details and publicly available outputs can be found on the project webpage https://www.interreg-danube.eu/approved-projects/measures.

References

Cokan B., Paraschiv M, Pekarik L (2021): Danube Migratory Fish Habitat Manual. Output of the MEASURES project. https://www.interreg-danube.eu/approved-projects/measures/outputs

Haidvogl G, Munteanu C, Reinartz R (2021): Strategy for ecological corridor conservation and restoration in the Danube catchment. Output of the MEASURES project. https://www.interreg-danube.eu/approved-projects/measures/outputs

Mozsár A, Kovács G, Paraschiv M (2021): Pilot release of Russian sturgeon and sterlet. Output of the MEASURES project. https://www.interreg-danube.eu/approved-projects/measures/outputs

NAIK-HAKI (2020): Ex situ gene stocks of Danube sturgeons. Output of the MEASURES project. https://www.interreg-danube.eu/approved-projects/measures/outputs

Scherhaufer P, Haidvogl G (2021): Developing stakeholder cooperation for ecological corridor conservation and restoration. Output of the MEASURES project. https://www.interreg-danube.eu/approved-projects/measures/outputs

Schmidt-Kloiber A (2021): MEASURES Information System – summary report. Output of the MEASURES project. https://www.interreg-danube.eu/approved-projects/measures/outputs

Lake Neusiedl and Seewinkel: a hotspot area of long-term ecological research in the Danube River Basin

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Abstract:

The Lake Neusiedl area near Vienna (Austria) has been of scientific interest for a long time. Based on the number of publications, research activity on terrestrial and aquatic ecosystems increased from 1960-1990 and declined thereafter. More interesting is the long-term change in research topics, which reflects the state of science and the impact of human activities, such as agriculture and tourism, on the one hand, and the growing awareness of wetland conservation on the other. During an early epoch, at the time of the last drying up of the lake (1865-1868), faunistic and floristic lists of species around Lake Neusiedl and its soda pans were common. The research focus shifted from 1930-1959 to biocoenological studies of flora and fauna, from 1960-1989 to species conservation issues and from 1990-2020 to themes of habitat conservation. From 2008 onwards, the research emphasis lies on ecosystem services and on the overwhelming impact of global warming.

Figure 1. Soda pan, National Park, 2015 (photo: Katrin Teubner)

Results and Discussion: Ecological research perspectives from 1860 to 2020:

The steppe lake Neusiedl is surrounded by soda pans ('Salzlacken', *fig. 1, 2)* and builds up a wetland impacted by remarkable water level fluctuations (Dinka et al., 2004). Its location near Vienna, the capital of Austria, has already attracted much attention, at least for scientific investigations during two centuries until now. A compilation of plant species from botanical surveys by more than 30 botanists for the Neusiedler See area was published as a species list (page 470 ff 'Pflanzen-Aufzählung', of about 950 plant species) by Szontagh (1864). This publication, however, goes beyond a botanical work and describes the geology and the salt composition of soils of the soda lake area, and thus documents a high level of interest at early times. It was published when the shallow Lake Neusiedl began to dry up. The last complete desiccation of the lake, which had no outflow at all that time, occurred from 1865 to 1868 (Herzig 2014, Tolotti et al. 2021). In the following the Hanság- or Einser-Channel was built between 1909 and 1911, connecting the lake to the Danube River. It was aimed to drain the water body for using the lake area for agriculture, which however has never been achieved. Today the lock in the channel is used to regulate the water level of the lake, to ensure mainly that water level will satisfy tourism activities such as e.g., boating and swimming.

The number of publications shown in figure 3 includes articles in journals, books, university theses and published scientific reports in the Neusiedler See area and refers to the literature database 'Literature Vogelwarte 2' (Lazowski 2020, available at: http://biologische-station.bgld.gv.at/portfolio/interreg-projekt-vogelwarte-ii-2016-bis-2021/)

created within the project INTERREG 'Vogelwarte Madárvárta 2'. This database contains in total 1300 entries. The publication activity has gradually increased since 1930 and reached its highest number of 327 publications from 1980 to 1989, followed by the subsequent decade, 1990-1999, with a total of 269 publications. Afterwards, the number of publications per decade steadily decreased. The bar chart about the number of publications in figure 3, however, does not provide any information about the scope of the extent of published work and, therefore, the interpretation of the publication activity per decade should be here considered with caution. More important seems here to consider the evolution of research topics over the long period of time for the soda lake Neusiedl and its associated Pannonian wetland area.

