ASSESSMENT AND REPRESENTATION OF SPATIAL CHANGES OF AQUATIC VEGETATION DISTRIBUTION IN THE DANUBE DELTA. CASE STUDY: BABINA, CORCIUVATE AND CIORTIC LAKES – MATIȚA-MERHEI AQUATIC COMPLEX

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Abstract. The large wetland represented by the Danube Delta is characterized by various environmental conditions (terrestrial, swampy or aquatic), showing, among other characteristics, a rich and diversified vegetation. Its growth and distribution are controlled by the season and by the frequency of floods, and are influenced by erosion and accumulation processes. Topo-geodetic mapping of emerging aquatic vegetation is necessary for a better knowledge of its evolution and of the changes that occur in the aquatic ecosystems. Particular attention focused on the formation and movement of fixed and floating reed beds on lakes. By monitoring their dynamics, it would be possible to track the processes of obstruction or blocking channels and entrances in lakes, phenomena with negative consequences on navigation, fishing and tourism activities. Topo-geodetic assessment of the stability of the reed associations in the Danube Delta's lacustrine complexes and ecosystems is important, because these environments are the main habitats for wildlife existing there. Topo-geodetic mapping has been aimed at delineating the aquatic vegetation fields which have been continuously expanding in the last period, leading to the suffocation of the aquatic life of the lake ecosystems, due to oxygen deficiency in the water. The water bodies under our survey are: Babina Lake, Ciortic (Dracului) Lake, and Corciuvate (Rădăcinoasele) Lake, located in the central-western part of Matița-Merhei aquatic complex. The study carried out on the evolution of the vegetation areas within the three lakes was performed for two distinct periods, namely 2006 and 2018. After the processing and interpretation of the available data, a significant decreasing trend of the free water surface was evidenced, associated with an increase of the vegetation covered areas. The most important free water surface reduction was observed in Ciortic (Dracului) Lake (37.07%), then Babina Lake (13.38%) and Corciuvate (Rădăcinoasele) Lake (5.23%).

Key words: aquatic ecosystems, vegetation mapping, spatial patterns, temporal changes, eutrophication, Danube Delta

1. INTRODUCTION

Wetlands have been globally recognized for their ecological, economic, and cultural value, but, unfortunately, is estimated that 50% of the world's swamps have already been lost or degraded (Midwood & Chow-Fraser, 2010). Degradation and loss of wetland areas have a significant economic and social impact, such as increased flood risk and water quality degradation, with implications for the health and well-being of the population (Preda *et al.*, 2016). The significant diminution of the surface area of lakes in the temperate climate zone is associated with silting up and excessive vegetation growth, mainly caused by water eutrophication. The excessive growth of phytoplankton contributes to the shallowing of lakes and decreasing their surfaces, the free water area being populated with macrophyte species, especially emergent macrophytes (Lawniczak-Malińska & Achtenberg, 2018).

The eutrophication phenomenon determines negative consequences on lakes, such as water quality decrease, oxygen reduction in the bottom waters, increased water turbidity and other effects, which can have an impact on fish farming and affect the entire lake ecosystem.

Considered to be the largest wetland in Europe, the Danube Delta occupies an area of 4180 km^2, out of which 3510 km^2 represent the Romanian Delta (Gâşteşcu & Ştiucă, 2008). The Delta includes a large variety of ecosystems, including a complex hydrographic network, consisting of a multitude of main and secondary fluvial branches, interrelated with a labyrinth of lakes, ponds, backwaters, channels, brooks, artificial canals, as well as meadows, fluvial islands, marshes and swamps.

To protect and conserve the Danube Delta, the Romanian Government emitted the Decision 983/1990, followed by the Law 82/1993 adopted by the Parliament, which established the Danube Delta Biosphere Reserve structure, administration and protection regime. Thus, the Danube Delta Biosphere Reserve (DDBR) becomes a wetland of international importance with world natural heritage value, and a protection and conservation regime based on the promotion of economic development in line with the environmental support capacity and its natural reserves (Doroftei & Covaliov, 2013).

Lakes provide a variety of important ecological services and are affected by anthropogenic activities as well as by global climate change (Zhang *et al.*, 2017). Aquatic vegetation can also provide both ecological and socio-economic benefits such as increasing water quality, sediment stabilizing and further decreasing the rate of nutrient cycling, improving water quality and providing habitats and food for many aquatic species.

Numerous studies have focused on changes monitoring in the aquatic vegetation of lake ecosystems and identifying the mechanisms driving its distribution, dynamics, and abundance (Zhang *et al.*, 2017).

Aquatic vegetation plays an essential role in the governing of lake ecosystems, but in recent years, lake water quality has continuously deteriorated. The decreasing water quality is due to severe eutrophication, frequent algal blooms, changing areas with aquatic vegetation, and even the extinction of some plants (Chen *et al.*, 2018).

Lakes and wetland areas are difficult to investigate and, consequently, the information collected to study the temporal and spatial dynamics of aquatic vegetation must be enhanced (Villa *et al.*, 2018). Thus, increasing spatial extension of vegetation in lakes requires extensive research to know its dynamics over time, in order to make the best decisions to limit the effects of climate change on aquatic ecosystems (Cleland *et al.*, 2007).

2. MATERIALS AND METHODS

2.1. Study area

The lakes analyzed in this study are part of the Matiţa-Merhei depression (Fig.1), one of the largest aquatic systems in the Danube Delta. This aquatic complex is a deltaic unit located in the north-western part of the Danube Delta, between Chilia and Sulina branches and is bordered by the Cernovca Arm at north, the Old Danube (the Great M) to the south, the Chilia beach ridge - Stipoc Canal in the west and the Letea-Răducu beach ridges to the east. The hydrographic network is defined by the natural and artificial channels Eracle, Lopatna, Dovnica, Răducu, Bogdaproste, Sulimanca and Roşca (Bondar & Panin, 2001). This depression is part of the so-called "*fluvial delta*", with a total area of 24,240 ha, of which 20,000 ha are aquatic surface (Năstase & Năvodaru, 2010). The largest lakes in the complex are also those that give it its name: Lake Matiţa (642 ha) and Lake Merhei (1368 ha) (Gâştescu, 1971, Constantinescu & Menting, 2000), then Lake Trei Iezere (433.5 ha), Lake Bogdaproste (400.19 ha) and other smaller waterbodies, which are interconnected through brooks, natural and artificial canals, lakes which generally have depths of 0.5-1.0 m, but also over 3 m in Lake Matiţa.

