satellite images and field work

#### 4.2. Monitoring protocol and the geodatabase

The monitoring requirements provided the guidelines for the monitoring objectives, methodology and parameters. Apart from the principles and general guidelines given by the international and national legislation, the monitoring protocol was customised to the management requirements of study area. The resulting monitoring protocol described the indicators to be measured, their spatial and temporal distribution, the method of measurement or estimation, the source of data, and the reference level. The indicators included mapping of human activities, quantity and concentration of pollutants, water extent, mapping of size and condition of habitats, fauna population, and existence of pollution indicators. A detailed description of the monitoring protocol is available in [2].

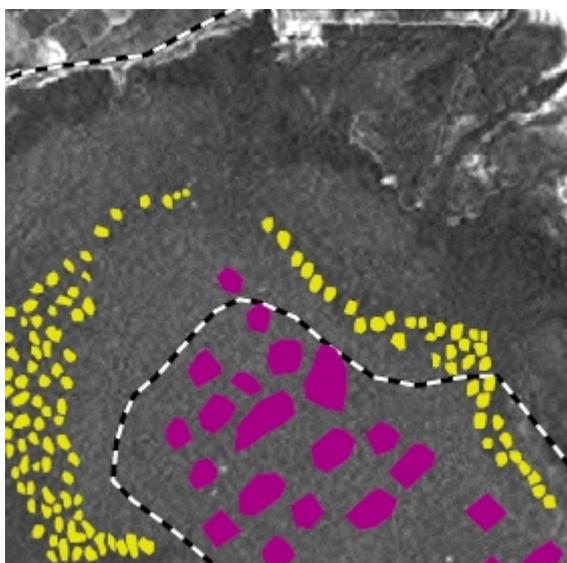
Initial step in the definition of the monitoring protocol was the determination of a baseline dataset, acting as the reference level for comparison of future conditions, in order to reveal environmental deterioration or success of conservation measures. Considering the lack of sufficient information so far, the current data (year 2004) were used as baseline data.

The designed geodatabase was implemented using ESRI shapefiles, raster images, and MS Access tables. The spatial features were directly populated into the geodatabase, while the attribute tables were linked to the spatial features, as appropriately.

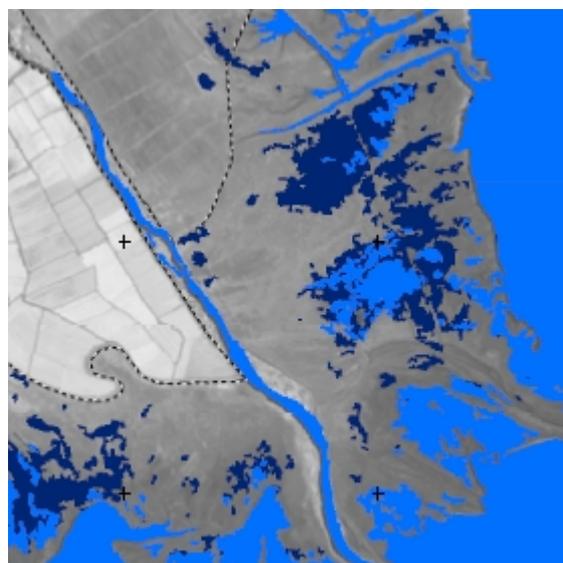
### 4.3. Application in the study area

The application of GlobWetland project in the study area has mainly focused on the use of EO data and techniques to derive spatial indicators. Hence, the most important findings from the application of EO in the delta of rivers Axios-Loudias-Aliakmonas are presented here.

The base maps and general landscape information products described the main characteristics of the wetland and wider area, and provided the background information useful in geo-registration of field work and other information products. The elevation information has facilitated interpretation especially in the form of shaded relief, which was extracted from the DEM.



**Figure 1:** Mussel farms in the mouth of Loudias river: pole (in yellow) and long-line (in dark red). North of the dotted line is the designated Ramsar area.



**Figure 2:** Seasonal change in water bodies extents at the Aliakmonas river delta: high level (dark blue) and low level (cyan).

The main characteristic observed in the human activities and pressures information products was the dominant expansion of irrigated fields (77% cover), mainly cotton, maize and rice. Fertilizers and chemicals from intensive agriculture drain in the wetland and aquifer posing a serious threat, but on the other hand, rice paddies are an important feeding ground for wildlife. Proximity analysis of the wetland with the human infrastructure has revealed an extensive agricultural road network of 306 km within a distance of 4 km from the wetland. Mussel farms stretch in a zone of the bay parallel to the delta. In total, 99 long-line and 284 pole mussel farms were identified (Figure 1), which exceed the carrying capacity of the bay. In terms of DPSIR (Driving forces, Pressures, State, Impact, Response) it was important to allocate the main anthropogenic pressures in order to be able to minimise pressures that have an impact on the natural resources of the protected area.

The indicators describing the wetland and water parameters include the updated habitats map, the seasonal extents of water bodies (Figure 2), the extents of wetland vegetation, and the borders of the designated areas. Wetland vegetation covers 90% of the area designated as Ramsar wetland, with the rest covered by fishing infrastructure and road network. Habitat map has revealed that 47 habitat types exist in the wetland, two of which

are priority types according to Annex I of Directive 92/43/EEC (1150: Coastal lagoons, and 6220: Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea). Water bodies cover 61% of the Ramsar site, of which 90% is covered by coastal waters. The seasonal change of water extents is relatively low (8% of area), mainly due to the existence of dykes.

The indicators describing long term changes revealed an expansion of settlements estimated to 27% of their extents in 1994, and road extensions and improvements estimated to 8% of the network in 1994. This is a direct result of the 11% population increase in the study area and increase of industrial activity (census of 1981 and 2001). On the contrary, acreage of irrigated crops was stable between 1994 and 2004. This is an indication that irrigation had already reached capacity before 1994. Also, 22% of the irrigated crops had a change in their spatial location. This could be the result of land degradation due to salts concentration and bad drainage, or increase of set-aside land as an implementation of the new European Common Agricultural Policy. The water extents have expanded during the last decade by 13.6%. Considering that the sea water level has not raised significantly during this period, the main reasons for this change could be the decrease of sediment deposits (due to diversion dams in the river course and decrease of water discharge), and the erosion of sea waves. Finally, changes identified in major land cover classes include abandoning rice fields and expansion of settlements.

## 5. CONCLUSIONS

This work presented the methods and results developed in the implementation of ESA's GlobWetland project in Greece, which aimed at the design and implementation of indicators for wetland monitoring using EO techniques. Monitoring requirements were evaluated and produced a list of required information products, which incorporated the international and local legislation. This led to the design of a monitoring protocol; a practical tool towards the management of a European Ramsar wetland, which incorporated successfully EO techniques. Finally, the methodologies were applied and evaluated in the study area (delta of rivers Axios-Loudias-Aliakmonas), which was one of the prototype sites of the GlobWetland project.

The importance of the information products can be directly derived by the obligations that are clearly defined in European directives and international conventions. Also, their usefulness to wetland management authorities is undeniable, as they facilitate reporting, support decision makers, and generally increase stakeholders' understanding.

Future work will concentrate on application of the developed methodologies in other Ramsar wetlands to render it operational. Also, innovative monitoring techniques integrating observations at multiple scale levels will be tested.

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