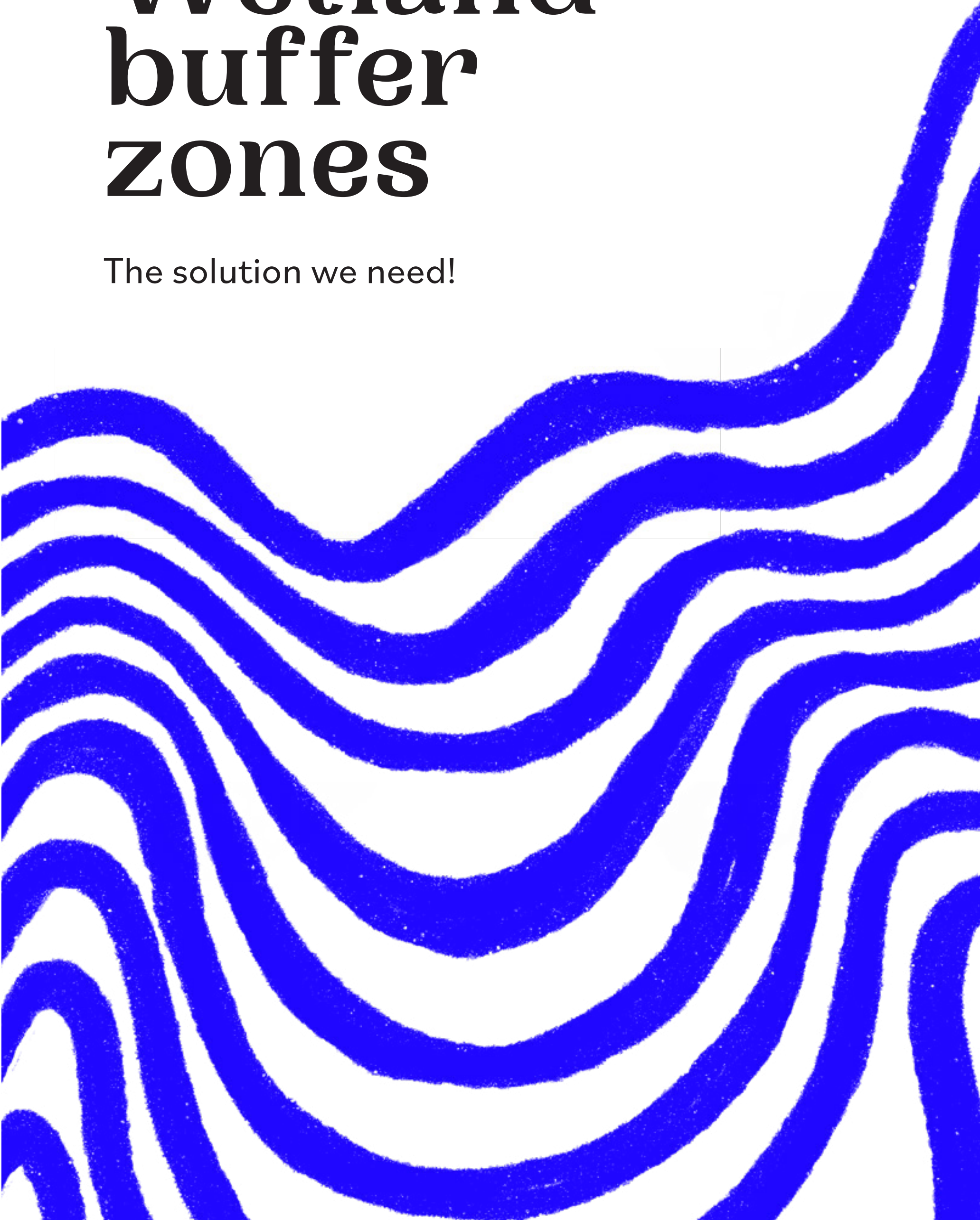
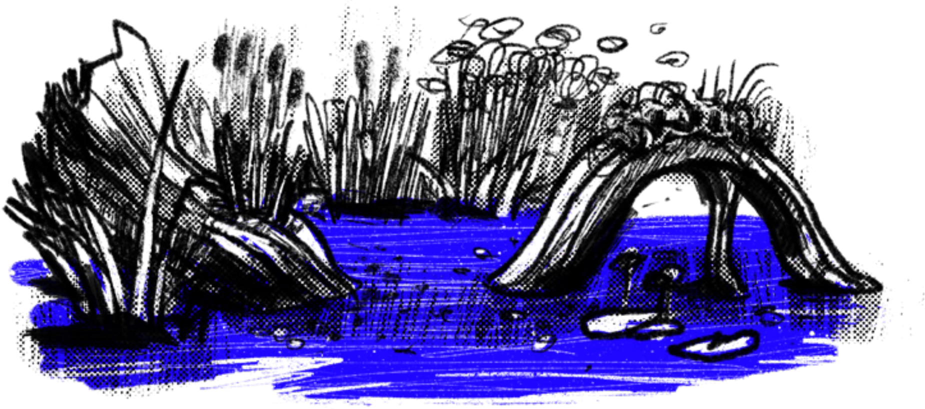
Wetland buffer zones

The solution we need!



