Chapter 7

Urban Wetlands and Riparian Forests as a Nature-Based Solution for Climate Change Adaptation in Cities and Their Surroundings

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Abstract Wetlands and riparian forests belong to the most productive, but also the most vulnerable, ecosystems in urban regions and cities due to their complex watershed system, often very high biodiversity and the pressure from urban land use and surface sealing. Wetlands and floodplain forests are often highly valued recreational areas, providing many benefits for urban dwellers, such as fresh air, moisture, oxygen and biogenic essentials as well as many cultural and place-based values. Wetlands and riparian forests are very efficient spaces for water and matter regulation, pollutants fixation and flood water retention. Thus, particularly for dense urban areas, they represent almost perfect nature-based solutions for risk mitigation and adaptation concerning both climate extremes: flood and drought. Moreover, they can serve as a buffer against high air temperatures and provide wetness during heat waves. However, urban wetlands and riparian forests are often endangered by urbanisation pressure, land take for construction purposes and pollution. This chapter provides arguments that urban wetlands being a nature-based solution for cities facing climate change and presents design options to expand and even create such wetlands in cities where remnants are no longer available.

Keywords Urban wetlands • Riparian forests • Nature-based solution • Climate change adaptation • Cities

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7.1 Introduction: What Is the Value of Wetlands and Riparian Forests in Cities?

Wetlands and riparian forests belong to the most complex ecosystems on the planet. Their water balance and watershed systems are highly complex in terms of the ongoing interactions between ground-, interflow and surface waters (Haase and Nuissl 2007). Wetlands are able to store an enormous amount of water in their sediments, soils and vegetation. They can buffer extreme air temperatures due to the flows of evapotranspiration they create. Their typically loamy, clay and silt-rich floodplain soils are fantastic buffers and transmitters of all kinds of organic and inorganic pollutants emitted; they represent a kind of 'translocation area' for matter and are a sink and source of pollutants at the same time. Mature floodplain trees sequester and store considerable amounts of CO₂, contributing to climate change mitigation. In terms of flora and fauna, wetlands and riparian forests provide multiple wet and perennial habitats and, consequently, are home to thousands of species (Fig. 7.1).

Since the industrial revolution and in particular since WW II, cities represent the main 'habitat' for humans, with about 55% of the world population and current estimates assume that some 75% of the global population will live in cities by 2030 (UN 2016). Cities are places of close contact between humans and nature, where society and biodiversity are privy to complex interactions and co-evolution in terms of typical urban niches adapted gene mutation and species creation (Alberti 2015).

Many cities have been established along rivers due to the economically and defense-related strategic location and the availability of water resources and fertile soils (Kühn and Klotz 2006). Thus, wetlands, riparian forests and cities already share a long history punctuated with synergistic interactions and risk creation (Schanze 2006). More specifically, river floods endanger humans and their properties and humans in turn destroy wetlands and floodplain forests by means of construction, surface sealing, groundwater regulation and tree cuttings. However, when society supports the proper functioning of wetlands, these habitats and their forests can produce significant ecosystem services for urban dwellers, including the aforementioned regulation functions as well as being recreational areas and places for all age groups to experience and

Leipzig, Weiße-Elster-floodplains

Vienna, Danube floodplains

Fig. 7.1 Typical urban wetland and associated floodplain forest in Leipzig, Germany, and Vienna, Austria (Photos: Dagmar Haase)

enjoy nature and, what is more, providing cool places during hot summers and thus to support physical health of urban dwellers (Haase 2003; Andersson et al. 2015).

As outlined previously, wetlands and riparian forests offer a multitude of services which benefit both society and biodiversity. They are ideal nature-based solutions for regulating the effects of climate stress and climate change that cities are increasingly faced with, including heat waves, long dry spells, floods and related accumulation of polluted sediments. Furthermore, and in addition to their importance in water flow regulation, they are stepping stones for species of different taxa and place of the creation of novel or altered habitats and the survival of endangered species (Elmqvist et al. 2015).

