SİNOP ÜNİVERSİTESİ
2007

EKOLOJİ2024
11.ULUSLARARASI EKOLOJİ SEMPOZYUMU
“SU VE İKLİM DEĞİŞİKLİĞİ”

EKOLOJİ2024 | **ECOLOGY**2024

11.ULUSLARARASI EKOLOJİ SEMPOZYUMU

11. INTERNATIONAL ECOLOGY SYMPOSIUM

SU VE İKLİM DEĞİŞİKLİĞİ
WATER AND CLIMATE CHANGE

29 Mayıs - 1 Haziran 2024
29 May - 1 June 2024

SİNOP / TÜRKİYE

Artificial Wetlands in the Fight Against Global Warming: Reducing Carbon Footprint and Enhancing Biodiversity

Özgür Eren ZARİÇ[1,2]* and Abuzer ÇELEKLİ[1,2]

[1] Gaziantep University, Faculty of Art and Science, Department of Biology, Gaziantep, Turkey
[2] Gaziantep University, Environmental Research Center (GÜÇAMER), Gaziantep, Turkey

***Corresponding Author:** Özgür Eren Zariç, ozgurerenzaric@gmail.com

Abstract

Artificial wetlands have emerged as significant ecological assets in urban and regional frameworks, contributing to sustainability goals and climate mitigation strategies. These engineered ecosystems mirror the carbon sequestration capabilities of their natural counterparts by capturing and storing atmospheric carbon dioxide (CO_2, thereby serving as vital negative emission technologies in the fight against global warming. The process leverages anaerobic conditions to protect existing soil carbon while concurrently facilitating atmospheric CO_2 sequestration through vegetation. Despite the potential release of greenhouse gases such as methane (CH_4 due to anaerobic conditions, certain wetlands demonstrate a net greenhouse gas sink capability, where the carbon uptake substantially offsets climate-forcing emissions. This functionality underscores the importance of understanding carbon uptake drivers to optimize wetland management as a natural climate solution. Moreover, integrating artificial wetlands into urban areas fosters community resilience, reconnecting people with their local ecosystems and enabling collaborative governance for environmental management. Through place-based approaches, artificial wetlands address carbon-zero ambitions and enhance local biodiversity, providing many ecosystem services. These systems' rehabilitation and sustained management are pivotal in preserving their role as carbon absorbers and fostering biodiversity amidst continuous climate change and urban development. In case studies, it has been observed that restored swamp areas rapidly turn into net CO_2 sinks after restoration. Site-specific factors such as land cover and vegetation development are essential in annual carbon budgets. Studies show that the impacts of previous land uses and hydrological changes are mitigated, highlighting the potential of wetland restoration to provide effective long-term carbon sequestration. In conclusion, artificial wetlands are promising for mitigating climate change impacts through carbon sequestration and biodiversity enhancement. Their success depends on careful design, management, and integration into broader sustainability and climate adaptation frameworks. Future research should focus on optimizing wetland restoration practices to maximize their ecological benefits and explore their scalability.

Keywords: Artificial wetlands, carbon sequestration, climate change mitigation.

Introduction

The impacts of global warming and the significance of negative emission technologies are paramount in the contemporary discourse on climate change, extending even to the extent that they will affect our food supplies (Haikola et al., 2021; Wiskerke, 2020). Global warming, attributed primarily to the increase in greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) due to human activities, has significantly increased Earth's average surface temperature, indicated in Figure 1 (Çelekli and Zariç, 2023b). The Intergovernmental Panel on Climate Change (IPCC) has underscored that the phenomenon is widespread, rapid, and intensifying, affecting every region on Earth in multiple ways (Srivastava et al., 2021). The consequences include but are not limited to, increased heatwaves, changes in precipitation patterns leading to more intense droughts and flooding, sea level rise, and the thawing of permafrost, all of which have profound implications for natural and human systems (Çelekli and Zariç, 2023c). Due to the severity of the consequences of climate change, efforts to colonize Mars are underway (Çelekli and Zariç, 2024a). The current state of global warming is such that human activities since the beginning of the Industrial Revolution have significantly influenced the pace and extent of climate change (Fleming, 2009). The IPCC's Sixth Assessment Report highlighted that the best estimate of the global average surface temperature increase between 1850 and 2019 was approximately 1.07 °C (Legg, 2021); Figure 1 indicated global temperature anomaly and atmospheric CO2 concentration (Shrestha, 2022).