This lake complex, dominated by reed, includes both large surface lakes with more or less active water exchange, and lakes with reduced water-exchange, partially covered with floating vegetation, fixed and floating reed beds (Năstase & Năvodaru, 2010).

Fig. 1. Location of the Matiţa-Merhei Aquatic Complex within DDBR.

The main objective of our research is to analyse the evolution of the area occupied by vegetation in three lakes of the aquatic complex Babina, Ciortic (Dracului) and Corciuvate (Rădăcinoasele) lakes for the period 1962-2018 (Fig. 2). The three water bodies were investigated in two distinct moment (2006 and 2018), and for comparison, lakes contour map of 1962 was regarded as the reference image. The available data for 2006, were collected between

10-15th August, when the average of Danube water level at Tulcea gauge station was 145 cm, and for the year 2018, the measurements were performed during the 11-13th August, when the average of Danube water level at the Tulcea gauge station was 155 cm. So, as can be seen from the above, the comparison was made at similar water levels in similar time periods.

Fig. 2. Location of the study area (detail).

2.2. Methodology

The topo-geodetic mapping of aquatic vegetation in the studied lakes is particularly important because it is necessary to know as much details about its evolution in space and time. Topo-geodetic measurements are intended to provide a series of mathematical information regarding the covered area by the emergent aquatic vegetation from a lake at a particular time. By processing the field information and by materializing it on the maps, we can observe and quantify the phenomenon of extension or retreat of the vegetation from the studied area. Quantifying the extension/withdrawal of the vegetation area from a lake, help us to know how the lake is affected nowadays. The present paper is a preliminary study regarding topo-geodetic mapping of emerged aquatic plants, which will be further developed at the level of aquatic species mapping in the analysed lakes.

The authors have chosen 1962 as the reference year, because in that period the update of all topographic maps and cartographic materials was made, materialized in a first topographic base of the Danube Delta, used as a reference for all subsequent works. In this paper, the year 1962 is considered to establish the initial contour of each lake, and the results obtained for 2006 and 2018 are compared with this reference. We mention that the following map sheets: L-35-95-D-c and L-35-107-B-a from the topo-hydrographic maps, scale 1: 25000, represent the cartographic material used to plot the initial shape of the lakes. These maps were developed by the State Water Committee, updated in 1962 and printed in 1965.

For the topographic survey, a TRIMBLE R4 GPS with geodetic class receivers was used, as well as the TRIMBLE M3 DR5 total station. The kinematic method was the chosen technique of work in the present topo-geodetic study. The coordinates were obtained in real-time mode by Real Time Kinematic (RTK) technology, which is available directly in the field, permitting to enhance the precision of position data of the topographic points. The topo-geodetic measurements carried out in the field campaigns in August 2006 and August 2018 consisted in the collection of topographical points that highlighted the contour of the emerging and floating aquatic vegetation boundary, as well as the existing reed bed formations. Coordinates determination (X, Y) and elevation (Z) was made in Stereographic 1970 Projection System (National Official System in Romania), and the reference altimetric system used was the Black Sea-Constanta 1975 (The Official Altimetric System in Romania).

Data processing, editing and graphical representation of the results were made with specialized software, namely AutoCAD, Global Mapper 17.2 and ArcGIS 10. The last two software are dedicated to working with geographic information, allowing data spatializing from the field, advanced analysis and geoprocessing. The final results are thematic maps, which accurately represent the data of topographic measurements acquired in field campaigns. It should be mentioned that the topographic support on which thematic maps are elaborated is represented by the NACLR (National Administration for Cadastre and Land Registration) orthophotoplan, 2005 edition, scale 1:5000. The results obtained were combined and correlated with the information provided by the satellite images LANDSAT 8 OLI/TIRS for the year 2018 and LANDSAT 7 ETM for 2006. Both satellite images were downloaded from the USGS website (https://earthexplorer.usgs.gov/).

3. RESULTS AND DISCUSSION

In this paper, the authors developed an analysis of the evolution of the covered area by vegetation in three lakes for the following periods: 1962-2006, 1962-2018 and 2006-2018. It is worth mentioning that the periods for making the measurements were chosen to correspond to the maximum stage of vegetation development. We also took into account a significant aspect of such studies, namely to have similar hydrological regimes at the time of the measurements, in

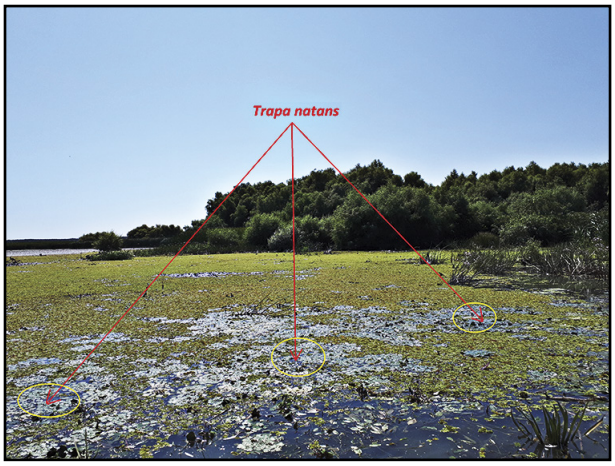

Fig. 3. Areas with *Trapa natans*.

