MULTIFUNCTIONAL AND MULTIMEDIA GIS SYSTEM FOR THE INVENTORY AND THE MANAGEMENT OF THE WETLANDS OF PUGLIA REGION (SOUTHERN ITALY)

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ABSTRACT - The Puglia region is characterised by an homogeneous calcareous basement, affected by karst processes, so as to have a noticeable water reservoir. Its wetlands are the result of the complex interaction of geo-hydrological, climatic and biogeographical factors. The conservation of these remnant wetlands is menaced by human activity: land reclamation, pumping of water table, loading of pollutants, tourism and poaching. In order to conserve these habitats a two phases project was carried out. In the first phase the wetlands were identified and mapped in a GIS system. In this way 36 wetlands were mapped. These areas were grouped into the following categories: ponds and marshes (15), artificial basins and saltpans (6), meanders (5), lakes (3), swamps (3), estuaries (2), lagoon (1), gulf (1). A description has been hot linked to each area: physical and biological characteristics, previous land uses, environmental perturbations; level of protection; restoration activities to be undertaken. In the second phase three sample areas were chosen to develop a method for their characterisation. The areas are: 1-Torre Guaceto, a brackish marsh bounded by sand-banks, 2-Frattarolo swamp, a salt swamp characterised by grasslands mainly composed by halophytes. 3-Lago Salso, an artificial basin created for agricultural and hunting purposes, characterised by a mosaic of vegetation, mainly composed of hydrophytes and hygrophilous species, and of sheets of water, which represent an idoneous nesting and roosting area for many bird species. A spatio-temporal GIS database was developed using 19 digital ortophotos in order to analyse the changes that have occured in the last fifthy years. Then the efficiency of a quantitative evaluation index was verified. This index was calculated using a GIS extension named Wetlands Rapid Assessment Procedure (WRAP). This procedure is based on the ranking of the ecological factors chosen for the evaluation: wildlife, vegetation, buffer area, hydrology and water quality. Multimedia information such as graphics, tables, ground photographs and digital video was used to highlight the more interesting characteristics of those wetlands and the GIS systems was modified to develop a more suitable user-interface for an easy access to both the spatial dataset and the multimedia information.

KEY WORDS - GIS, GPS, Puglia, wetland, WRAP.

INTRODUCTION

The Puglia region represents the south-eastern part of the Italian peninsula (FIGURE 1) and is dominated by the Mediterranean macroclimate (Macchia *et al.*, 2000). From a geological point of view it is characterised by an homogeneous calcareous basement, affected by karst processes, so as to have a noticeable water reservoir, which is fed only by rainfall in the south-central part of the territory and also by the drainage basin in the northern part (Richetti, 1975). Its wetlands are thus the result of the complex interaction of geomorphological, hydrological, climatic and biogeographical factors and constitute an integrated system which represents the geographic link between the western and the eastern part of the Mediterranean basin. This system is also important because of the conservation of plant and animal diversity since it represents the witness of wider and less disturbed environments. As is happening in the whole Mediterranean area (Papayannis, 1992; Hollis, 1992), the conservation of the remnant wetlands of Puglia is menaced by human activity: land reclamation, pumping of water table, loading of pollutants, eutrophication, unauthorised building, tourism, poaching and introduction of alien species. Wetlands perform a number of valuables functions such as flood control, nutrient and sediment retention, wildlife habitat recreation (Dugan, 1990). Altering the processes that support these functions can quickly degrade the values of the wetland and once a wetland has been degraded it can be very expensive to restore (Kusler & Kentula, 1990). For these reasons there is an increasing need for monitoring wetlands and their ecosystem components and quantifying the changes that occur.

GIS and remote sensing technologies have been widely used to identify, delineate and characterized habitat and vegetation types of wetlands both at a spatial and temporal scales (Ossinger *et al.*, 1993; Lyon & Adkins, 1995; Welch *et al.*, 1995; Dechka *et al.*, 2002; Schmidt & Skidmore, 2003). These data can be integrated together with multimedia in the form of text, digital photographs and digital videos focused on ecological parameters of the wetland habitats within an open GIS (Hu, 1999; Hu *et al.*, 2003; Hughes, 1996; Shiffer & Wiggins, 1993).