However, and not least because of the aforementioned properties, river regulation and drainage of wetlands have been common practice in most areas of Europe for centuries, with interventions increasing over the past 50–100 years. More than 50% of the European wetlands that existed 100 years ago have been lost mainly to urban developments (conversion into other land types) (European Commission 1995), leading to a substantial decrease in the number, size and natural habitat of large bogs and marshes and small or shallow lakes. As a result, both European legislation (e.g. the EU Birds Directive (1979) and the EU Flora, Fauna and Habitats Directive (1992; European Commission) and international agreements (i.e. the Convention on Wetlands of International Importance especially as Waterflow Habitat (Ramsar, Iran, 1971)) have implemented protective measures. A considerable part of European wetlands (>40,000 km² or about 0.5%) has been designated as ‘Ramsar sites’ under the international convention.

Next to cities themselves, roads have a major impact on wetlands and riparian areas in central parts of Europe characterised by a dense infrastructure, such as Austria, Belgium, Denmark, Germany, Luxembourg and the Netherlands. And, what is more, this pressure along with peri-urbanisation is expected to increase as settlement areas and transport networks expand (Fig. 7.2).

Fig. 7.2 Proximity of major transport infrastructure to Ramsar areas in selected European countries (European Commission 1995)

7.2 Ecosystem Services Relevant for Climate Change Adaptation Provided by Wetlands and Riparian Forests and Trade-Offs

Wetlands and riparian forests provide a multitude of ecosystem services (Haase 2014; Kroll et al. 2012). They are extremely efficient and important cooling elements in urbanised areas due to their continuous high groundwater levels, their wet soils and, in the event that they include a forest stand, the leaf-based shading and transpiration effects (Breuste et al. 2013). Concerning climate change adaptation, the suitability of wetlands is manifold ranging from their organic soils as carbon stores to its alluvial parts as areas for local climate cooling, what is more, the role of floodplains as means to slow down flood peaks, as space for water and allowing for floods to happen and for water storage to counteract droughts.

In Europe, almost all riparian or floodplain forests are broadleaf forests with originally unique but heavily modified, except a few situations, tree stands and forest habitats. Natural floodplain tree stands with large, green leaves which help to cool the surroundings more efficiently than typical park trees (Table 7.1; Haase and Gläser 2009; Elmqvist et al. 2015). Data from Manchester (UK) show, for example, that a 10% increase in tree canopy cover may result in a 3–4 °C decrease in ambient temperature (Gill et al. 2007) and save large amounts of energy used in air conditioning (Nicolson-Lord 2003; Akbari 2002).

Due to increasing car traffic and travel activities in most of the large and megacities worldwide, air pollution with particular matter (PM₁₀, PM_{2.5} and PM_{<1}), NO_x and ozone, has been considerably increasing in the last three decades since 1990 (Weber et al. 2014a, b). This pollution heavily and considerably impacts the respiratory and cardiovascular systems of urban populations. Consequently, the health thresholds are exceeded in many cases, which have led to transport regulations and limits such as no driving in city centres or higher standards for cars in the cities in cities like Delhi or Karachi as well as in Milan, Torino, Stuttgart and Sarajevo. Trees are efficient filters of such particular air pollution, although they cannot mitigate the whole of the pollution concentration (Baró et al. 2015). The results of a multiple-city study indicate that the average air quality improvements due to air purification supply by trees are relatively low at the city scale, e.g. nitrogen oxides, particulate matter or ozone varying, e.g. from 0.07% in Rotterdam to

Table 7.1 Leaf area index (LAI) of floodplain forest species and wetland lawns (in italic letters) compared to ‘classical’ urban tree species and grassland (defined as leaf area per soil unit, BFI = A(leaf)/A(soil unit))

Tree species	BFI
<i>Beech</i>	6–8
<i>Oak</i>	5–7
European larch	2–4
Forest pine	3–4
Spruce	5–10
<i>Lawn</i>	7
Grassland	1–2

0.81% in Stockholm for NO_2), although positive effects are likely to be more relevant in highly tree-covered areas such as urban forests; for example, the expected air improvements are higher than 6% for PM_{10} in Stockholm (Sweden) and Salzburg (Austria), assuming a 100% tree cover (Baró et al. 2015). For the city of Leipzig (Germany), the whole tree cover including the floodplain forests and the street and park trees is able to balance the CO_2 emissions of 6000 residents, which is about 1.5% of the urban population (Strohbach and Haase 2012).