Fig. 4. Areas with *Salvinia natans* and *Stratiotes aloides*.

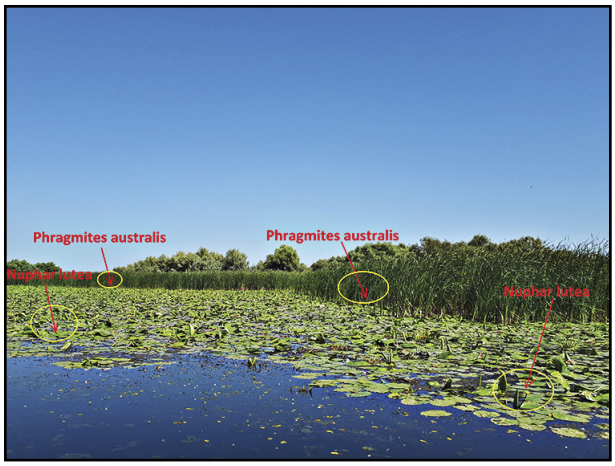

Fig. 5. Areas with *Phragmites australis* and *Nuphar lutea.*

Fig. 6. Areas with *Nymphaea alba (detail)*.

order to make a correct comparison and evaluation between the periods investigated. Only using such comparison criteria, qualitative results that can be considered and validated have been obtained.

Several species of aquatic plants have been identified on the free water surface of the studied lakes: *Trapa natans* (water chestnut) (Fig. 3), *Salvinia natans* (floating fern), *Stratiotes aloides* (water soldier) (Fig. 4), *Phragmites australis* (common reed), *Nuphar lutea* (yellow water-lilly) (Fig. 5) and *Nymphaea alba* (white water-lilly) (Fig. 6).

In the following we will present the vegetation evolution analysis in the three lakes mentioned above for two periods: 1962-2006 and 1962-2018.

Ciortic (Dracului) Lake

Ciortic (Dracului) Lake has a less extensive basin and shows morpho-hydrographic characteristics similar to neighboring lakes, meaning that the shoreline morphology is not well-defined, consisting of reed, cattail and fixed and/or floating reed beds. Through the canals and brooks network, it is linked with the other lakes in the region.

Ciortic Lake is located in the northern part of Babina and Corciuvate (Rădăcinoasele) lakes (Figs. 2 and 7), communicating in the southern part with Corciuvate Lake, through an area containing a group of three small fixed reed beds and a large one (7 ha). The initial contour of the lake (year of reference 1962) had an area of about 154.3 hectares and a perimeter of 6.1 km.

Through processing and analysis of the topo-geodetic data available in the archive and the information obtained from the LANDSAT 7 satellite imagery, it follows that in 2006 the lake had an area of 150 ha and a perimeter of 5.7 km.

Topo-geodetic measurements made in the field in August 2018, combined with the information taken from the LANDSAT 8 satellite imagery, revealed a lake area of 146.5 hectares and a perimeter of approximately 5.5 km.

In 2006, the free water surface decreased by 4.3 hectares (2.79%) compared to the initial contour of the lake in 1962;

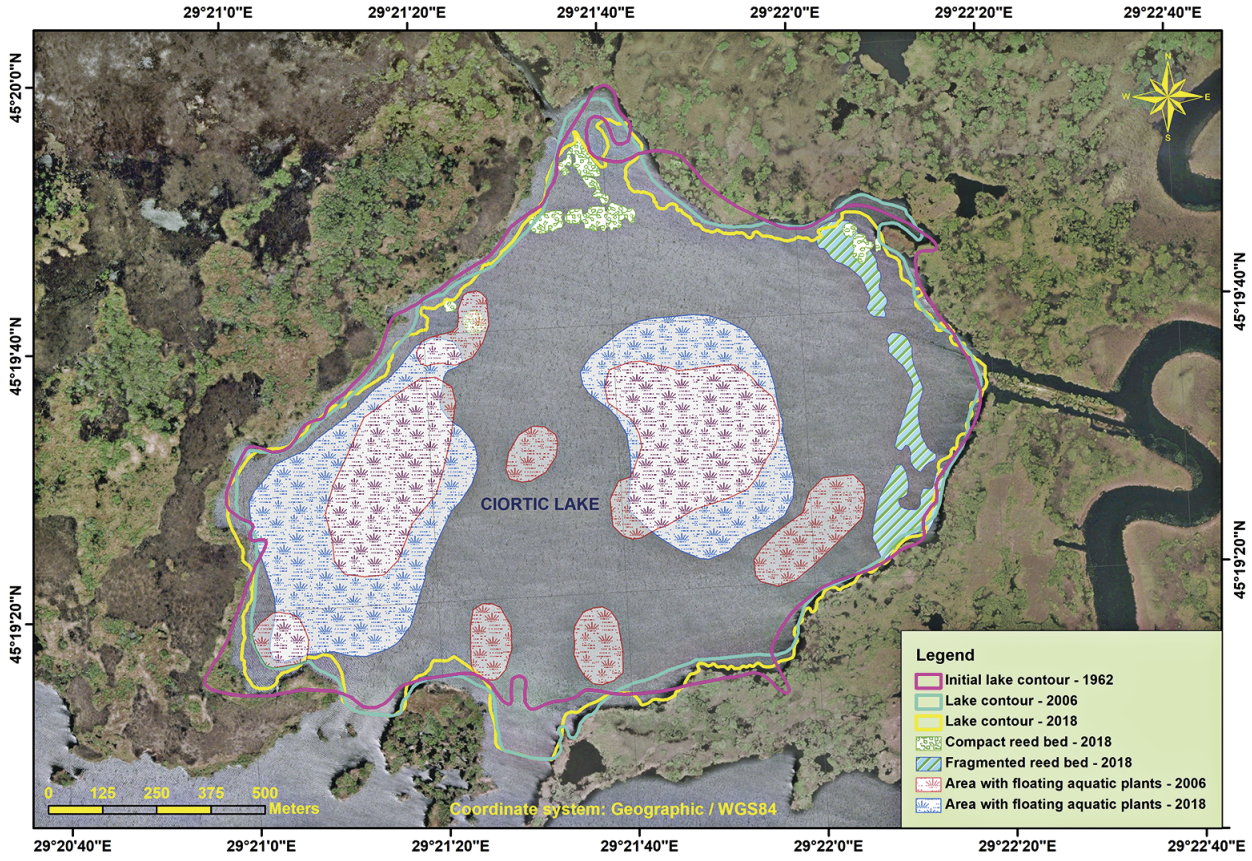

Fig. 7. Map of spatial changes of emerged vegetation and contour in Ciortic (Dracului) Lake during 1962-2018.

