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The Assessment of Artificial Water Surfaces Regeneration in Stachinez Swamps Protected Area by Using Remote Sensing and In–situ Data

Marcel TÖRÖK - OANCE[1,*], Rodica TÖRÖK - OANCE[2]

[1] Faculty of Chemistry, Biology and Geography, Department of Geography, West University of Timișoara, Timișoara, Romania
[2] Faculty of Chemistry, Biology and Geography, Department of Biology and Chemistry, West University of Timișoara, Timișoara, Romania
* *Corresponding author*, marcel.torok@e-uvt.ro

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Abstract

The Satchinez Swamps, a remnant of the swamps once specific for Banat Plain, is an ornithological reserve since 1942 and the habitat of many protected bird species. Draining works conducted in the seventies affected the reserve by decreasing the water surface area. Thirty-five years later, hydro-technical works aiming to restore the former aquatic surfaces within the buffer zone were conducted. Thus, in 2005 a water delivery canal from the discharge canal of Satchinez reservoir towards Balta Mare was built. The objective of this study is to assess the efficiency of the hydrological works carried out in 2005 by using temporal analysis of some normalized difference indexes derived from satellite images, in relation to precipitation data (recorded at Timisoara meteorological station) as an indicator for wetland restoration. We used geospatial data from different time periods: historical maps (1953, 1962 and 1984), orthophotos (1963, 1970, 2005 and 2012), oblique airphotos (2004) and 38 Landsat satellite scenes (1984-2015), two images per year, for the dry season respectively for the rainy season. We noticed a slight increase of the Normalized Difference Vegetation Index (NDVI) in Balta Mare and on the relict watercourse of Sicsău stream, which shows the expansion of reed and suggests an increase in soil moisture. During the dry season, for the period before the restoration works (1984 - 2004) there is a strong, very significant correlation between Normalized Difference Water Index (NDWI) and precipitations ($r = 0.7008$, $p = 0.0011$). After 2005, this correlation no longer occurs ($r = -0.1083$, $p < 0.05$), which demonstrates that precipitations are not the main water supply for Balta Mare anymore. For the 1984 – 2015 period, during rainy months the Modified Normalized Difference Water Index (MNDWI) indicate the presence of water in Balta Mare, but during the dry months, it demonstrates the lack of water which underlines the temporary character of this pond and confirms the field observations. We conclude that the restoration did not succeed in the rebuilding of the former water surfaces of Balta Mare, but has an effect in increasing the underground water level in this area followed by reed extension.

Keywords: *wetland restoration, air photo interpretation, NDVI, NDWI, MNDWI, Satchinez Swamps*

Rezumat. Evaluarea reconstituirii artificiale a suprafețelor acvatice din arealul protejat Mlaștinile de la Satchinez utilizând date de teledetecție și observații din teren

Mlaștinile de la Satchinez, rest al mlaștinilor specifice odinioară Câmpiei Banatului, au fost declarate rezervație ornitologică încă din anul 1942 și reprezintă habitatul multor specii de păsări protejate. Lucrările de desecare efectuate în anii șaptezeci au afectat rezervația ducând la scăderea suprafețelor acoperite de apă. După 35 de ani au fost realizate lucrări hidrotehnice cu scopul de a reconstitui vechile suprafețe acvatice din zona tampon. Astfel, în anul 2005, a fost săpat un canal de alimentare cu apă din canalul de descărcare al lacului Satchinez către Balta Mare. Obiectivul acestui studiu este de a evalua eficiența lucrărilor hidrologice efectuate în 2005 utilizând analiza temporală a unor indici normalizați de diferențiere derivați din imagini satelitare în corelație cu datele de precipitații (înregistrate la Stația Meteorologică Timișoara) ca indicator al gradului de reconstituire al mlaștinii. Am utilizat date geospațiale din diferite perioade de timp: hărți istorice (1953, 1962 și 1984), ortofotoplanuri (1963, 1970, 2005 și 2012), fotografii aeriene oblice (2004) precum și 38 de imagini satelitare Landsat (1984-2015), câte două imagini pentru fiecare an, una pentru intervalul ploios și cea de a doua pentru perioada secetoasă. Am observat o ușoară creștere a indicelui normalizat de diferențiere a vegetație (NDVI) în Balta Mare și pe cursul relict al pârâului Sicsău, fapt care se explică prin expansiunea stufului și care sugerează o creștere a umidității solului. În sezonul uscat, pentru perioada de dinaintea lucrărilor de restaurare (1984-2004), se înregistrează o corelare puternică, extrem de semnificativă, între indicele normalizat de diferențiere a umezelii (NDWI) și precipitații ($r = 0.7008$, $p = 0.0011$). După anul 2005 această corelare nu mai apare ($r = -0.1083$, $p < 0.05$), ceea ce demonstrează că precipitațiile nu mai reprezintă principala sursă de apă pentru Balta Mare. În perioada 1984-2015 în lunile ploioase indicele normalizat modificat de diferențiere a apei (MNDWI) indică prezența apei în Balta Mare, dar în lunile secetoase demonstrează lipsa acesteia, ceea ce evidențiază caracterul temporar al acestei bălți și confirmă astfel observațiile din teren. În concluzie, lucrările de restaurare nu au dus la refacerea fostelor suprafețe de apă din Balta Mare, dar au avut totuși un efect în creșterea nivelului apei freatice în acest areal, ceea ce a dus la extinderea stufului.

Cuvinte-cheie: *restaurarea mlaștinilor, aerofotointerpretare, NDVI, NDWI, MNDWI, mlaștinile de la Satchinez*

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Introduction

The Satchinez Swamps ornithological reserve is located in Timis county, Romania, between Satchinez and Bărăteaz villages, in the floodplains of Ier river. The protected area currently includes, in addition to the actual reserve, located within Mărășești - Râtu Lișului area, a buffer zone located alongside Ier river, from east of Bărăteaz up to Râtu Mare, south-west of Satchinez (Fig. 1).