Respect nature and restore deteriorated landscapes — there is no other future!



The problems you will read about in this brochure stem from subordinating the rural landscape to a single land use function — intensive farming, while neglecting multifold other ecosystem services[1] provided by wetlands.
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. Draining wetlands exacerbated a number of other problems: the severe water eutrophication caused by the inflow of agricultural fertilisers, resulting in toxic cyanobacterial blooms (see below) and oxygen deficits, a significant reduction in water retention, resulting in both droughts and floods, emissions of greenhouse gases (GHGs) from decomposing peat soils adding to the global warming, and the progressive disappearance of plants and animals associated with wetlands and natural rivers. All these changes 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 we need to do is, in short, rewet riverside wetlands by installing locks in drainage ditches or disconnecting drain pipes, remove or move the dikes back from the rivers and reshape regulated riverbeds so that they regain natural features.

1 — Ecosystem services — direct and indirect benefits for human society and economy provided by ecosystems.

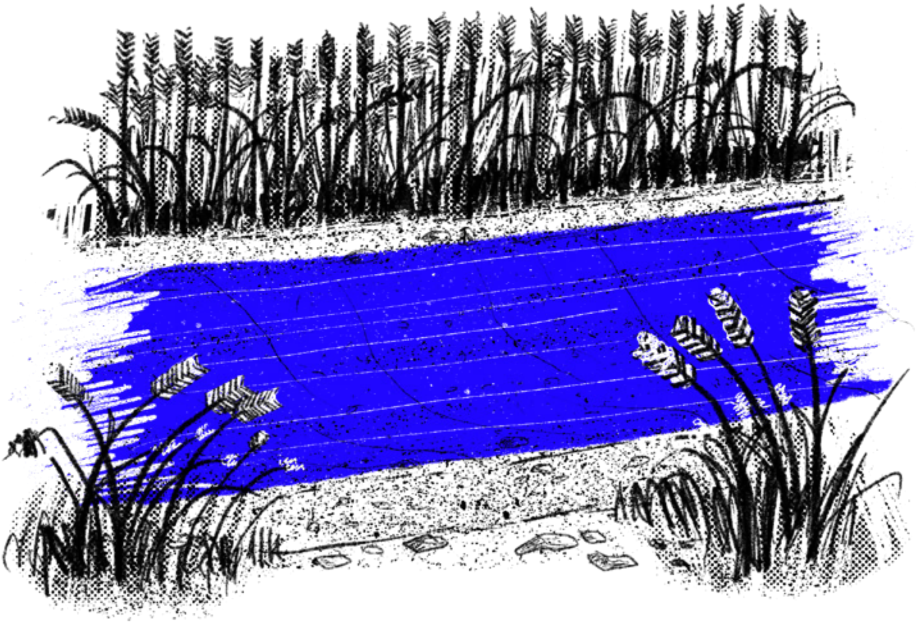
Converting riverside areas into wetland buffer zones does not necessarily mean that they are withdrawn from agriculture. On the contrary, an innovative economy — mowing and harvesting wetland plants and their meaningful utilisation — can even increase the efficiency of water treatment by the wetland. The spread of wetland agriculture and the development of ways to use wetland biomass can increase public acceptance of wetland restoration. What is more, our research conducted in three European countries has clearly shown that public acceptance of wetland restoration is already very high!

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 faced with 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 the 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.

This brochure is a shortened version of CLEARANCE 'Guidelines for multifunctional wetland buffer zones' available online at guidelines.clearance-project.com. To read additional chapters and see links to further reading and cited literature, please visit the website.

Enough is enough! What are nutrients and what is wrong with them?



There are several sources of nutrient pollution of open waters. Point sources like wastewater treatment plants can be widely 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 biggest 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 nature resources important for human life — as well as for the sake of nature conservation.

Nutrients, plants, and agriculture

Intensive agriculture is today the single most important 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 in addition with 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 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.

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 significant additional nutrient source for ground and surface waters.

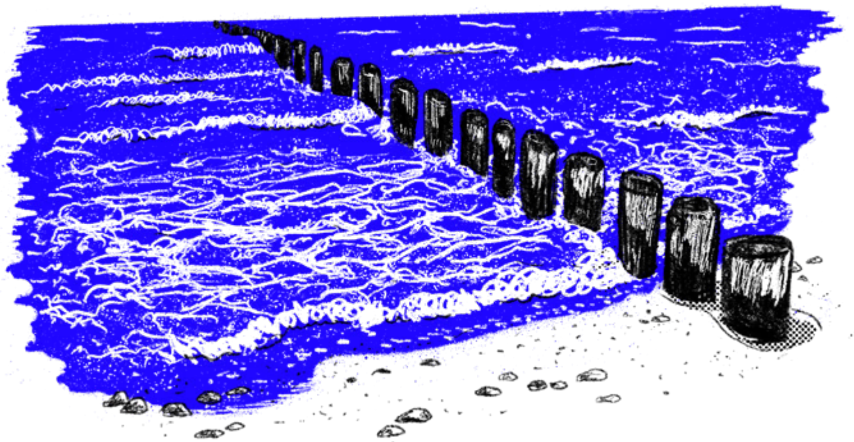
In rivers, nutrient pollution triggers replacement of flora typical for clear waters by faster growing plants characteristic for eutrophic waters. Some of them, such as *Elodea canadensis*, are invasive species, displacing European native flora. Slower-growing plant species become overgrown by filamentous 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 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 Sea — 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 km². The highest increase occurred in the second half of the 20th 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 — creation of the wetland buffer zones.



