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SPECIAL SECTION

River culture: How socio-ecological linkages to the rhythm of the waters develop, how they are lost, and how they can be regained

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Abstract

The hydrological patterns of all natural water bodies pulse in variable rhythms of high and low water. The biodiversity of these ecosystems is driven by the changing nature of the environment, allowing different life strategies to coexist, e.g., by the fast reuse of nutrients when aquatic biota flourish in the recently wetted zones and vice versa. Much of the human culture in hydrosystems has developed as an adaptation to this rhythm, e.g., by using the flood-fertilised floodplains for agriculture or fisheries, or by seasonal migration into or out of the floodplain (transhumance). Technological advances have allowed humans to control, change, or even eliminate this natural water rhythm by building dams, dikes, and canals. Consequently, important ecosystem functions fail, often resulting in failure of human life-support systems but also in the failure and decline of cultural activities. I argue that the loss of socio-cultural connectivity to the rhythms of rivers and other hydrosystems occurs in four phases: (i) loss of direct relationships (e.g., uses of waterborne resources), (ii) loss of indirect relationships (cultural activities that are connected to these uses), (iii) turning away from the river/hydrosystem (often caused by decreased water quality), and (iv) total oblivion (caused by removal or burial of the hydrosystem). Reintegrating more riverine rhythms into human life would not mean to step back in time but rather to find a combination of revised traditional ecological knowledge, learning from nature, changing values in the context of use of natural resources, and innovations. This paper draws on social-environmental aspects of the River Culture Concept – which attempts to reintegrate respect for the pulsing nature of hydrosystems into modern, sustainable management – and on diverse case studies. Examples are presented on how River Culture Concept approaches may contribute to revitalising socio-ecological linkages to the rhythm of the waters.

KEYWORDS

environmental flows, flood pulse, human–river relationships, integrated river basin management, nature-based solutions

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1 | INTRODUCTION

All emanations of life on Earth occur in rhythms, regular patterns of movements that are originally driven by physical processes. Movements of planets and solar cycles cause the rhythmic change of the distribution of light, heat, and electromagnetic energy on earth, provoking complex daily, annual, and multiannual patterns of, for example, climate, precipitation, or temperature (Breus et al., 1995). Due to the complex interactions between the different components of the environment, such as the effect of superposition of snowmelt and precipitation events on river discharge, the nature of these rhythms is variable. Consequently, the period in which a certain environmental situation may occur can be anticipated, but the precise moment, its dimensions, and its dynamics remain unknown. This has deep consequences for the evolution of life strategies of all biota and for human culture.

The field of chronobiology analyses how biota, including humans, adapt their life cycle strategies to these physical rhythms (Dunlap et al., 2004). Moreover, by reacting to these physical rhythms, organisms produce rhythmic life patterns by themselves and may stimulate those of other species. For example, the annual salmon run in the North American Pacific tributaries provides a rhythmically occurring cornucopia of energy for predators, scavengers, and even forest trees (Helfield & Naiman, 2001; Jager, 2014). Classical ecological studies analyse the ability of biota to adapt their life strategies to windows of opportunity (i.e., the co-occurrence of favourable parameters) and windows of susceptibility (i.e., the co-occurrence of unfavourable parameters) in their environment, resulting from combined abiotic and biotic rhythms. For example, winter moths develop best if oak leaves are well developed when their eggs hatch in early spring but before the leaves contain high amounts of antifeedants; hatching too early would result in starvation of the caterpillars, hatching too late would result in their intoxication (Feeny, 1970). Due to climate change, the match between the forecasted period of these windows by species traits and the real period of its occurrence is increasingly lost (Renner & Zohner, 2018).

Humans, having physiological functions similar to those of other animal species, have developed behavioural and cultural adaptations to environmental rhythms (such as hunting during animal migrations) during their evolution, but they also influence the natural rhythms in many ways (e.g., by using artificial light, heating, or controlling the flow of rivers) which often affect other biota that depend on natural rhythms.