Wetlands are also a sink for matter and could become, depending on the geochemical milieu and flooding, a source of matter (Haase and Neumeister 2001). Fluvisols, the typical soil type of wetlands, are able to bind many organic and inorganic compounds due to their high contents of fine grain material (clay, silt), Fe oxides and, in their topsoils, up to 10% organic carbon (Table 7.2; Haase and Neumeister 2001). Thus, a closed coverage layer of wetland soils is the best protection against the pollution of the local and regional aquifers that provide fresh water for urban dwellers (Haase 2009). Thus, the soils and tree cover of wetlands and floodplains serve as a highly efficient metabolic body for nutrient fluxes and pollutant, benefiting the humans settling around these areas.

Next to the many abiotic properties and processes that are beneficiary for humans, wetlands and riparian forests provide excellent and unique habitats for not only humans but also many other species (Elmqvist et al. 2015). Floodplain forest trees such as *Quercus* (oak) or *Fraxinus* (ash) as well as *Salix* (willow) or *Carpinus* (beech) are habitat to up to 1000 animal species and thus critical elements of local and regional food chains. Whole food webs/chains are linked through particularly old floodplain forest trees with mighty stems and thick bark, and wetlands are larger landscape elements that link habitats at the regional scale as fauna migration and nesting areas (Alberti 2015). Due to the high variety of species that inhabit wetlands, these landscapes are specifically robust against single pests and thus act as natural pest control (Alberti 2015) as the survival rate of the ecosystem is higher when not all species are affected. At the same time, being wet habitats and charac-

Table 7.2 Matter sink and matter flow balancing functions of fluvisols compared to other urban substrates

Soil/substrate property	Fluvisol	Regosol (sand)	Cambiosol	Gleysol (clay)	Regosol (sand)
Infiltration capacity	+	++	±	--	++
Nutrient accumulation	+	--	—	++	--
Nutrient cycling	++	—	+	+	—
Pollutant accumulation	++	—	+	++	—
Water capacity	++	--	+	++	--
Water flow balancing	+	—	++	—	—
Mechanical filtering	+	+	++	—	+
Chemical filtering	+	--	—	++	--
Drainage	±	++	--	—	++
Erosion susceptibility	—	±	+	--	±

with ++ is very good/high, + is good (high), ± is medium, — is poor/low and -- is very poor/low

terised by closeness to water, they provide ideal breeding grounds for the spread of invasive species such as the tsetse fly, *Aedes aegypti* or *Amenophelis* that inflow from south and are carrier of so far unknown illnesses such as yellow or dengue fever or types of ticks bringing *meningitis* and *encephalitis* as well as bringing endemic malaria possibly back to Europe (Medlock and Leach 2015). Thus, while using wetlands as a nature-based solution to flood alleviation, air cooling and pollutant fixers to address those threats, they can also create trade-offs and disservices (Döhren and Haase 2015).

Potentially the most important and widely known property of wetlands and floodplain forests are their role as a flood moderator; their function as drought moderator is far less known (Haase 2011). Wetlands and floodplains are spaces to naturally store and ‘save’ water in times of high rainfall and long periods of precipitation. Historical wetland management has made use of the high water storage and spatial inundation capacities of floodplains and thus created the most fertile and productive landscapes in former centuries, such as the Hungarian Tisza floodplains (Haase 2011), the Oder valley in Germany (Dalchow and Bork 1998) or the area of Kaliningrad in Northwestern Russia. Only in case they were object of an artificial embankment and river regulation, wetlands can change from places of saving water to places that let water easily migrate into surrounding spaces creating loss of life, loss of property and loss of assets being a clear trade-off (Scheuer et al. 2012).

