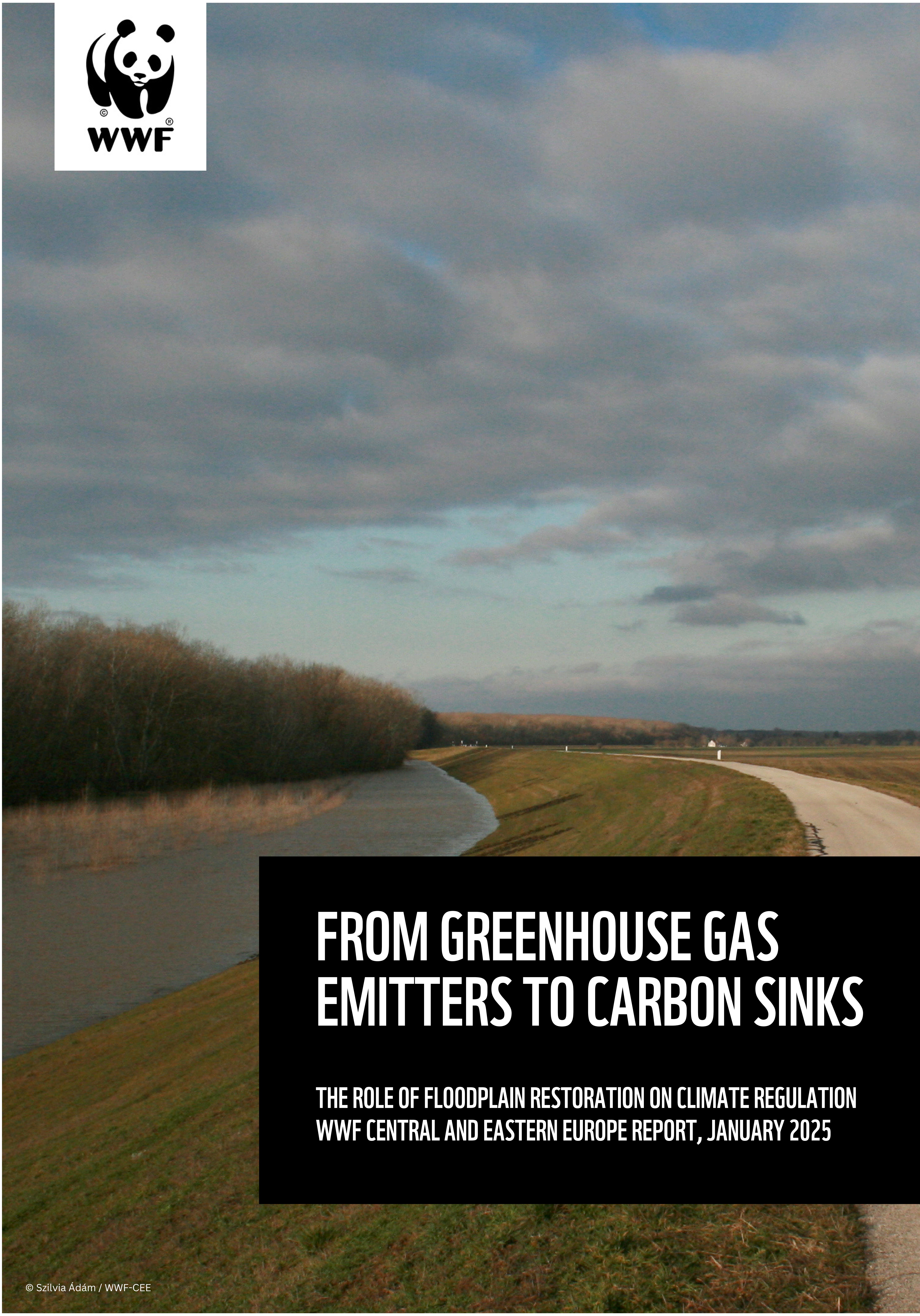

FROM GREENHOUSE GAS EMITTERS TO CARBON SINKS

THE ROLE OF FLOODPLAIN RESTORATION ON CLIMATE REGULATION
WWF CENTRAL AND EASTERN EUROPE REPORT, JANUARY 2025

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ABSTRACT

The three-year-long (2022-2024) pilot research estimated the greenhouse gas **balance** (net amount of carbon sequestration reduced by the greenhouse gas emissions) of **floodplain restorations** along the Tisza River on local (two sample areas, 20-30 ha), landscape (Nagykörű deep floodplain site, 4500 ha) and regional (along the Hungarian part of Tisza, 150 000 ha) scales. After the elaboration of a theoretical landscape vision as the first step, a scientific expert board (experts for soil, vegetation, meteorology, climate, modeling, plant physiology, GIS, and land management) was established, whose intensive and efficient cooperation was essential to complete this pilot research which yielded promising results and conclusions. To examine the fluxes of the three main greenhouse gases (GHGs), carbon-dioxide, methane, nitrous oxide CO_2, CH_4, N_2O), are essential to consider, since ecosystems could be both sources (emitter) or sinks of these gases, depending on field conditions. Considering the unavailability of such data on floodplains and their restoration from a climate regulation perspective for this region, the present pilot research fills a significant knowledge gap.

According to the overall results, based on field measurements, biogeochemical model runs, and predicted land use changes induced by hypothetical inundation of former floodplains, it can be concluded that the observed and proposed **floodplain restoration, at all three analysed scales, has a positive impact on the greenhouse gas balance.** The impacts of periodic **floods,** such as increased biomass production and improved habitat conditions, enhanced the[1] ecosystems' carbon sequestration ability which was able to offset the total GHG **emission of the restored area locally** which is relevant, since nitrous oxide is a gas with 298 times, methane with 34 times more warming potential of carbon dioxide over a 100-year timeframe. However[2], drought reduces the carbon sequestration potential, which will be more challenging in the future, but the controlled periodic flooding mitigates the negative impacts of droughts. Moreover, **on a landscape or regional scale,** the areas may **change from a significant net greenhouse gas emitter to a net sink due to inundation-induced land use change.** Intensively cultivated arable lands with high fertiliser use proved to be the worst choice from a climate regulation point of view due to their significant nitrous oxide emission coming from the used fertilisers.

