REMOTELY SENSED BASELINE DATA FOR MONITORING THE PROTECTED WETLAND OF DELTA AXIOS-LOUDIAS-ALIAKMONAS

Thomas Alexandridis[1], Efthalia Lazaridou[2], Charalampos Topaloglou[1] and George Zalidis[1]

[1]Aristotle University of Thessaloniki, School of Agriculture,
Lab of Applied Soil Science and Lab of Remote Sensing and GIS, 54124 Thessaloniki, Greece

[2]OMIKRON Ltd, Environmental Department, 53 Martiou Street, 54248 Thessaloniki, Greece

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SUMMARY

The delta of the rivers Axios-Loudias-Aliakmonas is a wetland of international importance according to the Ramsar Convention. In this area, a number of important habitats for rare and endangered species are suffering various threats, due to human activities and intervention. This paper presents the methodology for creating baseline data for wetland monitoring. The data requirements are presented, and remote sensing methods are set out for the analysis of high-resolution satellite images. Operational methods outlined here provided spatially distributed information of high quality. Need for fieldwork was kept to a minimum, as automated image analysis techniques were preferred against traditional surveys. This information was presented in the form of thematic maps, which describe pressures acting in the basin, state of ecosystem as a result of the pressures, and temporal changes of pressures. These comprise baseline data, which, following the monitoring protocol, will be implemented in an universal geodatabase, providing a valuable tool for wetland management authorities.

KEYWORDS:
wetlands monitoring, remote sensing, baseline data.

INTRODUCTION

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 (Directives 92/43/EEC, 2000/60/EC), or indirectly, by the process of reporting (Ramsar Bureau). An essential element of a monitoring scheme is the baseline data and the reference level (temporal definition), which are used to compare the progress according to a desired target or standard value (baseline monitoring) [1]. The identification of baseline data can be a difficult task for large wetlands, which are transient ecosystems in nature, and are often inaccessible during many months of the year. Remote sensing can provide spatially distributed data for environmental earth observation. The most notable advantages of using satellite imagery are the concise view of large areas, the acquisition of repeated measurements for rapidly evolving processes, the ability to collect data for remote areas, and the multi-spectral nature of the observations. Remotely sensed data have been used for the study of wetland and aquatic ecosystems [2], for mapping ecological conditions of a delta [3], to assess water quality [4], and characterize marine eutrophication [5]. Human environmental impacts have also been studied with remote sensing and GIS techniques, including point and non-point sources [6, 7]. Also, pressure, state and impact indicators, as derived from a DPSIR approach (Driving forces, Pressures, State, Impact, Response), have been estimated using earth observation techniques [8]. The aim of this paper is to contribute towards the design and evaluation of a monitoring protocol for wetlands` monitoring using earth observation techniques. To achieve this, monitoring requirements were examined for a wetland complex, baseline data for pressure and state indicators were produced, and the selected operational remote sensing methods were evaluated for their accuracy.

DESCRIPTION OF STUDY AREA

The delta of the rivers Axios-Loudias-Aliakmonas is a wetland of international importance according to the Ramsar Convention (site code 59, area 11,808 ha). In this area, a number of important habitats for rare and endangered species exist. Thus, it is part of a Specially Protected Area designated by the implementation of European Directive 79/409/EEC (site code GR1220010, area 29,551 ha), and proposed as a Site of Community Importance following the implementation of European Habitat Directive 92/43/EC (site code GR1220002, area 33,676 ha).

The study area is defined as the designated Ramsar wetland complex and the surrounding rivers' basin, where main pressures act. It is located in Northern Greece, near Thessaloniki bay (Figure 1). The landscape is flat with elevations ranging from 0 to 150 m above mean sea level, as it was formed from alluvial depositions of rivers. The climate is Mediterranean with warm dry summers, and a mean annual precipitation of 450 mm [9].

