Ioana-Toroimac G., Zaharia L., Moroșanu G.A. (2021) Post-restoration satellite survey of a wetland on the lower Danube River in Romania, pp. 28-33. In Gastescu, P., Bretcan, P. (edit, 2021), *Water resources and wetlands*, 5th International Hybrid Conference Water resources and wetlands, 8-12 September 2021, Tulcea (Romania), p.235

5th International Hybrid Conference Water resources and wetlands, 8-12 September 2021, Tulcea (Romania)

# POST-RESTORATION SATELLITE SURVEY OF A WETLAND ON THE LOWER DANUBE RIVER IN ROMANIA

**Gabriela IOANA-TOROIMAC[1], Liliana ZAHARIA[1], Gabriela Adina MOROȘANU[2]**
[1]University of Bucharest, Faculty of Geography, Blvd. Nicolae Bălcescu 1, 010041, Bucharest, Romania, tel. +40213053822 E-mail: *gabriela.toroimac@geo.unibuc.ro*
[2]Romanian Academy, Institute of Geography, Str. Dimitrie Racoviţă 12, 023994, Bucharest, Romania, +40213135990

**Abstract.** Understanding the effects of former river restoration actions is essential for gaining scientific knowledge, feedback and guidance for future restoration projects. In this context, the objectives of our study are to analyze the surface-water variability and to assess the hydrological effects of restoration actions by means of riparian wetlands monitoring in the Lower Danube floodplain, in Romania. Independently from the monitored restoration project, we conducted an analysis of the Normalized Difference Water Index (NDWI) based on Landsat imagery (1984-2020) in the area of Gerai Marsh. We found that Gerai Marsh is connected occasionally to the Danube River, during large floods. The effects of restoration by reshaping local canals to (re)create the old Gerai Marsh were statistically detected in our study at the scale of 5 years post- versus pre-restoration and at $p < 0.10$. Our study confirmed the role of independent monitoring by standardized indicators from satellite remote sensing for understanding the effects of riparian wetland restoration. This kind of objective results could contribute at setting guidelines for an improved strategy to restore the Lower Danube River and other large rivers floodplains.

**Keywords**: river restoration, Landsat, Gerai Marsh, riparian wetland, floodplain, Danube River.

## 1 INTRODUCTION

Understanding the effects of former river restoration actions is essential for gaining scientific knowledge, feedback and guidance for future restoration projects towards more effective results (Morandi et al., 2014). In practice, despite the increasing concern and funding for river restoration, the information on the success or failure of such actions is still limited (Castillo et al., 2016; Angelopoulos et al., 2017). This is mostly due to the shortage of monitoring data. River restoration projects are frequently underfunded for pre- and post-project monitoring while long-term monitoring financial efforts are even rarer (Gonzáles et al., 2015). Moreover, major part of the projects conducts the assessment based on non-standardized indicators, depending on the demands of actors and financing sources (Castillo et al., 2016), as well as other political drivers (Morandi et al., 2017). Furthermore, the effectiveness of the restoration solution should be compared to some references, either relative (e.g. pre-restoration), absolute (e.g. good ecological status) or pre-established (e.g. historic baseline, desired image) (Morandi et al., 2014; Wohl et al. 2015), by using similar metrics (Lisenby et al., 2016). Both spatial and temporal scales should be considered in evaluating the effects of restoration works (Kondolf et al., 2006).