Floodplains are the mosaic of different ecosystems that offer various land uses and products (wet meadows - mowing or grazing; forests - timber; orchards - fruits; open-water surface of oxbows - angling etc. – and all of them are habitats for rare species). Besides the many other well-known ecosystem services provided by floodplains (natural products, spawning sites, recreation, etc.), their flood peak mitigation value or their climate adaptation benefits such as drought mitigation, groundwater infiltration, and favourable microclimate due to increased evaporation are not generally known, or the value is not considered, as their climate mitigation role has not been estimated before. Nowadays the former floodplains are mostly used as arable lands. **In our research, we found that if two-thirds of the analysed former deep floodplain along the Tisza River were converted to extensive land use in harmony with controlled periodic flooding, the climate mitigation potential would be significant.** Therefore, more sustainable land use, where natural floods have space in the landscape, is also justified.

Restored floodplains offer a scalable solution for climate change mitigation and ecosystem restoration, underscoring the vital role of nature-based solutions in achieving EU climate goals.

Over 90% of Hungary's former floodplains are now flood protected areas, natural river dynamics are very limited, critical habitats and ecosystem services are endangered.

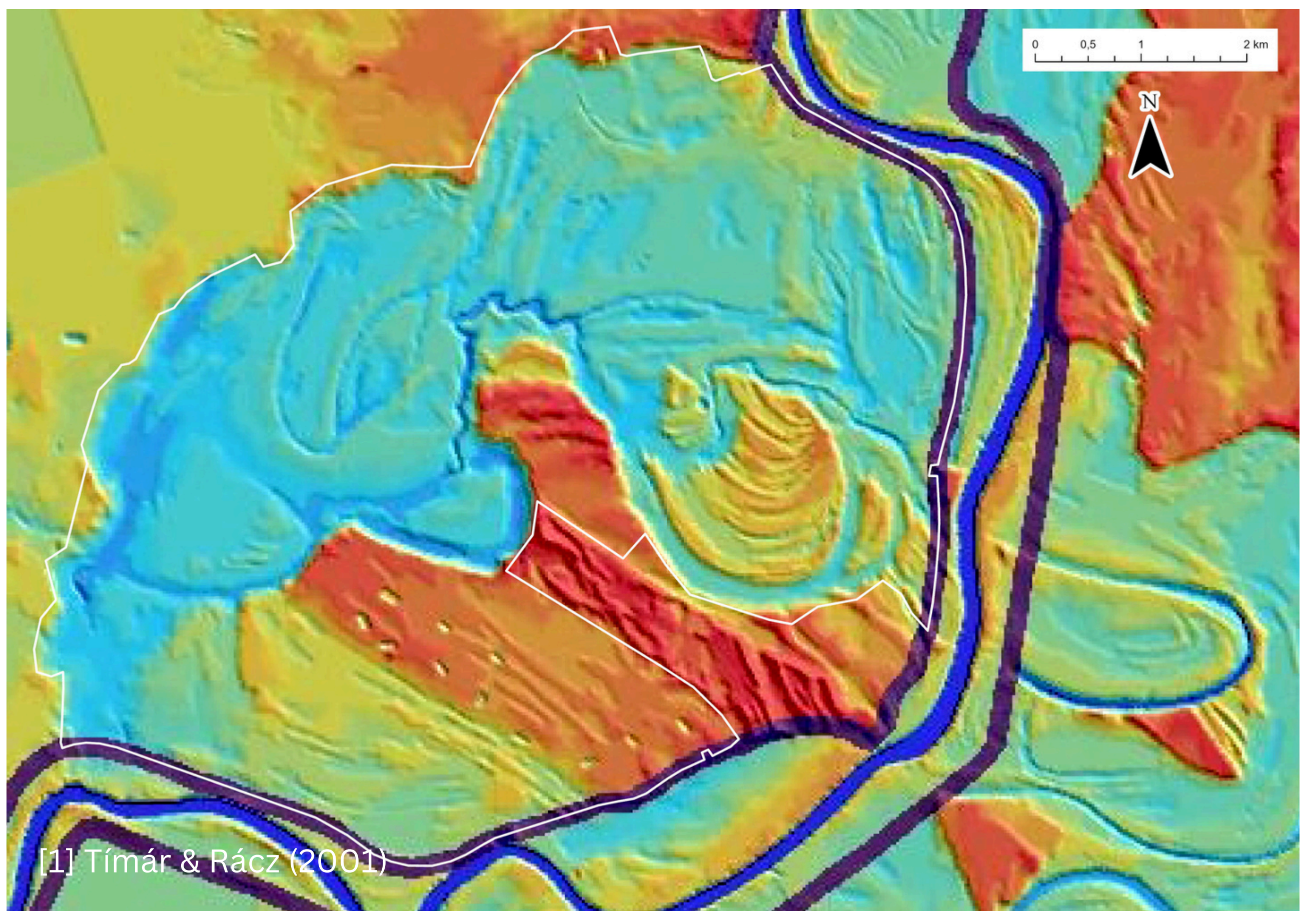
Periodic flooding driven by natural river dynamics **once played a vital role** in shaping the landscape of the Great Plain in Hungary, and its functioning. River regulations over the past centuries drastically reduced the extent of the active floodplain areas, placing more than 90% of former floodplains behind flood protection dykes. Several habitats and species of both Hungarian, and European importance have been endangered, and the once-provided ecosystem services have been damaged or completely disappeared. Nowadays, these flood-protected and drained former floodplains are mainly used as **arable lands** and are strongly **affected by the negative impacts of climate change, leading to the drying of the landscape.** In this landscape, the drought, as the lack of water can be interpreted as the negative consequence of the large-scale flood protection of the past, recent drainage of lands, and climate change-induced extreme weather events.

