

GIS ASSESSMENT OF GLOBAL CHANGE IMPACTS ON THE DYNAMICS OF THE SREBARNA LAKE ECOSYSTEM

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Abstract

The changes in Srebarna Lake ecosystem, which occurred in the last thirty years, are analyzed in this study considering both anthropogenic and natural stressors. Comparative analyses were performed with GIS and remote sensing data in order to assess the lake evolution after its designation as a protected area, and following global changes that have occurred in the last decades. The recent evolution of the lake ecosystem presents evidences of both human induced and natural changes. Natural events, namely the wet deposition regime, regulate riverine floods and drought periods influencing the lake hydrology. The Danube river management as well as water uses in its watershed have similar impacts. The challenge for the future is to assess the dynamics of the Srebarna Lake ecosystem using geoinformation technologies for ensuring the future maintenance of the lake in its present status.

Keywords: *Environmental change, GIS, Remote Sensing, Land use/cover change, Srebarna Lake*

INTRODUCTION

The earliest written reports on Lake Srebarna were published by the Austrian naturalist Eduard Hodek in 1882. After him, Lake Srebarna had also been described in the works of Kalbermatten (1891), Lorenz-Liburnau (1893), Reiser (1894). At the same time Felix Kaniz described Srebarna in his travel notes as “El Dorado of wading birds”. The first Bulgarian publication about the lake was that of Prof. St. Petkov, who published information on certain Srebarna plants in 1911. Since then more than 273 research papers, reports, reviews, ecological assessments, etc., on Srebarna were published until 1998 (Management..., 2001).

During the last century the Srebarna Lake was designated first as a Breeding ground for wading birds in 1942 and later as Natural protected area (1948), Ramsar site (1975), UNESCO biosphere reserve (1977), Monument of World Cultural and Natural Heritage (1983) and Important Bird Area (1990). Threatened species as *Pelicanus crispus*, *Phalacrocorax pygmeus* and *Aythya nyroca* are breeding in the reserve. Since 2001 the lake management is in accordance with the Management Plan for the Srebarna Managed Natural Reserve.

The regular annual penetration of the lake by floodwater from the Danube is a very important factor for its existence. During the last 60 years the lake ecosystem underwent significant changes towards strong eutrophication and anthropogenically speeded-up succession because of the interrupted natural connection with the Danube water due to both natural and man-made factors. The most important of them were the dike built in 1948 and demolished in 1979, the hydro-technical complex “Zhelezni Vrata 1 and 2” built in 1970, the dry period between 1984

and 1993 and the new canal built between the lake and the Danube in 1994. All these events led to drastic changes in the whole wetland system. The last restoration programs provided successful interventions, e.g. canal dredging, which led to a partial recovery of the ecosystem functioning. Nowadays Srebarna is still faced to the challenge of the global change.

STUDY AREA

The Srebarna Biosphere Reserve is situated in the northeast part of Bulgaria within the region of the Aidemir Alluvial Lowland on the right bank of the Danube River (44°07 N, 27°04 E). The lake altitude is 10-13.2 m (*Figure 1*). The watershed of the lake is 1070 km², (Modev, 2004) and the biosphere reserve's area is 9,02 km².

Geology, geomorphology and soils

The Srebarna Lake was formed about 8 000 years ago following the inundation of the riverside terrace. The relief in the area is both undulating and flat, showing alternations between deep ravines and flat inter-plane spaces, creating conditions for soil erosion processes. The number of the dry valleys in the catchment is 222 with total length of 760.5 km.

In structural respect the considered territory is situated in the Moezian platform. The region is characterized by a platform regime of development and almost horizontal embedding of the layers. The basic structures are with fault disturbances, restricting blocks of different size and outleveling. The studied territory falls within the tutrakan graben-like depression. The faults are not displayed at the surface, which provides evidence that they were not active in the neogene-quaternary and contemporary stages of the earth crust development in the region of the Srebarna Lake (*Figure 2*).

