WETLAND BUFFER ZONES:

the solution we need!

Guidelines of the CLEARANCE project

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1. Respect nature and restore deteriorated landscapes – there is no other future! *Wiktor Kotowski*

We started writing this brochure in Spring 2020, at a time when the whole world was experiencing the COVID-19 pandemic. The pandemic continues, and like everyone else in the world we are scared, worried about the fate of our loved ones, and overwhelmed by the size of the crisis. In our countries the state of epidemics has been declared, the functioning of our universities has been severely restricted, and the protection of the health and lives of millions of people at risk is by far the most important public concern today. We are wondering how to write and speak about environmental protection and whether there is still room for this message in the public space in these times.

On the other hand, observed changes in rainfall, lowering water levels in rivers in Central Europe in recent years as well as now, pose serious challenges to the environmental management. Although it might be too early to draw forecasts on this issue for the coming years, the recurrent deep and long droughts, and serious floods that were seldom seen over the 20th century have now become a ‘standard’ situation, which has driven governments and stakeholders to think about possible solutions for water-related issues, for industry, agriculture and individual household use. In this context, there has not been a more suitable time to focus on wetlands and their role in limiting surface runoff, improving water quality, and providing refuges for a variety of species.

This brochure deals with the problems arising at the interface between the land and water – generated jointly by the intensive development of large-scale agriculture, climate change caused by the burning of fossil fuels, and the drastic transformation of the rural landscape. Negative consequences are the severe water eutrophication caused by the inflow of agricultural fertilisers, resulting in the toxic cyanobacterial blooms and oxygen deficits, a significant reduction in water retention, resulting in both droughts and floods, and the progressive disappearance of plants and animals associated with wetlands and natural rivers. Wetland drainage also adds to the emissions of carbon dioxide, which is released from decaying organic soils after drainage and exacerbates the greenhouse effect. Over the last three years, the authors of this brochure have worked together in the international research project “CLEARANCE-CircuLar Economy Approach to River pollution by Agricultural Nutrients with use of Carbon-storing Ecosystems”, in an effort to summarize the state-of-the-art on how these negative trends can be reversed by restoration of wetland buffer zones along rivers in the agricultural landscape and their lost ecosystem services. Ecosystem services are those aspects of ecosystem functioning, which are directly or indirectly used by human society, being often important to our economy, as well as simply essential for our wellbeing. In addition to reviewing the literature and summarizing our research on ecosystem services of riverside wetlands, we studied the benefits and costs of their widespread restoration along rivers in Poland, Denmark, and Germany, and asked people in these countries what value riverside landscapes have for them.

Straight channel excavated across a drained peatland

The pressure of intensive agriculture virtually erased from the landscape most areas deemed unproductive – such as various types of wetlands, and the vast majority of rivers have been regulated, turning meandering watercourses into straight channels. The peatlands were cut with networks of drainage ditches and transformed into hay meadows or arable fields reaching directly till the banks of regulated canals. The increase in agricultural areas and the constant rise in fertilizer use caused more and more nutrients end up in the rivers. These are primarily nitrates and phosphates, which, in addition to increasing crop yields, began to generate algal blooms in lakes and the sea, which are quickly reached by nutrient-rich waters of regulated rivers. This is the so-called eutrophication process, which is described in **chapter 2**. The destruction of riverside wetlands and the simplification of the river ecosystem has significantly reduced the natural water purification capacity. Meanwhile, draining wetlands exacerbated a number of other problems, and all these negative consequences can be summarized as a deepening climatic and ecological crisis. The good news is, however, that by restoring riverside wetlands, we can minimize or even solve many of these problems! What are wetland buffer zones, how they can be created, and how they retain nutrients is described in **chapters 3-5**.

In **chapters 6-7** we discuss how the re-establishment of riverside wetlands can lower the risk of drought and floods, as well as reduce greenhouse gas emissions. **Chapter 8** focuses on plants and animals that live in riverside wetlands or are in one way or another dependent on their existence. We try to convince readers that recovering habitats for these wild species is not only a pure expression of empathy for wildlife, but it is in our own interest. Converting riverside areas into wetland buffer zones does not necessarily mean that they are withdrawn from agriculture. On the contrary, an innovative economy – mowing and harvesting wetland plants and their meaningful utilisation – can even increase the efficiency of water treatment by the wetland.

Chapter 9 presents some ideas on how to develop wetland agriculture (or paludiculture – the agriculture on wet peatlands) and how to use biomass from cultivated wetland plants – reed, cattail, sedge, or alder.

Chapters 10 and 11 present the results of our research on how Polish, German and Danish citizens value the riverside landscape and to what extent awareness of the ecosystem services provided by wetlands increases our willingness to finance wetland restoration projects. In our opinion, this is a very important study showing a high level of public acceptance for the ecological restoration of the rural landscape. We present economic arguments, i.e., the cost-benefit analysis of a large-scale riverside landscape restoration campaign. The balance is clear: creating wetland buffer zones pays off much more than maintaining the current state. Finally, we also present a short description of the legal, economic, and social regulations that could help to implement the presented scenario (**chapter 12**).

The overall message of this publication is that returning wetlands to their societal, environmental, and economic functions is not only feasible but also necessary – in fact, it is the only way forward. We are increasingly facing severe symptoms of climate and environmental crisis, such as droughts, extreme heats, sudden flash-floods, worsening water quality, and the sharp decline of biological diversity. Wetland restoration is a cost-effective adaptation and mitigation measure to jointly address all these problems. There is no filter for fertilizers more effective than a wetland, there is no other way to retain water in the landscape than wetland and river restoration, and there is no other way to maintain threatened species than by restoring their habitats.

In light of the current climate and environmental crisis, which is increasingly having a direct impact on the social, economic, and political situation, there is a need to move away from immediate and short-sighted actions towards long-term solutions. The restoration of wetlands and the creation of wetland buffer zones is not a quick process, nor one that will have immediate and easily noticeable effects. Instead, it is an investment for the future that will pay for itself slowly but will bring more and more benefits over time.

2. Enough is enough! What are nutrients and what is wrong with them? *Wiktor Kotowski*

There are several sources of nutrient pollution of open waters. Point sources like wastewater treatment plants can be usually ignored as nowadays, due to technical progress and stricter regulations, they provide efficient improvement of water quality. On the other hand, the excess of fertilizers ending up in rivers and seas due to inadequate use in agriculture remains a severe problem, and is still the largest diffuse source of overloading nutrients in aquatic ecosystems. How is it possible that fertilizers, which significantly increase yields on fields and are the foundation of current farming practices and a source of wealth, pose a serious threat to the environment? How can nutrients, so beneficial for crops, become pollutants? What is “too high fertilization level”? These questions are probably often asked by many farmers when they hear demands to reduce fertilization for the sake of saving natural resources important for human life – as well as for the sake of nature conservation.

Nutrients, plants, and agriculture

Intensive agriculture is today the most important single source of water pollution in Europe. The biggest problems are caused by the key substances included in fertilizers – mainly compounds of phosphorus (phosphates) and nitrogen (nitrate and ammonium). Nitrogen and phosphorus are essential **nutrients** for plants and all other organisms. Nutrients also comprise oxygen, carbon, or hydrogen – but these commonly occur in excess in nature, and thus their availability usually does not limit plant production. The situation with nitrogen and phosphorus is quite different – in most terrestrial habitats it is the amount of one or both of these elements (i.e. co-limitation) that determines how much plant biomass can grow during the growing season. Such limitation is well known for agricultural land, where harvesting crops or hay causes a continuous depletion of nitrogen and phosphorus in the soil. That is why we replenish them with fertilizers. Phosphorus occurs in the soil in the form of more than 200 minerals, like apatite, strengite or vivianite. The phosphorus release under natural soil conditions occurs predominantly as a result of decomposition of dead organic matter or weathering of apatite rocks.

Nitrogen accounts for 78% of the atmospheric air but most plants are not able to use this source directly, except for those species that have symbiotic nitrogen-fixing bacteria on their roots, like the legumes. Other plants depend on nitrate ions present in the soil, and to a lesser extent on nitrite and/or ammonium ions. Under natural conditions, plant-available nitrogen compounds originate mainly from the decomposition of organic matter, and some amounts are also constituents of precipitation. The nutrient content in the soil is usually much below the highest possible plant productivity, so by fertilizing the fields with nitrogen and phosphorus (and with the addition of other elements), we can significantly increase yields.

Obviously, the more we fertilize, the higher the yields, although this happens only up to a certain threshold above which the plants are unable to assimilate more nutrients. Nutrients not used by the plants on the fields move with seepage waters to the groundwater and eventually end up in rivers and seas. The higher the difference between crop plant uptake and an application rate and/or dose of fertilizers in the field, the more nutrients are transferred to surface waters. As soon as nitrates and phosphates enter aquatic ecosystems, they might cause severe problems.

Nutrients in surface water – why is eutrophication a problem?

In aquatic ecosystems, higher plants compete for light and nutrients with various types of algae – from single-celled planktonic organisms to plant-like multicellular organisms. Just like on land, the total biomass production of water plants and algae depends on the supply of nitrogen and phosphorus. One group of organisms traditionally classified as algae are cyanobacteria (or blue-green algae). Many of them have the unique ability to fix atmospheric molecular nitrogen dissolved in water. We will come back to this fact later, describing the course of **eutrophication** (nutrient overload) in aquatic ecosystems.

Algal bloom in water in a small stream

Apart from the decomposition of dead organisms and nitrogen fixation by cyanobacteria, an important source of nutrients in water is the input from adjacent land. If there was no intensive agriculture, and assuming that all point sources of nutrients have been eliminated by technical solutions, the amount of nutrients reaching the waters from the land would be significantly lowered. The nutrient requirements of the aquatic organisms are normally satisfied by internal recycling processes. However, because a large part of Europe's land area has been transformed into arable land (e.g. almost 50% of the area in Poland and Germany, and more than 60% in Denmark), runoff became a significant additional nutrient source for ground and surface waters.