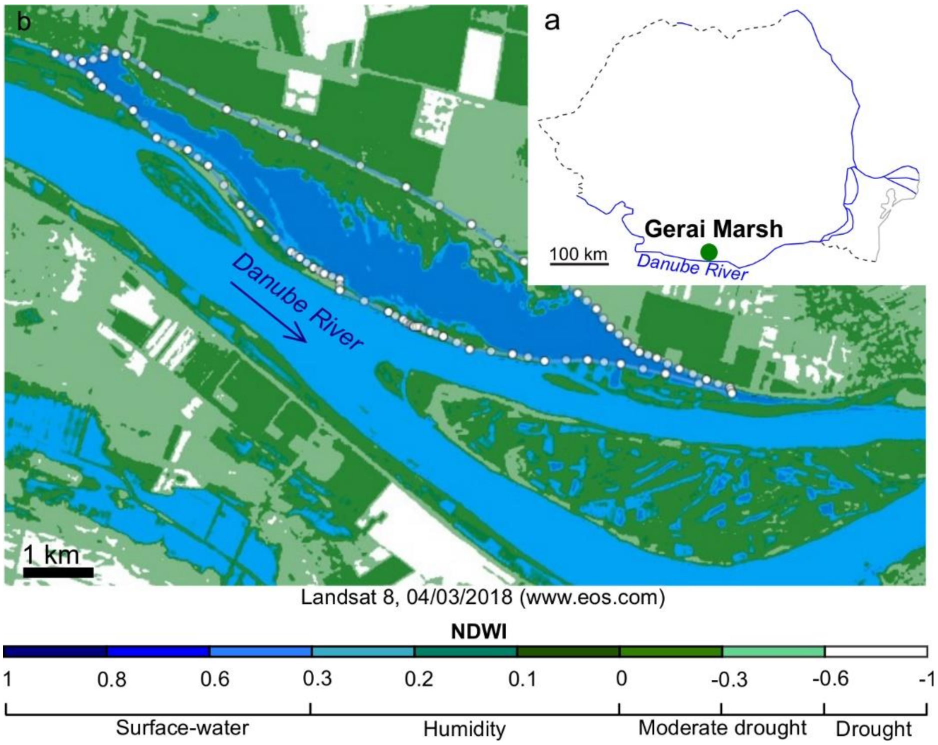
The hydrological effects of wetland restoration are reflected by their behavior in terms of water content: the water level, hydropattern, and residence time (U.S. EPA., 2008). The water level is an indicator of the vegetation types most likely to occur. The hydropattern refers to the timing, duration (i.e. hydroperiod), and distribution of wetland water levels. The residence time of a wetland is often related to its hydropattern, in that wetlands with large water level fluctuations may have shorter residence times. Some information about the spatial and temporal hydrological variability of wetlands can be extracted from satellite images, depending on their technical features (Guo et al., 2017). For example, the Landsat imagery is the most used remote sensing data in wetland research (Guo et al., 2017). Good results were obtained in terms of wetland inundation, most precisely in terms of spatial extension and duration or hydroperiod (e.g. Díaz-Delgado et al., 2016; Hopkinson et al., 2020; Kissel et al., 2020). Overall, remote sensing for wetland management is an increasingly valuable tool for the assessment of restoration success (Dawson et al., 2016).

In this context, the objectives of our study are to analyze the surface-water variability and to assess the hydrological effects of restoration actions by means of riparian wetlands monitoring, using satellite imagery. In this context, the research aims at answering the following question: did a project succeed in recreating riparian wetlands? The study focuses on a wetland located in the Lower Danube floodplain, in Southern Romania.

## 2 STUDY AREA

The Lower Danube River corresponds to the downstream sector of the river, from the entry in Romania to the outflow in the Black Sea through three main branches within the Danube Delta, with a length of 1075 km (i.e. 38% of its total length of 2780 km). After being embanked and drained for agriculture for more than half a century (Constantinescu et al., 2015), in the last decades the objective of the Lower Danube River restoration was to recreate riparian wetlands and reconnect them with the river (Hein et al., 2016). To illustrate the effects of the restoration actions, we worked on the case study of the Gerai Marsh located in the Lower Danube floodplain, in southern Romania (Fig. 1a). It is a protected area of international importance within the Ramsar convention. This case study is demonstrative for one of the major anthropic drivers of changes along the Lower Danube – the agriculture, as well as for the restoration projects in the Lower Danube Green Corridor, performed in the last decades along the Lower Danube River in both Romania and Bulgaria.

The Gerai Marsh is represented on old maps as a submerged area (10.1 km$^2$) with a non-functional island covered by vegetation. The Danube floodplain was embanked and drained in the 1970s under the program for regulating the drainage and flooding. Thus such works were carried on channels inside the marsh, works of art (bridges, culverts, roads, mining, etc.), including for draining rapidly the surface-water remaining after the floods of the Danube River (Dimache et al., 2012). Therefore, the formed Gerai Marsh lost the surface-water patches. The restoration project was implemented in 2011. Dams and canals were built at the local scale in order to maintain a higher water level to ensure ecological effects proper to birds nesting (Dimache et al., 2012). The main channel exceeds locally 1 m in depth, has a low slope (0.001 m/m), and a width of 20-160 m (Dimache et al., 2012). The project ignored the reconnection with the Danube River. In our study, we delimited the Gerai Marsh (Fig. 1b) according to the historical conditions (10.1 km$^2$), which are also reference conditions used in the restoration project to recreate a wetland ecosystem.