7.3 Urban Wetlands as a Nature-Based Solution and Options for Their Design

As discussed in the previous sections, wetlands and their riparian or floodplain forests as such are solutions created by nature to store, distribute and hold water in ecosystems and whole landscapes. This function has been largely impacted by humans, mainly in cities and urban areas to use the water as resource and the river as transportation means, on the one hand, and to protect human lives and assets from floods on the other hand (see Haase 2011, Kubal et al. 2009 and Meyer et al. 2009). However, the last big floods in Europe (Elbe, Oder, Mulde, Tisza, Rhine to list a few) drew attention to the fact that technical or built protection against water will not provide 100% protection to people in cities against floods, particularly when taking climate change and longer heavy precipitation events into consideration. Moreover, events such as the hurricane Katrina in the USA in 2005 or the last Elbe flood in Germany in 2013 with hazardous bursting of large dams made very clear that technological solutions in case they fail can produce enormous damage and casualties as their capacities are enormous in terms of how much water they can collect/hinder to flow, actually much more than any nature-based solution can (see also a global map by Scheuer et al. 2012).

But, which efforts could instead be reinvested in restoring and maintaining the functionality of wetlands/floodplains? The revitalisation of large and smaller rivers

and thus a continuous and more natural inflow and distribution of rainfall water in a larger area have been shown to improve protection against horrible flood events along rivers and coasts (Fig. 7.3; Middelkoop et al. 2004; Krysanova et al. 2008). A restoration of the (remnant) riparian vegetation would assist in reconnecting rivers with floodplains and to provide greater instream ecosystem complexity, particularly in urban areas (see examples in Fig. 7.3). In addition to restoration, wetlands could also be created, including so-called balancing ponds, and thus natural functions created by a kind of nature mimicry in the surroundings of cities. Also bioswales as their smaller version could be created along streets in, e.g. housing areas to take up and hold rainfall water and, what is more, moisturize the dry urban air after the rainfall event for a while (Fig. 7.3; Haase 2016). Also permeable surfaces can support this moistening of urban areas. A high channel diversity in the wetlands themselves but also in form of bioswales and integrated into the street network would reduce the speed of (superficial) flood transmission. All these measures are known in hydrology and hydrological construction; however, in urban planning they need better introduction and a cooperation between landscape planners, ecologists, green infrastructure specialists on the one hand and hydraulic engineers on the other to

Recreation areas to promote health and happiness

Tree planting to clean the air and to filter pollutants

(Re-)Greening waters to buffer noise and to filter pollutants

Revitalization of wetlands rivers to balance the urban water cycle

Bioswales to store rainwater in streets and to lower the flood risk

Constructed wetlands to regulate ground- and surface water flows

Restoring fluvisols to bind and immobilize pollutants

Room for rivers to alleviate floods and to safe cities from hazards

Nutrient-cycling for food production in cities and prevent food import

Fig. 7.3 Nature-based solutions linked to wetlands, riparian forests and floodplains (Photos: Dagmar Haase)

Table 7.3 Nature-based and artificial/built water retention and climate change adaptation measures for relevant spatial response units

Spatial response unit	Grey measures	Green measures
Cities	Infiltration devices	Filter strips and bioswales
	Dams, dikes	Permeable surfaces and filter drains
	Walls	
	Underground drainage	Green roofs and green walls
Urban regions	Basins and ponds	Wetland restoration/construction
	Dams, dikes	Floodplain restoration
	Reservoirs	Re-meandering
		Restoration of lakes
Larger river catchments	Dam and dike systems	Natural bank stabilisation (also at catchment level)
		Afforestation and forest protection
	Reservoirs	Maintaining and developing riparian forests
		Afforestation of agricultural land
		Afforestation of unused land and pastures
		Buffer stripes of agricultural fields

According to Vanneuville and Werner (2012), modified

make the suggested nature-based solutions effective and successful (as already mentioned by Pahl-Wostl 2007).