Actual land use of former floodplains (left), one of the many potential land uses after restoration (right)

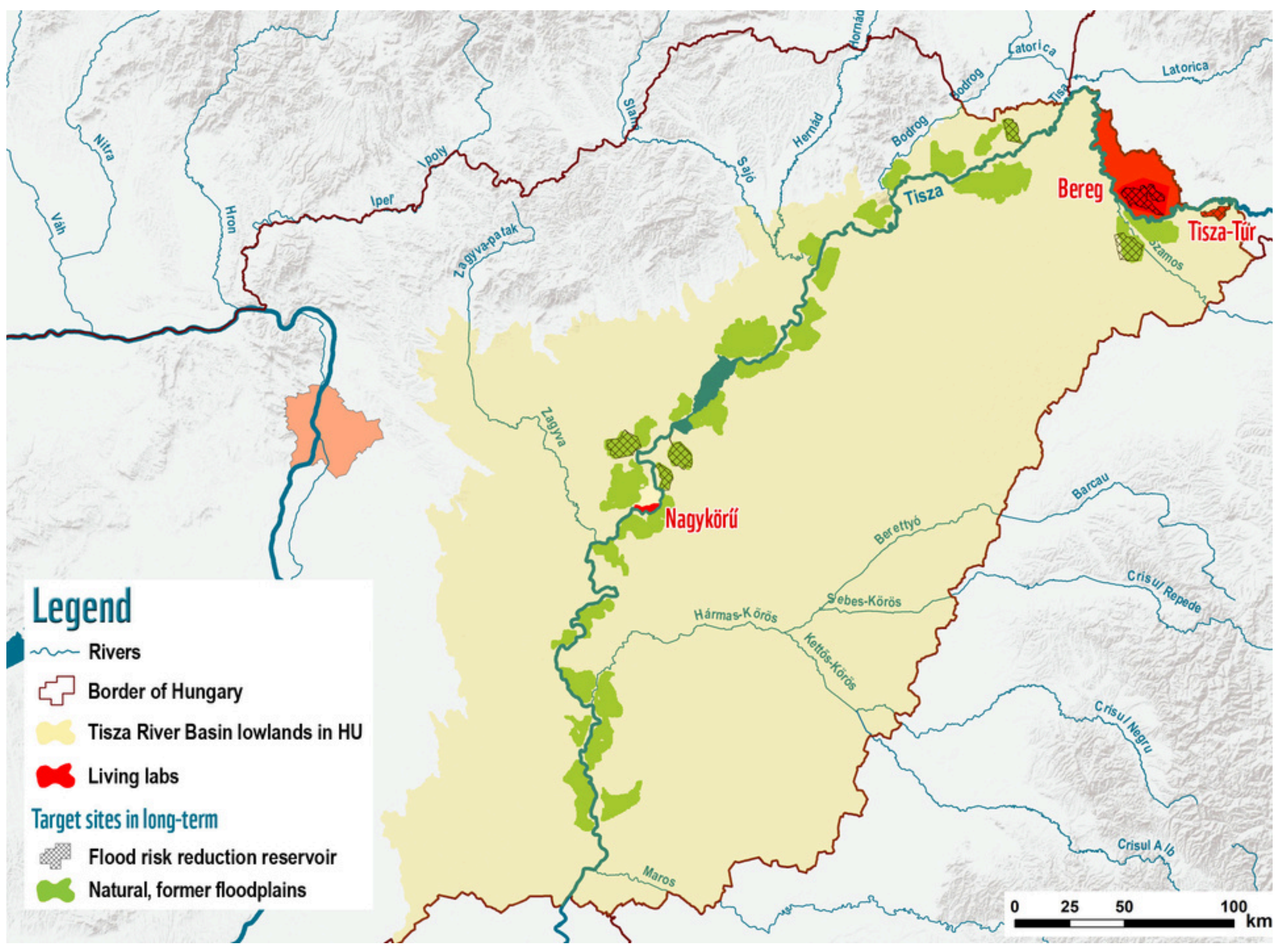
WWF Hungary, in cooperation with local farmers and municipalities, is investigating the possibilities of restoring the former floodplains in several locations along the Tisza River. The concept focuses on reducing artificial drainage and releasing **natural periodic floods into the depressions of the former floodplain areas**, retaining the water there for as long as permitted by land uses. Implementing these natural **water retention measures (NWRM)** on a smaller or larger scale requires transitioning to more sustainable land uses such as floodplain pastures, mowing fields, orchards, and wetlands adapted to the landscape's features. The intensively cultivated arable lands are often impacted by inland water, then drought, within short periods, and have low productivity, so the **change in land use** of deep floodplains can be considered an economic goal too. The long-term goal of floodplain restoration, besides the ecological and nature conservation benefits, is to **increase the water resources stored in the soil** and **improve the water balance of the Tisza Valley**, which can represent an important step forward in restoring the landscape-scale water cycle. But what is the role of flooding from a climate perspective? Our climate is controlled by the circulation of greenhouse gases (GHG), which are influenced by ecosystems. They can reduce or increase the atmospheric concentration of GHGs. Their balance depends on the ecosystem type, natural conditions, locality, and land use. Over a 100-year time horizon, the global warming potential of methane is 34 times stronger than CO2, while that of nitrous oxide is 298 times stronger. The **net greenhouse gas balance (NGB)** indicates that the ecosystem is an overall positive or negative provider in terms of climate regulation and takes into account the three main greenhouse gases **(CO2, CH4, N2O)** with many other important factors such as meteorology, soil type, and management practices (harvesting, fertilisation, mowing, grazing, etc.). The pilot research estimated the **net greenhouse gas balance** of **floodplain restorations** along the Tisza River on local, landscape, and regional scales.