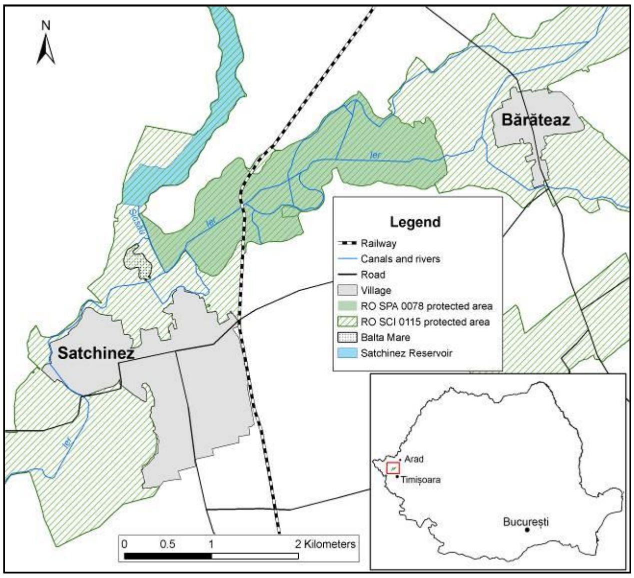

Fig. 1: Location of the study area

Satchinez Swamps was declared a natural reserve in 1942, covering approx. 200 hectares (Kiss, 1999). Nowadays, Satchinez Swamps Reserve is part of the Natura 2000 sites, representing RO SPA 0078 (268 hectares). The reserve and the buffer zone (1072 ha) are also included in the RO SCI 0115 protected area (2290 hectares) (Brînzan, 2013) (Fig. 1). The importance of these swamps comes from the fact that this is the habitat of several protected species of aquatic birds: *Egretta alba, Egretta garzetta, Ardea cinerea, Ardea purpurea, Nycticorax nycticorax, Plegadis falcinellus, Phalacrocorax pygmeus* etc. (Nadra, 1962, Kiss, 1999, Stănescu, 2005). The diversity of ornithofauna is demonstrated by the large number of bird species (167 bird species) identified between 2003 - 2005, which means more than half of the Romanian avian fauna (Stănescu, 2005). Among them, *Crex crex, Aythya nyroca* and *Falco vespertinus* are globally protected species (Brînzan, 2013).

Nevertheless, between 1960 and 1970 several draining works were conducted, in order to convert some land areas into agricultural use. Consequently, the protected area decreased and the water surface area was also reduced as a result of the draining works, bearing an impact on avian fauna and natural habitats (Kiss, 1999, Stănescu, 2005). During the 1963-2004 interval, the water surface area decreased by approximately 3 hectares, while the reed (*Phragmites australis)* covered surface grew from 220 hectares to 284.5 hectares, revealing the clogging tendency of the swamp (Török-Oance and Török-Oance, 2005, 2008). Hydro-technical works were also carried out, in order to supplement the water intake of the central part of the Reserve, works which were abandoned after 1989. The consequence was the significant decrease of water level in the Reserve during the immediately following period (Stănescu, 2005). Between 1999 and 2002, under LIFE 99/NAT/RO/006394 project, the current hydrotechnical system was rehabilitated following unclogging works to the reserve's water supply canal and repair works of the dams of the hydrotechnical system, aiming to restore and preserve the reserve habitats (Stănescu, 2005). The following project, LIFE 02/NAT/RO/8573 (2002-2005), included also hydro-technical works in the Balta Mare area. Thus, a water supply canal was digged from Sicsau canal towards Balta Mare in order to restore this former aquatic surface located in buffer zone. The buffer zone is important because it represents, due to its water surfaces, a feeding place for birds, and also for lowering the anthropic impact over the reserve itself. The anthropic impact over the reserve is high and diverse: agricultural activities, hydrotechnical work, cutting and setting fire to reed, felling trees, fishing, hunting, transportation (Török-Oance and Török-Oance, 2005).

Knowing the current status of the swamp, as well as the changes that have occurred is essential for its preservation and for choosing the proper decisions necessary for a sustainable management. Considering it is a remnant of the swamps once specific for Banat Plains (Stănescu, 2005), and that it was significantly and repeatedly transformed by hydrotechnical works, we ask ourselves the legitimate question if and how much this area has been rehabilitated after the reconstruction works carried out in 2005.

Generally, the main purpose of the restoration works of the swamps is to restore the hydrologic drainage system and the vegetation to its initial state (Melesse et al., 2007), which would enable the restoration of the ecosystems. Monitoring the achieved outcomes is necessary to determine the efficiency of the intervention (Klemas, 2013). Unfortunately, the monitoring has not been accomplished anymore for the Satchinez Swamps.

The objective of this study is to assess if the hydrological works carried out in 2005 in the buffer zone for the purpose of rebuilding the former surfaces occupied by water (Balta Mare area) - eliminated by the draining works carried out in the seventies - had the expected effect. Since this is not apparent in the field, as Balta Mare is, just like in the previous years, temporary, we used the remote sensing data to reach an objective conclusion. The methodology we propose uses temporal analysis of normalized difference indexes for vegetation, moisture and water, derived from satellite images, in relation to precipitation data as an indicator for wetland restoration. So, we started from the premises that within Balta Mare area the values of the moisture indexes should be more dependent on the amount of precipitation in the years preceding the restoration than after the building of the water delivery canal from the discharge canal of Satchinez reservoir towards Balta Mare. Due to the random additional water intake, other than from precipitations, this correlation should be weaker after 2005.

Materials and methods

Data

In order to perform the temporal analysis of the studied area, historical maps from different time periods were used. The maps are drawn at detailed scale to enable such analysis. Thus, there were used topographic maps, at scale 1:20.000 (Mănăştur sheet) from 1953 and at 1:25.000 (Satchinez sheet) from 1962, 1984 respectively.

In order to perform a more objective analysis, orthophotos were used (Table 1). There is no detailed information regarding the image acquisition date, only the year in which the aerial photography was conducted.

Since there are no more recent orthophotos, for 2016 we used for visual analysis a very high spatial resolution satellite image (VHR), acquired on the 21st April (source: Google Earth). The image is comparable, in terms of spatial resolution, with aerial photographs.