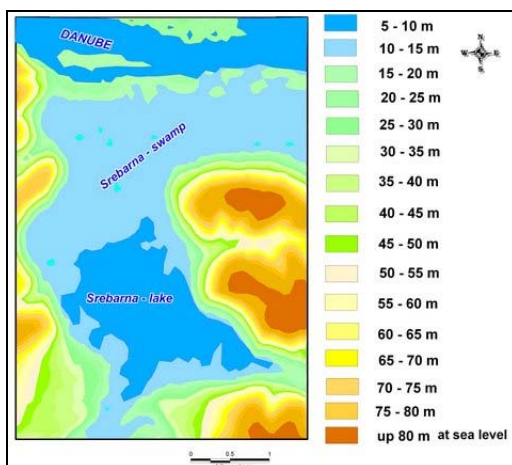


Figure 1. Hypsometric map of the Srebarna Lake catchment

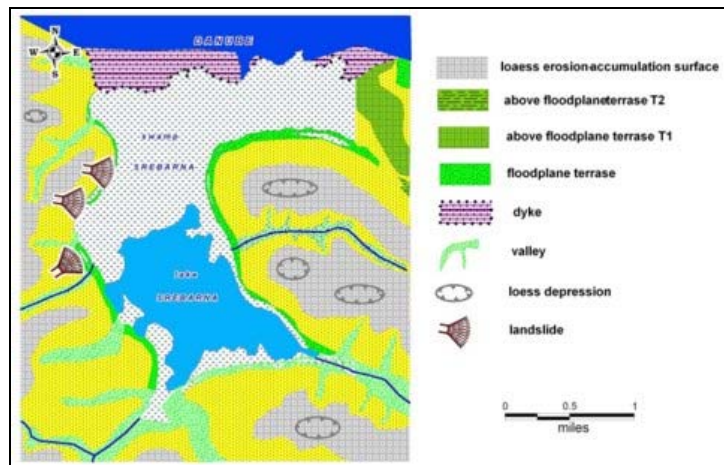


Figure 2. Geomorphological map of the Srebarna Biosphere Reserve

The considered region is characterized by the distribution of lower cretaceous, neogene and quaternary sediments. The lower cretaceous is represented by the ruse formation, which is outcropped at the surface in small sections to the south of the Srebarna Lake. It is built of strong, cracked and karstified limestones. The neogene materials are represented by calcareous, thin-layered clays, sandy at some places, with pontian age. This formation is the base of the Srebarna Lake. The materials are with very low permeability and are in fact a water barrier. The Quaternary is represented by eopleistocene, pleistocene, aeolian formations, alluvial depositions and Holocene. The Eopleistocene deposits of varigrained gravels are covered by red loess clays or directly by loess. They are outcropped at the ridges with relative height of 80-100 m above contemporary river terraces. The Pleistocene aeolian alluvial formations represent reddish sandy clays. They are covered everywhere by loess and in the region of the Srebarna Lake outcrop in the Kalushevo gully and in the southwest part of the reserve. The Pleistocene-aeolian formations are of typical loess and cover the periphery of the reserve. The Pleistocene-alluvial formations affiliated to the river terrace of the danube are differing in size, well-rounded gravels mixed with sand. In most of the cases they are covered by the loess complex. The sediments formed in the region of the lake during the Holocene have alluvial and marsh origin and cover everywhere the lake bottom. They are represented by gray-brown deposits, not well compacted, rich in organic substances. The thickness of this upper layer is between 2.5 and 3.5 m and is approximately equal for the greater part of the lake. Only in the north-east periphery a local thinning of the marshy layer (up to 1.2 m) is observed, where a form has been shaped that

resembles the old bed of the dragaika natural canal. The sediments were formed mainly during the last period, after the diking of the danube river, when the water balance of the wetland was disturbed.

It follows from the performed analysis of the geological-hydrogeological conditions that except for surface water, the Srebarna Lake is also recharged by karst water from the lower cretaceous (aptian) aquifer horizon through hydrogeological windows and is drained in the alluvial aquifer horizon. Hence the role of groundwater is of substantial importance for the water exchange in the lake.

The main soil forming materials are Quaternary loess sediments, as well as Pliocene clays, marls and calcareous sandstones. The soil forming materials within the alluvial lowlands are river deposits and loess formations, and within dry vallies such are diluvial and alluvial-diluvial deposits. The following types of soils are represented in the studied area: Calcic Meadow-Chernozem-like, Haplic Chernozems, Alluvial and alluvial-meadow, slightly swamped soils, Meadow marshy soils, lacustrine marsh soils, the greater part of them being covered by the water of the lake (Management...2001).

Climate

The reserve belongs to the Temperate climatic zone, the region of the Danube Lowlands. It is characterized by cold winter and very hot summer.