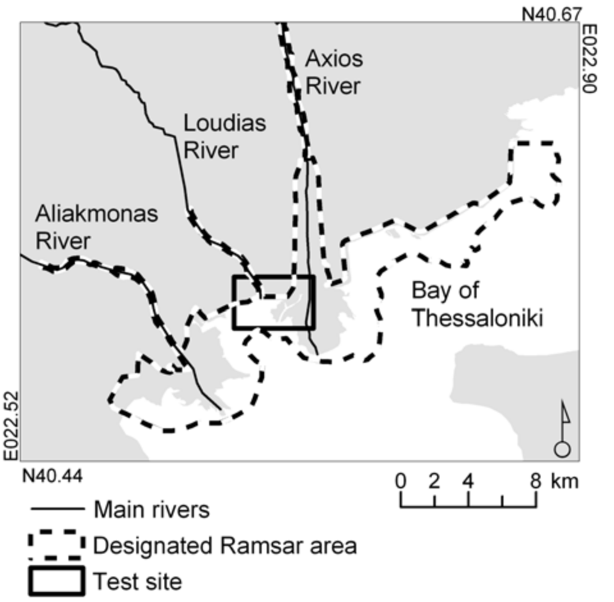

FIGURE 1 - Location map and test site.

Main economic activity in the study area is agriculture. The presence of an extensive irrigation and drainage system (total area 30,000 ha) 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.

A test site was selected within the study area, in order to create detailed sample maps and facilitate the display of results. This includes a part of Axios river delta with emergent and wetland vegetation, the surrounding irrigated agricultural land, and an area covered with coastal water (Figure 1).

MATERIALS AND METHODS

Monitoring requirements frame

European directives and national legislation, which take into consideration relevant studies and reports, have posed the need for managing the natural ecosystem in an efficient way: assess the active pressures, design actions and measures for conservation – remediation, and assess the progress of measures. This process, together with the institution and establishment of the Management Body of the protected area, underlined the necessity of a monitoring scheme. The latter would be implemented through a monitoring protocol, which would describe, among others, the sampling strategy, the sampling method, the methods of analysis, the scale and frequency of data collection, the statistical methods, and the interpretation procedure. Also, the need for an universal geodatabase was derived, which would facilitate data storage, retrieval and analysis.

In short, 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. These 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. Initial step for 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.

In this study, baseline datasets that were derived from remote sensing and GIS techniques are presented. Additional fieldwork and measurements in a laboratory are needed to fulfill the requirements of the monitoring scheme.

Data sources

After definition of data requirements for monitoring, the national datasets were examined for available geographic data. These were black and white photomaps (scale 1:5000, source: Ministry of Agricultural Development and Foods) acquired in 1996, and topographic maps (1:50,000, source: Hellenic Military Mapping Agency) of the study area. These provided very high positional accuracy information, but with poor and outdated thematic content. Therefore, they were only used as auxiliary data for the georegistration of the satellite images. Another source of existing information were the vector habitat maps of the Natura 2000-proposed Sites of Community Importance [10], following the European habitat Directive 92/43/EEC. Despite the detailed field sampling (which involved identification of species and location using Global Positioning System), existing base maps used were outdated (1978), and the scale (1:50,000) was insufficient to describe spatial variability of the wetland.

The main sources of new data collection were Earth Observation satellites with diverse characteristics. A high-resolution (10-m pixel size) multi-spectral (green, red, near-infrared and mid-infrared bands) image was acquired on 19/08/04 by SPOT 5 HRV satellite. The acquisition date were carefully selected in a period where cloud cover, which could obscure information on the ground, was an unlikely event, and where both natural and cultivated vegetation was at full growth, being easily distinguished. The second image was acquired on 04/08/04 by RADARSAT at fine beam mode (8-m pixel size). This satellite acquires data in the microwave area of the electromagnetic spectrum, whose unique characteristics include penetration of cloud, and sensitivity to parameters different from optical sensors, such as ground roughness, moisture conditions and landscape aspects. These concurrent images were used to describe the present pressures and the state of the ecosystem. Another archive-image was used for multi-temporal analysis. This Landsat 5 TM image was acquired on 09/08/89 at medium resolution (30-m pixel size), and with a higher multi-spectral content (blue, green, red, near infrared, middle infrared, thermal infrared and short-wave infrared bands).

Detailed fieldwork was necessary for preparation of image processing algorithms, and for quality assessment of the results. Therefore, 310 field observations were collected using handheld GPS (Global Positioning System) receiver, describing various land cover types and habitats on dates concurrent with the satellite images (September 2004).