In rivers, nutrient pollution triggers the replacement of flora typical for clear waters by faster-growing plants characteristic for eutrophic waters. Some of them, such as *Elodea canadensis*, are invasive species, displacing European native flora. Slower-growing plant species become overgrown by filamentous algae, which reduce photosynthesis. The growth of expansive plants and algae causes a decline in species richness – both among plants and animals, including fish.

In rivers, there are usually no **algal blooms** (mass occurrences of algae, often changing the water colour to green) or periodic oxygen deficits, because they are prevented by turbulent flow and mixing of water. However, algal blooms become a serious problem as soon as the nutrient-rich water enters a lake, dam reservoir, or a coastal zone of the sea.

In a lake or coastal sea waters, a natural ecological state is when the shallower parts of the bottom are overgrown with submerged plants and algae, which consume most of the available nutrients and produce plenty of oxygen during the daytime through intensive photosynthesis. However, as the inflow of nutrients to the water increases, algae start to develop more and more abundantly. Algae also assimilate nitrate and phosphate, but because they float in the water, they increasingly block the light available for submerged plants. At some point, when the level of nutrients exceeds a certain critical value, algae become so abundant that they completely cut off the light from submerged plants, and all primary production (i.e. the growth of photosynthetic organisms) is taken over by planktonic algae. Underwater "meadows" and kelp forests, which supplied the deeper layers of water with oxygen, and were home to a variety of animals, including various fish species, disappear. Meanwhile, single-celled algae that multiply rapidly at the water surface die just as quickly, sinking to the bottom. The supply of large quantities of dead organic matter triggers intensive bacterial decomposition. The decomposer bacteria consume the remaining oxygen available in the water. Thus, considerable amounts of sediments accumulate on the bottom, in which organic matter further decomposes anaerobically, releasing methane and toxic hydrogen sulfide. Most animals cannot live in such oxygen-depleted water. Periodical oxygen deficits result in mass mortalities of fish (more and more often observed in the summer months both in lakes and in sea bays). In the seas and larger lakes, repeated oxygen deficits over the following years lead to the creation of so-called "**dead zones**", in which animals in deeper water layers are almost absent. As the concentration of nutrients increases, cyanobacteria start to dominate the algal communities. In addition, their ability to fix atmospheric nitrogen gives them an advantage when phosphate concentrations are elevated in water. What is more, cyanobacteria are favoured by high temperatures, so their blooms become more frequent as the climate gets warmer. **Cyanobacterial blooms** have an additional feature compared to blooms caused by other algae: they produce serious toxins, which are released into the water. That is why blue-green algal blooms make bathing in the sea or lakes dangerous during the summer months, and the beaches on the Baltic Sea coast are often closed during the most attractive holiday season.

Baltic – the sea with the highest density of dead zones in the world

The Baltic Sea is surrounded by densely populated agricultural countries. Every year more than 580 000 tonnes of nitrogen and 29 000 tonnes of phosphorus reach the Baltic Sea through rivers (HELCOM 2018). It has been calculated that over 46% of nitrogen and 36% of phosphorus coming with river waters originate from agricultural sources (so-called non-point pollution); the remaining categories are natural background (supplies from natural ecosystems) and point sources – industrial and municipal pollution. HELCOM research indicated that 97% of the Baltic Sea area is affected by eutrophication, and 12% is in the worst category of eutrophication. The anaerobic zones, although always present in the Baltic Sea due to strong water stratification, have increased more than tenfold since 1900, from 5.000 to 60.000 km^2. The highest increase occurred in the second half of the 20^{th} century. Their density is so high that the Baltic Sea began to be called the world's largest marine dead zone (Jokinen et al. 2018). It is estimated that due to eutrophication-induced oxygen deficiency in the bottom zones, the total biomass of animals in the Baltic Sea decreased by 3 million tonnes or about 30%. Over the last 30 years, rising water temperatures have been an additional factor accelerating oxygen depletion in the Baltic waters. Unfortunately, if no strong countermeasures are implemented as soon as possible, the situation will worsen as pollution exacerbates. In this brochure, we present one of such countermeasures – the creation of the wetland buffer zones.

3. Fantastic beasts and where to find them? Few words about wetland buffer zones *Ewa Jabłońska, Wiktor Kotowski, Dominik Zak*

Wetland buffer zones (WBZ) are wetlands located between agricultural areas and a stream, river, or lake, whose main function is protecting surface waters from nutrient pollution by non-point sources. They capture lost fertilizers (natural and artificial) from the fields before they reach the watercourse or reservoir, and by doing that they improve the quality of surface waters. In addition, like all wetlands, WBZs reduce the risk of flooding and drought, improve the aesthetic and recreational value of the riverside landscape, regulate the climate locally (by increasing air humidity) and mitigate the effects of global climate change by maintaining local water circulation, provide habitats for numerous plant and animal species, and offer opportunities for biomass harvesting. Programmes to create and restore WBZs to control area-based agricultural pollution have been developed in several countries over the last decades. Therefore, WBZs are a multifunctional solution offering economic, safety, and nature benefits. Most of these functions of buffer zones are directly related to their wetland character and are provided by wetland wildlife.

Types of WBZs

WBZs are characterised as interfaces between land and water with varying widths, from a few to several hundreds of metres. A recent meta-analysis has proposed some detailed recommendations (Lind et al. 2019). Thus, already a 3 m wide buffer zone acts as a basic nutrient filter. However, to maintain a high floral diversity, a 24 m wide buffer zone is required, while a 144 m wide buffer is needed to preserve bird diversity. WBZs are usually strips of land, adjacent to rivers. However, other forms and locations can sometimes be more functional and effective. These include groundwater-fed areas such as fens or river floodplains. A section of the natural riverbed can also be considered a WBZ. It acts as a buffer for the lower course of that river or for the river of which it is a tributary. Overall, different WBZ types can be distinguished based on their dimensions, soil composition, hydrology, and vegetation, determining specific management measures.

1. **Wetland banks** – A narrow strip of "wet land" along the river can be achieved by rising the river water level, e.g. by placing logs or boulders in the channel. The higher water level in the river results in the inundation of land in its proximity.


Wetland banks

2. **Two-stage channel** – A regulated channel can be modified to form a two-stage profile, with additional space for wetlands on the upper terrace. During low water levels in the river, the river flows freely on a lower, narrower terrace, creating natural meanders over time, while on a higher terrace a WBZ may develop due to groundwater seepage. During the high water level, the river flows within a higher terrace across the entire width of the riverbed.

3. **Meandering channel –** A section of naturally meandering or re-meandered river can act as a WBZ towards the lower section of the river or another river of a higher order.


Narewka river (PL): left picture – restored re-meandered section in the background, old straightened section in the foreground, right picture – restored re-meandered section; photo J. Gornia

4. **Undrained fen** – Natural fens are peat-accumulating wetlands, typically developing in groundwater discharge sites, usually dominated by sedges but sometimes also reedbeds, shrubs, and trees.

Undrained fens (Rospud valley, Biebrza valley)

5. **Rewetted fen –** Fens that have been drained and have the upper part of their peat deposit mineralized and turned into 'moorsh' soil can be treated as WBZ only after rewetting, which reduces their carbon and nitrous oxide emissions and re-establishes conditions for denitrification[1]. Only sites with water levels close to the peat surface (or above) for most of the year can be classified here. Caution should be taken because rewetting of drained peatlands can cause a release of phosphates from decomposed peat[2].

6. **Floodplains –** Most floodplains, with silt and sandy soils with low organic matter content, are sites for effective removal of phosphorus during sedimentation and effective uptake of nitrogen and phosphorus by vegetation.

Narew floodplains

[1] Denitrification – reduction of nitrates to elemental nitrogen carried by bacteria.

[2] The risk of phosphate release due to the rewetting of drained peatlands can be assessed by examining the iron/phosphorus ratio of the soil. When it is lower than 10, a risk of phosphorus release to downstream systems is possible and further management should be considered. Removal of the highly degraded peat topsoil is regarded as the most effective method of reducing the eutrophic status of rewetted fens. On the other hand, harvesting of plant biomass in rewetted fens is an additional effective method for the permanent removal of nitrogen and phosphorus from the soil-water nutrient cycles.

7. **Wetlands at drainage pipe outflow** – When most water from agricultural land is discharged into the river through drains and not as a surface or sub-surface runoff, it is necessary to recreate the conditions for a natural wetland or make a constructed wetland at the intercepted drainage outlet. Based on Danish experience, several types of WBZs were distinguished by Hoffmann et al. (2020).

4. Do it yourself - how to create WBZs? *Marta Wiśniewska, Ewa Jabłońska*

The scope of work needed to create a WBZ depends mainly on the geomorphological conditions and the current degradation status of the river and riverine landscape. To restore **wetland banks** along a moderately degraded river, the placement of some tree trunks or stones in the riverbed would usually suffice. However, if the river was highly regulated and the riverbed is deeply incised, some (retention) sluice gates should be built to reduce water flow and cause enough inundation of riversides to allow for the development of wetland banks.

Woody debris in a river

Restoration of **floodplains** is possible along larger rivers with sufficiently wide valleys and also requires raising the river water level by the placement of some natural obstacles or construction of weirs with shutters, enabling flooding of areas in the stream valley. In this case, moving the dikes away from the river might be necessary.

Creation of a **two-stage channel** demands some earthworks – excavating the floodplains and levelling of the excavated soil, bank strengthening, as well as construction works aiming to raise the water level in the channel (tree trunks, stones or constructed weirs), but also rebuilding the existing infrastructure (mainly road culverts). Furthermore, it was assumed that the implementation of this kind of WBZ would require a land purchase in a relatively narrow belt along each side of the stream.

Earthworks are also needed to re-**meander a channel**. They include dredging the meandering channel or construction of dams directing the water to newly built meandering channel sections. Building new culverts necessary after the change of channel course and land purchase for the areas covered by the project are also required here.

To **rewet a drained fen** mainly damming of existing drainage network is needed. Ditches may be blocked by building new weirs or simply by stacking sandbags with sand or other sediment material, e.g. gravel.

A simple weir, photo Ł. Kozub

The best allies in the creation of wetland banks and floodplains are beavers, which build small dams on rivers, canals, and ditches.