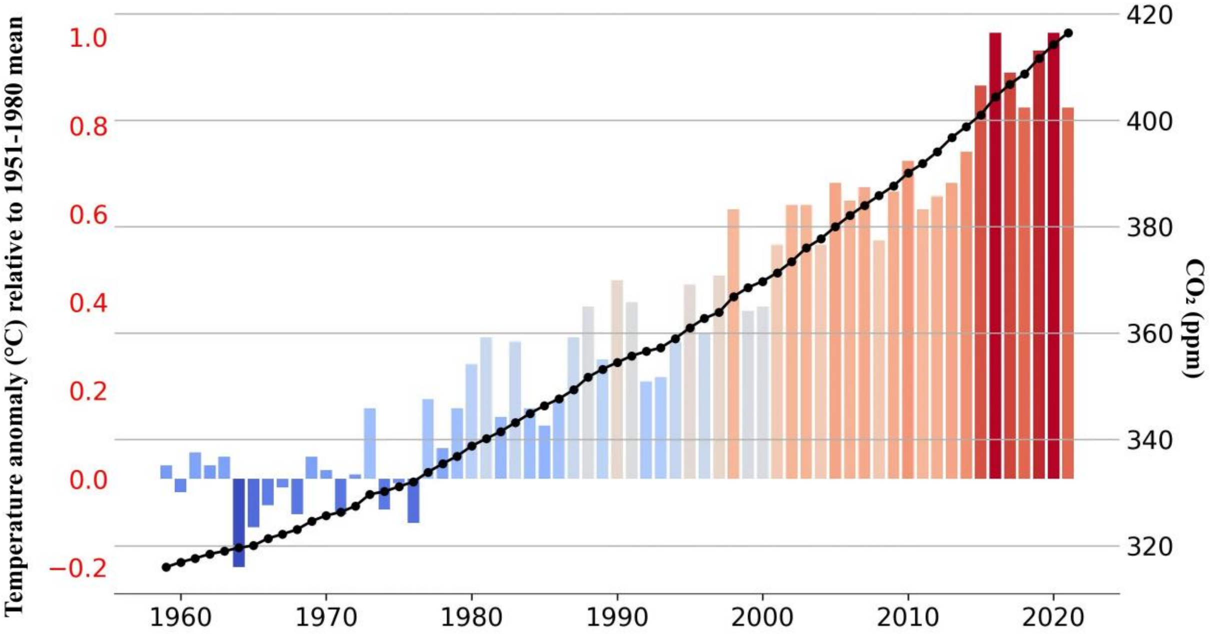

Figure 1. Global temperature anomaly over 1959- 2021 with CO_2 concentration (Shrestha, 2022)