Table 1: The orthophotos used in this paper

Date	Scale/Spatial resolution	Film type/ Bands	Format	Source	Observations
1963	1:5000	Panchromatic film	Hard copy	IGFCOT*	The orthophoto captures the reserve area before the anthropic intervention.
1973	1:10000	Panchromatic film	Hard copy	IGFCOT*	The orthophoto captures the moment immediately following the hydrotechnical works performed for draining and for building the Satchinez reservoir.
2005	1:5000/0.5m	Red, Green, Blue	GeoTiff	ANCPI**	The orthophoto captures the hydrotechnical works for restoring Balta Mare area, under LIFE 02/NAT/RO/8573 project.
2012	1:5000/0.5m	Red, Green, Blue	GeoTiff	ANCPI**	The most recent colour orthophoto available for the study area.
2012	1:5000/0.5m	NIR, Red, Green	GeoTiff	DTM***	The most recent colour infrared orthophoto available for the area on study

* Institute of Geodesy, Photogrammetry, Cartography, and Territorial Planning
** National Agency for Cadastre and Land Registration
*** Military Topographic Directorate

The Landsat program, started in 1972, is the longest-running enterprise for monitoring the earth surface with satellite imagery. Landsat 5 started image acquisition in 1984. These are compatible, in terms of spectral and spatial resolution, with the images collected by more recent satellites, Landsat 7 and Landsat 8 (http://landsat.gsfc.nasa.gov/). So, in order to assess the efficiency of the hydrotechnical works carried out to restore Balta Mare area, we used 38 Landsat satellite scenes (path 185 and row 028) acquired between 1984-2015 by different sensors: Thematic Mapper (TM), Enchanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI) (images courtesy of U.S. Geological Survey). All the scenes used are georeferenced and terrain corrected (Level 1T) and the cloud coverage level for the study area was 0%. Only for four years, there were no cloud-free images in rainy months (May or June) (Fig. 2).

Two scenes were used for almost every year, one from May or June, when the maximum amount of precipitations is recorded, and the second from August or September, period characterized by a significant decrease in the amount of precipitations,

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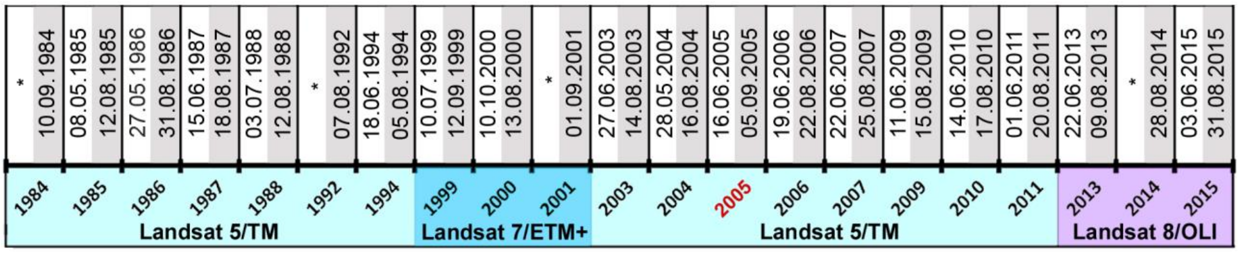
which leads to the drying up of temporary ponds. The spectral bands used in this study to calculate the normalized difference indexes are: blue (BLUE), green (GREEN), red (RED), near infrared (NIR) and shortwave infrared 1 (SWIR 1). All bands have the same spatial resolution (30 m) and were used to calculate some normalized difference indexes for vegetation, moisture and water.



* = no cloud-free images

Fig. 2: Landsat scenes used in this analysis and their acquisition date

Photographs taken during 2004, 2005 and 2016 field campaigns, as well as aerial photographs from 2014 have also been used. The aerial photographs were taken by Dan Stănescu and Marcel Török – Oance, who took two flights with a motor-glider, at approximately 300 m altitude above the reserve on 4th May 2004 (Török - Oance and Török - Oance, 2004). At that moment, the most recent aerial photogram was dated back to 1973, so these aerial photos represent the only objective geo-spatial information regarding the status of the protected area just one year before the beginning of the restoration work in buffer zone. Out of these photographs, only those capturing Balta Mare area were selected for comparison.

The monthly average precipitation values for the analysed period (1984 - 2015) recorded at Timisoara meteorological station was used. Given the short distance to the protected area, of only 26 km in straight line, and the existence of a plain landform, characterized by morphometric and morphological homogeneity, we considered that the data recorded at this meteorological station were relevant for the study area. We considered that soil and vegetation moisture, as reflected by the normalized difference indexes values, are determined mostly by the amount of precipitations on longer period of time, including the water resulting from snow melting, than monthly amount of precipitations. For example, the time lag between the response of plants to increasing of moisture could be until two months (Richard and Poccard, 1998). Thus, we considered more suitable for this analysis to use the amount of precipitations in that year until the acquisition date of the satellite image instead of monthly precipitation values.

Methods

The printed orthophotos dating back to 1963 and 1972 were scanned and georeferenced in the Stereo 1970 projection system (Török - Oance and Török - Oance, 2004). The spatial resolution obtained is 1 m, with a Root Mean Square Error of 0.79.

Since the normalized difference indexes derived from the satellite images acquired in different years were to be compared against one another, in order to observe the occurred changes, it was necessary to perform radiometric corrections of the images (Ko et al., 2015). Consequently, the atmospheric correction of the images was performed, and each band was calibrated in terms of radiance to the superior level of the atmosphere (top of atmosphere radiance) using QUAC tool (Envi software).

Since the analysed area is much smaller than a Landsat scene, we extracted only the area under study from each scene, according to the boundaries of the protected area.

The following differentiating normalized indexes were used in this study: Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Modified Normalized Difference Water Index (MNDWI).

NDVI (Rouse et al., 1974) is used to estimate the distribution and density of green vegetation per image pixel. Its values are ranging from -1 to 1, the positive values represent green vegetation, while the negatives values represent water bodies.

$$NDVI = (NIR - RED)/(NIR + RED)$$

NDWI illustrates the water content of the vegetation and soil (Gao, 1996, Wilson and Sader, 2002) and assess the hydrous potential of vegetation and soils. NDWI is an efficient and accurate index for wetland detection (Ashraf and Nawaz, 2015). The value of NDWI for the dry vegetation spectrum is negative and for the green vegetation spectrum is positive. Water has also positive value. It is calculated using the infrared spectral band (NIR) and the shortwave infrared (SWIR 1), according to the formula:

NDWI = (NIR – SWIR 1)/(NIR + SWIR 1)

MNDWI (Xu, 2006), was built for aquatic surfaces detection, and reduce the similarity with built areas, vegetation or soil. It uses the green spectral band (GREEN) and the shortwave infrared (SWIR 1), according to the formula:

MNDWI = (GREEN – SWIR 1)/(GREEN + SWIR 1)

The MNDWI is an effective index for detecting open water and wetland environments (Jones, 2015, Sun et al., 2012, Thomas et al., 2015).