INVESTIGATION SCALES

The **local scale investigation** took place in two sample areas (20-30 ha) in Nagykörű village, located on the bank of the Tisza River. One of the pastures is periodically flooded by the river, while the other is located in a flood-protected area (the distance between them is circa 1.5 km, while their altitude and the distance from the river are the same). The **net greenhouse gas balance was estimated for both sites**, based on the results of **process-oriented biogeochemical model runs** (Biome-BGC-MuSo) for **pre-defined scenarios** (flooding, lack of flooding, and arable land use of the sample areas). For the model many parameters were measured on the field by **installed permanent devices** (meteorology, soil moisture, and soil temperature; 2022-2024), by a **research institute** (soil, GHG emission, plant assimilation, LAI, NDVI, etc.; 2022-2023) and by **scientific experts from universities** (biomass above and below the ground; vegetation coenology; in 2023). We additionally used data from the archives (water level, meteorology; 2002-2022), official databases, scientific literature, and **the projections of ALADIN climate model (2025-2053).**



On a **landscape scale**, we **estimated the restoration impacts of the former deep floodplain [2] areas around Nagykörű** (4 500 ha). First, we analysed the area's former nature-based land use on a historical map from 1845, before the Tisza River was regulated [3], then analysed the current land use through a recently published ecosystem map [4]. To estimate the spatial extent and persistence of potential floods, we used inundation maps for three flood levels, which were provided by other research [5] based on digital elevation models. The potential inundations were simulated and overlapped with the land use layers using geographic information tools (ArcGIS Pro). These parameters played an essential role in predicting the changes in ecological conditions, which determine the potential future ecosystem types of each patch of the deep floodplain area. According to the results, average net greenhouse gas balance values were added per hectare into the spatial extent of each ecosystem category (mainly from scientific literature [6, 7, 8, 9, 10, 11, 12], in the case of pastures we used the results of our local level investigations) to estimate the net greenhouse gas balance for the whole deep floodplain.



On a **regional scale**, we attempted to **estimate the impact of the restoration of all the deep floodplain areas along the River Tisza** (approx. 150,000 ha) **on the greenhouse gas balance**. For this, we used the spatial distribution of every deep floodplain area determined by previous research [2]. As this regional scale is vast, we used a simpler methodology than was presented for the deep floodplain area (landscape scale). The current land use categories were determined using the Corine Landcover map (CLC 2018). For future potential land use conversion we used the rates of an already implemented floodplain restoration project in Fokorúpuszta, 15 km downstream from Nagykörű [13, 14]. The GHG values of each ecosystem type were used from international and national literature data [6, 7, 8].

RESULTS: LOCAL SCALE

Field measurements proved that, compared to the flood protected area, the floodplain with periodical floods had higher productivity, cooler and wetter soil, even in the summer of the historic drought in 2022

Researchers in action on the field

Although biogeochemical modeling for the past/present (2012-2024) and for the future (2025-2053) with six pre-defined scenarios were carried out for both areas (active floodplain site and flood protected site), only the results of the active floodplain site is considered as significant (the flood protected site severely dried out during droughts, so its functioning as ecosystem was limited). The real situation is the pasture with floods, and 5 additional simulations were modelled: floodplain pasture without floods; floodplain site used as arable land with intensive maize production combined with floods; and / or with or without use of fertilizers.

The net greenhouse gas balance (NGB) is able to determine whether a given ecosystem is an overall positive or negative provider in terms of climate regulation (consider the three main GHGs: CO2, CH4, N2O, and many other important factors such as land management, soil, meteorology etc.). Based on the model run results (averaged cumulative fluxes of the components) the floodplain pasture without flood is a greenhouse gas emitter, while under flood it becomes a GHG sink (Figure 1). However, flooding leads to high production, thus high carbon sequestration, but the rate of sequestration is projected to decrease in the future, due to climate change.