Beaver dams on small rivers: left picture – beaver dam on a small river and resulting floodplains; right picture – beaver dam and resulting wetland banks alongside a ditch, photo Ł. Kozub

Undrained fens seem to be the easiest to maintain – as they literally require to do nothing in their vicinity, but on the other hand, their maintenance is the most difficult – because any changes at the catchment level leading to decrease in groundwater supply to the fen are deleterious to its fragile ecosystem. The maintenance of natural fens may also be threatened by climate warming and associated groundwater level drawdown, therefore active conservation of these ecosystems means also fighting climate change.

5. Nutrient capture in WBZ – how it works? *Dominik Zak*

Water purification by WBZs results from the removal and capture of nutrients present in waters moving from land to stream or from an upper course of a river to its lower course. The term "**nutrient removal**" describes the processes facilitating the export of specific nutrients from incoming waters to the atmosphere, often through chemical changes of the nutrients. **Nutrient capture** and **nutrient retention** occur due to their uptake from the transfer water and accumulation in the soil and plant biomass within the WBZ. In addition, WBZs may also help to remove other pollutants, like herbicides and pesticides, heavy metals, and biologically active compounds. To act as a nutrient sink, a WBZ needs to have hydrological connectivity to incoming waters, thus allowing for biological, chemical, and physical processes to take place, lowering the nutrient content in water leaving the WBZ system.

Following different mechanisms of nutrient removal and capture by WBZ can be distinguished:

1. **Nitrogen removal via bacterial processes**, including nitrification and denitrification, depends on groundwater levels or the presence of oxygen. Under oxic conditions, the process of nitrification transforms ammonium to nitrate and nitrite, whereas under oxygen-free conditions the process of denitrification is responsible for the reduction of nitrate to nitrite and further to nitrous oxide and dinitrogen gases. Gradients of oxic and anoxic zones within WBZs allow for both processes to occur together, i.e. effective simultaneous removal of ammonia, nitrate, and nitrite.

2**. Nutrient capture by vegetation**. This process is important for both nitrogen and phosphorus and additionally also for other nutrients, especially potassium. Plants take up nutrients from incoming waters and incorporate them in their below- and aboveground tissues. These nutrients can be further transferred to the next trophic level through herbivory (refer to point 6) or partly returned to the system via decomposition pathways (refer to point 7). Part of the biomass may be removed from the cycle for a longer time through burial in organic sediments, particularly as peat. In riverine wetlands, peat is primarily produced from the roots of plants. Aboveground biomass can also be harvested manually and removed from the system (refer to point 3).

3. **Nutrient removal through biomass harvest**. Aboveground biomass has been traditionally harvested in riverine wetlands for use as hay and litter in animal husbandries. This type of land management was largely abandoned in the second half of the 20th century due to a lack of profitability. During the last decades, the concept of paludiculture has emerged, picking up positive elements from traditional utilisation of biomass from wetlands and developing new utilisation schemes. Thanks to this, paludiculture gained importance as a means to commercially cultivate peatlands under wet conditions (though typically after re-wetting). Wetland agriculture can enhance the water purification function by completely removing nutrients from the system while offering an entry to a circular economy to produce fodder, energy and building materials or agricultural substrates from wetland plants.

4. **Precipitation of phosphorus in the soil**. Phosphates can form insoluble compounds with calcium and complexes with iron hydroxides, which may lead to P immobilization in riparian areas. However, these processes, especially concerning iron, depend on redox[3] conditions in the soil, so increasing wetness and the establishment of oxygen-free conditions favour the re-mobilization of phosphorus. WBZ soils with iron to phosphorus ratios above 10 are considered low-risk soils for rewetting, as phosphates released from the soil would be resorbed to iron hydroxides at the soil surface (redox interface) (Zak et al., 2010). A redox-stable and thus more persistent Fe-P form is the precipitate of vivianite which is formed under anoxic conditions at high concentrations of ferrous iron and phosphate, preferable under neutral pH conditions (Zak et al. 2010, Rothe et al. 2016).

[3] Redox potential – reduction/oxidation potential – in relation to elements or substances, is a measure of their capacity to acquire electrons (=being reduced), or lose electrons (=being oxidized). Concerning soil, in aerated soils the redox potential is usually relatively high (and the conditions are oxidizing), while in oxygen-deficient soils, e.g. under waterlogging, the redox potential is relatively low, and the conditions are reducing.

5. **Physical sorption of phosphate to mineral particles**. Phosphates can adsorb to mineral particles present in the soil or suspended in water, which contributes significantly to P removal from water. This suspended particulate P adsorbed to mineral particles may be deposited on river floodplains during flooding events, deposited in new sediment layers in sites with slow-flowing or standing water, or become incorporated in local biological cycles and partly removed with biomass harvest.

6. **Deposition by flooding**. Temporal inundation with river water can provide particulate phosphorus (see point 5), organic matter carried by the river, which decomposes after water recedes, and finally dissolved nutrients brought by floodwater, which are captured by floodplain vegetation.

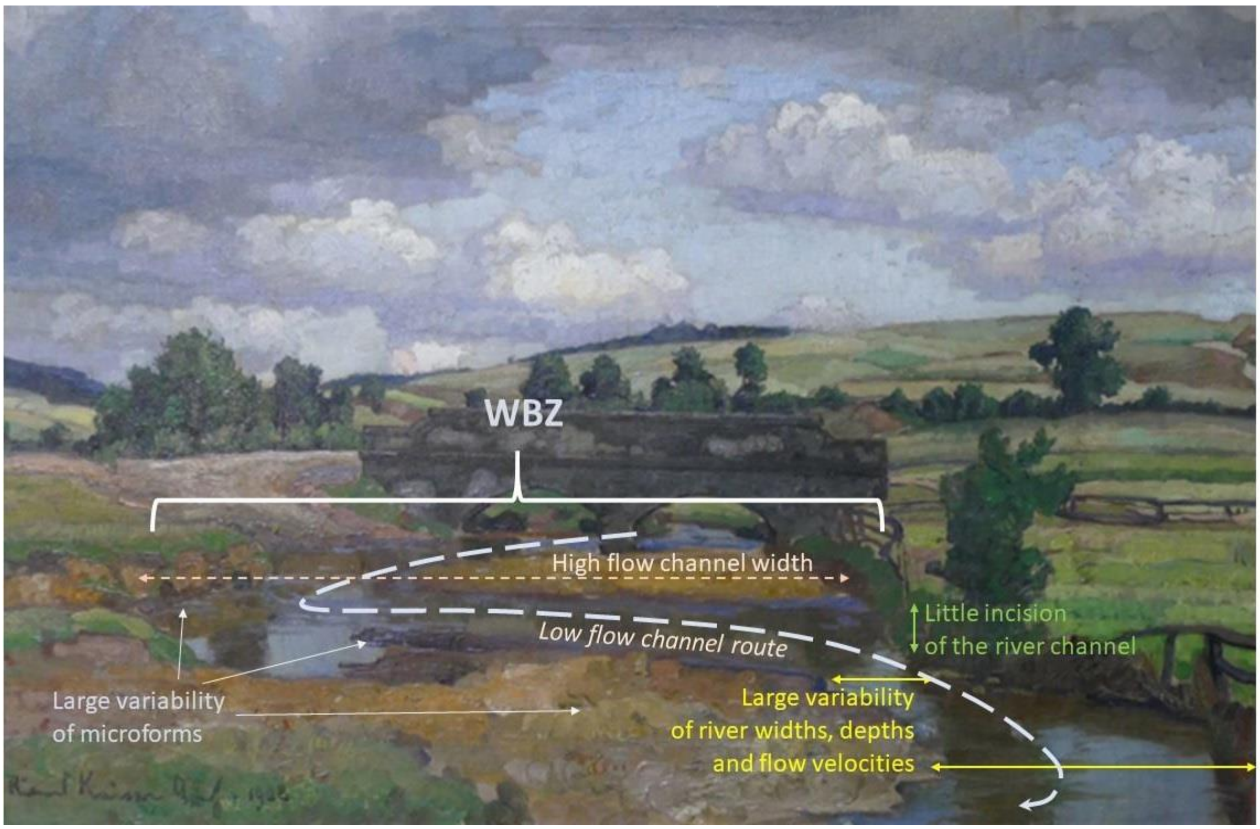
7. **Sedimentation under inundated conditions**. If permanently flooded conditions are created, a novel “shallow lake type” ecosystem may be created, and a fine muck layer would form over the surface of the degraded peat. This muck accumulates through the sedimentation of clays and silts, plus detritus and decomposed organic matter. It can act as a sink but also as a potential source for internal remobilisation of nutrients (Cabezas et al. 2014).