The visual exploration of cartographic materials and aerial photographs integrated in GIS (ESRI ArGIS 10.1 software), from different periods of time, enabled the analysis of the evolution of the study area and the evaluation of changes in wetland ecosystem (Török-Oance and Török – Oance, 2004, Cserhalmi et al., 2011). The ponds, rivers and canals, the alterations of which were tracked over time in order to observe the impact of reconstruction works, were extracted by digitization.

For each and every year, the values of the normalized difference indexes were extracted as ASCII files from Balta Mare, which were later on statistically analysed in InStat software. The statistical analysis of the data focused on extracting the descriptive statistical variables, variation analysis and the analysis of the relationship between variables. The interpretation of the correlation coefficients was as follows: $r > 0.7$ = strong correlation, $r = 0.4–0.7$ moderate correlation, $r < 0.4$ = weak correlation (Holmes et al., 2014). For statistical tests, the following interpretation of two-tail P values was used: $P < 0.05$ = significant, $P < 0.01$ = very significant, $P < 0.001$ = extremely significant, $P > 0.05$ = not significant (Marzilier, 1990).

Since NDWI and NDVI are often related with the amount of precipitations (Richard and Poccard, 1998, Roerink et al., 2003, Quinn and Ephstein, 2015), a change detection analysis was conducted between the normalized indexes for two periods during which the same amount of precipitation was recorded: 2003 (339.5 mm) and 2009 (348.8 mm). The first moment was selected before digging the canal (14th August 2003 Landsat scene), and the second moment was chosen after 2005, when the canal was already built (15th August 2009 Landsat scene). These moments are to be called T1 and T2 hereinafter.

Field mappings of the interest areas were conducted and photographs were taken for the sectors in which the swamp reconstitution was attempted. In order to reveal the occurred changes, the photographs were compared to photographs dating back 10-12 years ago (Török - Oance and Török - Oance, 2004).

Results and discussions

Wetland restoration is a new field of research which is developing rapidly. The restoration can be expensive and time consuming. Given the poor understanding of the complex processes that determine the character of a wetland, the restoration of the original conditions is often unsuccessful (Klemas, 2013).

Considering that hydrology is the most important element in the creation and maintenance of wetlands, water management is the key in restoring wetlands (Acreman et al., 2007). Wetland systems are vulnerable to changes in water intake, both in terms of quantity and quality (Mitsch and Gosselink, 1993).

The main purpose of the analysis of historic mapping and old orthophotos was to determine a geo-spatial reference point representing the state of the reserve prior to its transformation through extensive hydrotechnical works. This is important because the current study attempts to determine the efficacy of the ecological restoration works of the protected area and this cannot be achieved without such a spatial-temporal benchmark.

All historic maps indicate the presence, of a wetland area north of Satchinez, covered with reed and ponds (Fig. 3 and Fig. 4). The largest surface in this area is occupied by Balta Mare (approximately 6 hectares). This is one of the areas transformed by the draining works carried out in the seventies and which was to be restored by hydrotechnical works in 2005. The 1953 and 1984 maps record this area as lake or pond, while the 1962 topographic map records Balta Mare as a hardly accessible swamp.

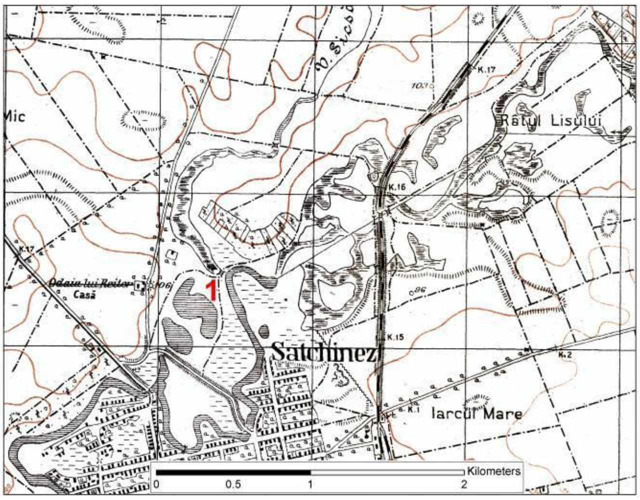


Fig. 3: Balta Mare (1) drawn on 1953 topographic maps, scale 1:20.000 (Mănăştur sheet)

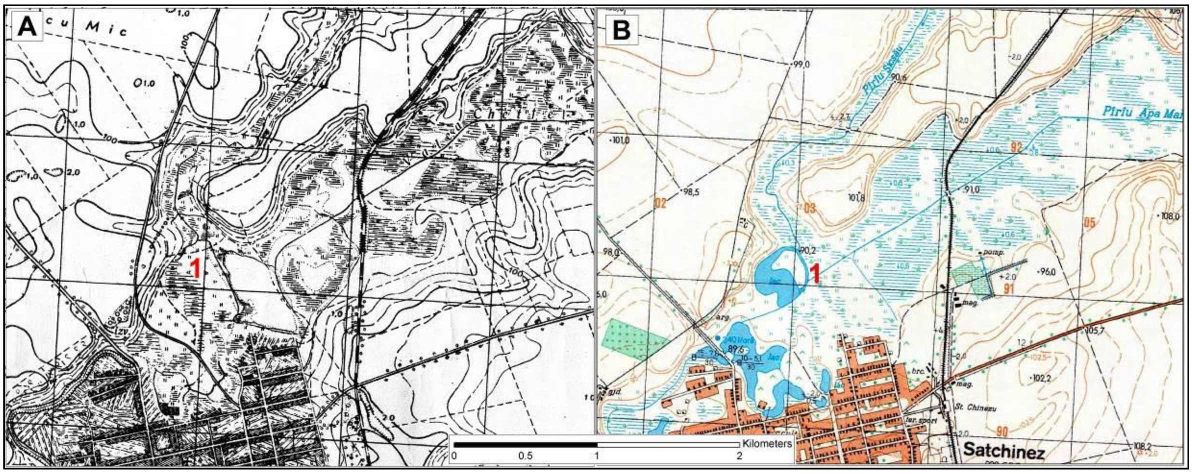


Fig. 4: Balta Mare (1) plotted on 1962 topographical map (A) as hardly accessible swamp and plotted on 1984 topographical map (B) as pond (scale 1:25000)