Fantastic beasts and where to find them? Few words about wetland buffer zones

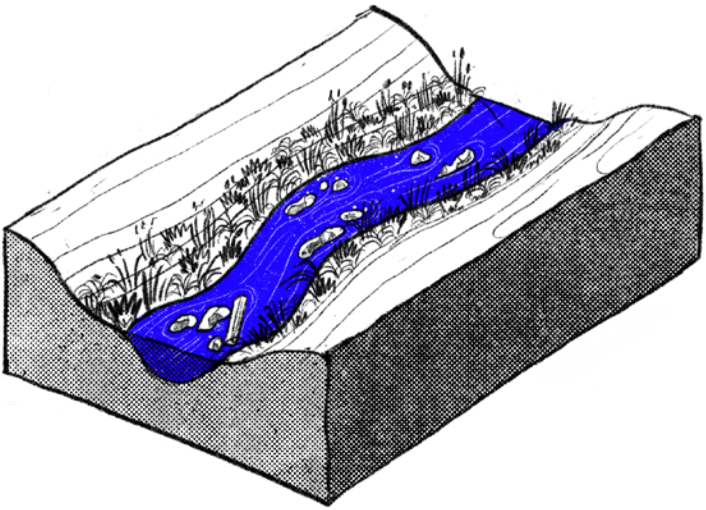
Wetland buffer zones (WBZ) are wetlands located between agricultural areas and a stream, river or lake, whose main function is protecting surface waters from nutrient pollution by non-point sources. They capture lost fertilizers (natural and artificial) from the fields before they reach the watercourse or reservoir. 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.

Types of WBZs

WBZ are characterised as interfaces between land and water with varying widths, from a few to several hundreds of meters. 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.

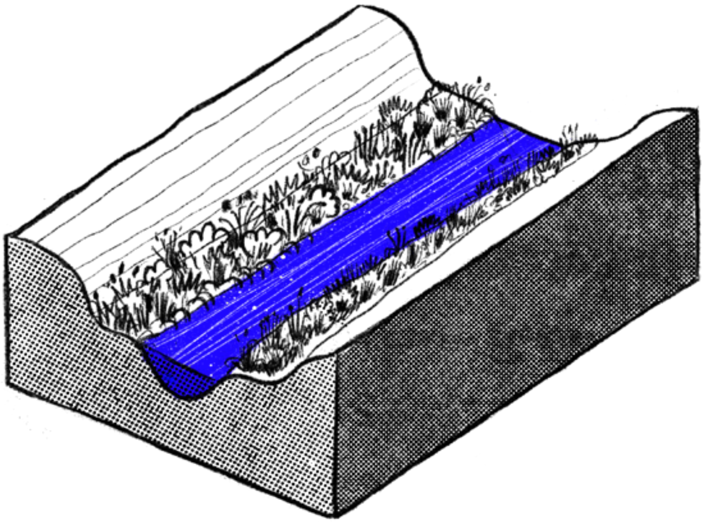
01 Wetland banks

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. Higher water level in the river results in inundation of land in its proximity.



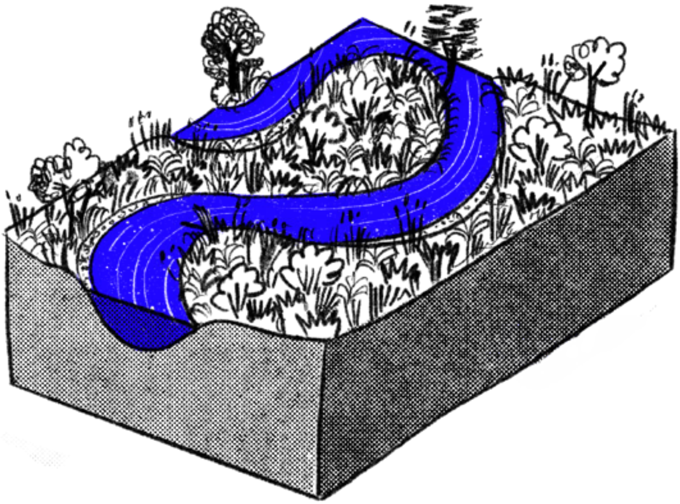
02 Two-stage channel

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.