The Silistra meteorological station is the nearest one to the Srebarna Lake and has an altitude of 16 m. The records from this station describe the climate in the region as follows: average annual air temperature (11,6°C); average air temperature in January (-1,7°C) and in July (23°C); minimum temperature (-32°C); maximum temperature (41°C); annual precipitation sum of 487 mm with maximum in June (63 mm) and minimum in September (30 mm). The Srebarna wetland is very sensitive to the yearly rainfall variations. The precipitations in the area drop significantly in summer (159 mm) and in autumn (113 mm).

The Srebarna Lake ecosystem was affected significantly by the driest period recorded in the last century (1983-1993). The drought caused a diminution of the discharge of the Danube tributaries of approximately 31% with respect to the average of the period 1890 – 1996 (Gerasimov et. al., 2003). It was supervened by a long-term positive trend in precipitation with extremes in 2005 exceeding the norm for the region (1960-1990) with about 184%. The second wet year in the investigated period is 2002. Since the beginning of this positive tendency after 1993 the year 2000 is the driest one.

At present, the most serious concern is for the effects of global climate changes. Basically, the prediction for precipitation trends provides evidence for an increased frequency of sharply occurring droughts which will have impacts on river discharge and, indirectly, on lake maintenance (Tran et al., 2003). The challenge for the future is to assess whether the technical solutions which were successfully applied in the past will be sufficient for ensuring the maintenance of the lake in its present status.

The simulation results from an ensemble of 18 regional climate scenarios based on a thorough analysis of IPCC findings, giving a quantitative view of probable regional climate change impacts in the Upper Danube Basin. Based on the mentioned scenario simulations, water delivery to downstream countries, which depend on Upper Danube water, will decrease moderately to significantly until 2060 by -5% to -35% (ICPDR, 2010).

Hydrology

The Srebarna Lake is situated on the right bank of the Danube River, between kilometers 393 and 391 and the lake ecosystem is maintained by the annual flooding of the Danube River. The fluctuation in the Danube water level is very important for the lake. It must be high enough to let the river water flow through the canal which is 11-11.5 m above the sea level, and penetrate in the lake. Usually this is possible only during the months of the maximum river discharge in spring (April and May). The average annual level of the Danube at the Silistra gauge is 354 cm but it can vary in a very wide range (with maximum high 862 cm and minimum high -33 cm at Silistra gauge) during the seasons and years. It is well illustrated by the graphs below (*Figure 3*). The extreme levels in the same gauge for the last decade were registered in September 2003 (-26 cm) and in April 2006 (853 cm).

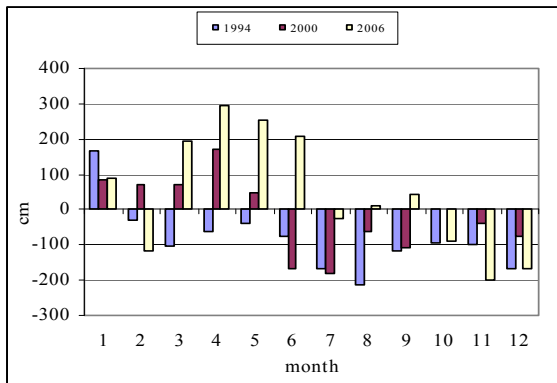


Figure 3. Average monthly deviation of the Danube water level at Silistra in 1994, 2000 and 2006

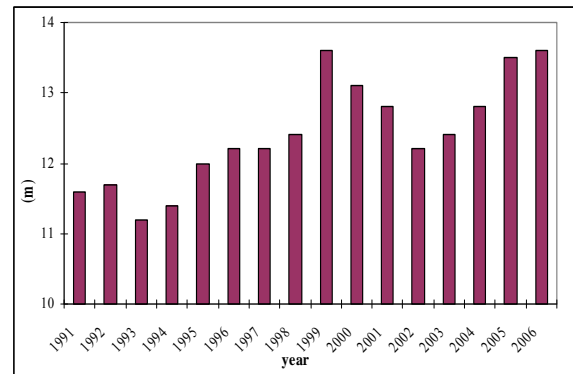


Figure 4. Annual water level in the Srebarna Lake (1991-2006)

There is strong interdependence between the level of the Danube River water and the level of the Srebarna Lake and groundwater in the floodplain where the lake is situated (Figure 4 and 5).