We can also notice a lack of consistency from one map to another when representing the other ponds bordering Satchinez village, both in terms of size and shape. The hydrographic network is not plotted on the 1953 map, but it is recorded on the other two maps. On the 1962 map, it is clearly visible that Balta Mare is supplied by Sicsău stream. The 1984 map, drawn after the draining works, reveals the changes in the hydrographic network occurred through the construction of draining canals, but, in our opinion, this map contains a few errors. Thus, according to this map, the Ier canal feeds Balta Mare but, in reality, the canal passes south of it, as it was built precisely for draining this pond. Satchinez reservoir and the sewerage works downstream of it are not recorded either.

The 1963 and 1973 orthophotos capture objectively the situation prior to the draining works, and the one immediately following their completion, respectively (Fig. 5). The 1963 orthophoto captures a moment which can be considered without any doubt the reference point for this analysis. No anthropic intervention over the hydrological network in the protected area is visible on the orthophoto. The valley of Sicsău river meanders extensively and is bordered by reeds and swamps that make the view of the watercourse difficult or even impossible in some places. However, Balta Mare has a clear outline, is surrounded by pastures and is fed with water in the north from Sicsău stream. It is mainly covered by reed, with small water pools. One can also notice the canal which ensures the discharge of water from Balta Mare back into the main watercourse of Sicsău.

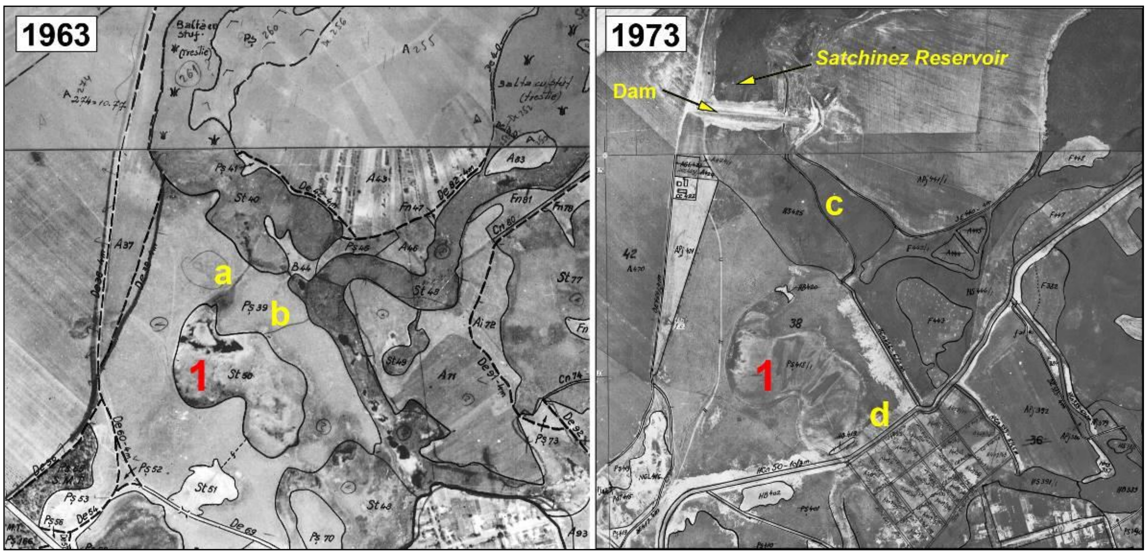


Fig. 5: The Satchinez Swamps Reserve and Balta Mare area (1) prior to the draining works (1963 orthophoto) and after their completion (1973 orthophoto). a and b, watercourses linking Balta Mare and Sicsău stream; c, Sicsău draining canal; d, Ier draining canal

The orthophoto taken in 1973 illustrates the main changes of the hydrographic network from the protected area, due to the hydrotechnical works conducted in the area: the construction of the dam and the reservoir on Sicsău valley, north of Balta Mare, and the transformation of the natural watercourses of Ier and Sicsău by making draining canals with depths of 3 m, 2 m, respectively. One can also notice, south of Balta Mare, the presence of ponds which would disappear in the following years due to the descent of ground water level dictated by building the draining canals. Balta Mare is listed as pasture, but it is easily recognisable due to the shape of the lake basin, shape which is maintained. The image texture suggests that it was artificially submitted under this type of land usage, since its wet meadow character is obvious (Fig. 5).

Since there are no aerial photograms for the period 1973 - 2005, in order to capture the state of the reserve before the start of ecological reconstruction we used aerial, oblique photographs, shot in May 2004. Thus, the aerial photograph (Fig. 6) illustrates Balta Mare area one year before the start of the reconstruction works within this area. The lake basin is easily recognisable, as its shape is identical to the one recorded on the old othophotos Both May and April of that year had a higher volume of precipitations than the multi-year average of those months. This explains the water pools in the centre of the area, which confers this area its temporary, very shallow pond character. It can also be noticed the low coverage with reed of the land surrounding the pond and of the former Sicsău watercourse and its reduced development when compared to the protected area.