Wetlands and oceans are known to be damaged by human impact (Çelekli and Zariç, 2024c; Zariç et al., 2024; Zariç and Çelekli, 2023). In this context, negative emission technologies that remove CO_2 from the atmosphere and ecological situations are analyzed with remote monitoring methods (Çelekli and Zariç, 2023a, 2024b; Haikola et al., 2021). Artificial wetlands represent a crucial strategy for carbon sequestration, leveraging the natural processes of vegetation to capture and store atmospheric CO_2 (Yuan et al., 2023). Artificial wetlands mimic the carbon sequestration capabilities of their natural counterparts and provide a myriad of ecosystem services (Clifford and Heffernan, 2018). They play a significant role in enhancing biodiversity, improving water quality, and offering flood protection, contributing to urban and regional sustainability goals (Alikhani et al., 2021). The integration of artificial wetlands into climate mitigation strategies underscores a growing recognition of the need for holistic approaches that address both the reduction of emissions and the removal of atmospheric CO_2 (Were et al., 2019). By capturing and storing carbon, artificial wetlands serve as vital components of the broader effort to combat global warming, highlighting the interconnectedness of climate action, ecosystem health, and biodiversity conservation (Nyman, 2011). The urgency of addressing global warming and harnessing the potential of solutions like artificial wetlands is apparent. As we face increasing climate variability and the escalating impacts of climate change, the development and expansion of negative emission technologies (Table 1), alongside aggressive emission reduction measures, are critical to achieving global climate goals and ensuring a sustainable future for all. Figure 2 shows the carbon footprint context path (Çelekli and Zariç, 2023b).

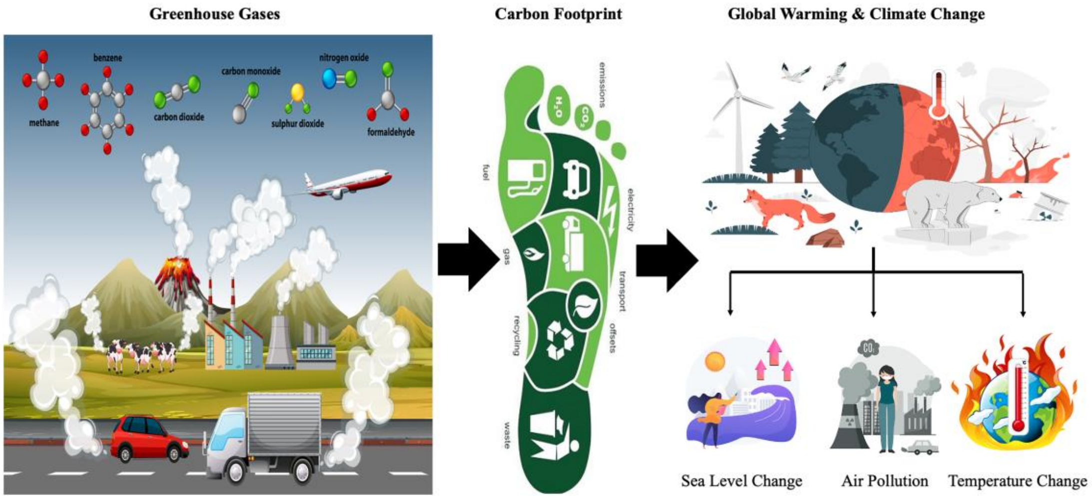

Figure 2. Carbon footprint context path (Çelekli and Zariç, 2023b)

Table 1. Summary of Negative Emission Technologies

Technology	**Description**	**Potential to Reduce CO_2**	**References**
Artificial Wetlands	Engineered ecosystems mimic natural wetlands, capturing CO_2 through vegetation and storing it in soil.	High in localized areas	(Were et al., 2019)
Direct Air Capture	Technological process that captures CO_2 directly from the atmosphere for storage or use.	High, scalable globally	(Erans et al., 2022)

Technology	Description	Potential to Reduce CO_2	References
Bioenergy with Carbon Capture and Storage	Utilizes biomass for energy, capturing the CO_2 produced and storing it underground.	Very high, scalable with energy production	(Babin et al., 2021)