Rhythms are important in human life in a way that exceeds humans' dependence on and interactions with their biotic and abiotic environments. Humans are attracted by pulse, tempo, and rhythmic patterns of acoustic or optical signals (Levitin et al., 2018) and rhythmic patterns are considered an integral part of mathematical thinking (Radford, 2015) so that their perception by humans can be defined in many different ways (You, 1994). Obviously, and most evidently in music, rhythms and their variations are of great importance for human creativity. In his essay *L'Esthétique des rythmes*, the French philosopher Henry Maldiney (1973, pp. 147–172) goes beyond the primary notion of rhythms as a streaming phenomenon (in the sense of 'defined by time flow'), as it occurs, e.g., in music, dance, and metrics of poetry, and introduces rhythm as a central element of non-streaming, visual arts, in which time is not immediately apparent, such as plastic art and painting, and concludes that all aesthetics derive from rhythm (Blümle, 2011).

This conceptual paper deals with the relationships between organisms (including humans) and the rhythmic nature of riverine hydrology. It draws on earlier publications on the River Culture Concept (Wantzen, Ballouche, et al., 2016; Wantzen, Tharme, et al., 2022), but here the focus is on the variable nature of hydrological rhythms and their specific effects on life. Contrary to recent papers focusing on the human perception of river rhythmicity (Jackson et al., 2022; Krause, 2022), the perspective of this article is from an ecological basis toward sociological mechanisms. However, all these papers, including the present one, have the common goal to value river systems integratively and to contribute elements to the transdisciplinary and sustainable management of riverscapes.

The next part of this paper analyses the nature of hydrological rhythms and their importance for biological and cultural adaptations. Then, the causes and consequences of losing these rhythms are discussed. Finally, management options to reintegrate them into human life are examined.

2 | NATURAL HYDROLOGICAL RHYTHMS IN AQUATIC ECOSYSTEMS: VARIATIONS TO A THEME

All kinds of water bodies are in motion, including those that are called 'stagnant'. Even minute local differences in precipitation, evapotranspiration, water density, the declivity of the landscape, porosity of sediments, and/or capillarity of soils suffice to make their waters move. Thereby they display rhythmic patterns concerning their hydrology – the distribution of water over space and time. In analogy to the alternating strong and weak beats in musicological rhythms, the

alternating events in hydrology are high and low water levels during daily tides, annual or multiannual flood–drought rhythms, but also the variable amount and velocity of water flow – resulting in alternating levels of energy to displace objects by erosion, transport, and sedimentation – and alternating concentrations of dissolved substances, as a mixture of the variable origins of the water (groundwater, interflow, surface runoff of different tributaries).

This rhythmic pattern is universal to any kind of aquatic ecosystem; however, there are characteristic types of rhythms for each type. Marine ecosystems have well-studied tidal rhythms, which shape biota and culture (Jones, 2011) and have great importance for place-making at the water–land nexus (Kaaristo, 2020). Lakes, if not regulated, also display rhythmic water-level fluctuations (Wantzen et al., 2008) and even the invisible groundwater ‘swings’ in rhythms, even if these generally have slower dynamics or lower amplitudes than surface waters (Fan et al., 2013). The degree of variation to the annual pattern is generally size-dependent: large water bodies have a less variable pattern than small ones. All these systems have in common that the general pattern of hydrological dynamics can be easily recognised when plotting long-term averages of water-level fluctuations. However, the precise shape of the time series (the annual hydrograph) is unpredictable due to the complexity of the above-mentioned interactions of the abiotic and biotic processes. There are no two identical hydrological years.

Since Aristotle, rivers have been the epitome of permanent change. In addition to the longitudinal flow from the mountains to the sea, the water makes vertical and lateral movements in expansion and contraction cycles. These pulses occur in daily, annual, and even multiannual flood patterns. The natural flow regime (Poff, 2018) is four-dimensional: high/low flows and flooding/drought occur in the longitudinal and transversal dimensions, respectively, combined with the vertical groundwater exchanges, and all these are permanently changing in a temporal dimension (Ward, 1989). The land–water nexus displays a spatio-temporal pattern of alternating dry and wetted areas, producing a ‘moving littoral’ crossing the planform of the landscape (Junk et al., 1989; Junk & Wantzen, 2004; Krause, 2022; Tockner & Stanford, 2002). Small streams react very quickly to rainfall or snowmelt effects and their discharge can increase substantially, resulting in high amplitudes and high frequencies of change (Allan & Castillo, 2009). With increasing size and decreasing altitude, natural, large rivers integrate the individual flow patterns of their tributaries, resulting in longer periods of floods and droughts and slower changes (Wohl & Lininger, 2022). These general patterns are influenced by the catchment size, the declivity of the landscape, and precipitation patterns especially in the piedmont zone of mountains; fast spring floods may occur even in large rivers after seasonal rains or snowmelt (Wohl & Lininger, 2022). Beyond these natural, annual patterns, there are multi-year phases of drier and wetter years, which may be driven by global climatic cycles (Liang et al., 2016), or human impacts like climate change (Feng et al., 2021) or damming (Grill et al., 2015; Jardim et al., 2020).