These data can be integrated with other data sets, such as hydrography, soil, surrounding land use, wildlife inventories to assess and quantify the ecological characteristics of the wetland (Ji *et al.*, 1992; Ji & Mitchell, 1995).

The aims of this research were:

1) To develop a GIS database showing the distribution of wetland habitats of the Puglia region through the combination of digital image processing, GIS, GPS and field-survey.

2) To assess wetland dynamic change through the analysis of digital aerial photographs.

3) To develop a computer-based interactive multimedia system, consisting of a graphical user interface and a GIS application module to allow an easy access to both the spatial data set and the multimedia information

4) To verify a method to quantify the current wetland conditions.

Material and Methods

GIS database

To develop a GIS database of wetland habitat localization, georeferenced black-and-white ortophotographs, dated 1997, and a Magellan-Sportrak PRO GPS receiver connected to the serial port of a laptop computer were used. This system expedited data collection and verification in the field.

The identification of wetlands followed the classification proposed by Pearce and Crivelli (1994). For each wetland a descriptive form was filled containing the following information: name of the area, administrative boundaries, type of wetland, area, ownership, bioclimatic and geo-hydrological, vegetational and faunistic characteristics, land uses, disturbances, level of protection, actions to be undertaken to improve the quality of the environment.

To develop a GIS database of wetland habitat and to study wetland changes, the aerial photographs of 1954, 1975 and the digital ortophotographs of 1997 were selected. The digital ortophotographs were already geo-referenced in the Universal Transversal Mercator (UTM) coordinate system, European Datum of 1959 and for this reason they were used to geo-reference the others. The 1954 and 1975 black-and-white photographs were scanned with an AGFA-DUOSCAN scanner and then saved in uncompressed TIFF format. The scanning resolution was chosen depending on the original scale of the photographs so as to obtain digital raster images of 1 m pixel size on the ground.

The image geo-referencing process required the identification of features that are easily recognised in both a digital raster image coordinate system (column and row) and a corresponding cartographic coordinate system of the digital ortophotographs (latitude and longitude). These features are referred as image control points (CPs) and ground control points (GCPs) respectively. Between six and ten CPs and GCPs were used to geo-reference each scanned photograph. The accuracy of the geo-referencing process was examinated using a root-mean-square error ($RMSE_{xy}$), a measure of the average total offset distance between all CPs and the corresponding GCPs based on the affine coordinates transformation model (Lillesand & Kiefer, 1987). For each scanned image, a RMSE ranging from 0.6 and 1.0 pixel was obtained. Finally, all the images were resampled to 1.0 m to obtain the data input to develop the GIS databe for the wetland change analysis.

Ground surveys

A vegetation map of the wetland was produced through the interpretation of digital images and the digitalisation on-screen using Arc View GIS software. Attributes were assigned for each polygon based upon field surveys carried out using the phytosociological method in the spring-summer of 2002. After verification, the digital vegetation boundaries were attributed to create the GIS database.

Colour photographs were recorded on the ground using a Canon Power Shot S45 digital camera. The colour photographs included panoramic views of the wetland and close-up shot of individual plant species. The digital picture was transferred to a personal computer and saved as Windows bitmap file (.bmp).

In addition to the still photographs, digital videos were recorded in the study area with a SONY DCR-TRV5E digital video camcorder. Digital video segments were downloaded onto a personal computer, edited using Adobe Premiere software and saved in Video for Windows format (.avi). Audio sound such as oral narration explaining the overview of the project was recorded on a personal computer and saved as Wave format (.wav) files.