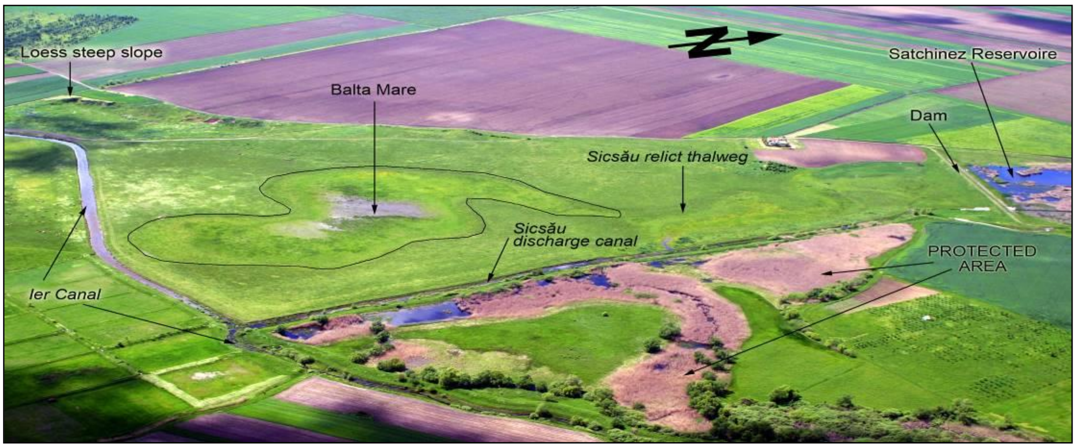


Fig. 6: The oblique aerial photograph of the Balta Mare area shot in 4th May 2004 from a motor-glider, at approximately 300 m altitude above the reserve

The 2005 orthophoto captures the state of the reserve 30 years after the draining works. Balta Mare retains its shape and character of wetland pasture. According to the findings on site, it operates as a temporary pond, with shallow water, only during the rainy spring months (Fig. 7). The construction of the water delivery canal (Fig. 8) from the discharge canal of Satchinez reservoir towards Balta Mare, on the Sicsău relict watercourse and the dam downstream (Fig. 6) which is designed to control the water flow directed towards the former pond can be seen on orthophoto. Some areas are impacted by the deposits of excavated materials as a result of digging the canal and by the construction of the road for accessing the work site, a road which is parallel with Sicsău discharge canal, on its right bank.

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*Volume **XV**, Issue **2** (**December 2016**), pp. **140-151***
*http://dx.doi.org/**10.5775/fg.2067-4635.2016.058.d***

Fig. 7: Balta Mare during the rainy season (March 2004) and the dry season (October 2016). The reed expansion in the central part of the lake basin is obvious in the picture from 2016

The 2012 orthophotos, in natural and near-infrared colours (Fig. 9), reveal the regrowth of vegetation in the sectors impacted by the works conducted in 2005. Balta Mare supply canal has a slightly irregular outline, due to the appearance of paludous vegetation and the bank erosion caused in some sectors by the cattle coming to drink water in that place. Balta Mare is covered with water in its central part, which can be easily visible on the NIR image. We believe this fact is not due in particular to the water drained towards Balta Mare through the canal built in 2005, but to the rainy period during which the image was acquired. Although we do not have the exact date of image acquisition, we can estimate it with enough certainty because the agricultural lots south of Ier canal are flooded, which happens only during the periods with heavy rainfalls. There can also be noticed a slight expansion of the area covered by reed adjacent to the dam and along the relict watercourse of Sicsău river.

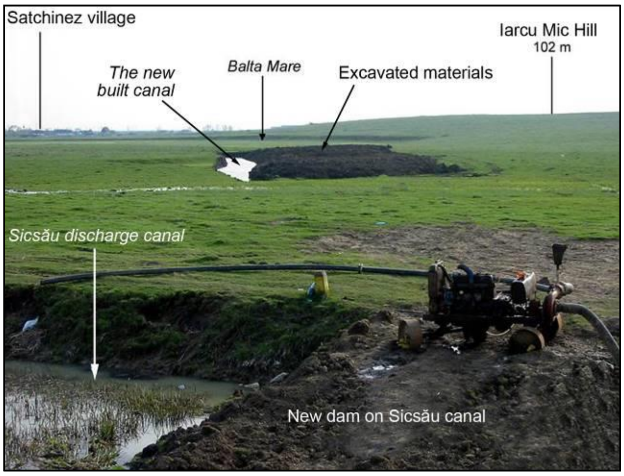

Fig. 8: The hydrotechnical works and construction of the water delivery canal in 12th April 2005

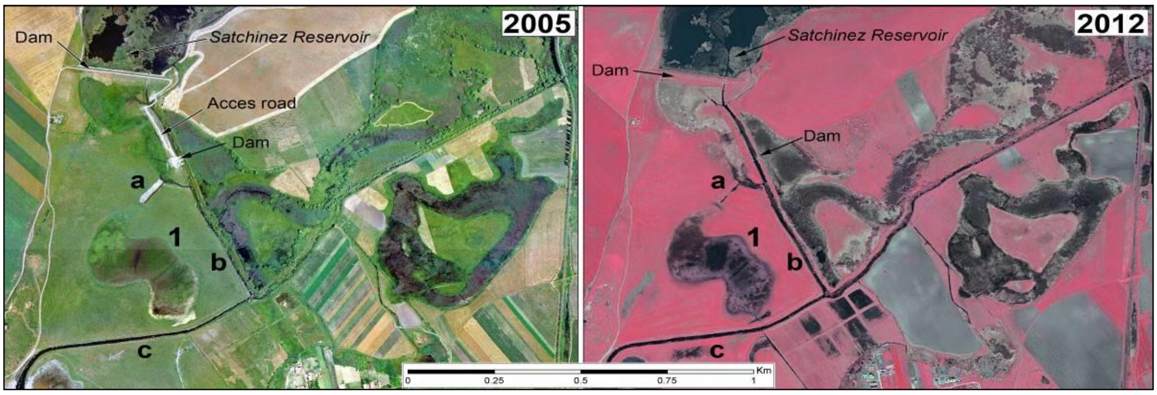

Fig. 9: The 2005 and 2012 orthophotos. 1, Balta Mare; a, the water supply canal built in 2005; b, Sicsău canal; c, Ier canal

The very high resolution satellite image, available on GoogleEarth, is the most recent image and captures the current state of the protected area. It illustrates a moment at the end of September, usually a month with low precipitations. There is no more water in Balta Mare, which clearly demonstrates its temporary character, despite the restoration works. It can also be noticed the advanced clogging stage of the water supply canal in 2016 (Fig. 10), a fact which we also noticed on site (Fig. 11).