Landsat 8, 04/03/2018 (www.eos.com)

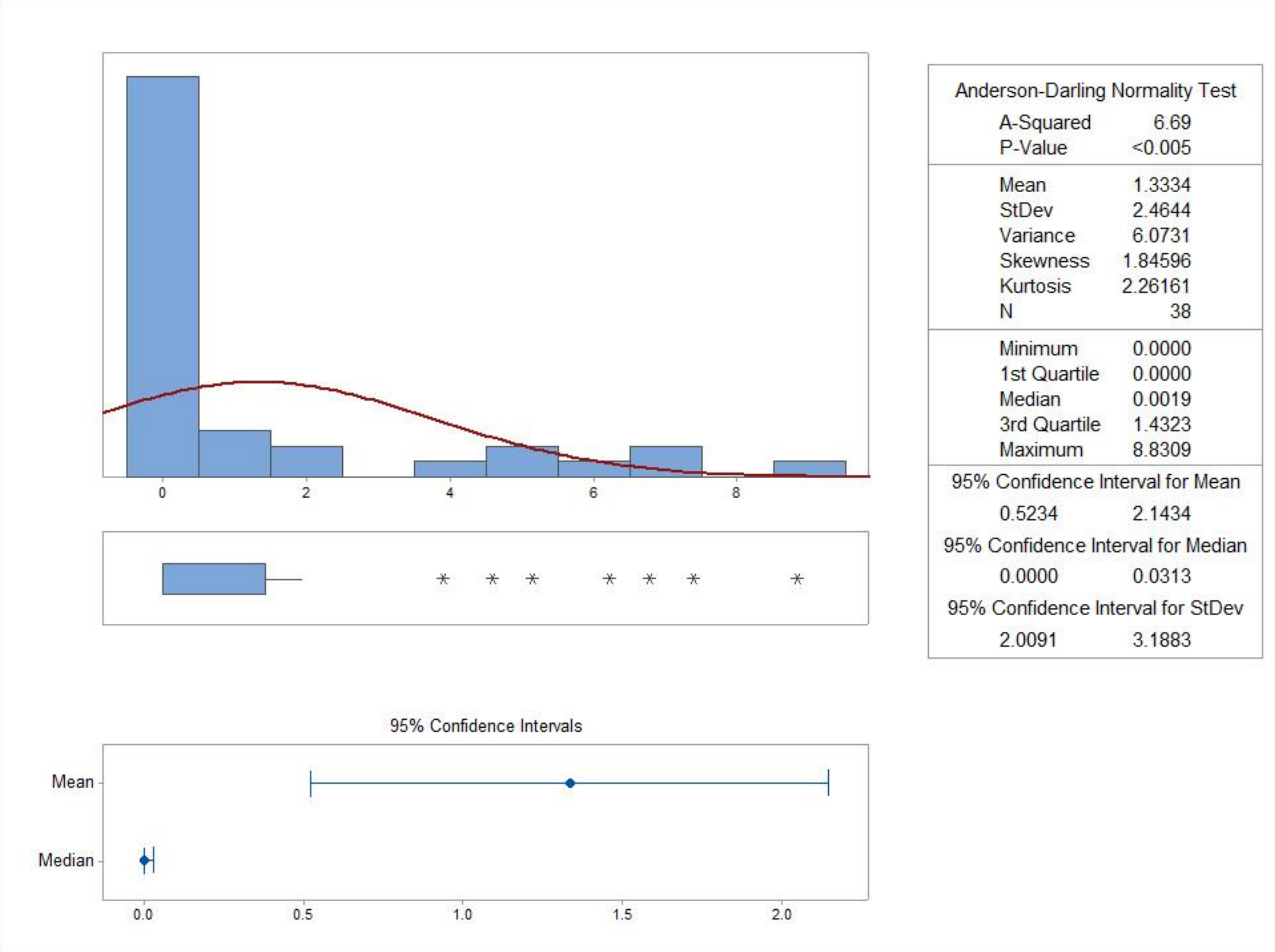
**Figure 1.** Gerai Marsh – (a) location in Romania; (b) example of Normal Difference Water Index (NDWI) spatial distribution (the Gerai Marsh is delimited by white points)