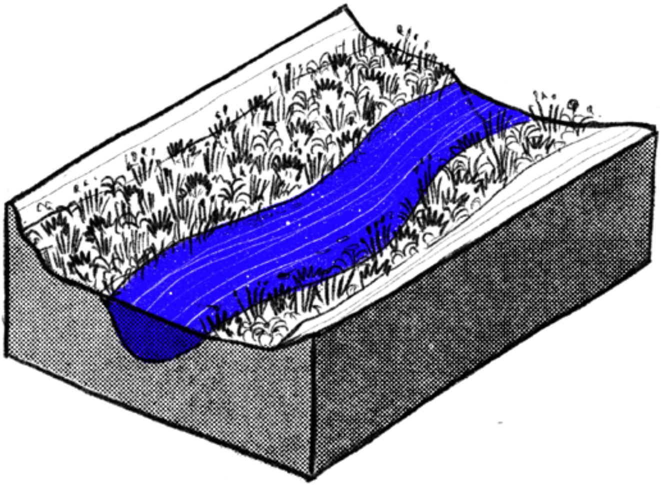
03 Meandering channel

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 higher order.



04 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.

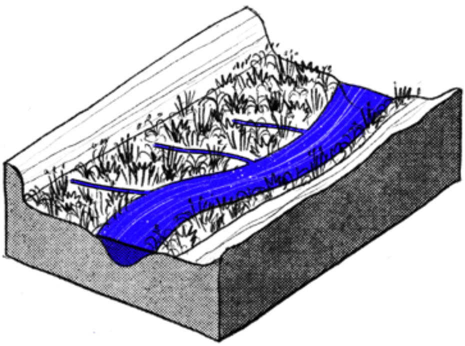


05 Rewetted fen

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[2]. Only sites with water levels close to 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[3].

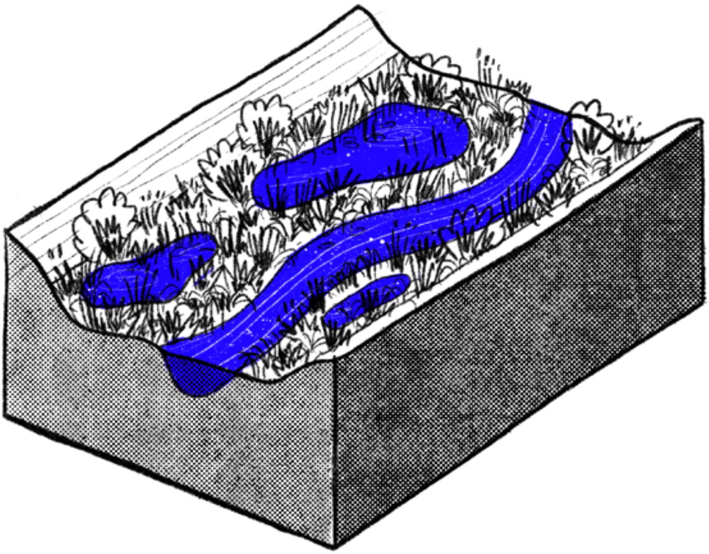
2 — Denitrification — reduction of nitrates to elemental nitrogen carried by bacteria.

3 — The risk of phosphate release due to 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 permanent removal of nitrogen and phosphorus from the soil-water nutrient cycles.



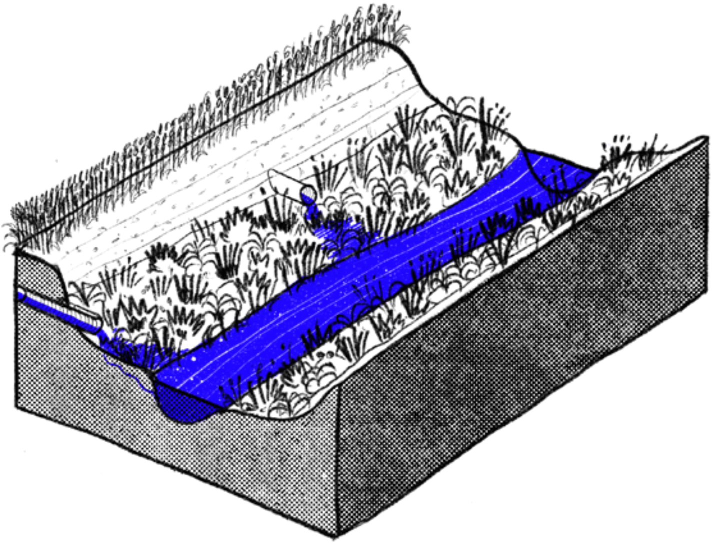
06 Floodplains

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.