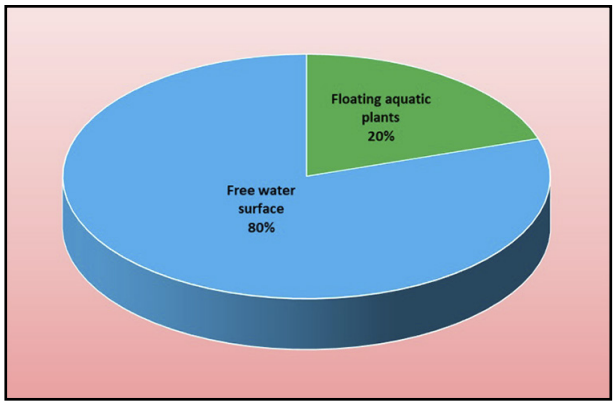

Fig. 8. Distribution of floating vegetation in 2006 in Ciortic Lake.

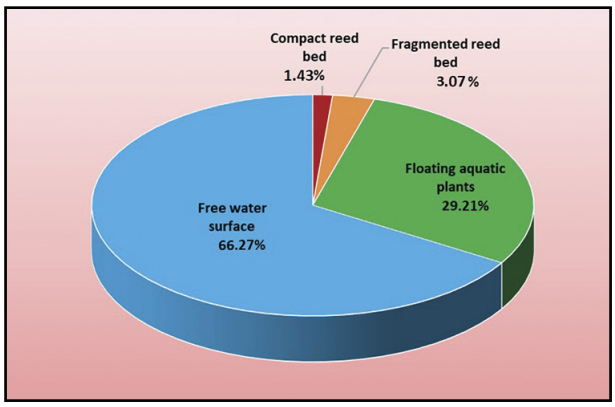

Fig. 9. Distribution of floating vegetation and reed bed formations in 2018 in Ciortic Lake.

the changes are recorded along the whole shoreline, with lower amplitudes in the east-north-east and west-north-west parts, and higher amplitudes in the southern, south-western, northern, and north-eastern sectors.

In the analysis performed for Ciortic Lake in 2006, no reed beds were identified on its surface, but several areas with floating aquatic vegetation were identified. The surface covered by the floating aquatic vegetation is about 30 ha (20% of the entire lake area) and the remaining120 ha stand for free water surface (80% of the total lake area) (Figs.7 and 8). Compared to 1962, the free water surface in 2006, excluding vegetation, decreased by 22.23%.

In 2018, the lake surface reduced by 3.5 hectares compared to 2006 (2.33%) and by 7.8 ha (5.06%) compared to the reference year 1962. Vegetation extension changes during 2006 and 2018 are significant in the northern extremity of the lake (Fig. 7). In this area, in the period mentioned above, a floating reed bed was attached to the shore, in the northern extremity of the lake, near the entrance of a canal directed to north. Our measurements performed in 2018 show an area of 49.4 ha which is covered

by the fixed reed bed (compact), fragmented reed bed and floating aquatic vegetation, which represents 33.72% (Fig. 9) of the total lake area. Thus, in 2018 it was observed a few fixed reed bed areas that are located near the shore in the northern, north-eastern, and western part of the lake. Fixed reed beds cover an area of 2.1 ha (1.43%). In addition to fixed reed bed areas, three areas with fragmented reed beds have been identified, located in the eastern part of the lake. Two of those are almost attached to the shore, and the area covered by them is of 4.5 ha (3.07%) The floating aquatic vegetation covers a significant area within the lake, about 42.8 ha (29.21%), represented by two areas, one located in the central part, the other one in the west-southwest of the lake. The remaining 97.1 ha (66.27%) represent the free water area (Figs. 7 and 9).

Regarding the changes that occurred during the period 1962-2018, a total loss of free water surface of 37.07% can be estimated. By decreasing the free water surface, results directly an increase of the area covered by the aquatic vegetation.

Corciuvate (Rădăcinoasele) Lake

Corciuvate (Rădăcinoasele) lake is located in the south of Ciortic Lake and in the north-eastern part of Babina Lake, showing morpho-hydrographic characteristics similar to these water bodies. Its banks are made up of riparian vegetation (reed beds), and the lake communicates to the south-east by two channels with Matița Lake, and directly, through reed bed islets, connects to the rest of the aquatic system of the Matița-Merhei hydrographic unit.

The (Corciuvate) Rădăcinoasele Lake is separated to the north of the Ciortic Lake, by a discontinuous belt of fixed reed beds. With Babina, the lake also has a limit formed by a chain of fixed reed bed islets, oriented northwest-southeast, showing certain mobility, which indicates that this boundary is one that changes permanently, depending on the water level. During high waters, a part of the reed beds bordering the Babina Lake is hold over (only the fixed ones) the others migrate, separate and form other smaller floating reed beds or attach to the shore. In its initial shape (1962), the lake had an area of about 84 ha and a perimeter of 6.4 km (Fig. 10)

The analysis and processing of the topo-geodetic data available in the archive, combined with the information provided by the LANDSAT 7 satellite images for 2006, shows a lake surface of 142 ha and a perimeter of 6,7 km.