Wetland Rapid Assessement Procedure

The environmental assessment of wetlands was carried out through a methodology developed by the South Florida Water Management District to assist in the regulatory evaluation of wetlands (Miller & Gunsalus 1997). The method was applied in three sample areas, which were analysed in detail: Torre Guaceto, a coastal brackish marsh, Frattarolo swamp, a salt swamp, and Lago Salso, an artificial basin. This method is named Wetland Rapid Assessment Procedure (WRAP) and it was set as an ArcView GIS extension by the GeoPlan Center of the University of Florida. WRAP consists of a standardised matrix of six variables that are used to evaluate the current wetland conditions by establishing a numerical ranking for individual ecological and anthropogenic factors. These factors include wildlife utilisation, wetland overstory/shrub canopy, wetland vegetative ground cover adjacent upland support/wetland buffer, field indicators of wetland hydrology and water quality input and treatment systems. The numerical output for the variables evaluates the wetland condition. The matrix can be used to evaluate a wide range of wetland/upland systems (e.g., marsh, swamp, ponds...) but it is not intended to compare different wetland community types to each other (i.e., marsh to wet prairie). Each wetland type is rated according to its attributes and characteristics. Although an interactive association among variables does exist, variables within the matrix have not been individually weighted. Individual variables can be eliminated from the evaluation if the evaluator decides that the specific parameter is not applicable.

This standardised index is one of the many indexes that can be used, but its advantages are:

1) It allows the quantification of the present situation so as to track trends over time and allows the comparison of different wetlands belonging to the same ecological typology.

2) It was already standardised and calibrated.

3) It is already integrated with ArcView.

The procedure starts directly from the main menu and is based on Habitat Assessment Variable, that is, following each variable description is a rating index containing a set of calibration descriptions and corresponding score points. A score of 3 is considered the best a system can function and 0 is for a system severely impacted or damaged. There is also the option to score each variable in half (0.5) increment. This provides the flexibility to score a variable that is not accurately described or fitted by the calibration description. If a variable cannot be computated it is signed as Not Applicable. The final score is computated following this formula $\Sigma V / \Sigma VMax$. Where SV=sum of the scores of each variable and $\Sigma VMax$=sum of the maximum scores of the variables used.

The index ranges between 0 (completely damaged) and 1 (when the system functions in the best possible way).

Development of the Multimedia system

The objective of developing the multimedia system was to provide the following functionalities:

1) The display and manipulation of geo-referenced images of 1955, 1975 and 1997 digital aerial photographs.
2) The display and manipulation of the corresponding digital vegetation mapping.
3) The retrieval of attributes from the GIS database.
4) The display of ground photographs and video clips.

These functionalities were developed using Avenue, the programming software of ArcView, and they were included in the tool bar of the basic user interface of ArcView (ESRI, 1996).

Results

Inventory

The inventory identified and mapped 36 wetlands that are now classified as sites of Community importance (Figure 1). These areas were classified into the following categories:

- 15 ponds and marshes
- 6 artificial basins
- 6 meanders
- 3 lakes
- 2 swamps

– 2 estuaries

– 1 lagoon

– 1 gulf

The total area counts for 128.000 ha, approximately the 0.06% of the region. At this level two specific tools were developed. The first identifies the geographic location of the site (FIGURE 2) and the second hotlinks the location with a descriptive form of the site in html format (TABLE 1).

The form contains synthetic information such as: name of the area, administrative boundaries, type of wetland, area, ownership, climatic and geo-hydrological, vegetational and faunistic characteristics, land uses, disturbances, and actions to be undertaken to improve the quality of the environment.

Characterization

An example of an up-to-date vegetation map for the Frattarolo swamp is shown in FIGURE 3. The user is able to retrieve the attribute information directly from the attribute table stored in the GIS database by zooming into an area, selecting the "Vegetation Info" tool and clicking on a polygon. A visual dialog will be displayed containing information such as habitat type, description, syntaxonomy classification, area and perimeter of the polygon. As an example the dialog of the *Puccinellio festuciformis-Sarcocornietum perennis* association is shown. This halophytic scrubs community, characterised by succulent chamaephytes and nanophanerophytes, colonises the micro-depression of the swamp on flooded clayey substratum, while the micro-reliefs, less frequently inundated, are occupied by the *Halimiono portulacoidis-Suaedetum verae* association dominated by *Suaeda vera* (Mariotti *et al.*, 1992; Biondi, 1998; Frondoni & Iberite, 2002).

In the same way it is possible to visualise the phytosociological table of the association and the corresponding syntaxonomical scheme by selecting the "Html hot link" tool and then clicking on the polygon depicting the spatial distribution of the communities in the digital vegetation map (TABLE 2). All the plant communities identified are reported in the syntaxonomical scheme at the end of the paper.