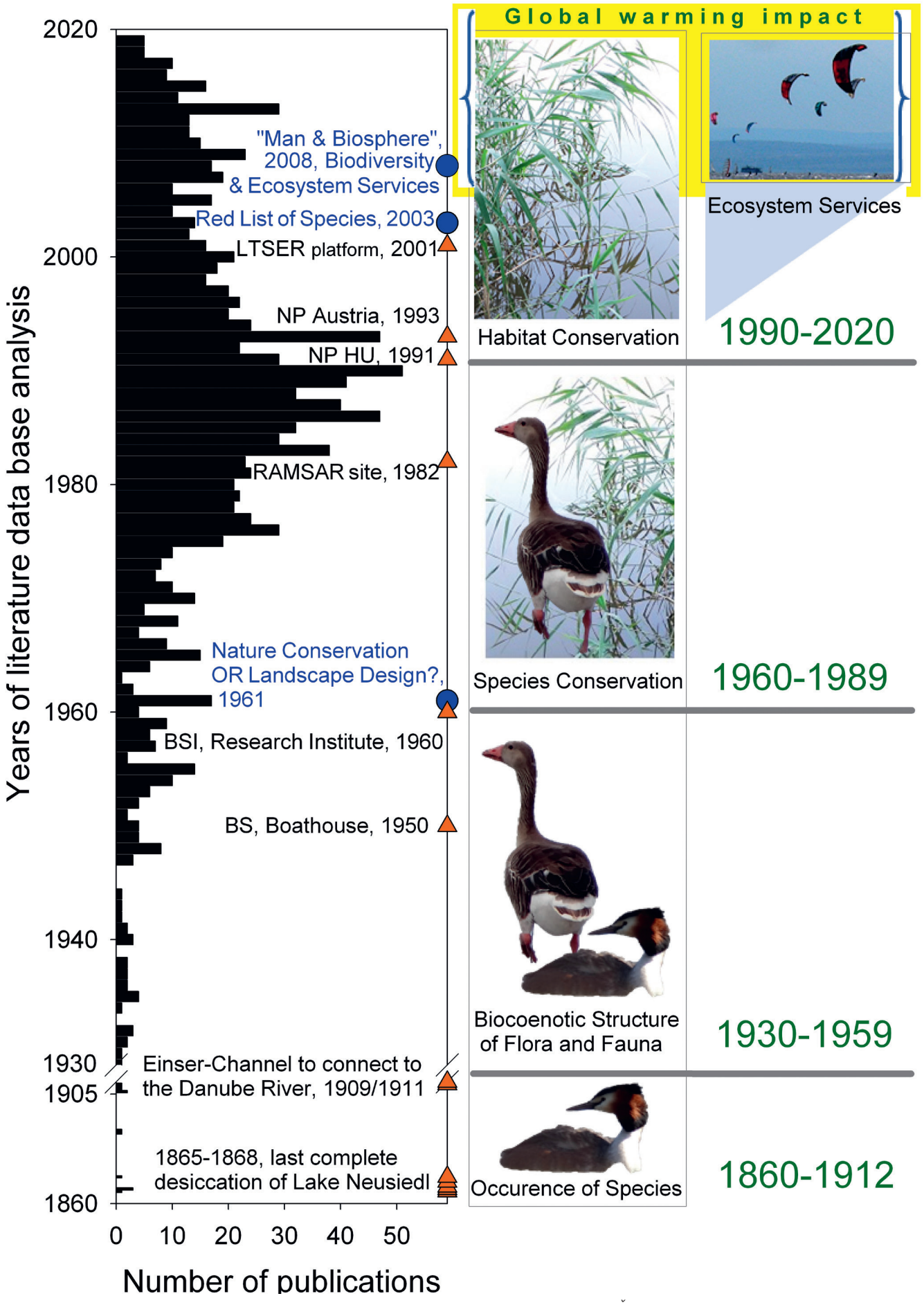
From 1930 to 1960, a number of animals and plants were systematically surveyed, as e.g., species of mammals, birds, fishes, amphibians, arthropods, arachnids, insects and molluscs as well as fungi, cryptogam flora and higher plants. **Biocoenological studies of flora and fauna,** as e.g., shown by Franz et al. (1937), became more common at that time. Apart from providing floristic and faunistic maps, the interpretation of the occurrence of terrestrial organisms started focussing more on the ecological context of their habitats. An outline of research advance at that period from geology, terrestrial fauna and flora including the reed belt and short reports about phyto- and zooplankton of Lake Neusiedl and some soda pans was published in a multi-author compilation entitled 'Landschaft Neusiedlersee (Lake Neusiedl landscape)' by Sauerzopf as editor (1959). The construction of a biological station, first a furnished boathouse (wooden construction on stilts) in the reed belt (1950, near Neusiedl am See) and later as a larger research institute on land (1960, near Illmitz), underpinned the importance of research interest in this unique wetland area *(fig. 3).* The situation of the late 50ies is described by Sauerzopf (1961) with an insightful article about the contemporary landscape situation under the pressure of urban development, entitled 'Neusiedlerseeraum – Erhaltung oder Gestaltung, Problematik der Großlandschaft' (Lake Neusiedl Area – protection or designed landscape contracting, facing a large sized landscape region). He described in detail the conflict of interest of the attempt to protect nature on one hand and of the rural adjustment due to large local interests for intensifying agriculture and tourism development on the other. According to a long-term assessment of the ecological vulnerability of the shallow steppe Lake Neusiedl by Tolotti et al. (2021), the late 50ies and following decade till 1970 are marked by excessive nutrient enrichment due to human activities (cultural eutrophication) as responded by algal and cyanobacterial blooms.