Fig. 10: Advanced clogging stage of the water supply canal (a) in 2016 (source Google Earth) compared with 2012 color orthophoto. 1, Balta Mare

The area covered with reed expanded noticeably compared with 2012, but the expanded reed remained at a low height compared to the reed in reserve.

Fig. 11: Advanced clogging of the water supply canal built in 2005. The banks are eroded or covered with reed (October 2016)

On all mapping and orthographic materials under analysis, Balta Mare is clearly outlined, having almost the same size and shape, both before and after the draining works. This is due to the existence of a depressionary landform, highly visible in the land surface, approx. 1.5 m deep in the west, at the base of the slight slope of Iarcu Mic hill. In this area, Balta Mare is clearly outlined from the hill slope by a steep slope sector. In our opinion, the lake basin of Balta Mare is created by suffosion and compaction of loess-like deposits forming the geological sub-layer of the study area. Such loess sinkholes were already noticed in this area (Morariu, 1946). The lake basin was also shaped by river erosion, due to its location in the former watercourse of Sicsău river (according to the 1963 orthophoto) and also by its relatively regular, meandered shape. The existence of this negative, concave landform explains why, in spite of the efforts made for draining the area, Balta Mare could never be transformed into a pasture, and retained its character of wetland meadow and, for several month per year, temporary pond (Fig. 7).

NDVI shows great variability through the years, both for Balta Mare and the entire protected area. The ANOVA analysis for the period 1984 - 2015 shows that NDVI values are significantly and extremely significantly different from one year to another, with a few exceptions. The correlation between NDVI and the volume of precipitations is statistically significant ($p=0.0237$), but moderate ($r=0.6789$), due to the presence of swamp-specific vegetation on large surfaces.

The comparative analysis between T1 and T2, performed by the image differencing method, reveals a slight increase of the NDVI value in Balta Mare area and on the relict watercourse of Sicsău stream, downstream of the dam, during August 2009 (Fig. 12). This fact is explained by the expansion of reed, as confirmed by the findings on site (Fig. 7 and Fig. 13) and suggests an increase in soil moisture. It has been demonstrated that there is a strong spatial autocorrelation between soil moisture and the density of reed and also that the increase in soil moisture enhances the reed growth (Mamat et al, 2016). The relation between vegetation and groundwater level could be an indicator of wetland restoration (Kopeć et al., 2013).

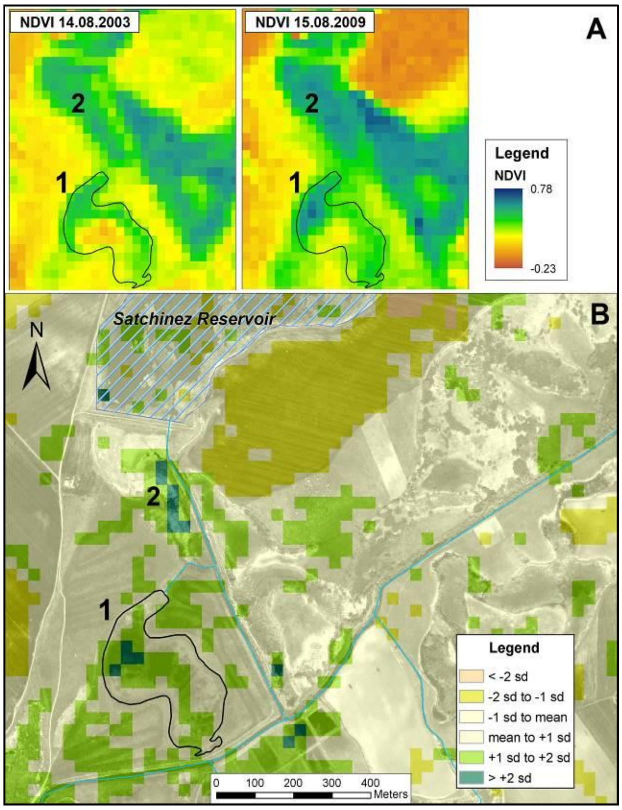

Fig. 12: NDVI comparison between T1 and T2 (A) and NDVI standardized difference image for the same interval (B). The values between +1 and +2 standard deviation show medium NDVI increase and values above +2 standard deviation indicates high NDVI increase. 1, Balta Mare; 2, the relict watercourse of Sicsău stream

NDWI analysis for Balta Mare reveals a moderate, but significant correlation with the volume of precipitations for the entire period under

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analysis (r = 0.4724, p = 0.0478). The values of the correlation coefficient for the period before conducting the restoration works (1984 - 2004) show there is a strong, very significant correlation between this index and the precipitations (r =0.7008, p = 0.0011) (Fig. 14 A). However, during the period between 2005 and 2015, this correlation no longer occurs (r = -0.1083, p <0.05) (Fig. 14 B), which demonstrates that precipitations no longer represent the only source of water supply for Balta Mare.

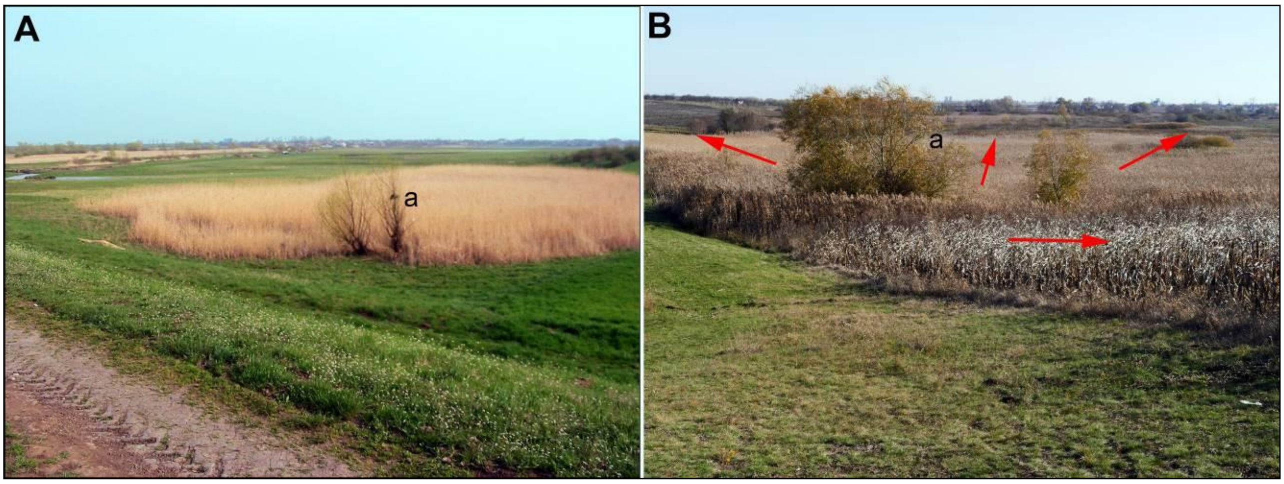

Fig. 13: Reed occurrence in 2004 (A) and in 2016 (B) at the relict watercourse of Sicsău stream south of Stachinez reservoir. The red arrows show the reed expansion directions. a, tree as a reference point