## 3 METHODOLOGY

For the monitoring of the surface-water, we employed the Normal Difference Water Index (NDWI), which was successfully used in previous studies to delineate land from open water, as well as to identify non-urban surface-water associated with wetlands (e.g., McFeeters, 2013). The index was estimated on Landsat scenes provided by the Earth Observing System (EOS, 2021). The Landsat scenes have the advantage of going back in time, therefore they allow to constitute a long time series of data. We used available Landsat satellite missions at 30 m of spatial resolution and 15 days of temporal resolution (5 TM and 8 OLI + TIRS). In our study focused on the presence of water, we were more rigorous in detecting the surface-water, therefore we set a higher threshold for this class, at NDWI = 0.3 (similar to the study of McFeeters, 2013). To analyze the variability of the surface-water, we created time series of NDWI. First, we considered the maximum extent of the surface-water. Therefore, we selected one Landsat scene per year. Over the period of 38 years (1984-2021), we analyzed 35 scenes for the Gerai Marsh. To analyze the long-term temporal variability of the surface-water, we completed the time series by replacing missing values with their mean for three years (2003, 2012, and 2019). Then, we focused on the timing and duration of the hydroperiod (namely the seasonal occurrence of flooding/inundation in a wetland). We selected all available scenes per year for a few years. In total, we analyzed 14 scenes in 2006, 7 scenes in 2010, and 9 scenes in 2018. Finally, we compared the effects pre- versus post-restoration by using the Mann-Whitney non-parametric test at a time scale of 5 years and 10 years.

## 4 RESULTS

The surface-water covers a mean value of 1.33 km$^2$ or 13.5% of the Gerai Marsh (Fig. 2). The median is close to 0, suggesting that in at least half of the years the surface-water is absent. The interquartile range is 1.43 km$^2$. The positive skewness indicates that values are tailed right while the positive kurtosis indicates a moderately-tailed distribution. The maximum annual values of surface-water in the Gerai Marsh do not have a normal distribution. Additionally, the boxplot in Fig. 2 shows numerous outliners.



| Anderson-Darling Normality Test | |
|---|---|
| A-Squared | 6.69 |
| P-Value | <0.005 |
| Mean | 1.3334 |
| StDev | 2.4644 |
| Variance | 6.0731 |
| Skewness | 1.84596 |
| Kurtosis | 2.26161 |
| N | 38 |
| Minimum | 0.0000 |
| 1st Quartile | 0.0000 |
| Median | 0.0019 |
| 3rd Quartile | 1.4323 |
| Maximum | 8.8309 |
| 95% Confidence Interval for Mean | |
| 0.5234 | 2.1434 |
| 95% Confidence Interval for Median | |
| 0.0000 | 0.0313 |
| 95% Confidence Interval for StDev | |
| 2.0091 | 3.1883 |

**Figure 2.** Distribution of surface-water area (km$^2$) in the Gerai Marsh according to data extracted in this study

We conclude that the flooding is occasional, not annual, in the Gerai Marsh. The highest eight values occurred in April, similar to the high-water phase of the hydrological regime of the Danube River, which is characterized by high discharges in spring, with the largest shares of the mean flow in April and May (11-12% of the average annual volume). The low-flow periods (less than 6% of the mean annual volume) are specific for autumn (in September and October) (Zaharia and Ioana-Toroimac, 2013). Pekarova et al. (2019) underlined a shift of the Danube's peak from May to April since the 1980s. The floods usually occur in spring and summer. Among the largest in last two decades occurred in April-May 2006 and July 2010.

Concerning the hydroperiod (Fig. 3), during the historical flood of the Danube in 2006, which corresponded to the maximum extension of the surface-water (8.83 km$^2$) in the Gerai Marsh, the hydroperiod lasted for approximately two months (April-June). In 2010, the surface-water was absent. In 2018, the surface-water reached 6.5 km$^2$ and the hydroperiod lasted until the beginning of May.

Subsequently, according to Mann-Whitney test, there is no statistical difference between the pre- and post-restoration situation at the time scale of 5 years and 10 years, at $p < 0.05$. Yet, at the time scale of 5 years, there is a difference between time series of 2007-2011 and 2012-2016, significant at $p = 0.06$, with higher post-restoration values then pre-restoration. While a small surface-water area was detected in 2009, larger areas were detected in 2013 and 2016 (Fig. 4).