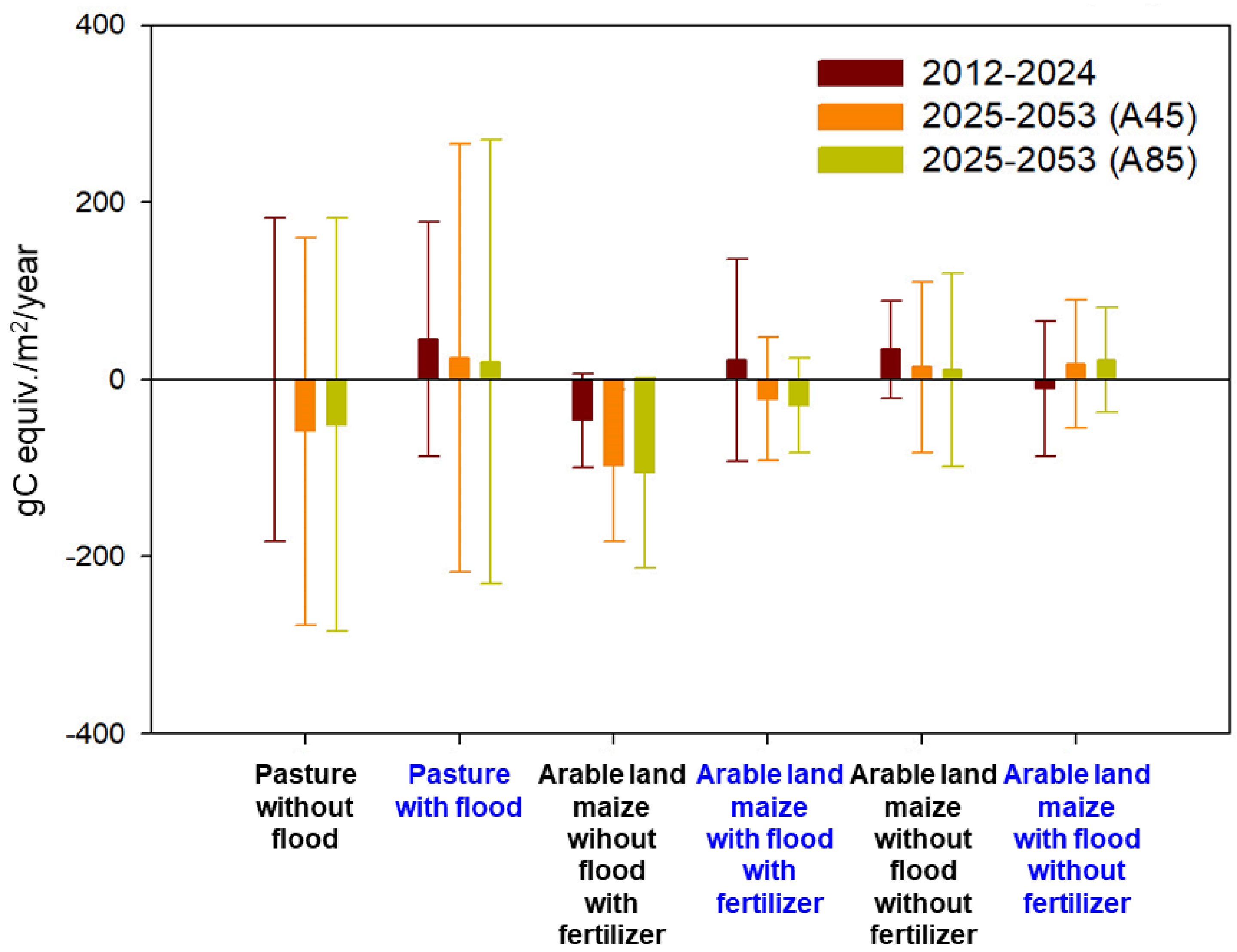
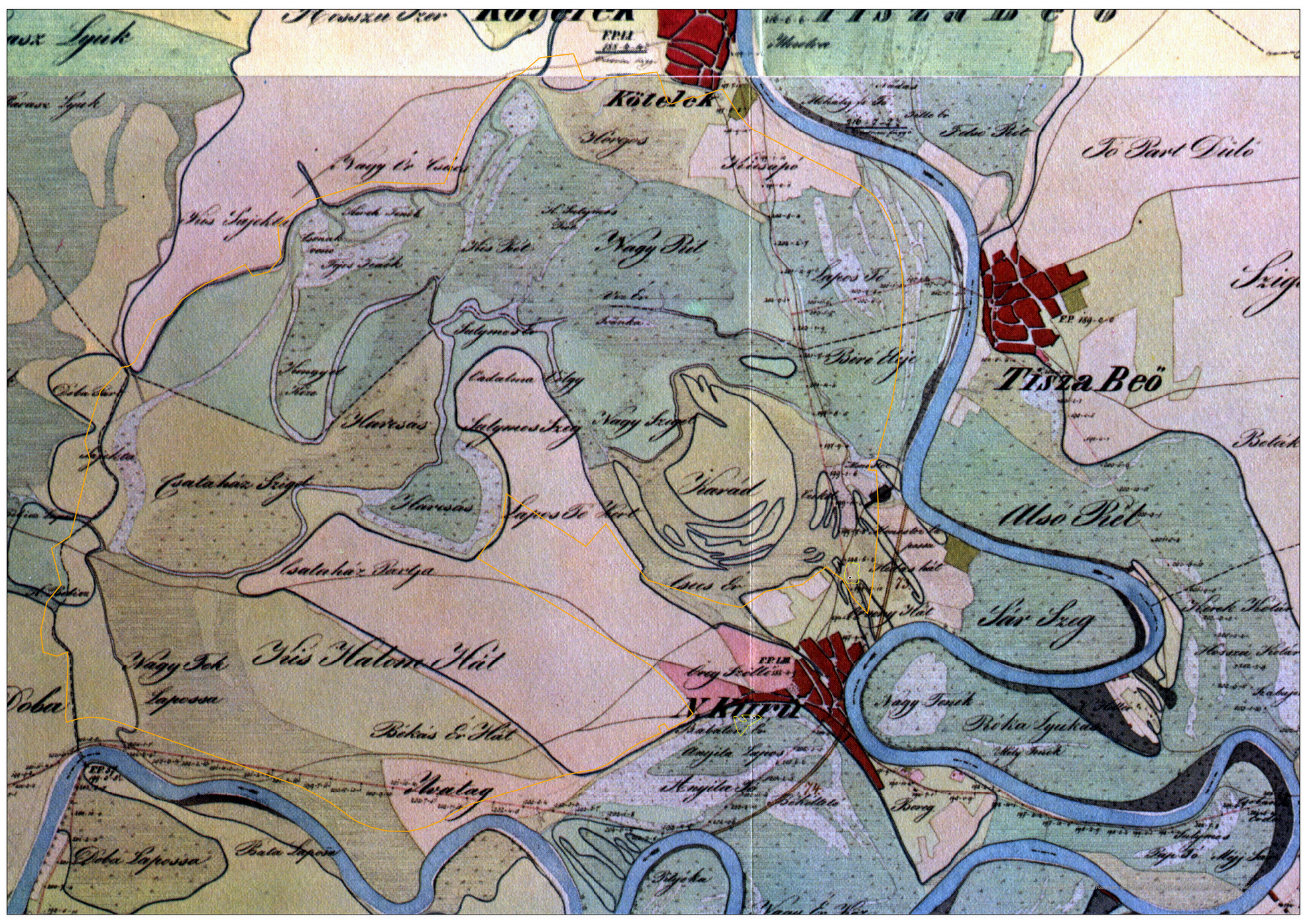


Figure 1. Cumultated net greenhouse gas balance (NGB) for the past (2012-2024) and future (2025-2053, A45 and A85 climatic projection) for 6 scenarios. Negative signs mean emission to the atmosphere. Scenarios: floodplain pasture - without flood, floodplain pasture – with flood, Arable land (floodplain -without flood), Arable land (floodplain with flood), Arable land (floodplain with flood - without fertilizer), Arable land (floodplain with flood without fertilizer)

In the simulation, when the floodplain pastures were converted into arable land, maize production was significant (as was the amount of carbon removal by harvesting), but nitrous oxide emissions resulting from fertilization also increased, so the intensively cultivated arable land scenarios are net emitters of GHGs. Moreover, the organic carbon content of the soil also decreased. If there was no fertilization on floodplain arable land, the area would be a net greenhouse gas sink with and without flooding, which could be a compromise.