If we compare hydrographs of rivers with music, one can interpret the annual or multiannual patterns as ‘variations to a theme’, similar to the acoustic artwork by Johann Sebastian Bach. In music, the frequency of the sounds or other signal patterns and the length of the rhythmic sentence may vary, but the overall pattern is generally recognisable. In the case of the ‘Goldberg Variations’, Bach modifies one sarabande-like theme, the aria, 30 times by making allusions to other musical forms or sentence types, such as gigue, polonaise, toccata (Williams, 2001). The ‘Shape of Song’ project by the mathematician and artist Martin Wattenburg visualises music, using a specific software, by drawing musical patterns in the form of translucent arches (<https://www.turbulence.org/Works/song/index.html>). His visualisation of three of the Goldberg variations (Figure 1) or the video display by Stephen Malinowski (<https://www.youtube.com/c/smalin>) show a combination of ‘reiterative-variable’ but not ‘purely repetitive’ patterns, which can also be found in many other pieces of music. Listening to these variations to a theme can be very inspiring to develop new ideas, and has a wide range of neurochemical effects (Chanda & Levitin, 2013).

In the case of its hydrological analogue, the annually varying hydrographs, alternating rhythms, and ‘variations to a theme’ open the opportunity for aquatic, terrestrial, and amphibious organisms (including humans) to develop a high diversity of life strategies (see the following section). Rhythmic hydrological patterns are one (but not the only) music to which life is dancing (Wantzen, Tharme, et al., 2022).

3 | HOW DO ORGANISMS DEVELOP ADAPTIVE MECHANISMS TO RHYTHMIC HYDROLOGICAL CHANGES?

The pulsating changes of flow and wetted area in floodplain systems represent the above-mentioned ‘windows of opportunity’ (i.e., offered resources that can be used) and ‘windows of susceptibility’ (i.e., risks that have to be avoided; see Figure 2 and Wantzen, Ballouche, et al., 2016). The ability of species to match elements of their life cycle – e.g.,