Topo-geodetic measurements obtained in the field in August 2018, associated with the information given by the LANDSAT 8 satellite images, revealed a lake area of 135 ha and a perimeter of 7.8 km.

In 2006, it was observed an increase of about 58 ha of total water surface compared to the initial situation of 1962, which means a 69.05% increase of the lake area. Significant changes in geometry and its surface have been identified. The lake contour changes are significant in the west and southwest, northwest, north and northeast, while in the other parts it is observed a lower amplitude (Fig. 10).

In 2006, on the lake surface were identified fixed reed bed formations covering an area of about 11 ha (7.75%). In addition, the floating aquatic vegetation fields, mapped in the same year, occupied a surface of 12.3 ha (8.66%), the total area covered by vegetation being 23.3 ha, which represents 16.41% of the whole lake surface. So, the remaining free water surface, excluding the compact reed beds and the floating aquatic vegetation, was 118.7 ha (83.59% of the total lake area) in 2006 (Fig.11).

Subsequently, in 2018, in the total water surface it was observed a decrease by 7 ha compared to 2006 and an increase by 51 hectares compared to the reference year, which means 60.71% of the initial area (1962). The changes that occurred during period 2006-2018 are visible, especially in the northeast extremity of the lake, the area where a fixed reed bed with a surface of 3.38 ha has been attached, isolating this part of the lake, nowadays appearing as a waterhole with a surface of 7.5 ha (Fig. 10).. In the same time, we identified withdrawals of the free water surface, simultaneous with the extension of the vegetation area, in the northern part of the lake, on both sides of the communication mouths with the Ciortic Lake. Decreasing of free water surface is observed in the eastern and south-eastern side and in some sectors of the southern part, the other parts showing certain stability of the lake boundary. The south-western side of the lake representing the boundary with Babina Lake, is a dynamic one, consisting of reed and floating reed beds, justifying an evident change by retracting of the current limit (2018), comparative with 2006 (Fig.10).

A few compact reed beds with an area of 13.2 ha (9.77%) were identified on the lake surface. There are numerous areas covered by fragmented reed beds, located in the north-east, east, south-east and south parts of the lake, which appear like a belt of reed beds delimited by small water corridors (Fig. 10); the area occupied by these fields is 17.8 ha (13,19%). Also, in the field campaign in 2018, we performed a mapping of the areas covered by the floating aquatic vegetation which occupies an area of 24.4 ha (18.07%) (Fig.12). Thus, the total vegetation area in 2018, covers 55,4 ha occupied by the compact reed bed, fragmented reed bed and floating aquatic vegetation areas, representing 41.04% of the total lake area. In 2018, the free water surface, excluding floating aquatic plants, was 79.6 ha (58.96% of the total surface of the lake) (Fig.12).

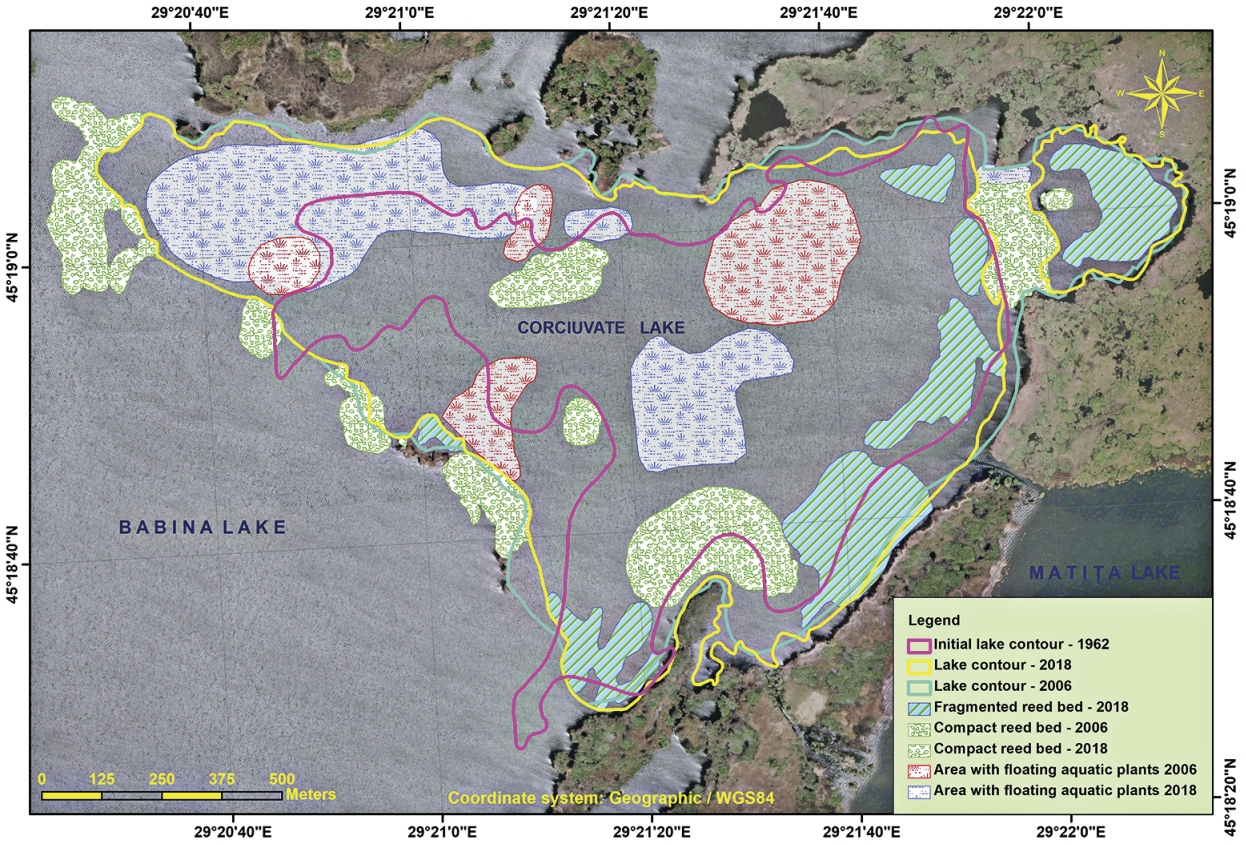

Fig. 10. Map of spatial changes of emerging vegetation and lake contour in Corciuvate (Rădăcinoasele) Lake during 1962-2018.