6. Wetlands retain water – how WBZs mitigate droughts and floods

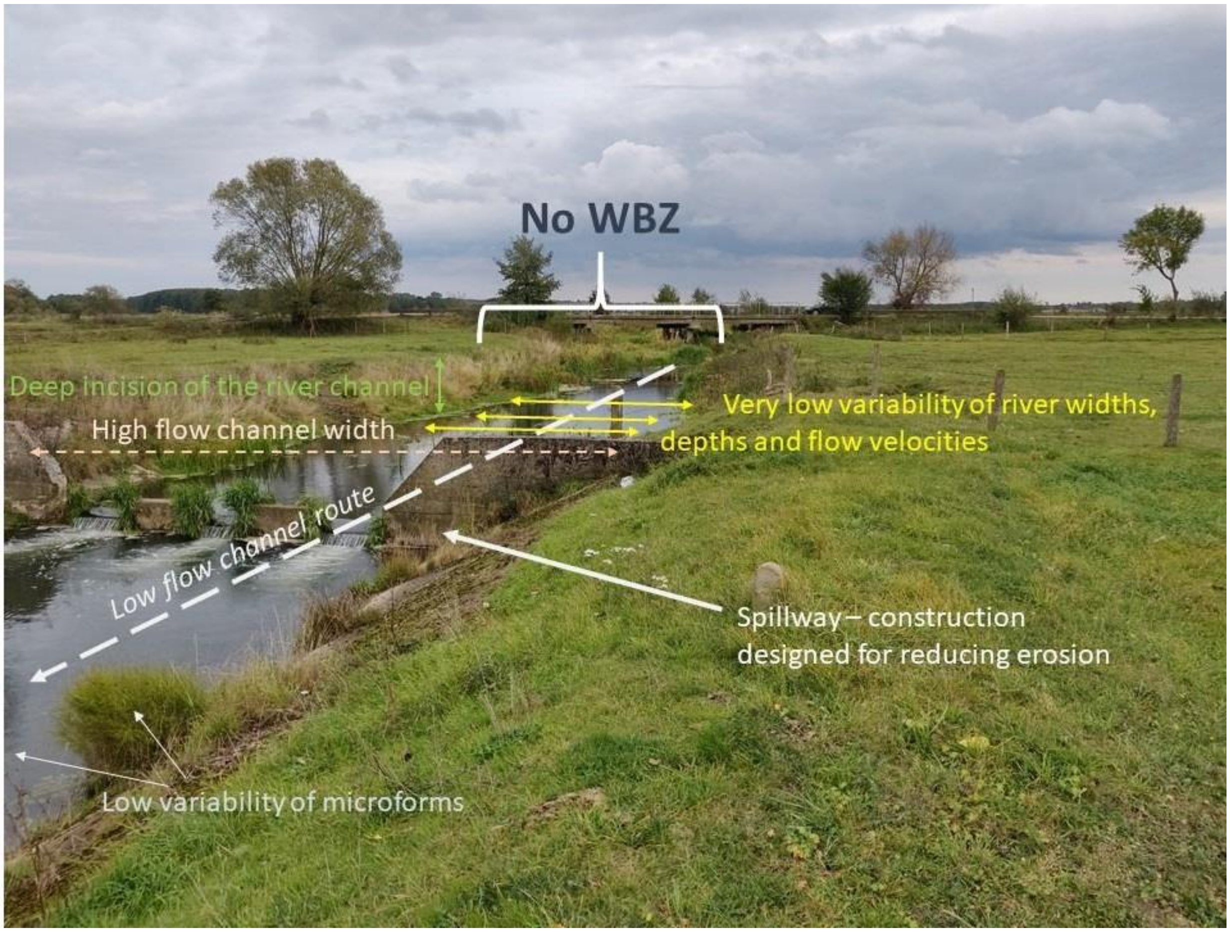
Mateusz Grygoruk, Wiktor Kotowski

Natural wetlands, rivers, and river-WBZ systems retain their functions mainly due to the water they are capable to store. The high content of water present in these systems results from the seasonal surplus of local water balance, formed either by the high supply of water or limited (slow) outflow. Water storage (so-called channel detention) in a river channel occurs due to the complex hydromorphology and sediment supply balanced with erosion. The persistence of such well-balanced systems allows for mitigating hydrological dynamics of the landscape by intercepting excessive amounts of water during floods. Stored volumes of water can be gradually released once the flood peak has been transferred downstream. Therefore, WBZs play a disproportionately important role in attenuating peak flow than the other types of wetlands in the landscape. The formation of river discharge during droughts by supplying baseflow with the outflow of water stored in wetlands remains more a catchment-scale phenomenon (Ameli and Creed, 2019).

The majority of natural WBZs that existed along watercourses in ecotones of aquatic and terrestrial ecosystems deteriorated due to the human-induced increase of the runoff. Direct consequences of modification of riverscapes by humans were the reduction of the area of ecotones and homogenization of hydromorphology of the river channel, that speeded-up water circulation at a micro-scale. A high demand for new land to be used for agricultural purposes did not leave the room for rivers and wetlands that were featured by large and seasonal variability of hydrological processes. Inherent elements of functioning WBZs, namely little incision of river channel even during low flow periods, presence of a variety of microforms, large variabilities of flow velocities, widths and depths, presence of wetland vegetation within and along river channel, have disappeared in most of the cases.



Agricultural river in Germany in the beginning of the 20th Century (Richard Kaiser – Landschaft mit Fluß und Steinbrücke; 1908) and the analysis of particular morphological features of the WBZ.



Agricultural river in Poland in the 21st Century and the analysis of particular morphological features of the riverside lacking a WBZ (River Ślina, NE Poland, photo: M. Grygoruk)

Changes in the hydromorphology of rivers described above have affected local and regional hydrological conditions in several ways.

First, straightened rivers, although equipped with elements of infrastructure aimed at the reduction of erosion, started flushing their sediments which resulted in the gradual incision and increased the drainage of groundwater from the adjacent aquifers[4]. The elimination of spring floods also enhanced drainage of valley habitats. River regulation was usually accompanied with drainage of adjacent wetlands by networks of ditches, which usually led to a drop in groundwater levels in their vicinities. Prolonged drainage resulted in the degradation of soil organic matter, which further decreased the capability of soils to soak-up and retain water. Special cases are peat soils, which quickly decomposed due to the drainage, in drastic cases turning into almost water-impermeable moorsh soil.

[4] Aquifer – a water-saturated layer of sediment or rock

The second effect is related to diminished water cycling. This is especially important in regions located far away from the sea, where the local evapotranspiration[5] supports a significant part of air moisture and precipitation. Wetlands are important sources of local humidity, especially during hot summer months. This water evaporating from wetlands and other riparian areas is not lost but comes back to the system as convection rains, fog, or dew, although not necessarily in the very same place. What is more, evapotranspiration from wetlands, feeding the air with water vapour, lowers evaporation from adjacent areas. Last but not least, evapotranspiration absorbs heat energy from the air, contributing to a significant cooling of the landscape. This absorbed energy is released back in the higher parts of the atmosphere when water vapour condenses forming clouds. All these mechanisms are diminished by drainage of wetlands, thus intensifying the threat of droughts caused by enhanced drainage of groundwater and the global climate change.

The third hydrological effect of river regulation and wetland drainage is the increased risk of flooding in lower reaches of the rivers. This can be easily explained by the accelerated runoff of rainwater from the landscape and diminished retention capacity of regulated rivers, cut-off from their floodplains. Consequently, more and more cities and settlements along rivers are threatened by floods – especially under increasingly unstable weather conditions caused by global warming. Also agricultural land on reclaimed riverine wetlands becomes increasingly prone to flash flooding, which under the current model of water management is often “cured” by a further deepening of the rivers (dredging, vegetation cutting or renewed regulations). Such short-sighted actions, however, result is even faster runoff and regional drainage during “normal” hydrological conditions, closing the vicious cycle of degradation.

Restoration of WBZs can, at least partly, compensate for these lost ecosystem services of wetlands. “Ecological wastelands” (now referred to as drained wetlands and straightened rivers) may again start to play their role. Their recreated morphology allows the WBZs to be flooded, not causing any major damage to the managed environment. In the face of the anticipated increase in drought recurrence in Europe, it is claimed that neither technical nor nature-based solutions can allow societies for the prevention of shortages of water. However, restoring WBZs will allow mitigating the negative effects of hydrological extremes (Lehner et al., 2006).

7. WBZs – good for climate! *Wendelin Wichtman, Wiktor Kotowski*

Everything that we do in the environment nowadays has to be seen through the context of the climate crisis. There is no doubt that climate change is the single most important global challenge that humanity ever encountered. And there is little doubt that the most important action to reduce climate change is the replacement of fossil fuels with carbon-free energy

[5] Evapotranspiration – field evaporation, encompassing direct evaporation of water from land and water transport to the atmosphere through vegetation.

sources. However, next to the reforms of the energy, industry and transportation sectors, the changes in the management of terrestrial ecosystems, including agricultural and wetland areas, are among the most urgent **mitigation**[6] and **adaptation**[7] measures.

WBZs can play a remarkable role for the climate in the context of a variety of processes. However, the role of functioning wetlands, especially of wet peatlands, for carbon sequestration and the climate is still widely underestimated (Leifeld & Menichetti 2018, Geurts et al. 2019). While drainage of peatlands has transformed them from carbon-sinks into significant sources of atmospheric carbon dioxide, rewetting can cut these emissions, thus constituting a vitally important mitigation strategy. On the other hand, WBZs also belong to adaptation measures, ameliorating the impacts of global climate change on terrestrial and aquatic ecosystems.

Impacts of WBZs on carbon cycling

WBZs on mineral soils

WBZs on mineral soils are more or less neutral in terms of carbon cycling. If sedimentation takes place in active alluvial soils[8], these sediments may indeed contain some stored organic carbon. But in general plant growth and decomposition are balanced, and carbon sequestration potential is low. However, if reconstruction of a WBZ results in reduced water table fluctuations, at high water levels this may lead to accumulation of litter above the soil surface and possibly, on the long run, to peat formation, which means a positive effect on the climate due to carbon sequestration.

WBZs on organic soils

For WBZs on organic soils, the picture is much more complex. Organic soils have been formed in peatlands by the on-site accumulation of undecomposed plant residues due to permanently waterlogged conditions. Under natural conditions, these sites are very effective long-term climate coolers, due to continuous carbon accumulation (Augustin et al. 2011). This process is, however, quite slow and contributes to climate regulation mainly on the scale of hundreds of years. Currently, this effect is completely masked by the release of large amounts of greenhouse gasses from peatlands drained by man for agriculture and forestry.