RESULTS: LANDSCAPE SCALE



Historical land use of the deep floodplain around Nagykörű before the river regulations started (left), current land use of the same area (right)

To upscale into landscape level (surrounding Nagykörű, circa 4500 ha), we simulated floods into the deep floodplains located now in a flood protected area and estimated the net greenhouse gas balance (NGB) change as a result of the flooding. For predicting future land use we considered many factors such as the current land use, the spatial extent, water depth, and duration of potential floodings on each patch, and the restoration potential of different ecosystem types. The net greenhouse gas balance (NGB) was assigned to each land use category based on literature and modeled data. Since two-thirds of the arable lands that are net greenhouse gas emitters need to be converted into wet, productive grasslands and other ecosystem types (orchards, floodplain forests, other wetlands), the balance switched from net emitter to net sink of GHG (Figure 2).

The greenhouse gas balance of the deep floodplain around Nagykörű village (~4500 ha) now and after a potential floodplain restoration induced land use change

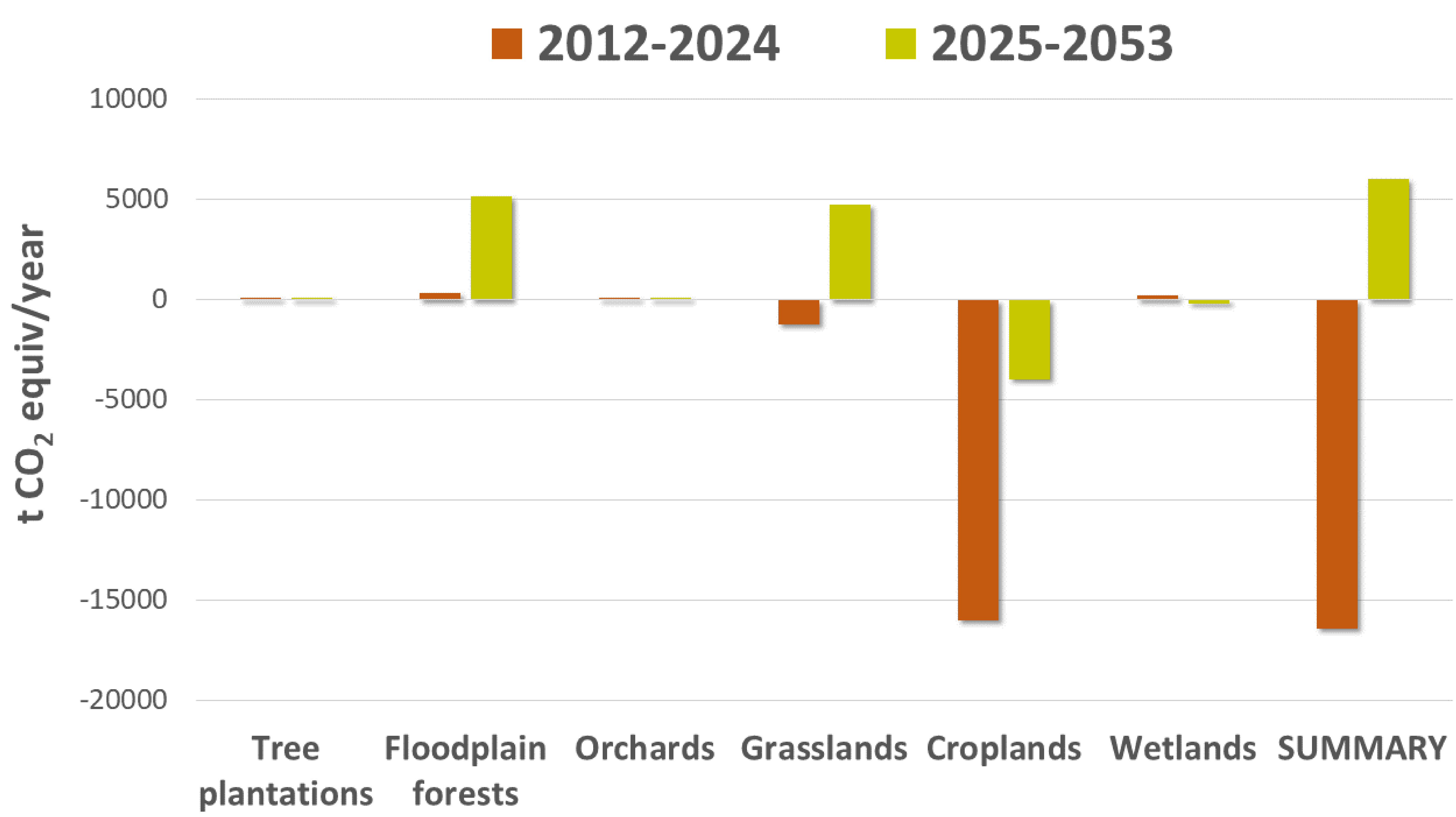


Figure 2. Greenhouse gas balance (NGB) of the project area surrounding Nagykörő (~4500 ha) before and after the restoration of the deep floodplain (positive values = carbon sequestration, negative = emission)

RESULTS: REGIONAL SCALE

Active floodplain during flooding near the sample area of the pilot research in Nagykörű (left), recently restored floodplain near Szolnok (right)

To upscale to a regional level, we theoretically examined the restoration and periodical inundation of all the existing deep floodplain areas along the Tisza River (approx. 150,000 ha). Due to its large extent, we used a simpler methodology and determined the land use conversion through rates experienced by completed floodplain restoration from the Middle-Tisza.