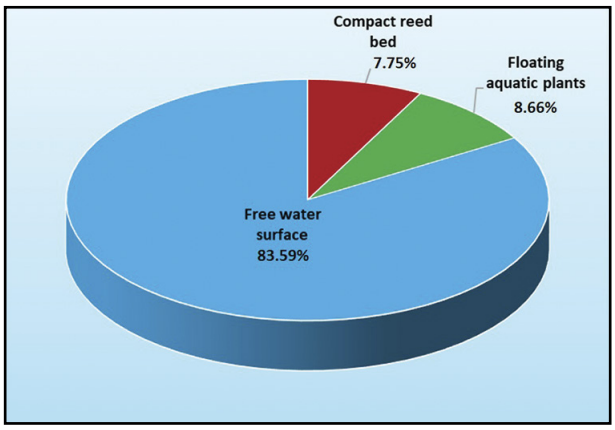

Fig. 11. Distribution of floating vegetation and reed bed formations in 2006 in Corciuvate Lake.

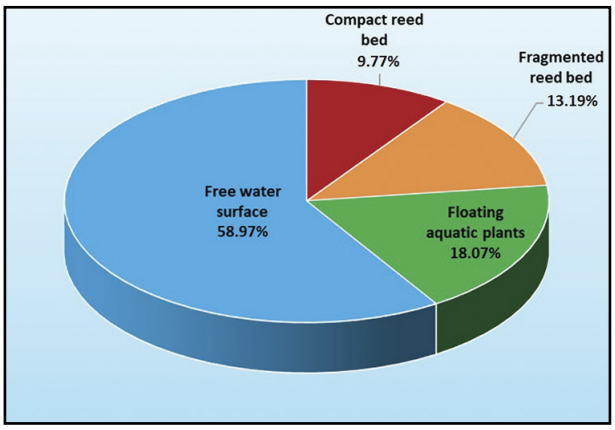

Fig. 12. Distribution of floating vegetation and reed bed formations in 2018 in Corciuvate Lake.

Babina Lake

Babina Lake has a large basin and shows a morpho-hydrographic particularity, in the sense that its shoreline is not well defined/marked, consisting of reed, cattail and fixed or floating reed beds. It is part of a complex of lakes that connect with each other by brooks and canals, through the vegetation mass and even under the reed bed formations. The lake depth varies depending on the water level on the main branches, and the degree of transparency is also depending on the hydrological regime. The northern extremity of Babina Lake was initially a lake, called Curățata, well-defined on the Topo-Hydrographic Map of 1962.

Babina Lake is located in the south-southwest of Corciuvate Lake of which it is separated by a movable limit, given by a series of reed beds that changes on the water level and season (Figs. 2 and 13). The lake also communicates with Matița Lake through the Babina-Matița canal located in the eastern part and which, in its last part, joins the Lopatna