For the period 1960 till 1989, the focus of scientific studies was about increasingly endangered wetland species and thus the need for **species conservation** measures (nature conservation). Furthermore, wetland observations called for spatial landscape planning to control and modify

Figure 2. *Soda pan, 2019. Trend of much earlier dry out in summer, than years before (photo: Katrin Teubner)*

risks by eutrophication, pollution and urbanisation. Apart from this, new methods as e.g., by airborne optical imaging for ecological habitat monitoring (lake bottom and the reed belt of Lake Neusiedl see Csaplovics 1989, and also later publications as e.g., Csaplovics and Nemeth 2014) but also advances in limnology about deterioration of ecosystems by eutrophication (e.g., Löffler 1979) increasingly attracted research interest. As a result, a culminating number of publications in local and international journals was achieved in the 80ies as mentioned before. In view of this broad knowledge increase, the late 80ies became marked by establishing the National Park 'Neusiedlersee-Seewinkel/Ferto-Hanság Nemzeti Park', which was agreed upon in a bilateral cooperation and finally appointed for Hungary in 1991 and afterwards for Austria in 1993 for each wetland territory respectively *(fig. 3).* According to Borsdorf and Lange (2005a), this was the 5th category to protect Neusiedler See area from 1932 onwards (among others e.g., the nomination of Lake Neusiedl and the lakes in Seewinkel as a Ramsar site in 1982), followed by the designation as a Natura 2000 area (year 2000), as cross-border cultural landscape Fertö/Lake Neusiedl of UNESCO World Heritage Site (in year 2001) and 'Neusiedler See-Leithagebirge Nature Park' (in year 2005).

According to priority settings on the biosphere reserve of the Pannonian soda lake Neusiedl wetland, understood as an integration of diverse conservation categories (Borsdorf and Lange 2005b), also the topics of publications about species were beyond simple surveying but focused on **habitat conservation,** habitat availability and landscape-scale conservation from 1990 to 2020. In particular, endangered species were of research interest during this study period as for example of birds (Dvorak et al. 2017) and fishes (Wolfram and Mikschi 2003), but also for selected taxa (e.g., gastropod species Vertigo angustior by Schrattenecker-Travnitzky and Zechmeister 2020). Furthermore, surveys of the ecological habitat status and conservation concepts in parti-


Global warming impact
Ecosystem Services
Habitat Conservation
1990-2020
Species Conservation
1960-1989
Biocoenotic Structure of Flora and Fauna
1930-1959
Occurence of Species
1860-1912
"Man & Biosphere", 2008, Biodiversity & Ecosystem Services
Red List of Species, 2003
LTSER platform, 2001
NP Austria, 1993
NP HU, 1991
RAMSAR site, 1982
Nature Conservation OR Landscape Design?, 1961
BSI, Research Institute, 1960
BS, Boathouse, 1950
Einser-Channel to connect to the Danube River, 1909/1911
1865-1868, last complete desiccation of Lake Neusiedl
Years of literature data base analysis
2020
2000
1980
1960
1940
1930
1905
1860
0
10
20
30
40
50
Number of publications