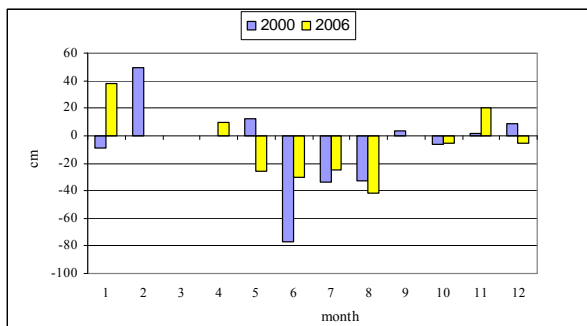


Figure 5. Deviation from the norm for the groundwater level in gauge No 3426, Aidemir

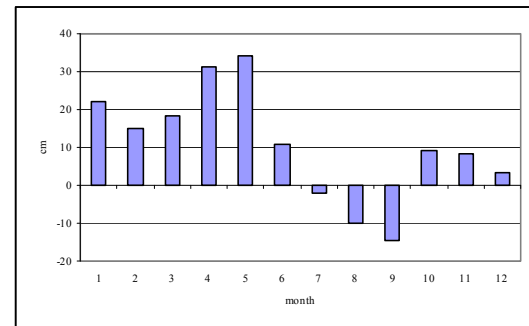


Figure 6. Annual level of the groundwater in gauge No 3426, Aidemir

The lowest level of groundwater is in accordance with the period of low precipitation and the lowest level of the Danube water is in summer and autumn (Figure 6.). The time lag between the changes in the Danube level and the groundwater level is about one week, (Geography..., 2002). The Srebarna Lake water, apart from the surface run-off, comes also as karst water from the Lower Cretaceous (Aptian) while the draining goes into the alluvial aquifer. Colmatage of the outcomes of the water from the Aptian aquifer disturbs the underwater feeding of the lake with groundwater (Management..., 2001).

Srebarna is a small lake of natural origin. It is currently in an initial phase of succession from lake to marsh to wet meadow. It is very sensitive to all environmental changes and the wetland ecosystem reflects to them very fast. The water level fluctuations resulting from a complex of factors as the fluctuations in temperature and precipitation, the alteration of groundwater level and the Danube water level, and the discharge of other rivers draining the lake catchment like Srebarnenska, Babuska and Kulnezha rivers, which run almost dry in summer and autumn. As a result the water depth in the lake varies from 1.1 m to 3.3 m at the "Dragaika" canal (13.2 m a.s.l.). Areas inundated at these water levels vary between 2.334 km² and more than 7.218 km² and the water volume impounded in the lake varies from 2.82 million m³ to 14.35 million m³. The thickness of bottom sediments is about 1.5-1.7 m (Management...2001).

Land use/cover

The produced map for 2006 year (Figure 7) represents the structure and spatial distribution of land use/cover in the study area. The quantitative assessment of the data shows that the water bodies comprise 860.8 ha (26.7% of all study area), wetlands – 249.2 ha (7.7%), forest and semi-natural areas – 787.1 ha (24.4%), agricultural areas – 1169.5 ha (36.4%) and artificial surfaces – 152.7 ha (4.8%). Water bodies in the study area include open water area of the Srebarna Lake, Dragaika canal and the Danube River. The wetlands vegetation species are represented by *Phragmites australis*, *Typha angustifolia*, *Typha latifolia*, *Schoenoplectus lacustris*, *Sch. triquetra*, *Sch. Tabernemontana*, *Salix cinerea*, etc. It should be noted that the open water areas and hygrophyte vegetation in the Srebarna Lake are characterized by dynamic nature of boundaries. Forest and semi-natural areas are composed of *Quercus cerris*, *Quercus pubescens*, *Quercus virgiliana*, *Quercus frainetto*, *Carpinus orientalis*, *Tilia argentea*, *Poa*

bulbosa, *Lolium perenne*, *Cynodon dactylon*, *Dichantium ischaemum*, *Chrysopogon gryllus*, etc. The poplar plantations, pine and acacia plantations, agricultural areas and artificial surfaces are observed in the reserve's buffer zone.