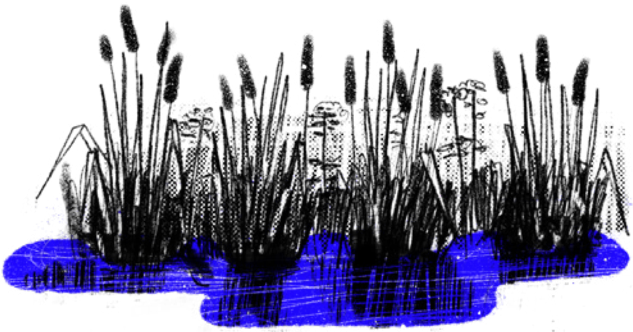


07 Wetlands at drainage pipe outflow

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 WBZ were distinguished by Hoffmann et al. (2020), two examples are shown below.



Do it yourself – how to create WBZs?



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.

More information can be found in the extended version of the brochure on the website.

Nutrient capture in WBZ – how it works?

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. Removal of specific nutrients from water often occurs through chemical transformations taking place in WBZ, whereas nutrient capture and retention occur due to their uptake and accumulation in the soil and in plant biomass within the WBZ.

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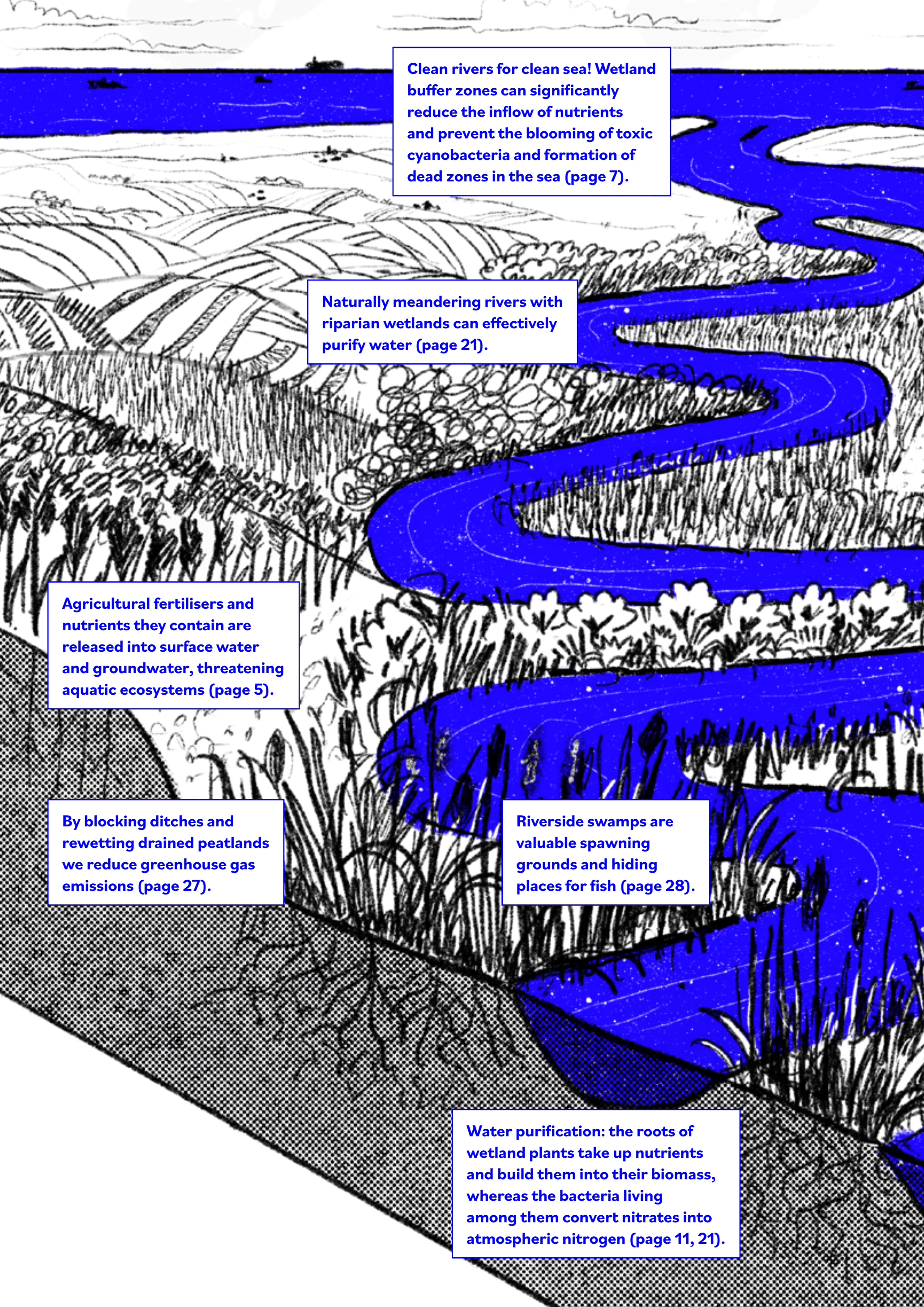
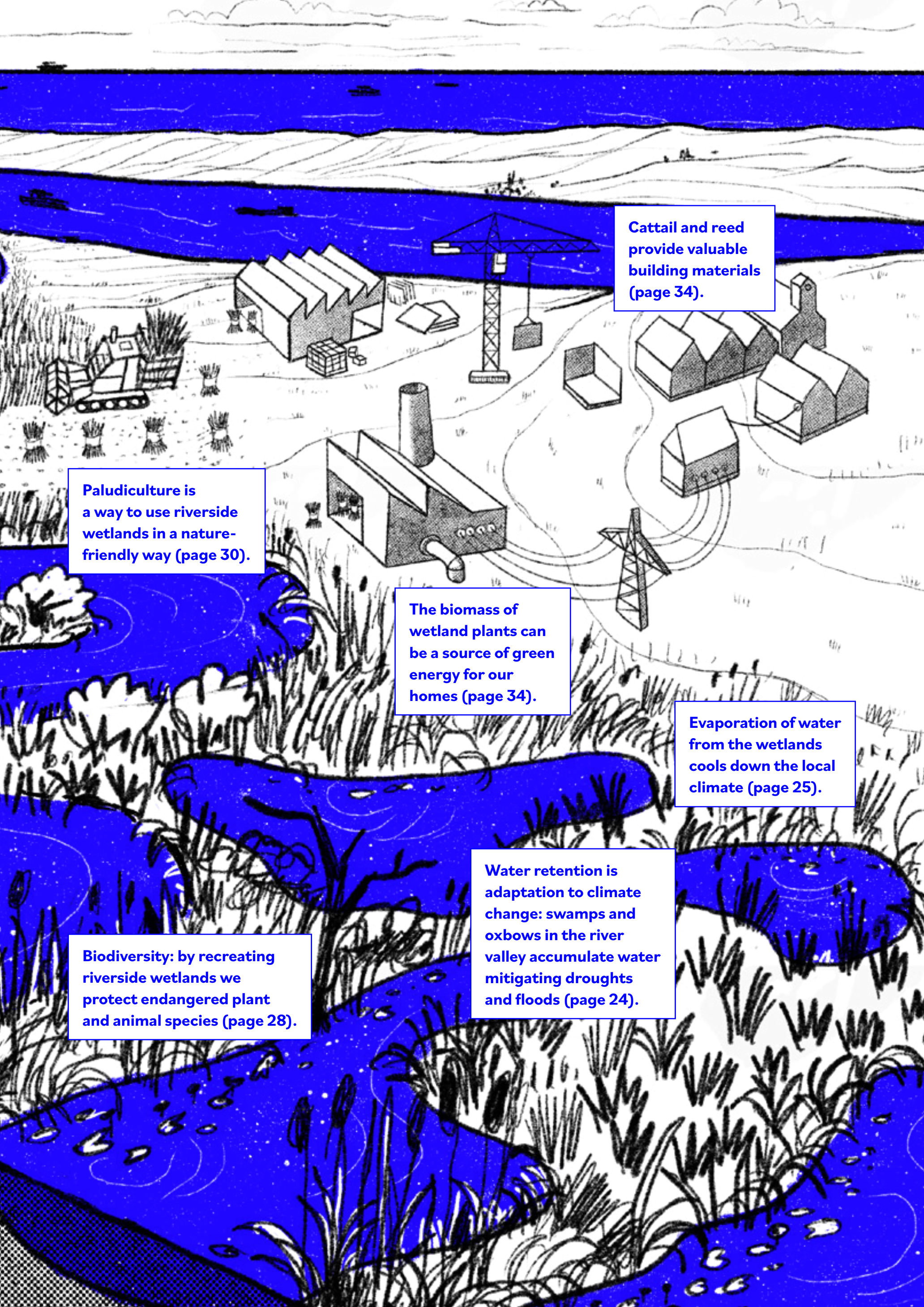
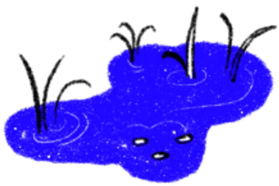