For estimation of the net GHG balance (NGB) we used data only from literature for each land use category. This result (Figure 3. - positive values mean GHG sink, negative values mean GHG emission) also indicated that the restoration of the floodplain is favourable from a GHG balance point of view, because the deep floodplains which are currently a significant net source of greenhouse gas emissions due to large-scale arable cultivation, act as net carbon sinks after the modeled land use change.

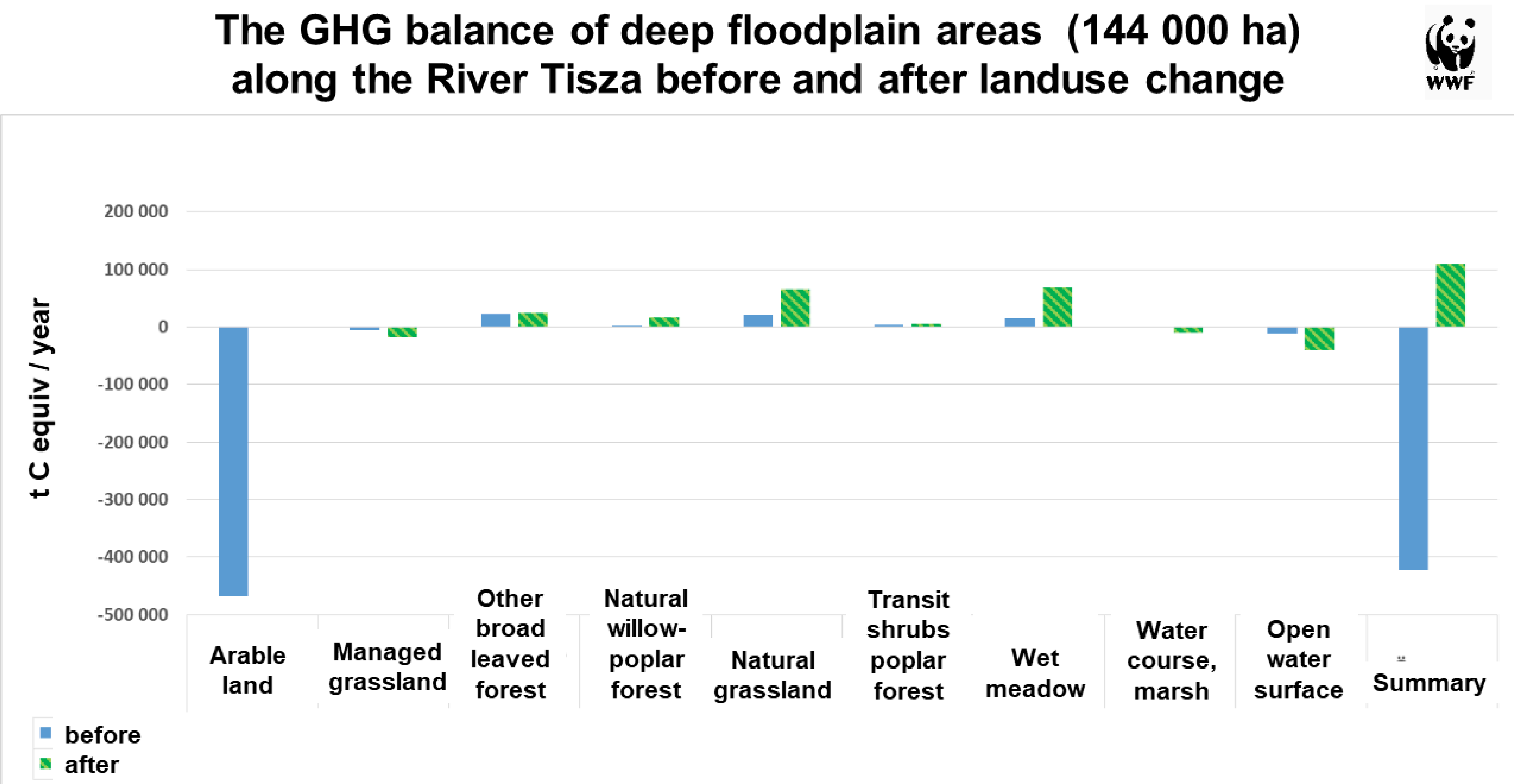


Figure 3. Greenhouse gas balance (NGB) of the deep floodplain areas along the Tisza River (~150,000 ha) before and after the land use conversion (positive values = carbon sequestration, negative = emission)

CONCLUSIONS AND THEIR DISCUSSION

According to the **field measurements and model runs**, natural periodical floods enhance biomass production, increase carbon sequestration, and, in sum, reduce greenhouse gas (GHG) emissions. Overall GHG emissions of periodically flooded sites can be offset by their increased carbon sequestration ability. The naturally flooded pasture site has been proven as GHG sink, while the flood-protected pasture was estimated as neutral in the past, but predicted to be an emitter in the future due to climate change-induced droughts. Climate projections indicate that drought periods with heatwaves will increase in the future, reducing the carbon sequestration potential, thus further underscoring the importance of natural water release and retention measures. From a GHG perspective, intensively cultivated arable lands with high fertilizer inputs proved the worst land use option. However, periodic flooding without fertilization can allow arable lands to sequester carbon with acceptable yield averages.