Biodiversity

The existence of a wide variety of habitats is a prerequisite for the extremely high biodiversity of the reserve which at present composes of 1430 vegetation species and 1338 animal species. Among these, 223 are bird species, of which 22 are rare and threatened of extinction. Of all 139 vascular plant species hosted by the Reserve, 11 are rare or endangered. Some 19 fish species occurred in the lake until 1948. There are 21 reptile and amphibian species, and 41 mammal species. The avifauna is the most diverse animal kingdom group found in and around the Srebarna Reserve: a total of 223 bird species. The nesting colony of Dalmatian Pelicans (*Pelecanus crispus*) is represented by breeding pairs which number varies from 29 to 127 in the 1950-1980 period (Management...2001).

MATERIALS AND METHODS

In order to assess the lake evolution after its designation as a protected area, and following climate changes, which have occurred in the last decades, comparative analyses were performed with GIS tools (ArcGIS 9.2).

Data were obtained from different sources: publications, meteorological and hydrological data from the monitoring system of the National Institute of Meteorology and Hydrology, the Silistra gauge (1994-2007), and from the Srebarna Managed Reserve monitoring system (1991-2006). The climatic data from the Silistra meteorological station are for the period 1931-1980.

Other sources of information we used were the remotely sensed data which include multispectral images from Landsat MSS (acquired in August 19th, 1977), Landsat TM (September 4th, 1992), Landsat ETM+ (June 14th, 2000) and IRS P6 (April 5th, 2006).

A wide variety of ancillary data was used, such as digital topographic map (L35-139 Silistra), thematic maps, orthophotos, very high resolution satellite images, statistics, and ground truth data.

The year 1977 is representative for the most drastic changes in the Srebarna lake ecosystem after the complete interruption of the water exchange between the lake and the Danube River. The year 1992 is one of the driest in the drought period 1984-1993 and 2006 is representative for a year with very high Danube discharge in the records. The biggest Danube flood was registered for the historical records of the last 100 years on April 17, 2006. The year 2000 is representative for the changes in the lake after the restoration of the canal connecting it with the Danube River.

The applied methodological procedure for obtaining land use/cover data is summarized in the following main steps: data preparation, satellite image data interpretation, field checking, quality control and data integration in GIS environment. The multitemporal land use/cover data were obtained by computer aided visual interpretation of orthorectified multispectral satellite images applying the methodology and nomenclature of the CORINE Land Cover (CLC) project (Heymann et al., 1994; Perdigao and Annoni, 1997; Bossard et al., 2000; Feranec et al., 2006; EEA, 2007; Büttner and Kosztra, 2007; Steenmans and Büttner, 2007).

Land use/cover mapping at more detailed scale has direct links to the standard CORINE Land Cover data at scale 1:100 000. The developed nomenclature for the 4/5 level land use/cover classes includes 30 land cover types, taking into account the landscape specific features of the Srebarna Lake (Table 1). The following geometric criteria were used: the minimum mapping area of 1 ha and minimal polygon width of 25 m (the minimal polygon width is less for recognisable linear objects like canals and roads).

Table 1. Land Use/Cover Nomenclature (level 4/5)

Land Use/Cover Code	Land Use/Cover Class
1.1.2.2	Discontinuous built-up areas with family houses with gardens
1.2.1.1.1	Industrial and commercial units
1.2.2.1.2	Road network (1 st – 4 th class)
1.4.2.1	Sport facilities
2.1.1.1	Non-irrigated arable land with large fields
2.1.1.2	Non-irrigated land with small fields
2.2.1.1	Vineyards with large fields

2.2.2.1	Orchards
2.3.1.1	Pastures prevailingly without trees and scrubs
2.4.3.1	Agricultural areas with significant share of natural vegetation and with prevalence of arable land
2.4.3.2	Agricultural areas with significant share of natural vegetation and with prevalence of grasslands
2.4.3.3	Agricultural areas with significant share of natural vegetation and with prevalence of scattered natural vegetation
2.4.3.4	Agricultural areas with significant share of ponds and with prevalence of scattered natural vegetation
3.1.1.2	Poplar plantations
3.1.1.3	Broad-leaved forest with continuous canopy
3.1.1.6	Flooded broad-leaved forest
3.1.2.3	Plantations of coniferous forest
3.1.3.2	Mixed forest created by alternation of stands of trees with continuous canopy
3.1.3.3	Plantations of mixed forest
3.2.1.1.1	Natural wet grasslands prevailingly without trees and scrubs
3.2.1.1.2	Natural moderately wet grasslands prevailingly without trees and scrubs
3.2.4.3	Bushy woodlands
3.2.4.6	Wood-cutting areas
4.1.1.1.1	Fresh-water inland marshes with densely hygrophyte vegetation
4.1.1.1.2	Fresh-water inland marshes with moderately densely hygrophyte vegetation
4.1.1.1.3	Fresh-water inland marshes with sparsely hygrophyte vegetation
5.1.1.1	Rivers
5.1.1.2	Canals
5.1.2.1.1	Natural deep water bodies (above 2 m)
5.1.2.1.2	Natural shallow water bodies (up to 2 m)