The restoration and construction of wetlands would increase and enhance all of the aforementioned ecosystem services provided by wetlands and riparian forests and provide additional health benefits for urban dwellers such as cooling by tree shade, aesthetic improvement of biodiversity and healthy forest products to be foraged (e.g. fruits, mushrooms, herbs). In terms of the spatial configuration of wetlands as parts of larger river catchments, the aforementioned measures might be carried out either within cities or also upstream to be most efficient for flood protection, for example. This is a typical case for regional planning. Table 7.3 summarises again the various options of grey and green solutions in wetlands to face the effects of climate change.

7.4 Discussion and Conclusions

Several options have been outlined which utilise wetland and riparian forests' functionality as nature-based solutions to better face the consequences of climate change in cities and urban regions. The following are the key observations:

1. Wetlands, floodplains and riparian forests are very precious and in many respects unique ecosystems of high complexity that are able to 'deal' with large amounts of water in a spatio-temporal distribution scheme (uptake, storage, release) that

saves humans, their assets and whole cities from extreme flooding. They have to be kept, and in case of their destruction, they have to be restored whenever economic and social trade-offs permit it. Moreover, rivers should be—as far as possible and at locations where possible—reconnected with floodplains to enhance natural water storage in the whole catchment system.

2. Wetlands can provide inspiration for how water storage could work also for non-lowland situations such as top hill situations and inner city areas. Wetlands could be created/constructed as a kind of nature mimicry in the form of constructed wetlands in the peri-urban landscape and smaller bioswales along streets in densely built inner city locations as ‘smart and space saving’ accepting the basic structure of the grey environment. Together, natural and newly created/constructed wetlands could support the regulation of the magnitude and timing of water runoff and flooding as well as the recharging of aquifers.
3. We need to better understand and make use of the enormous balancing, buffering and metabolic capacities of wetlands and their forests in cities as well as the recreational opportunities and air pollution filtering capacities, as they cannot simply be replaced by technology or grey infrastructure solutions.
4. As cities have been built and transformed over centuries and as humans are the dominating creative factor in cities and urban regions, natural remnants of wetlands and floodplain forests have to be combined with technological/technical solution such as discussed under (2). Implementing wetland functionality, be it restoration or creation, can be a way and a new job creator to realise ‘mini-wetlands’ and ‘riparian trenches’ in areas disconnected from the river. The complementarity of both nature and technology under the supervision of society might be a clever, pragmatic but at the same time innovative solution to complex problems created by man and nature response.
5. A combination of ‘C&C’—conservation and construction—might be a coupled solution for most of our cities when it is about climate change adaptation. Along with this, a new way of urban governance including co-development and co-production to create real societal benefits and acceptance is needed to give this new ‘C&C’ a real chance.

However, as also discussed in this short contribution, wetlands as natural systems create trade-offs when it comes to human health and infectious diseases, particularly vector-borne diseases and regarding the loss of land for new developments. Knowledge about this fact or ‘disservice’ is a first step to create awareness. Strategies for public protection and, if needed, intervention are following steps to balance these trade-offs. Climate change itself can increase the ‘danger’ of new vectors and new infection risks, no doubt, but such trade-offs do not diminish the high value of wetlands and their riparian forests as natural solutions for adapting to climate change in cities and urban regions. For many cities across Europe, climate change and a gradual warming are already a reality, and based on recent temperature prognoses (IPCC 2016), the situation gets worse in terms of an increase in mean summer day and night temperatures and more heavy and less effective rainfall events. Thus, and despite a potential increase of vectors, there is a need to ‘switch tactics’ replacing grey for green.

Investing in restoring, protecting and enhancing ecological functionality and ecosystem services in urban wetlands is not only ecologically and socially desirable (cf. Elmquist et al. 2015), but as the contribution has shown, wetlands are socio-ecologically viable recognising their multiple services and all their associated benefits for the large number of beneficiaries in cities.

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