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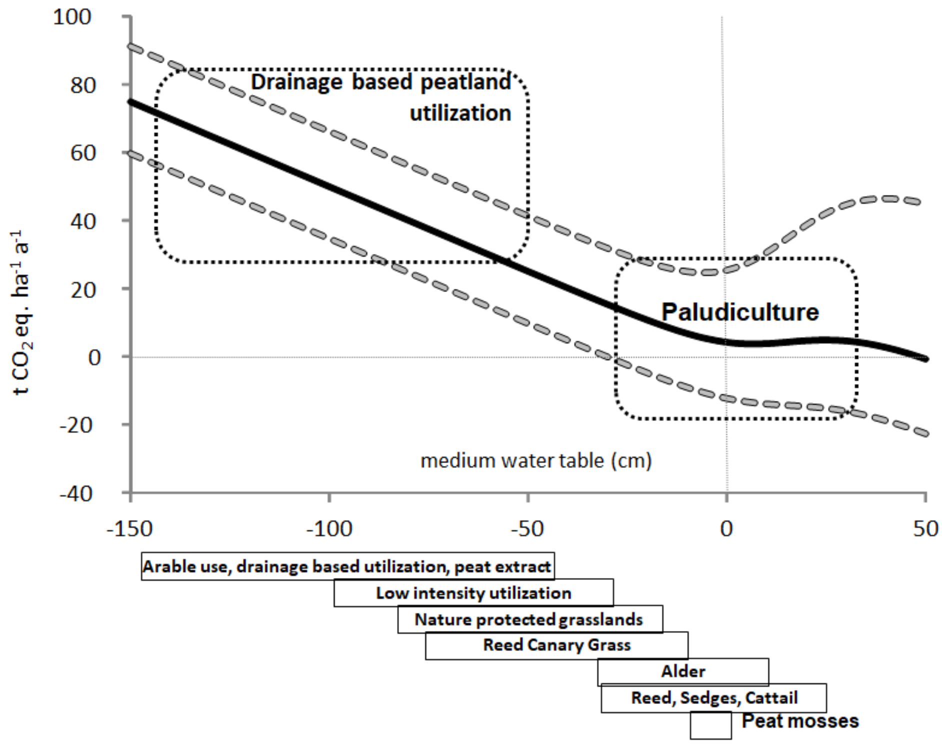
[6] Mitigation strategy – all measures taken to reduce the causes of climate change, especially those aimed at prevention or reduction of greenhouse gas emissions.
[7] Adaptation measures – all measures taken to reduce the effects of climate change.
[8] Alluvial soils – very fertile soils formed due to accumulation of material deposited by surface waters.

Box 1: What is a peatland?

Peatlands are wetlands in which peat has accumulated due to long-term imbalance between plant biomass production and decomposition. The decomposition of plant residues is reduced in the water-saturated environment, and humification processes stabilize the organic matter, retarding further decomposition. Fens, i.e. groundwater-fed peatlands along river valleys, are typical parts of Central European landscapes. They started to form just after the last ice age. During thousands of years, up to 10 metres of peat have accumulated building up an enormous carbon stock. Although peatlands cover only 3% of the land area worldwide, they store c. 30% of the total organic carbon stock of all soils. Peat soils have been increasingly modified by drainage for agricultural use in the course of the last 300 years. After draining, oxygen penetrates deeper into the soil, and intensive decomposition of peat starts in the upper aerated layers. As a result, the carbon contained even in quite recalcitrant organic matter is transformed into CO_2*, and the peatlands turn from a carbon sink into a significant carbon source. Soil surface level lowers down due to soil subsidence, and deeper drainage is required to maintain dry conditions for the facilitation of land-use practices. To stop the peatland degradation, and reduce high GHG emissions, rewetting is the only option.*

Drained peatlands cover only 0.3 % of the land surface worldwide, but they contribute to approximately 6 % of the global anthropogenic carbon dioxide emissions (Joosten et al. 2012). For this reason, the rewetting of drained peatlands is recognized as one mitigation strategy to reduce GHG emissions.

Three well-known types of greenhouse gases (GHG) can be emitted from peatlands to the atmosphere: carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Methane is mainly released under water-logged conditions, and its release is reduced by drainage, which, however, boosts carbon dioxide and nitrous oxide emissions. Their effects on global warming differ substantially, however, and the time-scale must be considered. For example, half of the CH_4 will be oxidised in the atmosphere within ca. 9 years, which must be included if climate effects of drainage and rewetting of peatlands are to be assessed. To make them comparable, they are translated into CO_2-equivalents (CO_2 eq). After balancing absorption and emissions of different GHGs, natural peatlands (mires) have a neutral climate impact on the short (decadal) time scales and a cooling impact on long (centennial to millennial) time scales. Drained peatlands are a source of substantial GHG emissions, especially of CO_2 and N_2O, which are caused by the decomposition of organic matter under aerated conditions. Also, methane is still emitted from drained peatlands, originating from anaerobic decay of dissolved organic substances in peat water and within drainage ditches. As a major factor so far, the water table is used to estimate the loss of GHG from peatlands. It was found that lowering the water table by several decimetres in drained peatlands causes large emissions from 25 to 60 tons CO_2 eq. per hectare per year, or even more (Couwenberg et al. 2011). By rewetting drained sites, and especially maintaining the water table near soil surface throughout the year, GHG emissions (CO_2 and N_2O) can be significantly reduced.



Meta-Analysis for CO_2 (n=236) and CH_4 Meta-
for CO_2 (n=236) and CH_4 (n=339)
(Couwenberg et al. unpub.)

Water table level [cm] in a peatland and corresponding GHG emissions [t CO_2 eq]. After Couwenberg et al., in prep.

Rewetting of formerly drained organic soils for the establishment of WBZs may not only reduce GHG emissions but also create a favourable environment for recovering peat-forming conditions and the carbon sink function, which is characteristic of well-functioning natural peatlands. Rewetting can indeed increase methane emissions, especially in the initial years due to the availability of easily degradable biomass, but they soon stabilise to the levels typical for undrained mires, which are an order of magnitude lower than carbon dioxide emissions (in CO_2 eq.) from drained peat (Couwenberg et al., in prep., Hiraishi et al. 2014, Günther et al. 2020).

The local cooling effect of WBZs

An often underestimated climate effect of functioning WBZs, both on mineral and peat soils, is the local cooling effect by increased evapotranspiration. In areas with sufficient water supply, most of the available radiative energy is used for evapotranspiration. As a result, the air over wet areas heats up less than over dry areas, and thus wet areas have a local cooling effect on the lower atmosphere, and fluctuations in temperature are moderated (Wahren et al. 2016), see also Chapter 6.

The climate effect of biomass harvesting in WBZs

The potential carbon sequestration, at least in the short-term, is not influenced by the harvest of the biomass from wet WBZs on organic soils, because peat formation in fens occurs generally in the subsoil due to accumulation of dead roots (Succow & Joosten 2001). However, harvesting improves near-ground light conditions for mosses or other low-growing plants, which will also affect the carbon balance of such managed systems. When no harvest is applied, woody vegetation, e.g. alder forests, may develop building up an additional carbon stock. In harvested wetlands, the annual litter production is reduced and partly removed by harvest, so that both labile carbon and nutrients will be taken out (see Chapter 8). Depending on the type of utilisation of the biomass harvested from WBZs, the climate effect differs. If the biomass is used for feeding cows or biogas production, it decomposes rather fast. The utilisation of biomass for construction and insulation materials sequesters the carbon for several decades outside any ecological system, which is highly desirable in times when the urgent reduction of greenhouse gas emissions is of utmost importance.

Utilisation of biomass harvested from WBZs and assessment of their climate effects (1: short-term: replacement of fossil fuels, 2: medium/long-term sequestration)

Type of vegetation	**Product**	**Effect on climate**
Sedges	Fuel for combustion	1
Sedges, reed canary grass	Fodder for cows/sheep	1 (+ 2)
Sedges, reed canary grass	Fuel for biogas	1
Reed	Thatch	2
Cattail	Insulation material	1 + 2
Reed and cattail	Construction plates	2

Summing up, stabilising the water balance by rewetting and establishing of WBZs have positive effects from the climate protection perspective. Some rules must be followed to ensure that this positive effect is not counteracted by negative effects elsewhere. Rewetting should always be performed appropriately, with a stepwise water level raising, so that higher methane emissions can be avoided (Gottschalk et al. 2019), and vegetation can adapt to changing conditions. Management practices like biomass harvest frequencies and long-term utilisation may increase the magnitude of the positive effects.

8. WBZs serve as habitats for threatened wildlife – why should we care? *Wiktor Kotowski*

By transforming rivers and riverside landscapes we contributed to the massive extinction of species inhabiting them. Restoration of wetland buffer zones, so needed for purification and retention of water, is a chance to also restore refuges of wildlife in transformed agricultural landscapes, saving thousands of species associated with wetlands. Their survival is also in our interest!

Rivers, lakes, and freshwater wetlands are the world's most threatened ecosystems. Since 1970, the Living Planet Index (LPI) decreased by 83% for freshwater ecosystems as compared to an average LPI decrease of 60% for all ecosystems (WWF 2018). In the European Union, mires are the most rapidly vanishing ecosystem, with their area decreasing by 4% every 10 years (Hicks et al. 2010). The most important information is that the sixth mass extinction is not something that only affects remote corners of the globe and rare, exotic species. Unfortunately not – it happens next to us and concerns many species of plants and animals until recently considered common!

Who needs dragonflies, mayflies and mosquitoes?

Recently, the scientific community has been circulating alarming news about the drastically rapid rate of insect extinction – first, the 75% decrease in biomass of flying insects during less than 30 years has been documented in German nature reserves (Hallmann et al. 2017), and then the catastrophic insect extinction was confirmed worldwide (Sánchez-Bayo & Wyckhuys al. 2019). In this latter study, it turned out also that freshwater-associated insects are the fastest declining group, and the main cause of their extinction is the destruction of habitats. In the case of wetlands, this means drainage and reclamation for agriculture. Noteworthy, the second most important cause of insect extinction is agricultural pollution. It does not take long to realize that the world as we know it cannot exist without insects, only to mention, for example, their role as plant pollinators or serving as food for other animals.

The borderland of land and water is the place where the inhabitants of both of these worlds meet, while at the same time, it has its own specific and extremely species-rich fauna. Here, in the shallow riverside waters, among rushes and reeds, the larvae of dragonflies, mayflies, midges, caddisflies, and many other insects spend their first part of life. At this time, they all provide the food base for fish, amphibians or larger invertebrates, and the diversity and abundance of insects and other aquatic invertebrates occupying diverse micro-habitats in the river allow for the coexistence of many species of fish with different diets. Larvae of aquatic insects are not only the food resource for other organisms, but they play an important role in the functioning of wetland habitats as micropredators, shredders, grazers and "bioturbators" affecting the decomposition of organic matter and nutrient cycling at a considerable scale (Adler & Courtney 2019). An equally important role in the ecosystem is played by adult flying insects from riverside wetlands. The same species become food for whole groups of birds nesting along rivers or visiting them as feeding grounds. Also bats come to the rivers at night to hunt quietly.