Furthermore, the GIS system offers the contemporaneous visualisation of the digital geo-referenced images of 1954, 1975 and 1991 and the wetland vegetation map in four separate map windows (FIGURE 4). In this way, zooming and panning into one area in one of the four map windows will correspondingly display the same area with the same map scale in the other three windows. This allows to easily highlight the changes that occur in an area. For example this system evidenced the progressive reduction of Lago Salso water surface during the last fifteen years. In fact, the water surface had a surface of 210 ha in 1954, 180 ha in 1975 and 79 ha in 1991. This phenomenon was probably caused by the lowering of the water table because of agricultural activities and the consequent filling up with earth of the humid area and the spreading of dense reeds.

The GIS system also allows access to the ground photographs and videos for each wetland site. The user can select the "Picture hot link" tool and then visualise the colour photographs at the location where they have been taken, and, in the same way, by selecting the "Video hot link" button, can display a digital video clip.

Evaluation

The TABLE 3 shows the result of the wetland rapid assessment procedure for the three areas analysed.

Although the three areas cannot be compared since they are different wetlands, that is characterised by different hydrogeological regimes, it is possible to notice how the highest score has been obtained by Torre Guaceto (0.4665), followed by the Frattarolo swamp (0.3883) and by the Lago Salso (0.3333). The values are however low taking into account the impacts caused by the drainage, the agriculture, the roads and the poaching have on the three areas. In particular the main problem of the marhes of Torre Guaceto is caused by canals for draining the water. These canals, in fact, noticeably reduced the hydro period and caused the reduction of sheets of water and the increase of bed of reeds.

The ecosystem of the Frattarolo swamp is menaced not only by the modification of the hydrogeological system but also by the impact of the herbicides due tothe flooding of the Candelaro stream.

The Lago Salso, which is characterised by a monotonous mosaic of bed of reeds and sheets of water, has a strong gradient of water depth, that can vary from few a centimetres in the inner part up to several meters towards the coast. For this reason, the inner part frequently dries up because of the strong water pumping from the adjacent farms.

CONCLUSION

Considering the increased concern over environmental preservation, expansion of urban development, and agricultural land uses, we hope this approach will prove valuable for a series of management aims: in fact this multifunctional GIS system provides an innovative way for integrating, analysing and presenting wetland information, thus enabling truly interactive co-operation among resource managers, policy makers and researchers.

Syntaxonomical scheme

Charetea fragilis Fukarek ex Krausch 1964
Charetalia hispidae Sauer ex Krausch 1964
Charion canescentis Krausch 1964
Charophyte formations of brackish or saline lakes and ponds

Ruppietea maritimae J. Tx. 1960
Ruppietalia maritimae J. Tx. 1960
Ruppion maritimae Br.-Bl. em. Den Hartog et Segal 1964
Ruppietum maritimae (Bég. 1941) Pignatti 1966
Vegetation of brackish water

Zosteretea marimae Pignatti 1953
Zosteretalia marinae Bég. 1941 em. R.Tx. et Oberd. 1958
Zosterion marinae W.F. Christ. 1934
Zosteretum noltii Harms. 1936
Submerged vegetation of lagoons and swamps

Potametea pectinati R.Tx. et Prsg. 1942
Potametalia pectinati W.Koch 1926
Potamion pectinati W.Koch 1926 em. Oberd. 1957
Potametum pectinati (Bég. 1941) Corbetta et Lorenzoni 1961
Submerged vegetation of fresh or weakly brackish water

Phragmiti-Magnocaricetea Klika 1941
Phragmitetalia communis W. Koch 1926 em. Pignatti 1954
Phragmition communis W. Koch 1926
Phragmites communis, Scirpus lacustris, Typha angustifolia and *Cladium mariscus* plant communities
Vegetation of higrophilous species of fresh water

Scirpetalia compacti Hejny in Holub, Hejny, Moravec et Neuhäusl 1967 em. Riv. Mart., Costa, Castroviejo et Valdés 1980
Scirpion compacto-littoralis Riv. Mart. in Riv. Mart., Costa, Castroviejo et Valdés 1980
Scirpetum compacto-littoralis Br.-Bl. (1931) 1952 em. Riv. Mart., Costa, Castroviejo et Valdés 1980
Vegetation of small higropilous species of fresh or weakly brackish water