Methods

This review synthesizes the current knowledge on artificial wetlands and their role in mitigating global warming through carbon sequestration and biodiversity enhancement. To gather and analyze the relevant literature, comprehensive searches were conducted in scientific databases such as Web of Science, Scopus, and Google Scholar. Keywords included "artificial wetlands," "carbon sequestration," "biodiversity," "water purification," "flood control," and "ecosystem services." Publications from the last two decades were prioritized to ensure the inclusion of the most recent findings and advancements. Studies were included based on specific criteria: those focusing on the design, implementation, and management of artificial wetlands, as well as research articles, review papers, and case studies discussing their ecological functions and benefits. Papers addressing the challenges and future directions for artificial wetland research and application were also considered. Relevant information was extracted from the selected articles, including methodologies, results, and conclusions. Data on carbon sequestration rates, biodiversity impacts, water purification efficiency, and flood control benefits were systematically reviewed and summarized. Comparative analyses were conducted to identify common themes, patterns, and gaps in the current knowledge. The gathered data were organized into thematic sections to provide a comprehensive overview of the topic. Key findings were highlighted, and their implications for the design and management of artificial wetlands were discussed. Future research directions and recommendations were proposed based on the identified gaps and challenges.

Results

Carbon Sequestration Mechanisms in Artificial Wetlands

Artificial wetlands capture CO_2 via photosynthesis, transforming it into organic matter that accumulates in soil (Rogerson et al., 2021). This process is enhanced under the anaerobic conditions that characterize these ecosystems (Were et al., 2019). Such conditions slow organic matter decomposition, preserving soil carbon and producing methane emissions (Mitra et al., 2005). This balance is influenced by site-specific factors such as vegetation type and historical land use, suggesting that artificial wetlands can significantly contribute to climate change mitigation with strategic management.

Impacts of Artificial Wetlands on Biodiversity

Artificial wetlands, constructed primarily for water purification, have emerged as valuable ecosystems for biodiversity conservation, compensating for the degradation of natural wetlands (Stefanakis, 2019; Zhang et al., 2020). These engineered ecosystems simulate natural wetland processes to optimize water purification but also provide sub-optimal habitats for various species, thereby contributing to biodiversity maintenance (Huang et al., 2022). However, the ecological processes in constructed wetlands can differ from those in natural wetlands, potentially promoting biological invasions or forming ecological traps for native species; despite these challenges, constructed wetlands can support diverse flora and fauna with proper management, enhancing local biodiversity and environmental resilience (Zhang et al., 2020). In urban areas, artificial wetlands enhance biodiversity and play a crucial role in creating natural spaces and connecting communities with their environment (Alikhani et al., 2021). These wetlands serve as green corridors, improving the urban landscape's aesthetic and recreational value and providing educational opportunities for residents. By integrating these ecosystems into urban planning, cities can enhance community resilience, promote sustainable development, and support biodiversity. Such integration requires a multifaceted approach, including stakeholder engagement and incorporating wetlands into broader environmental and social strategies. Moreover, wetland restoration has been shown to recover biodiversity and ecosystem services significantly lost due to degradation (An and Verhoeven, 2019). However, the effectiveness of these efforts can depend on factors such as the ecosystem type and specific restoration actions. Restoring biodiversity in these ecosystems is critical, as it often correlates with the recovery of ecosystem services, suggesting that biodiversity may be a prerequisite for the entire functional restoration of these areas. This highlights the importance of considering ecological and social aspects in the management and restoration of wetlands. In conclusion, artificial wetlands are vital in enhancing urban biodiversity, connecting communities with nature, and contributing to global conservation efforts. Their successful integration into urban landscapes requires careful planning, management, and engagement with local communities to ensure they provide both ecological and social benefits (Erwin, 2009; Zedler and Leach, 1998).

Management and Optimization of Artificial Wetlands

Maximizing the carbon sequestration capacity of artificial wetlands requires a comprehensive understanding of the ecosystems' dynamics and effective management strategies. These strategies must focus on enhancing the natural processes of carbon uptake and storage while minimizing the release of greenhouse gases like methane (Bernal and Mitsch, 2012).