Green frog/ Beautiful demoiselle

Among the insects that occur on the waterfront in large numbers, mosquitoes should also be mentioned. There are few insect species as important for the functioning of ecosystems as these. Aquatic larvae of mosquitoes recycle large amounts of fine detritus, accelerating the nutrient cycling in water. They are essential food resources for both, underwater organisms - e.g. fish or larger invertebrates like dragonfly larvae, and for terrestrial fauna – e.g. adult dragonflies, spiders, birds or bats. Creation of fully functional wetland buffer zones provides the habitat for all these predators, which then regulate the populations of aquatic insects, including mosquitoes.

Where pikes are born

The marshy river banks overgrown with rushes are one of the most important feeding grounds for fish; they are also the key spawning places for many species. Destruction of riverine wetlands has caused declines in river fish populations, and the occurrence of many species has become dependent on the stocking. Pike, one of our biggest predatory fish, used to spawn on riverside wetlands during spring floods. When the water was receding, the pike fry migrated to the ox-bows cut off from the main current, where the young fish safely lived to see the next spring flood, during which they could reach the river. Restoration of WBZs also means the recreation of pike spawning grounds, and simultaneously – support for angling activities.

Bird paradise

There are no habitats richer in bird species in Europe than riverine wetlands – floodplains, wet meadows, fens, or riparian forests. You could count species for a long time: various ducks that feed on plants and small aquatic animals, egrets, bitterns, terns and kingfishers hunting for fish, swallows catching mosquitoes, wading birds searching of small animals hidden in the mud, or the whole wealth of singing birds. In addition, there are numerous birds of prey, hunting for fish, small mammals, or smaller birds by the rivers. The protection of endangered bird species is today one of the main motives for re-creating wetland ecosystems. The synergy with the creation of WBZs for nutrient capture and water retention is obvious. Local economics will also take advantage of this opportunity: birdwatchers are among the most active tourists visiting rural areas.

Migration corridor

The vicinity of the river is a migration route for various animals – birds during seasonal migrations, larger and smaller mammals, but also insects and other invertebrates. But the ecological corridor is not an abstract riverbank, rather it is provided by a mosaic of natural and semi-natural riverside ecosystems. Their regular occurrence along the river also allows wild plants to spread, many of which are rare and gradually disappearing.

9. Wetland biomass – good for farmers and the business sector!

Claudia Oehmke, Wendelin Wichtman, Piotr Banaszuk

In the previous chapters, we explained how re-establishment of wetlands along rivers can help to reduce nutrient runoff from land to water, thus counteracting eutrophication of lakes and the sea, improve water retention and circulation, thus reducing risks of droughts and floods, mitigate climate change and help to adapt to it, and finally – restore and protect biodiversity. So why don’t we restore them right now everywhere? On the way to the widespread implementation of WBZs in riverside landscapes, there is one serious obstacle that can, however, be turned into a huge opportunity. This obstacle is the current agricultural use of once drained riverside areas. Corn or cereals are grown along the regulated rivers, or, at best, intensively managed humid meadows grow in between drain ditches and pipes. Such land use cannot be combined with the postulated rewetting of riverside areas. But there is a solution: the restoration of the WBZs does not require complete elimination of agriculture from the area, but only its transformation into so-called wetland agriculture or Paludiculture. Wetland plants can successfully be used economically. And with every tonne of biomass harvested from the wetlands, nutrients such as nitrogen and phosphorus are removed from the system. You will read about the different ways of wetland biomass utilisation in this chapter.

‘Wetland agriculture’ is a broad term we propose to address productive use of wetlands that can be combined with sustaining their ecological functioning and ecosystem services. This concept can include plantations of purposefully selected species, as well as harvesting spontaneously established vegetation. Our approach to wetland agriculture originates from, and encompasses, the idea of **Paludiculture** (Wichtmann et al. 2016) defined as agricultural land use of rewetted and wet peatlands with water levels near the soil surface – thus enabling to conserve organic carbon stored in peat. While the Paludiculture concept (lat. “*palus*” = swamp), has originally been developed to protect carbon in organic (peat) soils, a similar idea can be applied to wetlands on mineral soils, to combine biomass production with the delivery of all wetland ecosystem services we have discussed so far.

Many wetland plant species, like cattail, common reed and reed canary grass can grow well both on peat and mineral wetland soils. Wetland agriculture allows farmers to keep the added value[9] of wetland biomass after hydrological restoration. The wetland biomass can be used for a broad range of usage options, from energetic – as biogas or solid biofuel, to high added-value products - like insulation material, paper or fibre materials that can also be used as a substitute for oil-based plastic products, e.g. as packing material.

The implementation of wetland agriculture in WBZs brings along new challenges in farming practices (e.g. harvest techniques adapted to wet conditions), in policies (acceptance as a regular agricultural practice for subsidy systems), and in the market economy (the development of complete new value chains for the use of wetland biomass). But these challenges are opportunities! In addition to offering areas for restoring wetlands with their ecosystem services, wetland agriculture can bring about entry to a new bio-based **circular economy**, allowing to replace fossil fuel-based energy and materials with biofuels and natural products.

Circular economy

Improved water management should no longer violate the zero-waste imperative – the principle that lies at the heart of the ***circular economy*** *(CE). It rests on three basic assumptions: (1) durables, i.e. products with a long life span, must retain their value and be reused, (2) consumables, i.e. products with a short life span, should be used as often as possible before returning to the biosphere and (3) natural resources may only be used to the extent that they can be regenerated. Natural or restored wetlands can effectively be used for nutrient retention and biomass production, providing viable entrances to implement circular water economies.*

Which plants can be used?

For wetland agriculture in WBZs, highly productive wetland plant species like common reed (*Phragmites australis*), cattail (*Typha* spp.), sedges (*Carex* spp.), reed canary grass (*Phalaris arundinacea*), as well as black alder (*Alnus glutinosa*) can either be cultivated or will spread by natural succession after rewetting by raising water levels. Whether the plants establish spontaneously depends on the seed bank[10], availability of donor plants in the vicinity, rewetting intensity, nutrient availability, vegetation management, and many other factors. For example, under frequent summer mowing, species-rich wet meadows can be developed if habitat characteristics are suitable. The cultivation of wetland species by planting or sowing is more costly, but productive stands can be developed faster in this way. High biomass yields can be harvested after two to three years after implementation.

[9] Added value – increase in value of a given product as a result of a specific production mode.
[10] Viable plant seeds stored naturally in the soil.

Common reed, cattail, sedges and reed canary grass can build persistent monodominant stands with high yields under wet conditions

Wetland plant species and their nutrient removal potential

The highest amounts of nutrients can be removed by the above-ground harvest in summer to early autumn, and this season is optimal for all plant species. Common reed reached a maximum uptake in September and may accumulate about 300 kg of nitrogen (N) per ha per year, 30 kg of phosphorous (P) per ha per year, and 100 kg of potassium (K) per ha per year. Cattail can reach up to 500 kg N/ha/year, 50 kg P/ha/year, and 200 kg K/ha/year, with maximum uptake in August and September. Nutrient removal potential for winter harvest is reduced to 50 % for reed and to 70 % for cattail. However, uptake rates can vary between locations and soil nutrient supply. In the case of WBZs, a harvest between summer and autumn is thus recommended.

Sustainable and useful options for biomass utilisation

Wetland plant biomass can be used for several products or production chains. Some are already implemented on the market, but in the future, more possibilities can be tested to transfer knowledge from production chains that already exist for comparable biomass types like straw, grass, and wood.

Samples of dried and cut biomass from different types of wetland vegetation

1. **Fodder and cattle breeding** – the quality of fodder produced on wetlands largely depends on their nutrient status. In low-productive peatlands, plant biomass has a low feeding value. The situation is different in more nutrient-rich wetlands. The fodder and nutritional values of spring-mown cattail from eutrophic sites are high (Geurts & Fritz 2018, Geurts et al. 2019). The use of late-harvested cattail as fibrous roughage with low dietary inclusion rates and of cattail harvested before florescence in grass-based dairy rations with higher inclusion rates is also an option (Pijlman et al. 2019). Other plant species that are suitable for fodder production are reed canary grass (*Phalaris arundinacea*) and reed sweet-grass (*Glyceria maxima*) (Sundblad & Wittgren 1989).

2. **Building material** – during the last years, the demand for sustainable, health- and environmentally-friendly building materials increased steadily. Building material from wetland biomass meets these requirements. Due to their morphological characteristics, common reed and cattail show extremely good insulating properties. Common reed has been used for centuries as roof thatch on traditional houses that are common all over the world and is increasingly popular also in the construction industry for the lodging and luxury real estate sectors. The 'Thatcher's Craft' was recognised by UNESCO as an intangible cultural heritage in 2014. Currently, e.g. Netherlands, Germany, UK, and Denmark rely on the import of up to 85% reed thatch from Eastern and South-eastern Europe as well as considerable amounts from China (Wichmann & Köbbing 2015). The use of WBZs for reed thatch production could meet the regional demand.


Cattail insulation material, photo M. Wiśniewska

Cattail leaves contain layers of air-filled cells that remain intact after dying off in winter and give the cattail its remarkable insulation properties. The winter-harvested cattail can be chopped and pressed in insulation plates with the addition of a mineral lime. The plates have not only good insulation potential, but they can also be used as a load-bearing element because of its strength. In a first test project, a protected historical building was reconstructed with cattail plates in Bavaria (South Germany) in 2011. Cattail can also be used as blow-in insulation, that was experimentally installed in a small house in North-East Germany in 2017.

3. **Energy – solid biofuels** – the use of wetland biomass as a solid biofuel is an established technology. In Northern Europe reed canary grass has been successfully cultivated on former peat excavation areas and used for combustion (Heinsoo et al. 2011). The suitability of pellets

made from common reed, reed canary grass, and sedges from rewetted peatlands has been proved by chemical analysis and combustion tests in the Paludi-Pellets-Project (Dahms et al. 2017) – all biomass types showed a heating value of 17.4-18.8 MJ/kg.