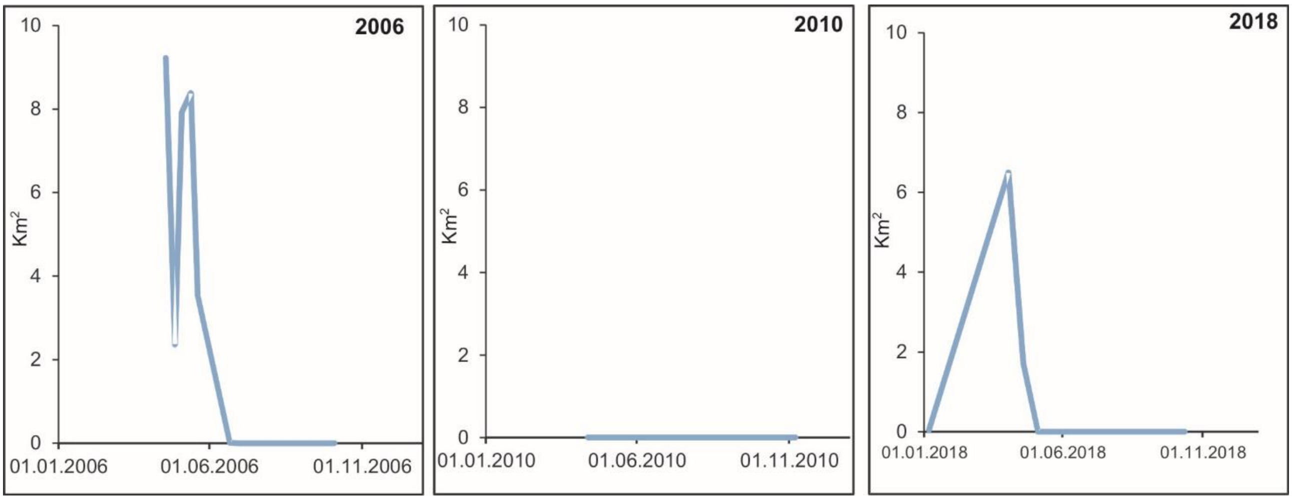


**Figure 3.** Examples of hydroperiod in the Gerai Marsh

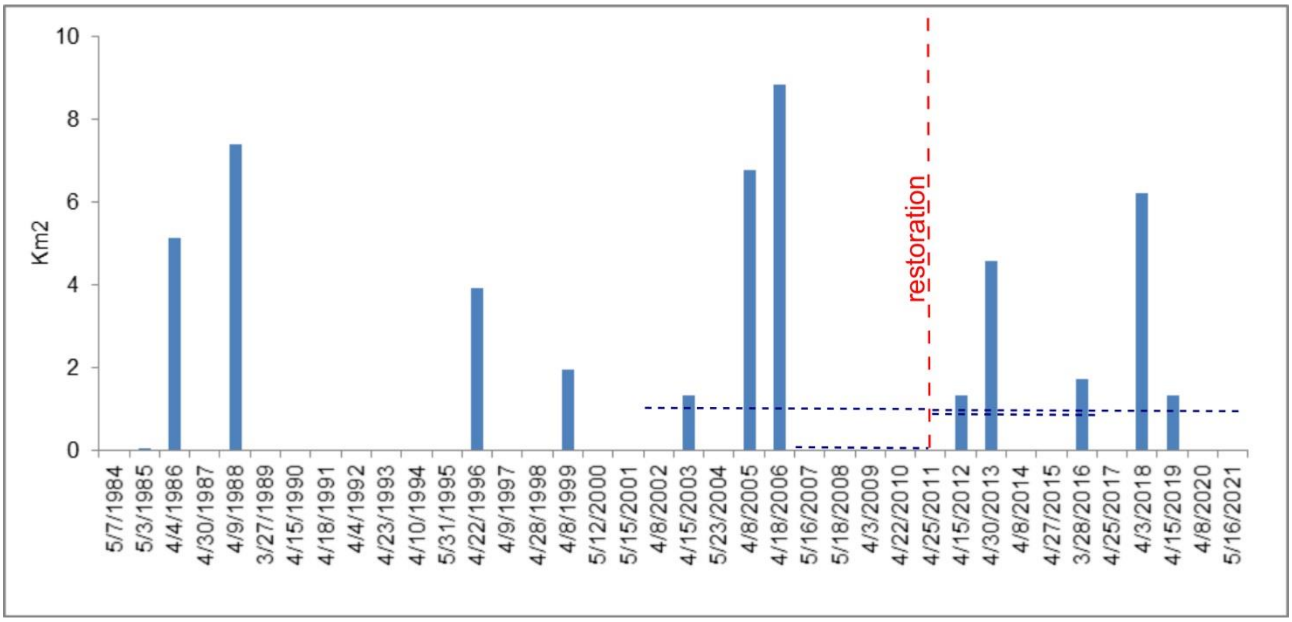


**Figure 4.** Variations of surface-water area in the Gerai Marsh – in dashed red line the year of the restoration (2011); in dashed blue line – mean values at 5 years and 10 years pre- and post-restoration