Information extraction

Data pre-processing

The satellite images were ortho-rectified using the photomaps as accurate geographic reference. The horizontal accuracy accomplished was ±8 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 [11].

Image enhancement is an integral part of digital image pre-processing. Thus, a sigma lee spatial filter [12] was applied in the RADARSAT image 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 SPOT 5 image, to enhance the appearance of the wetland parts of the image.

Image processing and analysis

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 analyses 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 digitizing. 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 [13]. 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 high-resolution 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. Basic assumption was that over the last years habitats did not change in type, but only in extent and shape of polygons, which implies that natural and human processes acting on the ecosystem resulted in smooth changes of transitional zones between neighbouring habitats, and not in drastic changes, such as appearance of new habitats or extinction of others.

Radar images' characteristics to detect changes in earth surface roughness were 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. In cases of dense inundated vegetation cover, it was impossible to penetrate and delineate the waterline, therefore, additional field visits were necessary.

The multi-spectral characteristics of optical sensors were employed to produce a land cover map of the study area. The optical images were submitted to an automated spectral classification using a probabilistic maximum likelihood algorithm. Spectral signatures for land cover classes were described with training sites that were identified during fieldwork. Eight major land cover classes were defined and used in the classification algorithm: irrigated crops, non-irrigated crops, mud or bare land, fruit trees, settlements or infrastructure, inland natural vegetation, marshland natural vegetation, and water. Similar classes were used for classification of Landsat 5 TM image, but since field data were not available, training sites were collected on the image with careful photo-interpretation.

Multi-temporal analysis

Multi-temporal analysis is a method to detect changes that have occurred from a given reference year. Changes can be studied in regular time intervals, in future, according to the monitoring protocol, and standard multi-temporal change detection techniques can be used [14]. When historical archives are available, multi-temporal analysis can be performed to detect changes that had happened in the past. In this study, multi-temporal analysis was assessed to detect changes in environmental pressures acting in the study area during the last 15 years.

Information extracted from Landsat 5 TM image (1989) was compared against equivalent information from SPOT 5 image (2004). This was performed for infrastructure layer and for irrigated agriculture class, which are part of land cover thematic layer and important pressures. For the former, road network and settlement extents digitized from both optical images were involved in a vector overlay analysis. Queries performed on the attribute table of the resulting dataset produced the change detection map and information on the area of settlement expansion and length of road extension. Changes of irrigated land were detected using direct post-classification comparison. Standard image overlay geographic analysis was used to detect areas where irrigation has expanded, and those where irrigation was abandoned.

Evaluation of accuracy

Baseline data evaluation was distinguished into two categories: geographic positioning accuracy and correctness of thematic context. Positioning accuracy was checked to ensure the correct geographic location of the mapped features. This was performed with visual comparison of results against the photomap and the toporaphic maps. The observed differences were compared with the nominal scale accuracy of the map, which was used as a threshold. Finally, accuracy assessment of the thematic context was examined using an error matrix [15]. A subset of samples collected during fieldwork (140 observations) was used as reference data. The observed value (e.g. land cover type) of each sample was compared against the estimated value on the same location. The resulting error matrix revealed the errors of omission and commission, as well as the overall accuracy of the method. Also, the probability that the result was significantly better than a random result was examined using the k statistic. This was used to assess the reliability of the examined methods.

RESULTS AND DISCUSSION

After assessment of available datasets and acquisition of new data, a series of information layers were created using the operational remote sensing and GIS methodologies presented (Table 1). These were visualized in form of thematic maps. A sample of these information layers for the test site is displayed in Figures 2-4.

The first set of thematic maps (Fig. 2) describes in a basin-wide scale (1:50,000) the location and size of pressures. Infrastructures data layer (road, railway, irrigation canals and settlement) was displayed together with the land cover map and the hydrological network of the study area. Elevation information was included in this map, to facilitate interpretation, in the form of a shaded relief, which was extracted from the DEM. The main characteristic observed from this map was the dominant expansion of irrigated fields (77% cover), mainly cotton, maize and rice. Fertilizers and chemicals from intensive agricultural drain in the wetland and aquifer posing a serious threat, but, on the other hand, rice paddies are an important feeding ground for wildlife. 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 minimize pressures that have an impact on the natural resources of the protected area.