Thero-Salicornietea Pignatti 1953 em. R.Tx. 1974
Thero-Salicornietalia Pignatti 1953 em. R.Tx. 1974
Salicornion patulae Géhu et Géhu-Franck 1984
Salicornietum emerici O. Bolós ex Brullo et Furnari 1976
Suaedo maritimae-Salicornietum patulae Brullo et Furnari 1976 ex Géhu et Géhu-Franck 1984
Vegetation of halophitic annual species on periodically inundated muds of salt marshes

Sarcocornietea fruticosae R.Tx. et Oberd. 1958
Sarcocornietalia fruticosae (Br.-Bl. 1931) R.Tx. et Oberd. 1958
Sarcocornion fruticosae Br.-Bl. 1931

Sarcocornienion perennis Riv. Mart. 1980
Puccinellio festuciformis-Sarcocornietum perennis (Br.-Bl. 1931) Géhu 1976
Suaedenion verae Riv. Mart., Luosa, Diaz, Fernandez-Gonzales et Costa 1990
Halimiono portulacoidis-Suaedetum verae (Br.-Bl. 1952) Molinier et Tallon 1970. Perennial vegetation of halophitic species on periodically inundated muds or salt marshes

Juncetea maritimi Br.-Bl. 1952
Juncetalia maritimi Br.-Bl. 1931
Juncion maritimi Br.-Bl. 1931
Juncenion maritimi Géhu et Biondi 1995
Puccinellio festuciformis-Juncetum maritimi (Pignatti 1953) Géhu in Géhu, Costa, Scoppola, Biondi, Marchiori, Peris, Franck, Caniglia et Veri 1984. Formations mainly composed of tall rushes on frequently inundated sandy or clayey substratum

Juncetum maritimo-acuti Horvatic 1934
Tall rush saltmarshes

Junco maritimi-Spartinetum junceae (O. Bolós 1962) nom. inv. prop. Filigheddu, Farris et Biondi 2000
Vegetation composed of high herbs on humid, weakly brackish depression beyond the dunal system

Elytrigio-Artemision coerulescentis (Pignatti 1953) Géhu et Scoppola in Géhu, Scoppola, Caniglia, Marchiori et Géhu-Franck 1984
Eriantho-Schoenetum nigricantis (Pignatti 1953) Géhu 1984
Vegetation composed of high herbs on humid, weakly brackish depression beyond the dunal system

Riassunto

È presentato un sistema multimediale e multifunzionale per l'inventario e la caratterizzazione delle aree umide della Puglia. Il lavoro ha previsto tre fasi. Nella prima fase è sono state identificate, classificate, cartografate e georiferite le aree umide. Per ciascuna area è stata elaborata una scheda descrittiva contenente informazioni sulle caratteristiche climatiche, idrogeomorfologiche, floristico-vegetazionali, faunistiche e sul funzionamento del sistema, i fattori di disturbo e le azioni da intraprendere per la conservazione del sito. Nella seconda fase sono state identificate tre aree campione sulle quali è stata effettuata un'indagine di dettaglio. È stata così prodotta una cartografia informatizzata delle comunità vegetali e un database spazio-temporale utilizzando fotoaeree digitali georiferite del 1954, 1975 e 1991 al fine di seguire le trasformazioni storiche. Nella terza fase, è stato calcolato un indice quantitativo basato su una metodologia denominata WRAP (Wetland Rapid Assessment Procedure). Questa procedura è basata sulla classificazione dei fattori ecologici scelti

per la valutazione: fauna, vegetazione, idrogeologia, area cuscinetto e qualità dell'acqua. Informazioni multimediali, quali grafici, tabelle, foto e video digitali, che evidenziano le caratteristiche più importanti delle aree umide sono state integrate nel sistema. Questo è stato modificato così da consentire un facile accesso alle sue diverse funzionalità sia quelle legate alle informazioni spazio-temporali che a quelle multimediali.

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