This extended nomenclature is based on the standard (3-level) CLC nomenclature using the recommendations of the PHARE countries, prepared for the European Environmental Agency (Feranec et al., 1995), the nomenclature for the land cover mapping of Hungary (Buttner et al., 2004) and the investigations of the Black Sea coastal zone (Vatseva, 2006).

RESULTS AND DISCUSSION

In the last 60 years, the Srebarna Lake has undergone significant changes with increased eutrophication and accelerated ecological succession, which were caused mainly by anthropogenic pressures. In 1948, the connection with the Danube River was interrupted due to the construction of a dike. The dike caused an immediate decrease of the reserve surface from 9 km² to 5 km², with an open water surface of 3.35 km². Afterwards, the reserve surface decreased dramatically to 2.5 km², with an open water surface of 0.6 km². Water exchange decreased two times compared to the previous period (Modev, 1994). Water stagnation and sediment retention were accompanied by siltation phenomena, with a significant decrease of water depth. In 1970, river damming with the hydroelectric power plants "Zheleznii Vrata 1 and 2" led to further management and restriction of the river discharge. Relevant impacts on the lake ecosystem were also caused by 9 small dams which were built upstream (Modev, 1994). The accumulation of reed detritus, bird excrements and the delivery of artificial fertilizers from the surrounding farmlands caused rapid enhancement of water eutrophication (Mishev et al., 1998). Since 1975, the reed harvesting was prohibited and this, combined with the diminished water depth, led to significant enlargement of the reed-beds.

The ultimate effect of water stagnation, reed spreading and siltation is an overall diminution of biodiversity. Fish species decreased from 19 in 1958 to 6 in 1978; the interruption of Dalmatian Pelicans breeding was observed from 1960 to 1963 (Mishev et. al., 1981). Some of the most rare and threatened vegetation species went extinct (e.g., *Aldrovanda vesiculosa*, *Carex disticha*, *Cicuta virosa*, *Hottonia palustris*, *Nuphar lutea*, *Stratioites aloides*, *Wolffia arrhiza*) or became rare (e.g., *Nymphaea alba*), (Mishev, 1998).

In 1979, a restoration program of the reserve was started with the demolition of 500 m of the dike. As a consequence, the lake was submerged by the Danube River floods in 1980, 1981, 1985 and 1989 (Mikhov, 1994). Water overflow removed the floating reed-islets and increased the open water areas. The positive effect of the applied measures was counteracted by a significant decrease of wet deposition, which determined a diminution of the discharge of the Danube tributaries of approximately 31% with respect to the average for the 1890-1996

period (Gerasimov et. al., 2003). After 1980, the regime of the Danube River was also affected, but to a lesser extent, by intensive water use, which accounted for a reduction of 16-22 % of the surface runoff (Modev, 2001).

After 1988, the natural inflow from rivers and outflows were negligible and the lake underwent progressive water stagnation. In addition, the karst springs in the southern part of the lake became inactive. The accumulated reed detritus led to progressive siltation with a dramatic decrease in the water depth. In 1993, the water column dropped to a depth of 0.3-1.0 m. Under these circumstances, a drastic decrease in number and abundance of bird species was observed. Only pelicans (with nutritional basis in Romania) and several trivial species remained in the lake. Many of the colonial nesting birds moved away to the small Danube island of Devnya (Komluka) (Mishev et. al., 1988).

The last restoration program was started in 1994, in order to cut a canal for opening an artificial connection between the lake and the Danube River. As a result many positive changes in the limnic ecosystem were detected, namely the increase of water depth, restriction of the reed areas and recovery of water quality.

Multitemporal analyses were performed using remote sensing data and GIS in order to assess the land use/cover change in the Srebarna Lake before and after the reserve's restoration programs implementation. The produced maps (Figure 7) show the structure and spatial distribution of land use/cover for 1977, 1992, 2000 and 2006 year.