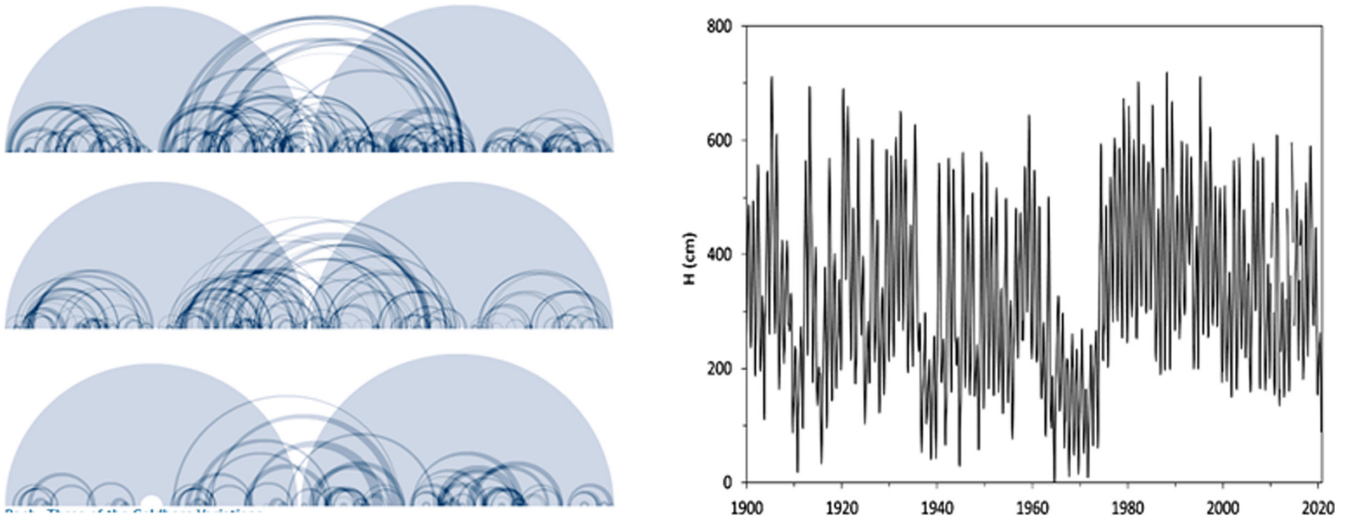


FIGURE 1 ‘Variations to a theme’. In three of the Goldberg Variations (BWV 988) by Johann Sebastian Bach (left) repetition of an AABB pattern and its variations can be visualized in the form of translucent arches by a specific software (Martin Wattenburg, <https://www.turbulence.org/Works/song/index.html>). The maxima and minima of the water level of the Paraguay River, Brazil (right, from Wantzen, Girard, et al., 2022), also show reiterating, recognizable, but modified patterns. In the case of the hydrological patterns, multi-year periods of drier and wetter years can be identified. These ‘themes’ are actually much more complex, as only two values per year are shown here. The annual patterns (not shown) form ‘subthemes’ with differently fast changing and long-lasting flood and drought periods.

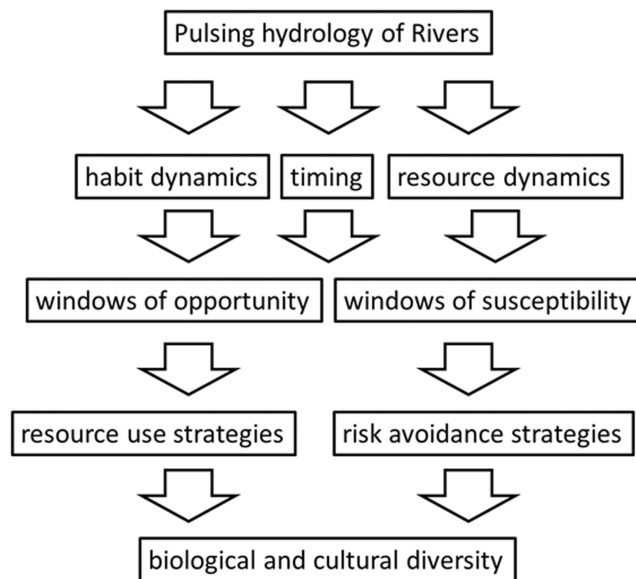


FIGURE 2 In the River Culture Concept, the parallel development of animal/plant adaptations and cultural forms according to hydrological rhythms have been postulated (after Wantzen, Ballouche, et al., 2016)

reproduction – in accordance with the timing and place-making of this alternating rhythm is subject to strong selective power. A mismatch could be fatal. Basically, the adaptive traits displayed by diverse floodplain biota are similar, including strategies for the survival of the adverse phase by developing drought- or flood-resistant forms, or by migrating out of the danger zone, or, vice versa, in the search for resources that have been brought by the phase change between wet and dry (see reviews, for example on plants, invertebrates, or fish, by Junk et al., 1997; Parolin et al., 2004; Wantzen, Marchese, et al., 2016). For example, in Lake Kinnereth, which has fluctuating water levels due to the flow pattern of River Jordan, minnows glue their eggs to recently flooded, but previously up-dried rocky shores, using the drought to remove algal biofilms that would prevent the sticky eggs from attaching to the rocks in the wave zone of the lake, which has the best oxygen concentrations for the development of offspring (Gafny et al., 1992).