## 5 DISCUSSION AND CONCLUSION

In the case of the Gerai Marsh, the post-restoration effects were not necessarily obvious. By analyzing the remote sensing images, only a slight efficacy could be detected at the time scale of 5 years. Yet, missing data of 2012 are likely to prevent us from obtaining significant statistical results. Hence, we consider that, overall, following the restoration actions, there was no additional water entry in the marsh. The same volume of water was probably concentrated along channels due to restoration works. These modifications are probably too small to be detected by satellite. For this case study, our methodology appears to be inappropriate, as the slight modifications in the riparian areas holding water are probably too small to be detected by satellite survey. Therefore, a better resolution of the satellite imagery and ground-based measurements would be necessary to better understand the effects of river restoration.

Did this project succeed in recreating riparian wetlands? Our study did not aimed at criticizing a restoration project, but most importantly to put in question the functionality of the restored wetland. We conclude that the restoration of the Gerai Marsh was marked by a slight increase of the surface-water lasting for a short period of time. The vegetation probably colonized the small patches of low-depth surface-water, with the marsh remaining generally disconnected from the Danube River. The riparian wetland is mainly connected to the Danube during high floods. Nonrandom values of the studied indicator, i.e. NDWI, suggest the occasional connectivity with the hydrological regime of Danube. Occasional overflowing events and discontinuous hydroperiod of surface-water patches demonstrate a weak connectivity. For the present, similar to other case studies, returning to the historic conditions in the Danube floodplain remains a myth (Dufour and Piégay, 2009).

Satellite remote sensing based on open access scenes is a low-cost way of monitoring riparian wetlands and restoration effects. It could give an overall image on the functioning of a large floodplain. Other restoration projects of the Lower Danube floodplain could be monitored by a similar methodology in order to obtain an overview on the efficacy of restoration projects on the Lower Danube River, as well as on the present-day hydrological functioning of the floodplain. Moreover, this kind of results could contribute at setting guidelines for an improved strategy to restore the Lower Danube River.

## REFERENCES

Angelopoulos, N.V., Cowx, I.G., and Buijse, A.D., (2017). Integrated planning framework for successful river restoration projects: Upscaling lessons learnt from European case studies, *Environmental Science & Policy*, **76**, 12-22, DOI: 10.1016/j.envsci.2017.06.005.

Castillo, D., Kaplan, D., and Mossa, J., (2016). A synthesis of stream restoration efforts in Florida (USA), *River Research and Applications*, **12**, DOI: 10.1002/rra.3014.

Constantinescu, S., Achim, D., Rus, I., and Giosan, L., 2015. Embanking the Lower Danube: from natural to engineered floodplains and back. In: P.F. Hudson, H. Middelkoop (Eds.), *Geomorphic approaches to integrate floodplain management of lowland fluvial systems in North America and Europe* (pp. 265–288). New York: Springer.

Dawson, S.K., Fisher, A., Lucas, R., Hutchinson, D.K., Berney, P., Keith, D., Catford, J.A., and Kingsford, R.T., (2016). Remote Sensing Measures Restoration Successes, but Canopy Heights Lag in Restoring Floodplain Vegetation, *Remote Sensing*, 8(7), **542**, 2-19, DOI: 10.3390/rs8070542.

Díaz-Delgado, R., Aragonés, D., Afán, I., and Bustamante, J., (2016). Long-Term Monitoring of the Flooding Regime and Hydroperiod of Doñana Marshes with Landsat Time Series (1974–2014), *Remote Sensing*, 8, **775**, 2-19, DOI: 10.3390/rs8090775.

Dimache, A., Iancu, I., Sirbu, N., and Croitoru, I., (2012). Practical solutions for ecological reconstruction of Gerai pond, pp. 215-219. In Gastescu, P., Lewis, W., Bretcan, P. (Eds.) *Conference Proceedings Water resources and wetlands*, 14-16 September 2012, Tulcea Romania, 648p.