Thematic maps describing the state of natural ecosystems were produced at a larger scale (1:20,000), and cover the extent of the Ramsar area. The updated habitats` map was displayed together with the extents of water bodies, the extents of wetland vegetation, and the borders of the designated areas (Ramsar, Site of Community Importance, and Special-Protected Area) (Fig. 3). Wetland vegetation covers 90% of Ramsar wetland area, 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-

TABLE 1 - List of information layers produced as baseline data for monitoring the wetland.

Name of map	Information	Scale	Extents	Method
Basic characteristics of study area	DEM	1:50000	Basin	Spatial interpolation
	Hydrological network	1:50000	Basin	Surface hydrology modelling and digitizing
Location of pressures	Settlements	1:50000	Basin	Digitizing
	Road network	1:50000	Basin	Digitizing
	Land cover	1:50000	Basin	Supervised spectral classification
State of wetland complex	Natural habitat types	1:20000	Ramsar area	Computer assisted photo-interpretation
	Water bodies	1:20000	Ramsar area	Digitizing
	Wetland vegetation	1:20000	Ramsar area	Subset of habitats map
Temporal changes of pressures	Changes in irrigation pattern	1:50000	Basin	Post classification change detection
	Changes in infrastructures	1:50000	Basin	Vector overlay analysis

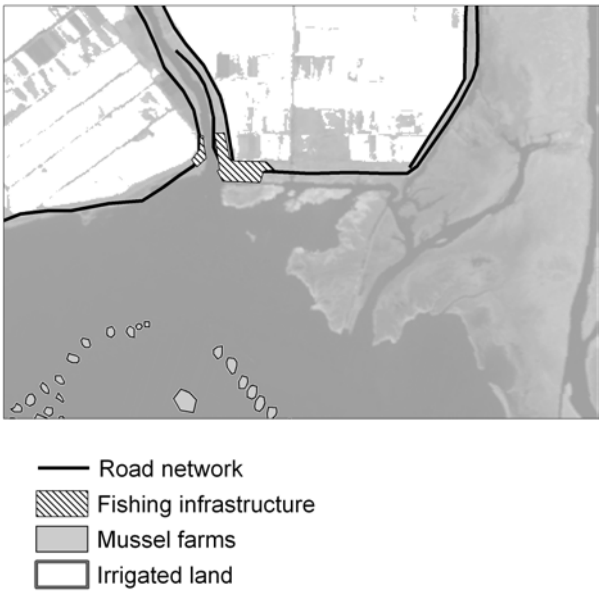

FIGURE 2 - Location and size of pressures at test site (year 2004).

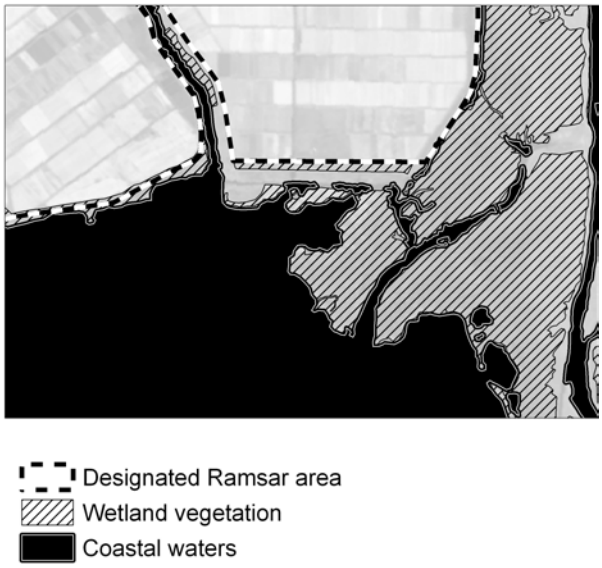

FIGURE 3 - State of wetland complex at test site (year 2004).