cular for the soda pans and related issues became relevant (Krachler et al. 2012). From 2008 onwards, research and nature protection activities were stimulated by biodiversity and ecosystem service studies in view of a sustained development of the Lake Neusiedl area (see 'Man & Biosphere' in Wrbka et al. 2012). The application of advanced limnological methods to quantify the degradation of Lake Neusiedl points in the same direction of preserving the ecosystem services underlying human well-being (e.g., Kirschner et al. 2008, Duleba et al. 2021). In recent decades it became evident, that habitat changes due to urban development are increasingly superimposed by global warming impact forcing a water level decline in the wetland area *(fig. 2)*, concerning the habitats of Lake Neusiedl and soda pans (Dokulil and Herzig 2009, Eitzinger et al. 2009, Weyhenmeyer et al. 2019, Tolotti et al. 2021, Zimmermann-Timm and Teubner 2021). Thus, high-resolution measurements of water bodies, i.e., Lake Neusiedl and soda pans, by recently installed on-line sensors during the project INTERREG Vogelwarte Madárvárta 2 are most relevant for climate research and thus contribute to track habitat change (Teubner and Lazowski 2020) in addition to monthly ecological monitoring or surveys in the wetland ecosystem. Since 2001, the biosphere Lake Neusiedl and Seewinkel has been designated as a platform for long-term ecological research, being part of data networks of Long-Term Socio-Ecological Research (LTSER, https://www.lter-austria.at/ltser-plattform-neusiedler-see-seewinkel/) and of Dynamic Ecological Information Management System - Site and Dataset Registry (DEIMS-SDR, https://deims.org/1230b149-9ba5-4ab8-86c9-cf-93120f8ae2).

References

Borsdorf A, Lange S (2005a): Biosphärenparks – Instrumente für die Integration unterschiedlicher Schutzkategorien - Beispiel Neusiedler See. In: Borsdorf A (Ed): Leben in Vielfalt, UNESCO-Biosphärenreservate als Modellregionen für ein Miteinander von Mensch und Natur. Austrian Academy of Sciences, 111-113. DOI: 10.1553/3-7001-3337-5

Borsdorf A, Lange S (2005b): Inspired by diversity: UNESCOs biosphere reserve as model regions for a sustainable interaction between human and nature. Vienna, Austrian Academy of Sciences

Csaplovics, E. (1989): Die geodätische Aufnahme des Bodens des Neusiedler Sees. Wiss. Arbeiten Burgenland, 84

Csaplovics E, Nemeth E (2014): Airborne Optical Imaging in Support of Habitat Ecological Monitoring of the Austrian Reed Belt of Lake Neusiedl. Proceedings of the GIS Science RSGIS4HQ, Vienna, Austria, 24-25

Dokulil MT, Herzig A (2009): An analysis of long-term winter data on phytoplankton and zooplankton in Neusiedler See, a shallow temperate lake, Austria. Aquatic Ecology 43(3), 715-725

◀ *Figure 3: Number of publications from 1960 to 2020 according to literature data base 'Literature Vogelwarte 2' (Lazowski 2020). Bars – number of publications, triangles – achievements concerning the landscape development, blues dots – major achievements documented by publications:*
Sauerzopf (1961), Wolfram and Mikschi (2003), 2008 begin of project 'Man & Biosphere', see Wribka et al. (2012). The four main periods of publication activities associated with major research topics in biology are described in the text. Abbreviations: LTSER - Long-Term Socio-Economic and Ecological Research, NP – National Park, HU – Hungary, BS – Biological station, BSI – BS Illmitz, RAMSAR - Convention on Wetlands of International Importance.

Dinka M, Ágoston-Szab E, Berczik Á, Kutrucz G (2004): Influence of water level fluctuation on the spatial dynamic of the water chemistry at Lake Ferto/Neusiedler See. Limnologica 34(1-2), 48-56

Duleba M, Földi A, Micsinai A, Várbíró G, Mohr A, Sipos R et al (2021): Applicability of diatom metabarcoding in the ecological status assessment of Hungarian lotic and soda pan habitats. Ecological Indicators 130, 108105

Dvorak M, Landmann A, Teufelbauer N, Wichmann G, Berg HM, Probst R (2017): The conservation status of the breeding birds of Austria: Red List (5th version) and Birds of Conservation Concern (1st version). Egretta 55, 6-42

Eitzinger E, Kubu G, Formayer H, Haas P, Gerersdorfer T, Kromp-Kolb H (2009): Auswirkungen einer Klimaänderung auf den Wasserhaushalt des Neusiedler Sees. BOKU-Met Report 1 ISSN 1994-4179. ISSN 1994-4187 (on-line) – http://www.boku.ac.at/met/report/