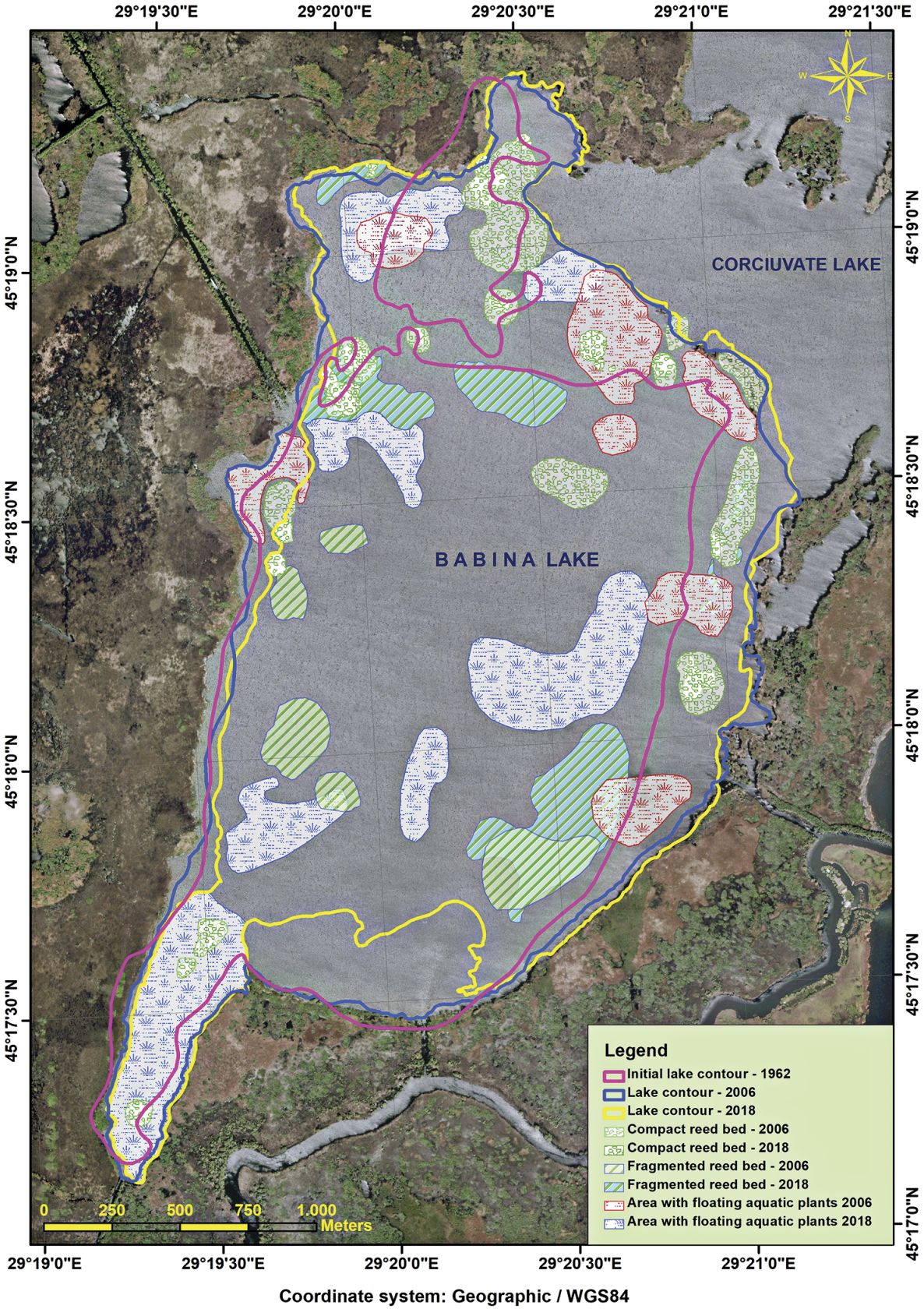

Fig. 13. Map of spatial changes of emerging vegetation and lake contour in Babina Lake during 1962-2018.

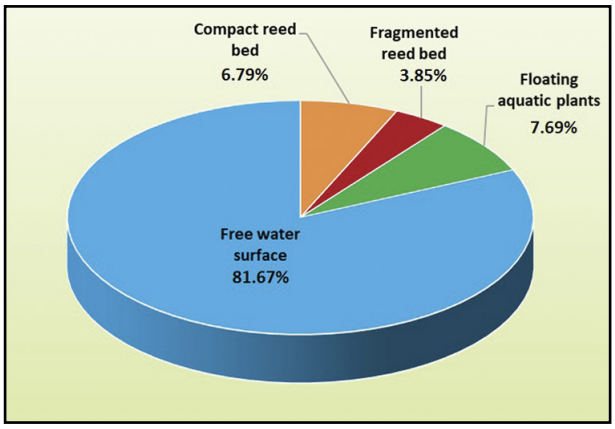

Fig. 14. Distribution of floating vegetation and reed bed formations in 2006 in Babina Lake.

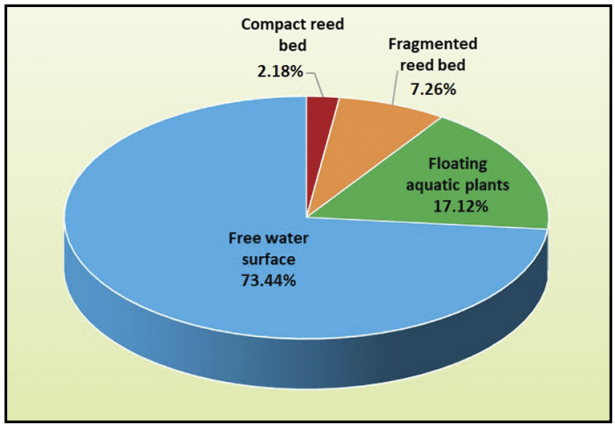

Fig. 15. Distribution of floating vegetation and reed bed formations in 2018 in Babina Lake.

channel. The initial shape of the lake (1962) had an area of about 378 ha, plus the surface of the adjacent water body – Curățata Lake (34 ha), located in the north of the Babina Lake. Therefore, the total area of Babina Lake had initially 412 ha and a total perimeter of 13,7 km. Significant changes occurred between 1962 and 2006, but these are not the subject of our paper, so they will not be analysed in detail.

The analysis and processing of topo-geodetic data available in the GeoEcoMar archive for 2006, shows a lake area of 520 ha and a perimeter of 12,8 km, which means an increase of the water surface by 108 ha (26.21%) during 1962-2006.

Significant changes are found in the northern part of the lake, where, over the time, the Curățata Lake was annexed to the Babina Lake. Also, the eastern part of the lake has undergone many visible changes by the withdrawal of the shore, due to erosion and, consequently, the narrowing of the land area between Babina and Lake Matița. The magnitude of the changes is lower in the southern end of the lake and on the west side (Fig. 13).

The topo-geodetic mapping of the lake surface in 2006 highlight an area with fixed reed bed of 35,3 ha, representing 6.79% of the total lake surface (Fig.14). Fixed reed bed formations are located in the northern part of the lake, at the boundary with Corciuvate Lake, on the eastern side, but also in the southern extremity of the lake (Fig. 13). Also, areas with fragmented reed beds which cover a surface of about 20 ha (3.85%) have been identified. The mapping of floating aquatic vegetation zones showed that these areas are placed mainly near the reed bed formations that are on the border with Corciuvate Lake, in the eastern and northern part, but also accumulated in a small bay located in the western part of the lake (Fig. 13). Floating aquatic vegetation covers an area of 40 hectares (7.69%) of the lake surface (Fig.14).

All these types of vegetation totalized 95.3 ha in 2006, which means 18.33% of the total lake area, the rest of 424.7 ha representing the free water surface (81.67% of the entire area) (Fig.14).