Strategies for Maximizing Carbon Sequestration

The design of artificial wetlands plays a crucial role in their ability to sequester carbon. Incorporating diverse vegetation and ensuring adequate water depth and flow can enhance the wetlands' primary productivity, thus increasing CO_2 absorption from the atmosphere (Salimi et al., 2021). The layout should mimic natural wetlands as closely as possible to exploit the inherent carbon storage processes (Were et al., 2019). Effective management practices are vital in maintaining the carbon sequestration potential of artificial wetlands. This includes regularly monitoring vegetation health, water quality, and soil conditions. Intervention measures, such as controlling invasive species and adjusting water levels, can help maintain optimal carbon capture and storage conditions. Restoring degraded wetland areas can quickly turn them into net CO_2 sinks (Valach et al., 2021). Restoration efforts should focus on re-establishing native vegetation and repairing hydrological functions to enhance carbon uptake (Collier, 2012). These efforts must consider site-specific factors like land cover, previous land use, and hydrology, as they significantly impact the carbon balance of wetlands (Valach et al., 2021).

Case Studies and Applied Research

Research has shown that peat-dominated ecosystems, including freshwater marshes, play a critical role in global carbon storage due to their long residence time and anaerobic conditions that protect soil carbon while supporting vegetation that sequesters atmospheric CO_2 (Lolu et al., 2020). Despite the potential release of methane, a greenhouse gas, some restored wetlands have been immediate net greenhouse gas sinks in specific years, with their high net carbon uptake offsetting the climate-forcing effects of methane emissions (Turetsky et al., 2014). This highlights the importance of understanding the drivers of carbon uptake in freshwater wetlands to optimize their management as natural climate solutions.

Artificial wetlands contribute to carbon sequestration through vegetation and soil processes, particularly in peat-dominated ecosystems where long-term carbon storage is facilitated by anaerobic conditions that slow decomposition (Lolu et al., 2020). Despite their potential, artificial wetlands also face limitations, such as methane emission, a potent greenhouse gas, which can reduce their net climate mitigation benefits (Were et al., 2019).

Beyond their role in climate change mitigation, artificial wetlands enhance biodiversity and provide various ecosystem services such as improving water quality, providing habitat for wildlife, and supporting recreational activities (Semeraro et al., 2015). Integrating artificial wetlands into urban and community planning can also enhance social values by reconnecting people with nature and supporting community resilience.

Discussion

Artificial wetlands are crucial in mitigating global warming through their ability to sequester atmospheric CO_2 and enhance biodiversity. They replicate natural wetland functions, effectively capturing and storing carbon while supporting diverse species and improving water quality and flood control. Optimizing restoration practices is essential for maximizing these benefits, involving selecting suitable plant species, designing for optimal water flow, and managing invasive species. Future research should delve into the intricate interactions within these ecosystems to refine their design and management. Additionally, integrating technological innovations could boost purification efficiency under various environmental conditions. Expanding artificial wetlands into urban and rural areas, supported by robust policies, is vital for achieving carbon neutrality. However, scalability, economic feasibility, and social acceptance challenges need addressing. Future studies should assess the carbon capture potential across different wetland types, ensure long-term sustainability under changing climate conditions, and explore innovative integration methods into broader environmental and urban planning frameworks. As research progresses, artificial wetlands are set to become increasingly significant in global sustainability and resilience efforts.

Acknowledgments

We want to express our gratitude and respect to The Scientific and Technological Research Council of Türkiye (TUBITAK) for the grant provided under the scope of the program (TUBITAK-BIDEB 2224-B 1919B022401753).

Author's Contributions

Özgür Eren Zariç and Abuzer Çelekli designed the overall review work.

References

Alikhani, S., Nummi, P., & Ojala, A. (2021). Urban wetlands: A review on ecological and cultural values. Water (Switzerland), 13(22), 3301.

An, S., & Verhoeven, J. T. A. (2019). Wetland Functions and Ecosystem Services: Implications for Wetland Restoration and Wise Use. Springer.

Babin, A., Vaneeckhaute, C., & Iliuta, M. C. (2021). Potential and challenges of bioenergy with carbon capture and storage as a carbon-negative energy source: A review. Biomass and Bioenergy, 146, 105968.