The selective ‘windows’ are not evenly distributed, rather they display locally or temporally clumped patterns. Likewise, the biological processes that follow do not occur in linear dynamics, but in so-called ‘hot spots’ or ‘hot moments’ for microbes (McClain et al., 2003), animals, and plants (Wantzen & Junk, 2006), and often include mass mortality within one population and mass growth of another at the same time. Humans are often unable to perceive these complex and nonlinear patterns, as they are used to anticipating monocausal and linear patterns (Vester, 1980), and as most scientists have a limited attention time (e.g., timing and duration of a field study) and may overlook events that occur once in a longer period.

Wagner and Schmidt (2004) analysed a 50-year pattern of daily recordings of adult aquatic insects and of the hydrological patterns in a small stream in Hesse, Germany. As a result, they could identify the driving natural factors for the success and failure of groups of insect species that are linked to a specific hydrological rhythm and could identify five ‘archetypes’ of flow patterns that are quite similar to the ‘themes’ in music. A spring spate, for example, turns over stones and cleans them of biofilms, which may be detrimental to baetid mayflies but a bonanza for stoneflies. In short, the variable goodness of fit between life cycle strategy and natural rhythm is the reason why we observe mass occurrences of a given species in one year, and of another species in the following. Due to the fact that even nearby streams have different hydrological patterns, or, using the musicological term, different variations to one theme, the resulting abundance patterns of the flow-dependent organisms also have locally variable patterns each year. The spatio-temporal mosaic pattern of evolutionary windows that are alternately opening and closing in streams (Pringle et al., 1988) and large river floodplains (Tockner et al., 2010) occurs in similar ways in these systems, however different the spatio-temporal dimensions (Junk & Wantzen, 2006).

An important detail in this context is that despite the fatal effects for a *part* of the population, a natural ‘window of susceptibility’ may hardly ever eliminate an entire species. Rather, this variation results in a ‘sequential biodiversity’. Variable year-to-year conditions allow the sequential peaking of populations of different species at the same place, resulting in a high sum of present species (Figure 3). Many different species with different patterns of sensitivity may survive, even if they dwell on similar resources and at the same site. The Intermediate Disturbance Hypothesis (Connell, 1978; Townsend et al., 1997), which predicts higher biodiversity on sites that show an intermediate position between permanent disturbance (allowing only the best disturbance-adapted species to survive) and absent disturbance (allowing only the strongest competitors to survive), gains an additional, *temporal* dimension here: the timing and nature (i.e., the rhythm) of the disturbance can vary between the years (or other time units), and consequently different survival (life cycle) strategies may be successful under temporally variable disturbance rhythms.

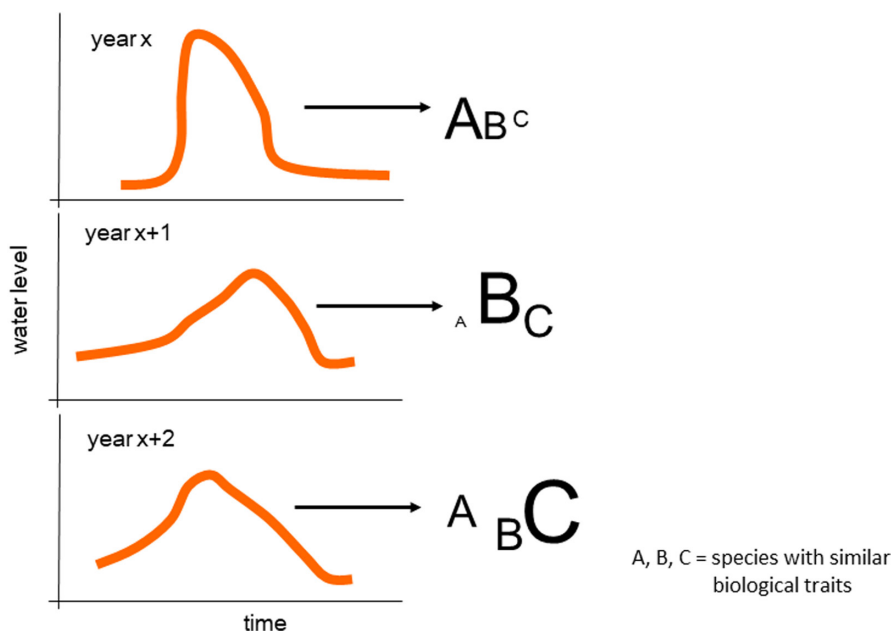


FIGURE 3 ‘Sequential biodiversity’ develops from the variable performance of different species with similar biological traits (A, B, C) in hydrologically different years ($x..x + 2$)