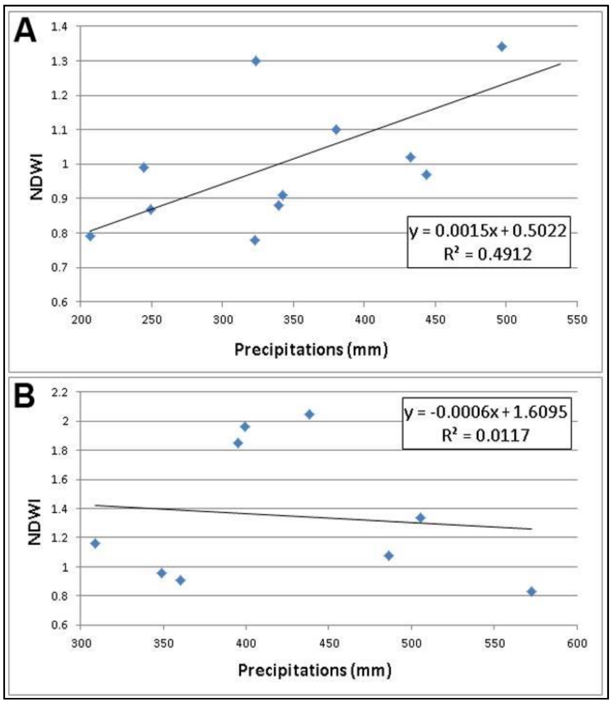

Fig. 14: Linear regressions and coefficients of determination between precipitations and NDWI in 1984 - 2004 interval (A) and after the completion of hydrotechnical woks (B), in 2005 – 2015 interval

Even throughout drier years, such as 2011, the NDWI value was quite high, and suggests an increase of the groundwater table level. A high groundwater table level is a key factor for wetlands (Mitsch and Gosselink, 1993), so we can consider the restoration works had a beneficial effect on preserving the wetland character of Balta Mare even in dry months.

Comparing the NDWI values between T1 and T2, one can also notice that average value in 2009 was higher than the one in 2003. Also, the comparison between the two sets of values using the Wilcoxon matched pair test show that these are extremely different ($p < 0.0001$). Even if there is a significant increase in NDWI values in Balta Mare area after 2005, however, these are not very high which reveals still low vegetation water content.

MNDWI was used to detect the presence of water in Balta Mare. During all the rainiest months (May or June Landsat scenes), one can observe the presence of water in Balta Mare area demonstrated by slightly positive values of MNDWI. No significant differences are observed after 2005. The MNDWI values extracted from all August and September Landsat scenes are negative, which demonstrates the lack of water. The situation is also similar after the construction of the water supply canal for Balta Mare. This clearly shows that the restoration works of the area did not lead to the recovery of Balta Mare. Despite the construction of the water supply canal, it dries up during dry months. The comparative analysis between T1 and T2 shows a slight decrease in MNDWI values, which can be explained by the advancement of reed (Fig. 7).

Conclusion

The type and the genesis of the lake basin of Balta Mare explain why this is the only pond in this area which retains its shape and size, both before and after the draining works. The loess sinkhole is recorded in all the cartographic documents and aerial photographs under analysis, ever since 1952. The presence of this depressionary landform also explains the preservation of the character of wetland meadow for this area even after the draining works, being artificially submitted as pasture in the cadastral plans, during the communist period.

The findings on site suggest that the restoration works do not seem to succeed in the rebuilding of the former water surfaces in Balta Mare. However, this method, namely the analysis of normalized differentiating indexes in relation with the precipitations is able to reveal some transformations of the Balta Mare area, as a consequence of the restoration works, transformations which are not easily observed in the field.

The MNDWI analysis underlines very clearly the temporary pond character of this area and confirms the field observations. During the 1984 – 2015 period, during the dry months (August Landsat scenes) MNDWI values indicate the total absence of water in Balta Mare.

NDWI is strongly correlated with the amount of precipitations until 2005. Afterwards, the values of this index are no longer correlated with the precipitations, which demonstrate that the supplementary induced water flowing into Balta Mare through the water supply canal has the effect of transforming this area by increasing the soil and vegetation moisture. This suggests the possibility of increasing the underground water level in this area, a fact which is also emphasized by the reed extension both in Balta Mare and along the relict watercourse of Sicsău river.

Balta Mare preserves its temporary character acquired after the draining works from the seventies, despite the efforts for restoring the former aquatic surfaces. An important factor which explains this fact is the presence of two draining canals in the immediate vicinity, significantly lower compared to the pond: Ier canal, just 20 m away to the south, and Sicsău, approx. 100 m eastwards. They continue to contribute to lowering the ground water level so that in dry seasons the water intake through the water supply canal built in 2005 is not sufficient to help water retention in Balta Mare.

We conclude that the restoration did not succeed in the rebuilding of the former water surfaces of Balta Mare, but it has an effect in increasing the underground water level in this area followed by reed extension.

Author contribution

Marcel TÖRÖK – OANCE: Concept of the paper, responsible for the Materials and methods, Results and discussion, and Conclusion sections, remote sensing data processing and air photo interpretation, cartographic design, in-situ observation.

Rodica TÖRÖK – OANCE: Research design, responsible for Abstract and Introduction sections, contributions to Results and discussion and Conclusion sections, statistical analyses and in-situ observation.

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