Dufour, S. and Piégay, H., (2009). From the myth of a lost paradise to targeted river restoration: forget natural references and focus on human benefits, *River Research and Applications* **25**(5), 568-581. DOI: 10.1002/rra.1239

EOS (Earth Observing System) (2021). *EOS Land Viewer*. https://eos.com/landviewer/. Accessed 30 June 2021

González, E., Sher, A.A., Tabacchi, E., Masip, A., and Poulin, M., (2015). Restoration of riparian vegetation: a global review of implementation and evaluation approaches in the international, peer-reviewed literature. *Journal of Environental Management*, **158**, 85-94, DOI: 10.1016/j.jenvman.2015.04.033.

Guo, M., Li, J., Sheng, C., Xu, J, and Wu, L., (2017). A Review of Wetland Remote Sensing, *Sensors* 17 (**777)**, 2-36, DOI: 10.3390/s17040777.

Hein, T., Schwarz, U., Habersack, H., Nichersu, I., Preiner, S., Willby, N., and Weigelhofer, G., (2016). Current status and restoration options for floodplains along the Danube River, *Science of the Total Environment*, **543**, 778–790, DOI: 10.1016/j.scitotenv.2015.09.073

Hopkinson, C., Fuoco, B., Grant, T., Bayley, S.E., Brisco, B., and MacDonald, R., (2020). Wetland hydroperiod Change Along the Upper Columbia River Floodplain, Canada, 1984 to 2019, *Remote Sensing*, 12, **4084**, 2-20, DOI:10.3390/rs12244084.

Kissel, A.M., Halabisky, M., Scherer, R.D., Ryan, M.E., and Hansen, E.C., (2020). Expanding wetland hydroperiod data via satellite imagery for ecological applications, *Frontiers in Ecology and the Environment*, 18(**8)**, 432-438, DOI: 10.1002/fee.2233.

Kondolf, G.M., Boulton, A.J., O'Daniel, S., Poole, G.C., Rahel, F.J., Stanley, E. H., Wohl, E., Bång, A., Carlstrom, J., Cristoni, C., Huber, H., Koljonen, S., Louhi, P., and Nakamura, K., (2006). Process-based ecological river restoration: visualizing three-dimensional connectivity and dynamic vectors to recover lost linkages, *Ecology and Society*, **11**(2), 5.

Lisenby, P., Croke, J., and Fryirs, K., (2016). Geomorphic effecttiveness: a linear concept in a non-linear world, *Earth Surface Processes and Landforms*, DOI: 10.1002/esp.4096.

McFeeters S.K., (2013). Using the Normalized Difference Water Index (NDWI) within a Geographic Information System to detect swimming pools for mosquito abatement: a practical approach, *Remote Sensing* **5**, 3544-3561, DOI: 10.3390/rs5073544.

Morandi, B., Piégay, H., Lamouroux, N., and Vaudor, L., (2014). How is success or failure in river restoration projects evaluated? Feedback from French restoration projects, *Journal of Environmental Management*, **137**, 178-188, DOI: 10.1016/j.jenvman.2014.02.010.

Morandi, B., Kail, J., Toedter, A., Wolter, C., and Piégay, H., (2017). Diverse approaches to implement and monitor river restoration: a comparative perspective in France and Germany diverse approaches to implement and monitor river restoration, *Environmental Management*, **60**, 931-946, DOI: 10.1007/s00267-017-0923-3.

Pekárová, P., Gorbachova, L., Mitkova, V.B., Pekár, J., and Miklanek, P., (2019). Statistical Analysis of Hydrological Regime of the Danube River at Ceatal Izmail Station, *IOP Conf Ser: Earth Environmental Sciences* **22**, 012035, DOI: 10.1088/1755-1315/221/1/012035

U.S. EPA., (2008). *Methods for Evaluating Wetland Condition: Wetland Hydrology*. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-08-024.

Wohl, E., Lane, S.N., and Wilcox, A.C., (2015). The science and practice of river restoration, *Water Resource Researches*, **51**, 5974-5997, DOI: 10.1002/2014WR016874.

Zaharia, L. and Ioana-Toroimac, G. (2013). Romanian Danube River Management: Impacts and Perspectives. In G. Arnaud-Fassetta, E. Masson, & E. Reynard (Eds.), *European Continental Hydrosystems under Changing Water Policy* (pp. 159-170). München: Verlag Dr. Friedrich Pfeil.