4 | HUMAN ADAPTATIONS TO AND MODIFICATIONS OF ENVIRONMENTAL FLOWS

Throughout evolution, *Homo sapiens* and other primate species have undergone an adaptive process to cope with natural rhythms, e.g., day–night shifts (Ross, 2000). Our seasonal to annual activity patterns vary according to day length, temperature, sunshine intensity, and other environmental drivers (Ross, 2000). Traditional human societies living in riverscapes have observed the rhythm of these events and adapted their resource use and risk avoidance strategies in a way very similar to other species. The benefits of floods and droughts by providing food and fertility, and creating colonisable space, have been attractive to humans since their earliest days, making floodplains the cradles of humanity and river corridors the natural distribution pathways for human populations and their cultures (Macklin & Lewin, 2020; Paine, 2019). Consequently, a large diversity of cultural adaptations according to natural flow regimes has developed (Figure 2), the success of which depends on its match with the actual hydrological situation (analogy to the ‘species’ in the legend of Figure 3).

In addition to direct use or direct avoidance of risks, humans have developed linkages between river flow and well-being, spiritual needs, cultural identity, and sense of place (Anderson et al., 2019; Jackson et al., 2022; Klaver, 2012; Kondolf & Pinto, 2017; Wantzen, Ballouche, et al., 2016; Wantzen, Marchese, et al., 2016; Wantzen, Tharme, et al., 2022). The rhythm of floods and droughts has become the pacemaker for cultural activities and religious relationships with rivers (Johnston et al., 2012; O’Keeffe, 2013). By bringing fertile soils and restructuring landscapes, rivers can give and take lives. This makes them archetypes of deities to be worshipped but also feared, e.g., in the Andean cosmology (Boelens, 2014), in Australia (Anderson et al., 2019), and in ancient Egypt (Bunbury et al., 2022) or Asia (Cao & Vazhayil, 2022). Bank slumping and other geomorphological risks were associated with river-dwelling monsters such as the ‘*minhocão*’ (giant worm) in the Paraguay River or the ‘*coulobre*’ (a giant snake) in the French Dordogne (Michau et al., 2022; Wantzen, Girard, et al., 2022). In larger floodplains, the hydrological cycle also produces an alternating pattern of ‘possession’, when the *terrestrial* phase allows the establishment of *territories* and the use of well-defined resources, and ‘commons’, when the aquatic phase homogenises the available resources and allows different users to access them, which results in similar but highly sophisticated social rules for alternating uses of space for cattle transhumance, drawdown agriculture, and fisheries in geographically distant places such as the Pantanal and the Niger Inner Delta (Berton, et al., 2022; Wantzen, Girard, et al., 2022). The morphology of the landscape plays an important role in these territorial patterns. In large and shallowly flooded plains, the time to migrate out of the flood risk area is longer, so that the timing of the respective adaptive behaviour needs to be defined in more detail than in steeper valleys where safe ‘terra firma’ is just nearby. Many cultures in large floodplains have developed artificial dry places by accumulating earth mounds that serve as stepping stones for migration between hydrological phases, or as living space during floods (Brockwell, 2006; Wantzen, Girard, et al., 2022; Whitney et al., 2013).

Animal and plant species, like beavers and water hyacinths, and also early history civilisations modify riverscapes, including the rhythm of the waters at the regional scale (Naiman et al., 1986; Wantzen et al., 2005), but without modifying the ‘themes’ of the time/space patterns of evolutionary windows that are crucial for the maintenance of biodiversity. One example is the Dujiangyan Irrigation Scheme in 256 BC in ancient China, a diversion dam project taking advantage of natural floods that provided multiple benefits of flood control, irrigation, and water/sediment transport that is still in use today (Cao et al., 2010). This heritage was also embedded with cultural elements such as the use of local materials for construction (e.g., bamboo cages), a water-releasing ceremony, and a water worship temple (Cao et al., 2010).