Clean rivers for clean sea! Wetland buffer zones can significantly reduce the inflow of nutrients and prevent the blooming of toxic cyanobacteria and formation of dead zones in the sea (page 7).
Naturally meandering rivers with riparian wetlands can effectively purify water (page 21).
Agricultural fertilisers and nutrients they contain are released into surface water and groundwater, threatening aquatic ecosystems (page 5).
By blocking ditches and rewetting drained peatlands we reduce greenhouse gas emissions (page 27).
Riverside swamps are valuable spawning grounds and hiding places for fish (page 28).
Water purification: the roots of wetland plants take up nutrients and build them into their biomass, whereas the bacteria living among them convert nitrates into atmospheric nitrogen (page 11, 21).



Cattail and reed provide valuable building materials (page 34).
Paludiculture is a way to use riverside wetlands in a nature-friendly way (page 30).
The biomass of wetland plants can be a source of green energy for our homes (page 34).
Evaporation of water from the wetlands cools down the local climate (page 25).
Water retention is adaptation to climate change: swamps and oxbows in the river valley accumulate water mitigating droughts and floods (page 24).
Biodiversity: by recreating riverside wetlands we protect endangered plant and animal species (page 28).

Wetlands retain water – how WBZs mitigate droughts and floods?



Natural wetlands, rivers and river-WBZ systems retain their functions mainly due to the water they are capable to store. River training and their regular maintenance by dredging 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 gradual incision and increased 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 of groundwater levels in their vicinities. Prolonged drainage resulted in degradation of soil organic matter, which further decreased the capability of soils to soak-up and retain water. Special case are peat soils, which quickly decomposed due to the drainage, in drastic cases turning into almost water-impermeable moorsh.

The second effect is related to the 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 air, contributing to a significant cooling of the landscape. This absorbed energy is released back in the higher parts of atmosphere, when water vapour condenses

4 — Aquifer — water-saturated layer of sediment or rock.

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

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 flush flooding, which under current model of water management is often “cured” by 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 WBZ’s to be flooded, not causing any major damage to the managed environment. In the face of anticipated increase in drought recurrence in Europe it is claimed that neither technical nor nature-based solutions can allow societies for prevention of shortages of water. However, restoring WBZ will allow to mitigate the negative effects of hydrological extremes (Lehner et al., 2006).

A longer version of this chapter can be found in the extended version of the brochure on the website.

WBZs — good for climate!

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**[6] strategy. On the other hand, WBZs are also **adaptation**[7] measures, ameliorating the impacts of global climate change on terrestrial and aquatic ecosystems.

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.

More information can be found in the extended version of the brochure on the website.

WBZs serve as habitats for threatened wildlife — why should we care?

Transforming rivers and riverside landscapes we contributed to a 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.

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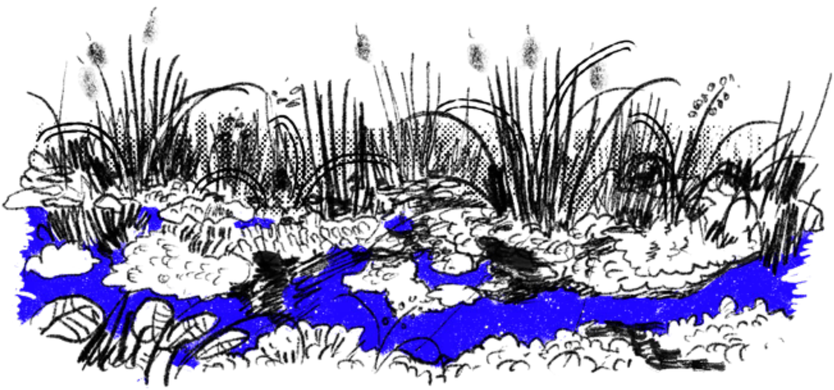
Wetland biomass – good for farmers and business sector!



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 adapting 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 re-wetting 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 be successfully 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 & Joosten 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.

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 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 an entry to new bio-based **circular economy**, allowing to replace fossil fuel-based energy and materials with bio-fuels and natural products.

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 be either cultivated or will be spread by natural succession after rewetting by raising water levels. Whether the plants establish spontaneously depends on the seed bank[8], 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.

8 — Viable plant seeds stored naturally in the soil.

Wetland plant species and their nutrient removal potential

The highest amounts of nutrients can be removed by 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 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.

1 — **Fodder and cattle breeding** — the quality of fodder produced on wetlands largely depends on their nutrient status. In rewetted low-productive peatlands plant biomass has a low feeding value. Suckler cows will be hungry and starving if they are supplied exclusively with such feed. The only ruminant species that seems to be

able to cope with this type of feed is the water buffalo. The situation is different in more nutrient-rich wetlands. The fodder and nutritional value of spring-mown cattail from eutrophic sites is high. 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. Other plant species that are suitable for fodder production are reed canary grass (*Phalaris arundinacea*) and reed sweet-grass (*Glyceria maxima*).

2 — **Building material** — during 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 since centuries as roof thatch on traditional houses, that are common all over the world, and is increasingly popular also in construction industry for the lodging and luxury real estate sectors. The 'Thatcher's Craft' was recognised by the UNESCO as an intangible cultural heritage in 2014. Currently, e.g. Netherlands, Germany, UK and Denmark rely on import of up to 85% reed thatch from Eastern and South-eastern Europe as well as considerable amounts from China. The use of WBZs for reed thatch production could meet the regional demand.

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 addition of a mineral lime. The plates not only have 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 a 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. 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. 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). In Northern Europe reed canary grass has been successfully cultivated on former peat excavation areas and used for combustion. 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 — all biomass types showed a heating value of 17.4–18.8 MJ/kg (Dahms et al. 2017). 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 on 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. Moreover, wetland agriculture is almost devoid of potential competition for space between biofuel growth and food-oriented agriculture — a frequent argument against biofuel crops.

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 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.