Bernal, B., & Mitsch, W. J. (2012). Comparing carbon sequestration in temperate freshwater wetland communities. Global Change Biology, 18(5), 1636–1647.

Çelekli, A., & Zariç, Ö. (2023a). Utilization of Herbaria in Ecological Studies: Biodiversity and Landscape Monitoring. Herbarium Turcicum. Advance Online Publication. https://doi.org/10.26650/ht.2023.1345916

Çelekli, A., & Zariç, Ö. E. (2023b). From Emissions to Environmental Impact: Understanding the Carbon Footprint. International Journal of Environment and Geoinformatics, 10(4), 146–156. https://doi.org/10.30897/ijegeo.1383311

Çelekli, A., & Zariç, Ö. E. (2023c). Hydrobiology and ecology in the context of climate change: the future of aquatic ecosystems. 6th International Eurasian Conference on Biological and Chemical Sciences, 539–545.

Çelekli, A., & Zariç, Ö. E. (2024a). Breathing life into Mars: Terraforming and the pivotal role of algae in atmospheric genesis. Life Sciences in Space Research, 41, 181–190. https://doi.org/10.1016/j.lssr.2024.03.001

Çelekli, A., & Zariç, Ö. E. (2024b). Plasma-Enhanced Microalgal Cultivation: A Sustainable Approach for Biofuel and Biomass Production. In A. Shahzad & M. He (Eds.), Emerging Applications of Plasma Science in Allied Technologies (p. 300). IGI Global. https://doi.org/10.4018/979-8-3693-0904-9

Çelekli, A., & Zariç, Ö. E. (2024c). Rising Tide of Ocean Acidification. Environmental Research and Technology. Advance Online Publication. https://doi.org/10.35208/ert.1407588

Clifford, C. C., & Heffernan, J. B. (2018). Artificial aquatic ecosystems. Water (Switzerland), 10(8), 1096

Collier, P. A. (2012). Wetland habitats: a practical guide to restoration and management. In Ecological Management & Restoration (Vol. 13, Issue 3). Csıro Publıshıng.

Erans, M., Sanz-Pérez, E. S., Hanak, D. P., Clulow, Z., Reiner, D. M., & Mutch, G. A. (2022). Direct air capture: process technology, techno-economic and socio-political challenges. Energy & Environmental Science, 15(4), 1360–1405.

Erwin, K. L. (2009). Wetlands and global climate change: The role of wetland restoration in a changing world. Wetlands Ecology and Management, 17(1), 71–84.

Fleming, J. R. (2009). The Great Warming: Climate Change and the Rise and Fall of Civilizations. In Physics Today (Vol. 62, Issue 3). Bloomsbury Publishing USA.

Haikola, S., Anshelm, J., & Hansson, A. (2021). Limits to climate action - Narratives of bioenergy with carbon capture and storage. Political Geography, 88, 102416.

Himalaya, B., S. (2022). Assessing global temperature anomaly using NASA's space studies — Part I | by Himalaya Bir Shrestha | Towards Data Science.

Huang, F., Huang, Y., Jia, J., Li, Z., Xu, J., Ni, S., & Xiao, Y. (2022). Research and engineering application of bypass combined artificial wetlands system to improve river water quality. Journal of Water Process Engineering, 48, 102905.

Legg, S. (2021). Technical Summary. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Climate Change 2021: The Physical Science Basis., pp. 44–45.

Lolu, A. J., Ahluwalia, A. S., Sidhu, M. C., Reshi, Z. A., & Mandotra, S. K. (2020). Carbon Sequestration and Storage by Wetlands: Implications in the Climate Change Scenario. Restoration of Wetland Ecosystem: A Trajectory Towards a Sustainable Environment, 45–58. https://doi.org/10.1007/978-981-13-7665-8_4

Mitra, S., Wassmann, R., & Vlek, P. L. G. (2005). An appraisal of global wetland area and its organic carbon stock. Current Science, 88(1), 25–35.