However, cultural evolution has allowed humans to manipulate their environment in a way that goes far beyond the ecological engineering known from other species, and much faster and more widely than a genetically fixed behavioural pattern would allow (Creanza et al., 2017). This includes the change of the rhythm of the waters into patterns that are more compatible with diverse human use forms and/or that reduce risks, but that include patterns which are incompatible with many life cycle strategies and cultural forms that have evolved over millennia.

For the sake of safety from deleterious flood events, for the use of hydropower or for irrigation, most rivers worldwide have been modified (Vörösmarty et al., 2010). In the case of the River Rhine, the arguments in favour of the so-called ‘correction’ of the river by Tulla in the 19th century and following work in the 20th century are well known. River braiding had increased flood risk for the rural and urban population and destroyed harvests, and malaria was killing a considerable proportion of the colonisers of the flood plain so that the governmental project was broadly supported by the local population (Cioc, 2002). Damming the Senegal River protected the human population from floods and provided a huge gain in colonisable space, which was highly appreciated by the citizens of St Louis (Senegal), despite the fact that soil

salinisation and the loss of fish and agricultural yields provoke severe problems in that area (Taïbi et al., 2022). In summary, the human perception of controlling floods was highly positive.

In the past 50–150 years, the impacts on rivers have changed from local and short-term to perennial and ubiquitous hydrological patterns, with increasing interdependences between diverse environmental impacts (Meybeck, 2002; Tiegs et al., 2019; Wantzen, Ballouche, et al., 2016). The rhythms of natural flow patterns have been transformed into new dynamics. Apart from the well-known impacts of dams that reduce sediment and water flow (Grill et al., 2019; Kondolf et al., 2014), both rhythm and the variability of flow was changed into unprecedented and often arrhythmic patterns. The original hydrology of rivers – in the literature called the natural flow regime (Poff et al., 1997), environmental flows (Arthington et al., 2018; Bunn & Arthington, 2002), or the flood pulse (Junk et al., 1989; Junk & Wantzen, 2004) – have become transformed into monotonous, ‘domesticated’ flows (Hein et al., 2021; Tockner et al., 2011).

Moreover, the predictability of the time interval – in which a crucial hydrological event should occur according to the million-year-old life cycle strategy of non-human biota or the cultural adaptations of traditional human communities (some of which are several millennia old) – is lost, making these strategies and adaptations obsolete. Today, anti-cyclical patterns cause unnatural ‘windows of susceptibility’, i.e., untimely flood and drought patterns driven by needs for navigation or energy supply, which may be deleterious on the ecosystem level. If a seasonally dry-falling floodplain becomes flooded, even just for one day, the entire cohort of fledglings of ground-breeding birds and freshly germinating terrestrial plants may be lost, while, vice versa, even short up-drying of flooded floodplains may kill fry of all fish species that have been spawning there (Sparks et al., 1998). Absence of flood also means absence of the flood pulse advantage (i.e., the use of the window of opportunity brought by the fertilising effect of floods (Bayley, 1991)) and consequently, severe losses in biodiversity and ecosystem services such as the annual fish yields, and all the cultural emanations that are linked to these rhythmic events.

5 | SOCIOLOGICAL EFFECTS OF THE LOST RHYTHM OF THE RIVER

The loss of hydrological rhythms has similar effects on cultural diversity and social processes as those on biodiversity and ecosystem functions described above. These effects were (and are) perceived by the people directly connected to the river (see case studies, e.g., in Jackson et al., 2022; Wantzen, 2022), but they were not taken into consideration in public policies, as these changes coincided with a loss of human–river relationships (Wantzen, Tharme, et al., 2022). The more a society became industrialised (and rivers were tamed), the less the knowledge or the cultural relationships with the river were considered important (Krause, 2010). On the global scale, streams and rivers are losing critical ecosystem functions due to multiple human stressors, with wastewater effluents, agriculture, and urban land use having the strongest effects (Brauns et al., 2022). Failure of ecosystem services formerly provided by the river, such as animal protein from fisheries or drinking water (Jähnig et al., 2022), caused by adaptation of the river to other uses, such as hydropower or sewage transport, could be replaced by other providers, such as farms or alternative water sources, for a very long time. In many cases, dams built above cities incentivised the colonisation even in high-risk zones of the floodplain, without being aware of the flood risk (Arnell & Gosling, 2016; Mondino et al., 2020).