The **landscape and regional scale estimations** proved that floodplain restoration-induced land use change as nature-based solutions, instead of intensive crop production, can transform the landscape from a net GHG emitter to a net GHG sink. While the current arable lands produce high amounts of nitrous oxide emissions due to used fertilizers. In contrast, wet grasslands, pastures, floodplain forests, and wetlands have low total emissions and significant carbon sequestration due to better water availability. It is important to note that food production in the form of floodplain agriculture remains possible in the area. Land use change is needed, but due to the diverse topography of these deep floodplain areas, some of the current land use could be maintained as it is. In the analysed case this ratio was one-third of the total area.

Natural flooding positively impacts the climate regulation service of ecosystems, improves the GHG balance, reduces emissions, turns areas into carbon sinks, and justifies extensive sustainable land uses. Floodplain restoration, as a nature-based solution, supports climate adaptation with mitigation benefits, reduces the vulnerability to weather extremes, and increases resilience.

“This unique study offers a new way of thinking about our floodplains, and encourages large-scale floodplain restoration across the Danube region, providing a pathway to address biodiversity loss and meet climate targets simultaneously. River floodplains are very complex and dynamic natural systems. These green corridors provide a wide range of ecosystem services. This project has gathered evidence and highlighted their positive role in climate regulation. As water follows gravity, the former deep floodplains can still be flooded naturally”.

Szilvia Ádám, Regional Freshwater Programme Officer, WWF Central and Eastern Europe

KEY TAKEAWAYS

- To estimate the role of climate regulation of an ecosystem or a landscape, the net balance of three main greenhouse gases (CO2, CH4, N2O) has to be considered.

- Periodical floods increase the carbon sequestration ability due to the enhanced biomass production both above and in the soil, which offsets the overall greenhouse gas emission, and improves the net greenhouse gas balance.

- Floodplain restoration-induced land use change can transform the landscape from a net greenhouse gas emitter into a net greenhouse gas sink.

- Shifting from arable land to sustainable land use in floodplain areas supports both climate and biodiversity goals.

- Floodplain restoration acts as a nature-based solution with climate adaptation and mitigation benefits.

- The drought reduces the carbon sequestration potential. Climate projections indicate more drought periods and heatwaves for the future, thus further underscoring the importance of natural water release and retention measures.

Historical drought period (2022. June 17.) active floodplain vs. flood protected site

REFERENCES

1. **Timár, G. és Rácz, T. (2001):** Földtani folyamatok hatása a Tisza-völgy árvízi biztonságára. Magyar Hidrológiai Társaság "Duna-Tisza medence víz- és környezetvédelmi nemzetközi konferenciája" (conference)
2. **Murányi, G. és Koncsos, L. (2022):** Analysis of nature-based flood management in the Tisza River Valley, Hungary. Pollack Periodica.
3. **Mészáros, J. (2015):** Folyószabályozási térképek geodéziai alapja Doktori (PhD.) értekezés, Eötvös Loránd Tudományegyetem, Földtudományi Doktori Iskola, Budapest.
4. **Agrárminisztérium (2019):** Ökoszisztéma alaptérkép és adatmodell kialakítása. Agrárminisztérium, Budapest
5. **Murányi, G. and Koncsos, L. (2023):** Mélyártéri vízkivételek lehetőségének statisztikai elemzése / Statistical analysis of inundation opportunities in the deep floodplains of the Tisza River. Magyar Hidrológiai Társaság XL. Országos Vándorgyűlés. Győr (conference)
6. **Horváth, L (2020)**: A LIFE16 CCA/HU/000115 projekt keretében megvalósuló vízi ökoszisztémák széntároló potenciáljának és üvegházgáz mérlegének becslése. Zöldfű – Levegőkörnyezet-szakértő Bt. 87 pp.
7. **Pinke, Z., Kiss, M., & Lövei, G. L. (2018).** Developing an integrated land use planning system on reclaimed wetlands of the Hungarian Plain using economic valuation of ecosystem services. Ecosystem Services, 30, 299-308.
8. **Koncz P., Horváth L., Somogyi Z., Kottek P., Weidinger T., Ács F., Kröel-Dulay Gy., Fogarasi J., Molnár A., Pásztor L., Popp J. (2021):** A tűzifatermelés, az éghajlat- és a mikroklíma-szabályozás mint ökoszisztéma szolgáltatás értékelése. Budapest, Agrárminisztérium, Budapest, pp. 191
9. **Juhos, K. and Tőkei L. (2012):** Carbon content of the biomass of vineyards and orchards in Hungary. An assessment based on large-scale field measurements, case studies and expert judgement. Budapest, pp 19.
10. **Koncz, P., Vadász-Besnyői, V., Csathó, A. I., Nagy, J., Szerdahelyi, T., Tóth, Zs., Krisztina, P., Szilvia, F., Marianna, P., Balogh, J., Bernadett, G., Kertész, P., Marianna, B., Nagy, Z., Bartha, S. (2020):** Carbon uptake changed but vegetation composition remained stable during transition from grazing to mowing grassland management. Agriculture, Ecosystems & Environment, 304, 107161.
11. **Hidy, D. (2024):** Modelleredmények. in: Ártéri helyreállítás üvegházgáz-mérlege a Tisza mentén „Greenhouse gas budget of floodplain restoration along the River Tisza in Hungary”. WWF jelentés.
12. **Dezső, J., Lóczy, D., Rezsek, M., Hüppi, R., Werner, J., & Horváth, L. (2020):** Crop growth, carbon sequestration and soil erosion in an organic vineyard of the Villány Wine District, Southwest Hungary. Hungarian Geographical Bulletin, 69, 281-298.
13. **REKK (2020):** Danube Floodplain Project 4.3. Munkacsomag, Magyar Esettanulmány: Közép-Tiszai Költség-Haszon Vizsgálat. Budapest, 45 pp.
14. **Ungvári, G. és Kis A. (2021):** Costs and benefits of land use adaptation to inundation scenarios in the Cibakháza-Tiszaföldvár floodplains. REKK, 33 pp.

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