Nyman, J. A. (2011). Ecological Functions of Wetlands. Wetlands, pp. 115–128.

Rogerson, R. J., Horgan, D., & Roberts, J. J. (2021). Integrating artificial urban wetlands into communities: a pathway to carbon zero? Frontiers in Built Environment, 7. https://doi.org/10.3389/fbuil.2021.777383

Salimi, S., Almuktar, S. A. A. A. N., & Scholz, M. (2021). Impact of climate change on wetland ecosystems: A critical review of experimental wetlands. Journal of Environmental Management, 286, 112160.

Semeraro, T., Giannuzzi, C., Beccarisi, L., Aretano, R., De Marco, A., Pasimeni, M. R., Zurlini, G., & Petrosillo, I. (2015). A constructed treatment wetland is an opportunity to enhance biodiversity and ecosystem services. Ecological Engineering, 82, 517–526. https://doi.org/10.1016/j.ecoleng.2015.05.042

Srivastava, L., Echeverri, L. G., Schlegel, F., Denis, M., Deubelli, T. M., Havlik, P., Kaplan, D., Mechler, R., Paulavets, K., Rovenskaya, E., & others. (2021). Transformations within reach: Pathways to a sustainable and resilient world-Synthesis Report. IIASA Report.

Stefanakis, A. I. (2019). The Role of Constructed Wetlands as Green Infrastructure for Sustainable Urban Water Management. Sustainability (Switzerland), 11(24), 6981.

Turetsky, M. R., Kotowska, A., Bubier, J., Dise, N. B., Crill, P., Hornibrook, E. R. C., Minkkinen, K., Moore, T. R., Myers-Smith, I. H., Nykänen, H., Olefeldt, D., Rinne, J., Saarnio, S., Shurpali, N., Tuittila, E. S., Waddington, J. M., White, J. R., Wickland, K. P., & Wilmking, M. (2014). A synthesis of methane emissions from 71 northern, temperate, and subtropical wetlands. Global Change Biology, 20(7), 2183–2197.

Valach, A. C., Kasak, K., Hemes, K. S., Anthony, T. L., Dronova, I., Taddeo, S., Silver, W. L., Szutu, D., Verfaillie, J., & Baldocchi, D. D. (2021). Productive wetlands restored for carbon sequestration quickly become net CO2sinks with site-level factors driving uptake variability. PLoS ONE, 16(3 March), e0248398.

Were, D., Kansiime, F., Fetahi, T., Cooper, A., & Jjuuko, C. (2019). Carbon Sequestration by Wetlands: A Critical Review of Enhancement Measures for Climate Change Mitigation. Earth Systems and Environment, 3(2), 327–340.

Wiskerke, J. S. C. (2020). Assessing the environmental impact of agriculture. 6th International Eurasian Conference on Biological and Chemical Sciences, 0–320.

Yuan, X., Qian, S., & Li, B. (2023). Carbon neutrality: A review. Journal of Computing and Information Science in Engineering, p. 23, 60801–60809.

Zariç, Ö. E., & Çelekli, A. (2023). Fishing in Kars-Ardahan Lake Çıldır: Ecological Interactions and Conservation Strategies. 7. Ulusal Alabalık Kongresi, 14.

Zariç, Ö. E., Çelekli, A., & Yaygır, S. (2024). Lakes of Turkey: Comprehensive Review of Lake Çıldır. Aquatic Sciences and Engineering, 39(1), 54–63. https://doi.org/10.26650/ASE20241353730

Zedler, J., & Leach, M. (1998). Managing urban wetlands for multiple use: research, restoration, and recreation. Urban Ecosystems, 2, 189–204.

Zhang, C., Wen, L., Wang, Y., Liu, C., Zhou, Y., & Lei, G. (2020). Can constructed wetlands be wildlife refuges? A review of their potential biodiversity conservation value. Sustainability (Switzerland), 12(4), 1442.