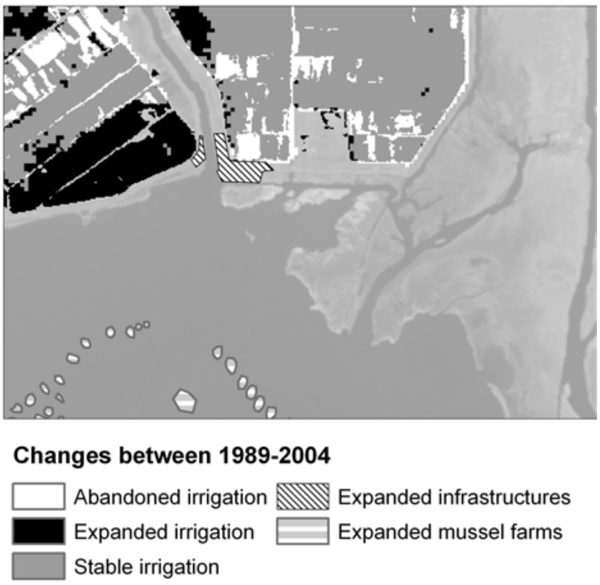

FIGURE 4 - Temporal changes of pressures at test site (1989-2004).

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. Water body maps and statistics refer to the low tide, since relevant images were acquired in the summer period. With additional satellite observations, the state of hydroperiod could be derived, which is a structural element of wetland complexes, proving the importance of these maps.

Thematic maps describing temporal changes of pressures included changes in settlement and infrastructure, and changes in irrigated crops (Fig. 4). Settlements expansion was estimated to be 27% of the extents in 1989, and road extensions and improvements were estimated to be 8% of the network in 1989. This is a direct result of the 11% population increase in the study area, and the increase of industrial activity (census of 1981 and 2001). On the contrary, acreage of irrigated crops was stable between

1989 and 2004. This is an indication that irrigation had already reached the capacity before 1989. 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 methods tested in this section will be used to detect the evolution of pressures and wetland impact, as directed by the monitoring protocol.

Accuracy of the presented baseline data followed the described methodologies. Positioning accuracy has already been checked during rectification of satellite images, with errors less than one pixel. Positioning of digitized features (infrastructure, hydrological network, the boundaries of wetland and water-bodies) was compared against the photomap. After visual comparison, no differences greater than the nominal scale accuracy of the equivalent maps were identified (±10 m for 1:20.000 scale, and ± 25m for 1:50.000). Overall accuracy of thematic classification was 83%, based on a sample of 140 points, and k statistic was 0.86. Extensive field observations had been used to correct ambiguities in habitat mapping. As a result, thematic accuracy reached 93%, based on a sample of 90 points located on the field and not used during mapping procedure. Testing the validity of the proposed methods was an essential phase before inclusion in an operational monitoring protocol.

CONCLUSIONS

The proposed methodology, for deriving baseline data, covered the needs for spatial information of a monitoring protocol. In particular, baseline data for land use, infrastructures, habitats, and hydro-periods were derived at the basin level. The operational remote sensing and GIS methods, outlined here, provided spatially distributed information of high quality. This information was presented in the form of thematic maps, which described pressures acting in the basin, and the state of ecosystem as a result of the pressures. Need for fieldwork was kept to a minimum, as automated image analysis techniques were preferred against traditional surveys, therefore reducing the total costs.

The implementation of the baseline data in a monitoring protocol was tested by detecting changes in environmental pressures during the last 15 years. Indeed, the change detection maps provided useful information regarding changes of certain land cover classes, which described the dominant pressures in the study area.

The importance of these baseline data can be directly derived by the obligations that are clearly defined in Directives 92/43/EEC and 2000/60/EC. Also, their usefulness to wetland management authorities is undeniable, as they would facilitate reporting, support decision makers, and, generally, increase stakeholders' understanding.

Other data requirements stated in the monitoring protocol, such as soil electrical conductivity, surface water quality (turbidity, temperature, phyto-plankton concentration) can be derived from microwave or hyper-spectral remote sensing, but operational methodologies are not available yet. Consequently, fieldwork and laboratory analysis, or a network of telemetric measuring stations, are essential to cover the monitoring requirements.

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CORRESPONDING AUTHOR

Thomas Alexandridis
Lab of Remote Sensing and GIS
Faculty of Agronomy
Aristotle University of Thessaloniki
54124 Thessaloniki
Greece

Phone: ++30 2310 998739
Fax: ++30 2310 998738
e-mail: thalex@agro.auth.gr

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