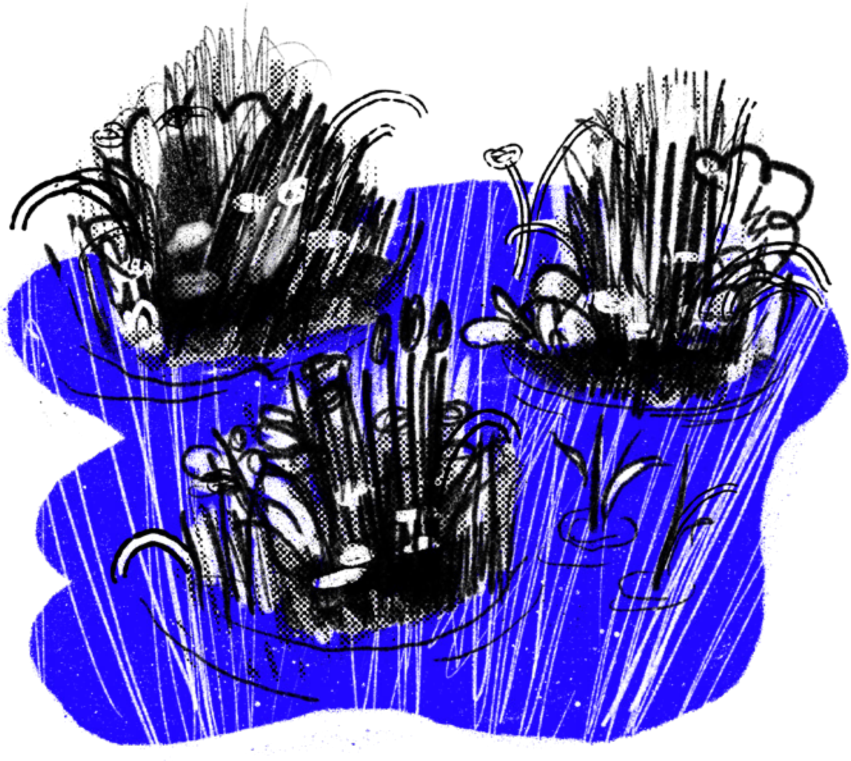
5 — **Furniture from black alder** — alder can be cultivated on eutrophic wet fen soils. The productivity of a 60 year old alder cultivation is high enough to provide about 420m^3/ha compacted wood. The harvest is still a critical point, but there is rope-based machinery available.

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 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. Right GHG balance can be retained when biomass is directly used to produce growing media.

People like WBZs along rivers!



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 population to answer hypothetical questions or to choose the favoured variant out of several alternatives. The latter method is referred to as 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, despite the fact that the Polish

GDP per capita adjusted by the Purchasing Power Parity (PPP)[9] 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.

9 — Purchasing Power Parity — indicator of a level of differences in prices between countries, enables comparison of the cost of living between countries.

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 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 with respect 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, 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 a 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.

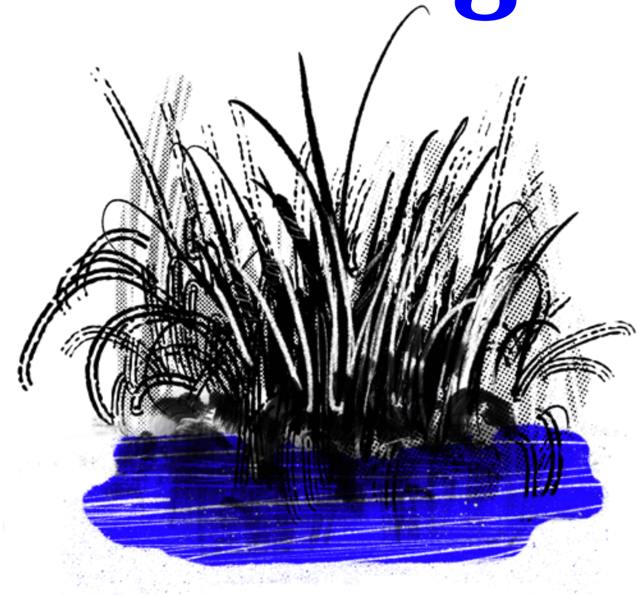
It seems that wild-looking rivers are simply attractive for people, whereas the respondents in three Baltic Sea countries possess good knowledge about small rivers, their current state and restoration prospects, riverine ecosystem services, and perhaps more generally — about the urgency to mitigate the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

Is their restoration and implementation expensive?

Wetland restoration is a cost-effective measure against nutrient pollution when compared to agricultural measures or waste water 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 of the local situation.

More information on the costs of implementing WBZs in Denmark, Germany and Poland can be found in the extended version of the brochure on the website.

Legal and economic challenges



The policy context of the Water Framework Directive (WFD) can offer a rich environment for WBZ-associated actions by acknowledging, promoting and funding wetland restoration and wet agriculture within integrated water management plans as well as associated policies. In particular, the instruments of the Common Agricultural Policy are crucial for meeting the goals of the WFD.

More information can be found in the extended version of the brochure on the website.

Project CLEARANCE

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.
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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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References

The list of cited literature is available in an extended version of the brochure on the website: guidelines.clearance-project.com

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