Practically every plant species can also be used as biomass for solid biofuel in adapted boilers. The best time to harvest biomass for combustion is late autumn or winter. According to new studies about solid biofuels, wetland biomass will contribute to a better CO_2 balance as "sustainable biofuels", similarly to wood chips or wood pellets. Since trees sequester a very high amount of C in the long term, the production of C-sink products, e.g. furniture, is more climate-friendly than burning them. Therefore gradual substitution of oil-based fuels by wetland biomass should be favoured (Wichtmann et al. 2019). Moreover, wetland agriculture is almost devoid of potential competition for space between biofuel growth and food-oriented agriculture – a frequent argument against biofuel crops.

A heating plant in Malchin (Northeast Germany, 800 kW) has been working since 2014 exclusively on wetland biomass from landscape maintenance, reed canary grass, and species-rich sedge meadows. About 300 ha of wet meadows produce 800-1200 tonnes of solid biofuel, which equates about 350 000 litres of conventional heating oil. The boiler used has a power of 800 kW and is adapted to wetland biomass (LIN-KA company). It provides heat for app. 540 households, a kinder garden, two schools, and office buildings. Additionally, the heating operation is assisted by a gas boiler that mitigates power peaks and in time of preventive maintenance. An economically viable implementation of a heating plant requires several conditions – an existing local heat network and close distance to potential biomass production sites (short transport routes) (Dahms et al. 2017).

4. **Energy – biogas** – the utilisation of wetland plants for biogas production seems to be an up-and-coming and sustainable option, delivering energy but also a digestate, which can be applied as a valuable soil fertilizer rich in carbon, nitrogen and phosphorous. Anaerobic digestion processes fresh or ensiled material of higher moisture content to produce biogas, which is then either converted in a combined heat and power plant to produce electricity and heat, or fed directly into the gas grid.

Biogas yield from landscape management plants varies widely between 80 and 550 Nm^3 t^{-1} volatile solids (VS), with amaximum value at 750 Nm^3 t^{-1} VS (Prochnow et al. 2005, Roj-Rojewski et al. 2019, Dragoni et al. 2017). Biogas production might be a reasonable utilisation pathway if the harvest occurs from early summer up to late summer. Later, increasing crude fibre content in feedstock worsens biomass quality and dramatically reduces biogas and methane yield.

An essential prerequisite for the economic operation of the biogas plant is the extensive use of heat. It also plays a vital role in achieving the lowest possible greenhouse gas emissions. Heat may be utilized in human settlements and production plants, e.g., in agri-food processing, horticulture, agricultural businesses, etc.

5. **Furniture from black alder** – alder can be cultivated for energy as well as for wood production on eutrophic wet fen soils. The productivity of a 60-year-old alder plantation is high enough to provide about 420m³/ha compacted wood (Wichtmann et al. 2016). The harvest is still a critical point, but there is rope-based machinery available (Röhe & Schröder 2010).

6. **Compost –** composting is an aerobic process in which microorganisms are involved to convert organic material to a relatively stable and environmentally friendly fertilizer. Residual biomass from landscape management is a suitable feedstock for carbon and nutrient recycling through composting as a mono- as well as a co-substrate processed along with organic waste, digestate, or sewage sludge. Cattail and reed composts were proven to possess beneficial properties, including high water retention, the content of organic nitrogen, and neutral pH. Since it has a positive influence on the properties of soil and the improvement of plant growth, compost may be used as a soil amendment in farming systems and as an alternative organic growing medium for gardening, mushroom industry, horticulture, and by groundskeepers, landscapers, and gardeners, which could substitute non-renewable peat, commonly used for these purposes.

However, we must not forget that during composting a large percentage of organic carbon always escapes into the atmosphere; thus, composting biomass for fertilizer replacement in agriculture may result in net GHG emission (Czubaszek et al. 2019). Right GHG balance can be retained when biomass is directly used to produce growing media.

10. People like WBZs along rivers! *Sviataslau Valasiuk, Marek Giergiczny*

Do people prefer to see straight, regulated rivers or wild, meandering ones in the proximity of their houses? How much do they value clean water in the local river? Would they like to render the Baltic Sea cleaner in thirty years from now? Do they prefer regular and ordered farmland landscape on the river banks over more natural and spontaneous vegetation? Or perhaps they would like the small rivers to be restored elsewhere but not in their 'backyard'? If they had to pay for water ecosystems management and governance, how would they distribute financial contribution between the local, national, and international levels? Does the very look, an aesthetical appearance of the small river in their immediate neighbourhood, actually matter to them?

In order to answer questions like these, economists conduct empirical studies putting people's preferences under scrutiny. Some of those preferences can be revealed from the people's real behaviour and decisions, while the others are being elicited by asking a sample of the population to answer hypothetical questions or to choose the favoured variant out of several alternatives. The latter method is referred to as the Discrete Choice Experiment, a survey-embedded approach able to retrieve people's willingness-to-pay (WTP) for complex natural goods – such as river management – and for their various components relevant for decision-making. Estimated WTP reflects stated benefits in monetary terms which people derive from, say, re-meandering of the small river near their village. Those benefits can subsequently be compared against the costs in order to sort out if people actually like contemplated re-meandering to be implemented.

In the CLEARANCE project, people's attitude towards natural-looking small rivers over human-transformed ones was investigated in lowland parts of Denmark, Germany, and Poland. The special focus was on the small rivers' restoration measures, namely restoring their streambed shape and wetland buffer zones. Surprisingly, even though the Polish GDP per capita adjusted by the Purchasing Power Parity (PPP)[11] factor is only about 55% of the Danish and 58% of the German, the WTP estimates of the Polish respondents for contemplated improvement of ecosystem services have the comparable order of magnitude with regards to WTP of the respondents from wealthier countries. Thus, if adjusted by the PPP factor, the annual WTP of Danes for the most ambitious restoration programme is 336 EUR, Germans are willing to pay 406 EUR, whereas Poles are willing to pay 372 EUR on average.

The respondents in all three countries are willing to pay for water improvement both in the rivers and in the Baltic Sea. Consistently in all studied countries, the WTP estimates for improvement of the water quality in the Baltic Sea are substantially larger than in the countries' rivers. For example, the WTP of German respondents to enjoy an improved quality of water in the Baltic Sea is 164 EUR and is 2.82 times higher than their WTP for the highest level of water quality in the rivers. In Poland, the same results are 135 EUR and 2.2 times, respectively, whereas in Denmark they are 105 EUR and 1.4 times. The considerable positive preferences towards the Baltic Sea water purity lay grounds for the multilateral action in this respect.

A very similar pattern across three countries was observed regarding preferences for riverbed shape and vegetation type in the respondents' close vicinity: they prefer meandering riverbeds over curvy and especially over straight ones. Intensive agriculture is the least preferred vegetation type. On the contrary, wild marshes and wetland agriculture – the options implying the highest and similar level of ecosystem services (i.e. water purity, biodiversity, and flood control) were assigned the highest WTP.

For example, WTP for meandering rivers relative to regulated straightened rivers varies from 87 EUR in Germany to 52 EUR in Denmark, which makes their restoration a socially desirable policy. Moreover, respondents in three countries put restoration of naturally meandering riverbeds and wild marshes (or wetland agriculture) WBZ on the local level before improvement of water quality in rivers on the country level: the appropriate WTP ratio in favour of the local programme attributes ranges from 3.14 times in case of Germany to 2.04 in case of Denmark. For the overwhelming majority of small rivers, it implies re-meandering of their riverbed shapes,

[11] Purchasing Power Parity – indicator of a level of differences in prices between countries, enables comparison of the cost of living between countries.

rewetting of floodplains, and restoration of wild marshes or development of Paludiculture. It seems that rewilding or restoration of rivers in the respondents' immediate neighbourhood could get very popular support. This tendency can be explained by the bundle of ecosystem services arising from the local small rivers' restoration and/or conservation action, including typically difficult-to-quantify aesthetic values. Therefore, the observable natural characteristics, such as meandering riverbeds and wild-looking riparian vegetation, are highly attractive for the people and can serve as proxy indicators of cultural ecosystem services.

It seems that wild-looking rivers are simply attractive for people, whereas the respondents in three Baltic Sea countries possess good knowledge about small rivers, their current state and restoration prospects, riverine ecosystem services, and perhaps more generally – about the urgency to mitigate the accelerating environmental crisis.

Riverside recreation places

11. Is their restoration and implementation expensive? *Marta Wiśniewska, Carl C. Hoffmann , Wendelin Wichtman*

Economists calculated that inland wetlands offer ecosystem services globally with an annual value of 1.5 trillion US $ per year (Costanza et al. 2014). Wetland restoration is a cost-effective measure against nutrient pollution when compared against agricultural measures or wastewater treatment plants (Trepel 2010). But wetland restoration, including (re)establishment of WBZs, can mean different actions and involve various categories of costs and benefits depending on the local situation. Due to human-made changes in the landscape, WBZ restoration usually needs to be supported by engineering solutions, as well as socio-economic measures. In Chapter 3, we mentioned different types of wetland buffer zones that can be suited to the local circumstances. The creation of a specific type of wetland buffer zone is associated with a specific set of interventions and, consequently, specific costs. Let us look at three case studies from three countries.

Denmark: a national programme for WBZ restoration

Denmark seems to be a leader in using WBZs to cope with the problem of eutrophication. Consequently, construction of wet buffers is consistently being implemented, which provides benefits in the reduction of N loads. Let us look at projects implemented just in 2013. They had a positive impact on the total area of approximately 4300 hectares with N capture at the level of 514 tonnes per year. The average cost of the investment per ha stood at 135.3 thousand DKK (approx. 18 thousand EUR).

Peatlands rewetting in North-East Germany

German peatlands restoration projects in Brandenburg and Mecklenburg-Vorpommern, although not focused on nutrient retention but rather aimed at biodiversity conservation, climate change mitigation, and paludiculture development, can be used to estimate different categories of costs incurred by WBZ development. Rewetting of fens drained in the 1980s incurred costs of infrastructure needed to maintain a certain level of groundwater, costs of design works, land purchase and, in some cases, compensation for lowered income to local farmers resulting from reduced intensity of agriculture, and finally the purchase of machinery adapted for management of wetlands and processing of wetland plants. Thus, for 21 projects carried out almost two decades ago in Mecklenburg-Vorpommern, on more than 7000 ha, total costs amounted to 1200-1800 EUR/ha. The average cost of a project carried out in the same region a decade ago was around 2800 EUR/ha. Similar per-unit costs were incurred in Brandenburg, where selected wetland areas in the Ucker Valley were restored.