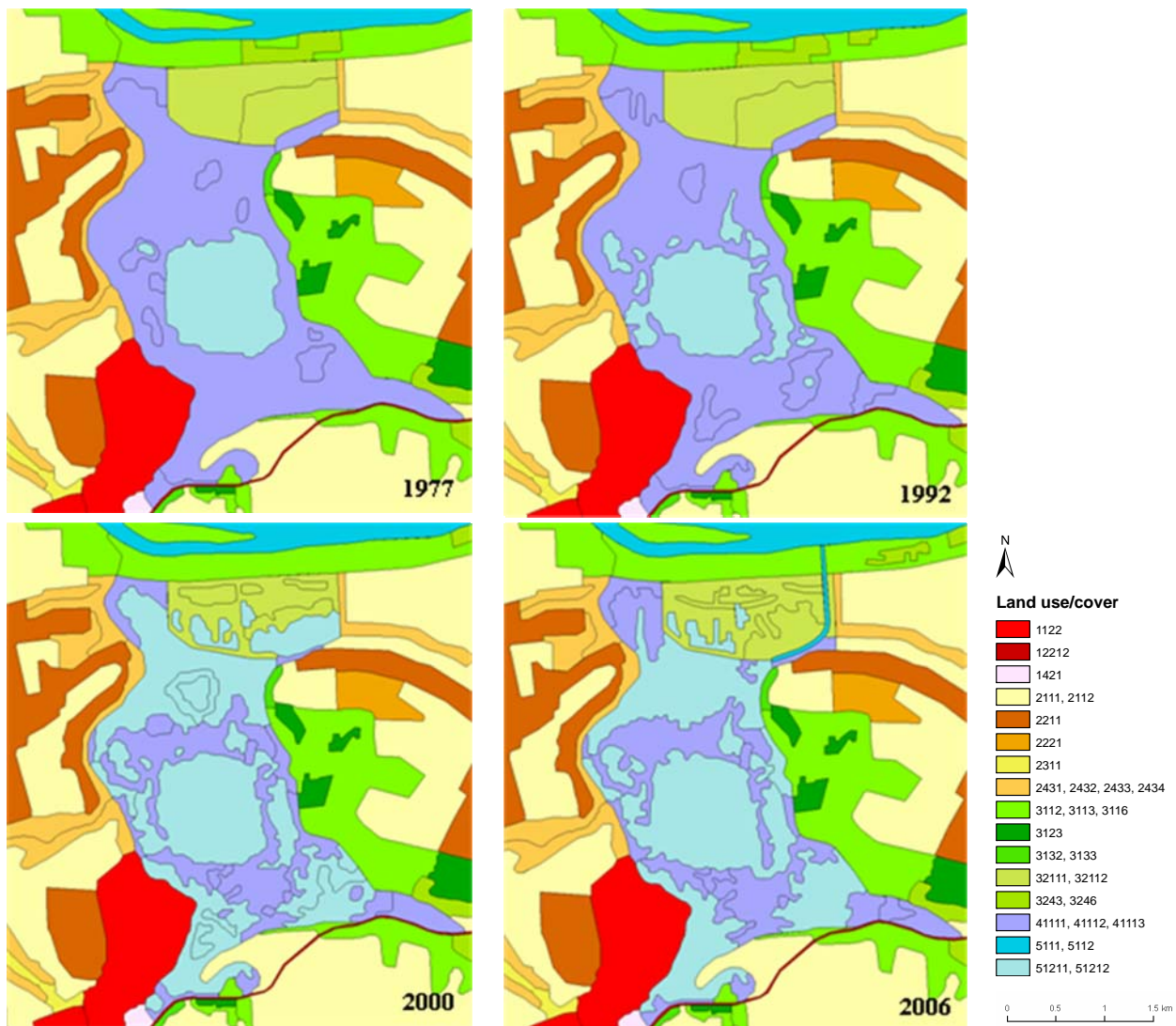


Figure 7. Land use/cover in the Srebarna Lake for 1977, 1992, 2000 and 2006 year

The quantitative assessment of the observed areas of reed (land use/cover classes: 41111, 41112, 41113) and open water (51211, 51212) in the Srebarna Lake for 30-years period is presented in Table 2.