The topo-geodetic measurements carried out in the field campaign in August 2018, combined with the information provided by the LANDSAT 8 OLI/TIRS satellite images (https://earthexplorer.usgs.gov), showed a lake area of 486 ha and a perimeter of approximately 13.6 km, resulting in a decrease of the lake surface by 34 hectares (6.54%), compared to 2006, and an increase of 74 ha (17.96%), compared to 1962. The most significant changes regarding the evolution of the vegetation boundary and of the free water surface, occurring between 2006 and 2018, were identified in the south of the lake, where massive reed beds have been attached to the shore (Fig. 13); the reed bed barrier is currently broken to facilitate the access in the lake from a branching of Eracle Canal. Important changes are also visible at the entrance of the Rădăcinoasele Canal, located in the western part of the lake. On both sides of the Rădăcinoasele Canal mouth, were identified areas of reed bed formations; more significant changes have been produced on the right side of the canal mouth, where the existing bay is currently covered with reed vegetation and two well-defined fixed reed beds. Considerable changes are also found in the southern extremity of Babina Lake, where the entire water surface is covered by floating aquatic vegetation and reed (Fig. 13).

The mapping of the reed bed formations on the lake surface shows 20 small fixed reed beds and two of medium size. The fixed reed beds are located in the northern, central-northern, western, eastern part and the southern end of the lake, near the shores. An explanation of this phenomenon could be found in the fact that the wind action on the free water surface of the lake, determines the mobility and placement of the reed bed formations near the shore, where the water has a lower depth. The reed beds can be attached for a while or permanently, depending on the hydrological regime (Fig. 13).

The area occupied by the fixed reed beds amounts to 10.6 ha (2.18%). Near to compact reed beds, there are fragmented reed bed formations, covering an area of 35.3 ha (7.26%) in Babina Lake. In addition, the mapping of floating aquatic vegetation has shown that it covers an area of approximately

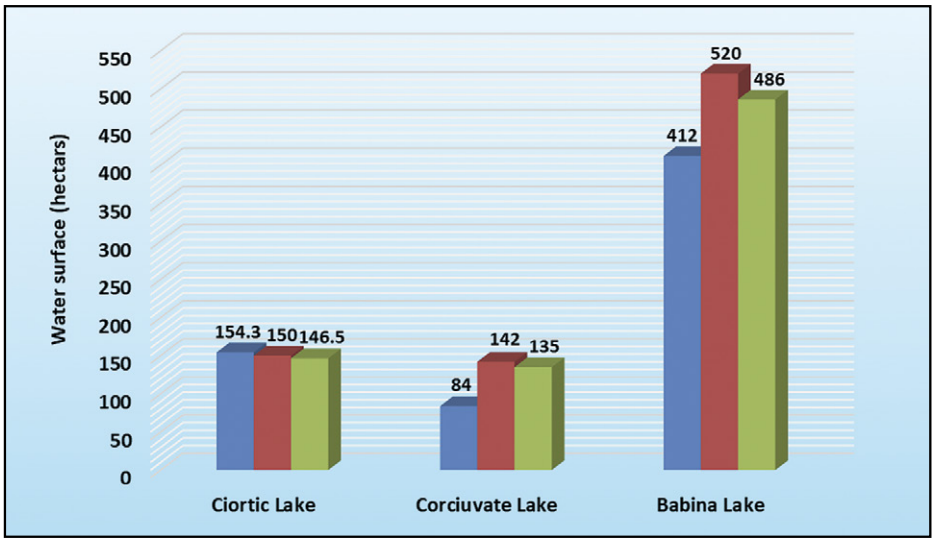

Fig. 16. Evolution of the water surface in the analysed lakes during 1962-2018.

83.2 ha (17,12%) (Fig.15). For 2018, an area of 129.1 ha was covered by fixed (compact) reed beds, fragmented reed beds and floating aquatic vegetation, corresponding to 26.56% of the total area, and the rest of about 356.9 ha (73.44 %) represent free water surface (Fig.15).

The topo-geodetic mapping of aquatic vegetation in the Danube Delta is important because it presents in an explicit way what changes occurred in the lacustrine ecosystems concerning floating aquatic vegetation, reed and fixed reed beds. The process of vegetation expansion on the water surface shows an almost continuous growth in the last period, endangering the submerged life of the lacustrine system through water oxygen depletion. This fact originate from the water eutrophication, a phenomenon that has accelerated uncontrolled in recent years. The undefined borders of the studied lakes determine an approximate appreciation of the mapped elements and the topo-geodetic interpretation of the results within the study.

Figure 16 presents the water surface evolution during the analysed period showing a constant decrease of its area in the Ciortic Lake, but a different situation for the other two lakes. For both the Corciuvate and Babina lakes there is a significant increase of the water surface between 1962-2006, due to the morphological changes of the surrounding area that occurred during this time. Between 2006 and 2018, both lakes show decreases of the water surface, the most significant being in Babina Lake.

From the processing of topo-geodetic data measured directly in the field and their correlation with satellite imagery from the same period, it results thematic maps such as: aquatic vegetation strip maps, reed bed formations maps, floating aquatic vegetation maps, lake shores maps etc.).

CONCLUSIONS

The interpretation of the results shows a clear tendency to increase the aquatic vegetation area on the studied lakes at the expense of the free water surface, which decreased considerably during the analysed periods. Our paper attempts to demonstrate that in the studied lakes the process of overcrowding and the reduction of the free water surface is related to the excessive growth of emerging vegetation due to the water eutrophication.

The eutrophication phenomenon is determined by nutritional pollution and is a reaction of an aquatic ecosystem to the addition in the water of various artificial or natural substances (nitrates and phosphates). The excessive growth of macrophytes and algae (algal blooms), causes eutrophication which can have negative consequences on the entire lacustrine system.

On the other hand, this study contributes to highlight the changes in time and space of the floating aquatic vegetation limits in the Danube Delta lakes.

The process of diminishing the free water surface from 2006 to 2018 is the most significant in Corciuvate Lake (from 83.59% to 58.96% = 24,63%), followed by Ciortic Lake (from 80% to 66.27% = 13.73%) and Babina Lake (from 81.67% to 73.44% = 8.23%). The corresponding absolute losses expressed in surface units (ha) for the 3 lakes are 67.8 ha for Babina Lake, 39.1 ha for Corciuvate Lake and 22.9 ha for Ciortic Lake.

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