Poland: catchment-scale analysis reveals high cost-effectiveness of WBZs

In Poland there are only a few small-scale wetland and river restoration projects, therefore their costs cannot be directly used to estimate the financial feasibility of WBZs. Therefore, the cost-benefit analysis of a hypothetical implementation of WBZs in the catchment of the lower Narew river (NE Poland) was carried out within the CLEARANCE project (Jabłońska et al. 2020). Two alternative scenarios were used: one that assumed large-scale restoration of fens and floodplains along Narew river and its tributaries, and another one that considered only rewetting of areas in close proximity of all rivers and streams in the catchment – wherever technically possible.

In the first scenario, if fully implemented, 88.5 thousand hectares of peatlands and 2.4 thousand hectares of riverside floodplains would be restored, resulting in the capture of 11%-30% of nitrogen load and 14%-42% of phosphorus load from the catchment area. Estimation of the costs incurred by this scenario took into account the density of the existing drainage network and measures designed for damming water and amounted to 38 million PLN (8.9 million EUR). In addition, costs associated with compensation for the income foregone by farmers were assumed to be at the level of subsidies functioning within the framework of agri-environmental and climatic measures in the Polish Rural Development Programme 2014-2020, co-financed from EU funds, i.e. ca. 1200 PLN/ha per year (~290 EUR/ha per year).

In the second scenario, nearly 4.2 thousand kilometres of buffer zones of the wetland banks type could be created, transformed watercourses of a total length of almost 600 km could be re-shaped to form two-stage channels, and about 440 km of rivers could be re-meandered over the entire catchment area of the lower Narew river. Implementation of this scenario would cost about 728 million PLN (nearly 171 million EUR), but would remove more nutrients than the first scenario: 33%–82% of nitrogen and 41%–87% of phosphorous. In addition, costs of river maintenance works (commonly practiced in Poland) at the level of 9.5 thousand PLN per kilometre of a watercourse (2.2 thousand EUR) would be avoided wherever two-stage channels and wetland banks would be implemented. At the entire catchment scale of the Narew river, the abandonment of a one-off mud purging of watercourses yields a saving of 45 million PLN (10.6 million EUR) – at the level of 6% of total investment costs.

Regardless of the possibility of avoiding some of the costs currently incurred, the amounts assigned to the implementation of programmed development scenarios of the WBZs in the Narew catchment may look high. However, the sum required for the implementation of both scenarios is equivalent to only 5% of the funds currently allocated to water and wastewater management projects in urban agglomerations in Poland. Costs of implementing WBZs in the entire Narew catchment are equivalent to the costs of building a 20 km long expressway.

12. Legal, economic and social challenges *Michael Trepel, Michael Bender, Rafael Ziegler*

About two-thirds of European wetlands that existed a hundred years ago have been lost. In addition to the loss of habitat for wildlife and loss of nutrient retention capacities, particularly drained peatlands are a potent source of greenhouse gases. Globally, the EU is the second largest source of greenhouse gas emissions from peatlands after Indonesia. 99% of these emissions are caused by 16 out of 28 Members States, especially from Northern and Central Europe. Member States have to develop appropriate rules and incentives, including funding possibilities for improved agricultural practice as well as wetland restoration and wetland agriculture, keeping in mind also the 2050 climate change goals of the Paris agreement and associated emission reduction planning.

EU: towards cross-compliance of water and agricultural policies

The legislative act that has received praise worldwide and has enabled many success stories of water protection is the **Water Framework Directive** (WFD). Still, its implementation is difficult and much delayed. New scientific insights and innovative ways for effective implementation are called for. One of the urgent tasks is market creation and the development of new marketing strategies for wetland agriculture and the bio-economy. The policy context of the WFD can offer a rich environment for this by acknowledging, promoting, and funding wetland restoration and wetland agriculture within integrated water management plans as well as associated policies.

A shared understanding of water as an inter-sectoral challenge for water management, agriculture, environmental protection, energy, industry, and transportation provides the basis on which the WFD is to be implemented. In particular, the instruments of the **Common Agricultural Policy (CAP)** are crucial for meeting the goals of the WFD. For example, the nitrate limit of 50mg/l is difficult to achieve if CAP instruments heavily subsidize intensive agriculture and the use of mineral fertilisers but not wetland agriculture on rewetted soils. Member States should be encouraged to draw on the state-of-the-art to ensure that wetland-adapted plants and value chain[12] options of wetland agriculture are appropriately recognized. **Cross-compliance** with WFD goals is needed, and the plan to include WFD nitrate and phosphate goals as well as buffer strips as a part of CAP conditionality is therefore much appreciated. The following postulates have arisen from a discussion workshop organized by the CLEARANCE project in Brussels for EU stakeholders and policymakers:

- Buffer zones should be defined functionally in terms of effective nutrient removal.
- Misuse of regional development funds for so-called “river maintenance” and “dredging” should be stopped and likewise CAP subsidies for agriculture on drained wetlands.
- Restoration and wetland agriculture or paludiculture as alternatives for local economy actors should be promoted.
- Climate protection and the co-benefits of wetland restoration for emission reduction, as well as improved water retention in the landscape, should be promoted, thereby improving terrestrial water cycling and climate change adaptation in times of increasing frequency of floods and droughts. Such climate mitigation and adaptation measures are vitally needed in CAP conditionality.

The CAP framework is generally suitable for realizing an EU-wide realignment of peatland maintenance and supplying (co-)funding for reaching the stated goals. Additional support may come from the **European Regional Development Fund** (ERDF).

Nutrient trading schemes in wetlands

Several authors suggest the development of nutrient trading schemes on a voluntary basis. The concept behind this idea is that society pays for required ecosystem services like denitrification of nitrate in restored wetlands. However, the quantification of the tradeable good in the form of nitrate leaching versus denitrification is highly uncertain for both sides of the trade. There is no

[12] Value chain – a sequence of activities undertaken by a company, including design, production, sales, delivery, and post-sale services, which eventually provide the added value for the customer and therefore also for the company. Value chain is a vital part of the strategic management and business value management.

standardization for nutrient leaching rates per farmland. At the same time, the nutrient retention rates in restored wetlands are highly variable. Complex spatial relationships between the source and the solution of the problem, and some legal issues also hinder the implementation of nutrient trading schemes. Nutrient emission trading is therefore still not ready for use in practice.

Other optional solutions on national or regional levels

Some options exist for promoting WBZ creation even without, or regardless of, dedicated national or international legislation. For enhancing wetland restoration at the landscape scale, there are three promising approaches.

1. Farmers restore wetlands on their own ground and clean their own surface runoff on a voluntary basis. Certificates can prove that the restored wetland is technically suitable for treating the nutrient runoff from the specific farm. This option could be effective on a large scale only if environmental standards are placed very high on the ranking of social values.

2. Environmental agencies set threshold values for wetland cover in catchment areas, which depend on the landscape degradation level. This concept operates only in highly agricultural areas, and cannot be easily applied to areas with a high proportion of natural wild landscapes. Farmers or farmer communities can get funded when offering land for wetland restoration.

3. As most wetlands occur on organic soils and there is a need to decrease greenhouse gas emissions from drained organic soils, farmers can be convinced to either cease agriculture on these sites or change intensive land use to paludiculture when economically feasible.

Barriers and opportunities

In the CLEARANCE project, we assessed barriers and opportunities regarding WBZs and wetland agriculture based on three regional workshops to which practitioners, officials, scientists were invited to participate: in Aarhus (Denmark), Greifswald (Germany) and Warsaw (Poland). The general conclusions of the workshops were:

1. Wetland agriculture in spite of its climate and water protection benefits is a marginalized option in current agricultural use, and even more so for wetland agriculture on WBZ.
2. Central barriers are institutional: There is no even-handed funding for wetland agriculture options on WBZ; the EU CAP and associated national policies continue to prioritize intensive agricultural options on dry and drained soils. Funding options via the water management plans of the WFD are also not currently used, not least due to insufficient knowledge and monitoring of WBZ co-benefits.
3. Opportunities for WBZ and wetland agriculture emerge where:
   - government from the municipal level up takes long-term responsibility to create systemic catchment solutions that create security for users to experiment with new options and

associated valued changes and that fosters partnerships with public, communal and private actors;

- WBZ protection without agricultural use is simultaneously pursued and communicated as an important alternative option, as depending on context agricultural wet use might not be desirable (f. ex. nature conservation) or economically viable (f. ex. size of land);
- extensive education is provided on the environmental benefits from the introduction of WBZs and from the change of existing management methods on drained wetlands to wetland agriculture;
- knowledge brokers such as applied scientists or specialized consultants accompany WBZ and wetland agriculture development;
- wetland agriculture is better communicated as innovative land use options for circular economy and new markets are being created for products made from biomass from wetland agriculture.

The CLEARANCE project

CLEARANCE – CircuLar Economy Approach to River pollution by Agricultural Nutrients with use of Carbon-storing Ecosystems

The CLEARANCE project aims to develop an integrated landscape-ecological, socio-economic and policy framework for using WBZs (WBZ) in circular economies of water purification and nutrient re-use in agriculturally used catchments. Authors would like to thank the EU and the Innovation Fund Denmark (Denmark), the Federal Ministry of Food and Agriculture (Germany), and the National Centre for Research and Development (Poland) for funding, in the frame of the collaborative international consortium CLEARANCE financed under the ERA-NET Cofund WaterWorks2015 Call. This ERA-NET is an integral part of the 2016 Joint Activities developed by the Water Challenges for a Changing World Joint Programme Initiative (Water JPI).

Project partners:

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More about CLEARANCE:

https://www.moorwissen.de/en/paludikultur/projekte/clearance/Index.php

http://opendata.waterjpi.eu/dataset/clearance-circular-economy-approach-to-river-pollution-by-agricultural-nutrients

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