Table 2. Correlation between reed and open water in the Srebarna Lake for 1977, 1992, 2000 and 2006 year

Land use/cover in the lake area	August 1977		September 1992		June 2000		April 2006	
	ha	%	ha	%	ha	%	ha	%
Reed	521,9	80,1	495,8	76,1	228,3	35,6	249,2	38,7
Open water	129,8	19,9	155,9	23,9	413,8	64,4	395,5	61,3

The results indicate that an eutrophication of the lake is increased dramatically in 1977 when the reed was covered more than 80% while the open water was decreased less than 20%. This negative correlation is observed even in 1992 in spite of all applied measures of the first restoration program of the reserve in 1979. The positive changes are observed only when the last restoration program in 1994 was implemented. As a result the open water area is increased about 60-65% in 2000 and 2006.

The climate variations are expressed very often by extremes like droughts and floods. The flood protection of the Reserve is based on a system of dikes along the Danube riverside. When the Danube water level is very high the river enters the Reserve from the northeastern part, which is outside the dike system. In this case the watershed region is not protected against flooding. The hypothetic changes in the flooded area in the Srebarna Lake were detected with a simple GIS simulation using MapInfo 8.5, Vertical Mapper tool (Figure 8).

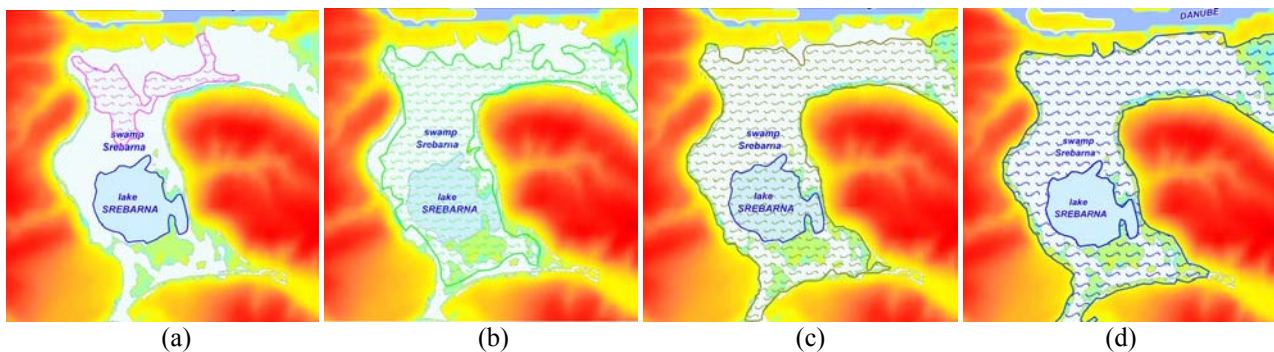


Figure 8. Changes in the flooded area in the Srebarna Lake due to the rise of the Danube River water level with 1m (a), 2m (b), 3m (c) and 4m (d) above the altitude of the canal.

The result from these simulations shows progressive trend of extending the flooded area as follows: the rise of the river level with 1, 2, 3 and 4 m causes respectively flooded area of 102 ha, 557 ha, 769 ha and 898 ha. These simulations provide also general information for the possible change in the water open area under certain conditions on the base of the Digital Elevation Model. There are many other factors which would influence a real event by different ways.

CONCLUSIONS

The Srebarna Biosphere Reserve management under the new conditions of rapid global change requires implementation of geoinformation technologies and ecosystem modeling. The study demonstrates that the multitemporal remote sensing data together with appropriate ancillary data and computer aided visual interpretation provide a quality basis for land use/cover backward change detection and mapping at more detailed scale. The developed and applied 4/5 level land use/cover nomenclature is compatible with the standard CORINE Land Cover (3-level) nomenclature.

Using simulations of the ecosystem behavior under different scenarios for changes in the natural or anthropogenic environment of the lake must be the next step in the Management plan of this protected area. The lessons of the past show that the lake is very sensitive to these changes and that its ecosystem is very fragile. On the basis of the previous experience and the good monitoring system in the reserve it will be much easier to implement GIS mapping and modeling for achievement of the future management goals in the wetland.

The ecosystem services provided from each hectare of the Lower Danube wetlands is estimated on the average to 500 Euro (IPCDR, 2010) and Srebarna Lake provides services of much higher value which are of significant importance for the world biodiversity.

The main future challenges we expect to arise from the possible climate change and the related to it decrease of the river discharge in the area and from the uncertainty concerning the implementation of the currently discussed EU Strategy for the Danube Region.

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