Franz H, Höfler K, Scherf E (1937): Zur Biosoziologie des Salzlachengebietes am Ostufer des Neusiedlersees. Verh. Zool.-Bot. Ges. Wien 86(87), 279-363

Herzig A (2014): Der Neusiedler See–Limnologie eines Steppensees. Denisia 33, 101-114

Kirschner AK, Schlesinger J, Farnleitner AH, Hornek R, Süß B, Golda B et al (2008): Rapid growth of planktonic Vibrio cholerae non-01/non-0139 strains in a large alkaline lake in Austria: dependence on temperature and dissolved organic carbon quality. Applied and Environmental Microbiology 74(7), 2004-2015

Krachler R, Korner I, Dvorak M, Milazowsky N, Rabitsch W, Werba F, Zulka P, Kirschner A (2012) Die Salzlacken des Seewinkels. Erhebung des ökologischen Zustandes sowie Entwicklung individueller Erhaltungskonzepte für die Salzlacken des Seewinkels (2008-2011), Naturschutzbund Burgenland, 200pp. ISBN 978-3-902632-23-4

Lazowski W (2020): Zusammenfassung von Umweltdaten in Form eines Umwelt-Informationssystems – Leistungsteil „Zusammenführung von bereits vorliegenden Umweltdaten" Vogelwarte Madárvárta 2, report, 28pp (available at: http://biologische-station.bgld.gv.at/wp-content/uploads/2021/11/Vogelwarte-2_Bericht-Lazowski-2020.pdf)

Löffler H (ed) (1979): Neusiedler See: The Limnology of a Shallow Lake in Central Europe. Junk Publ, The Hague-Boston-London: 543

Sauerzopf F (1961): Neusiedlerseeraum - Erhaltung oder Gestaltung (Problematik der Großlandschaft). Burgenländische Heimatblätter 23, 170-180

Sauerzopf F (Ed.) (1959): Landschaft Neusiedler See. Wissenschaftliche Arbeiten aus dem Burgenland, Eisenstadt. 23, 208 pp

Schrattenecker-Travnitzky R, Zechmeister T (2020): Zum Vorkommen der Schmalen Windelschnecke Vertigo angustior Jeffreys, 1830 im Neusiedler-See-Gebiet. Arianta (8), 6-12

Szontagh M (1864): Enumeeratio plantarum phanerogamicarum sponte crescentium copiosiusque cultarum territorii Soproniensis. Commentariorum C.R. Societatis Zoologico-Botanisae, Vindebonae, 14, 463-502

Teubner K, Lazowski W (2020): Umweltinformationssystem Neusiedler See-Sodalacken: Die Erfassung und Nutzung alter und neuer ökologischer Daten / Organising ecosystem knowledge for Lake Neusiedl and its soda pans: The use and reuse of ecological data resources. Summary Meeting, INTERREG Vogelwarte Madárvárta 2, Ferto-Hanság National Park Directorate Monograph series 5, 133-141

Tolotti M, Guella G, Herzig A, Rodeghiero M, Rose NL, Soja G, Zechmeister, T, Yang D, Teubner K (2021): Assessing the ecological vulnerability of the shallow steppe Lake Neusiedl (Austria-Hungary) to climate-driven hydrological changes using a palaeolimnological approach. Journal of Great Lakes Research 47(5), 1327-1344

Weyhenmeyer GA, Hartmann J, Hessen DO, Kopáček J, Hejzlar J, Jacquet S, Teubner K et al (2019): Widespread diminishing anthropogenic effects on calcium in freshwaters. Scientific reports 9(1), 1-10

Wolfram G, Mikschi E (2003): Rote Liste der Fische und Neunaugen des Burgenlandes. BFB report, 71 pp

Wrbka T, Hainz-Renetzeder C, Kuttner M, Hermann A, Brandenburg C, Ziener K et al (2012): Biodiversity and Ecosystem Services as scientific foundation for the sustainable implementation of the Redesigned Biosphere Reserve "Neusiedler See". Man & Biosphere Report, DOI: 10.1553/bioserv-neusiedler-see.

Zimmermann-Timm H, Teubner K (2021): Folgen der Grundwassersenkung am Beispiel Neusiedler See - Seewinkel (Burgenland, Österreich). In: Lozán JL, et al. (eds) Wissenschaftliche Auswertungen in Kooperation mit GEO, Hamburg, 142–149. DOI:10.25592/warnsignal.klima.boden-landnutzung.19