Early warnings by scientists, such as that by Stephen Forbes alerting about the loss of floodplains in the State of Illinois in the late 19th century, remained unheard for a long time (Schneider, 2022). Today, societies become increasingly aware of the ‘collateral effects’ of lost natural flow patterns. Climate change is enhancing the flood and drought problems. There are hardly any free-flowing rivers, or even river sections, left in the world (Grill et al., 2019) and experts claim the urgent need to recover environmental flows (Arthington et al., 2018; Tickner et al., 2020; Vörösmarty et al., 2018). The carrying capacity limit of most aquatic ecosystems has been trespassed, resulting in dramatic losses of biodiversity. WWF’s Living Planet Index shows a worldwide average loss of 84% of riverine or otherwise freshwater-bound vertebrate populations (WWF, 2020). Practically all long-distance migrating fish species of the world are threatened with extinction or are already lost; large Palearctic fish species have been reduced by as much as 97% (He et al., 2019). Both, biodiversity and extinction rates, are disproportionately high in rivers (Dudgeon, 2019; Dudgeon et al., 2006). Vörösmarty et al. (2010) showed from independent data sets that human water security is threatened in the same way as riverine biodiversity, by the same drivers (however, in different proportions). In clear words, we are no longer talking about losing one fish species or another but about the survival of the human species.

Loss of cultural diversity connected to rivers seems to display similar sharp declines as those recorded for biodiversity, but the dimensions of degradation are yet unfathomed (Wantzen, Tharme, et al., 2022). Since the local studies on the Pantanal wetland (da Silva & Silva, 1995) and Finnish rivers (Krause, 2010), the cultural effects of living with,

and of losing, riverine rhythms have recently been analysed in Honduras, India, Canada, New Zealand, and Australia (Anderson et al., 2019), in Canada and Colombia (Jackson et al., 2022), and in 24 case studies worldwide (Wantzen, 2022; summarised in Wantzen, Tharme, et al., 2022).

All these studies highlight the connectivity between hydrological rhythms, biodiversity, and cultural diversity, and alert how fast these linkages are being lost. The loss of rhythm has cascading effects on human–river relationships. This process can be described in four steps.

1. Loss of direct relationships: The relationships resulting from the direct use of riverine resources (e.g., fishing, specific handicraft techniques like wattle) are lost. This step is an immediate effect of the loss of resources, e.g., the collapse of a fish population.
2. Loss of indirect relationships: In a second phase, all the cultural activities that are indirectly linked to this (e.g., poetry of fishermen), the memory of the spiritual relationship and social rules and practices deriving from pulsing rivers are interrupted, including the above-cited alternating practice of private and shared use of resources. The first two steps are connected to practices driven by the rhythm of the river.
3. Turning away from the river: The third step is caused by a replacement of objects and objectives that were connected to the river by others. In this phase, the river loses its importance in social place-making, e.g., the regular meeting of women at the riverside to exchange news (Prothi et al., 2022), as the functions of the river banks have been replaced by other features, such as water supply or washing machines. This ‘turning away’ from the river is strongly enhanced by the loss of water quality and the disgust caused by putrid waters (Wantzen et al., 2019), and it favours the fourth step.
4. Complete oblivion of the river: Rivers and other hydrosystems disappear from the public memory when the water body has been completely removed or buried.

The further this disconnection process advances, the more difficult it is to reverse it by participatory processes or governmental decisions due to decreasing public interest.

6 | HOW TO RE-ESTABLISH THE RHYTHM OF THE RIVER IN MODERN SOCIETIES?

Obviously, awareness of the problem is the first step towards its solution, and any attempts to solve the problem should try to revert the above-cited cascade of effects of rhythm loss. However, no restoration project can turn back the wheel of time, and innovative methods or management practices known from other systems need to be combined with techniques that have proven to be successful in the past.

Individuals and societies all over the world are increasingly becoming conscious that a lifestyle out of phase with the rhythm of nature causes problems for human wellbeing and that a ‘reconciliation with the river’ (Ziegler, 2014) is urgently needed. Such a reconciliation can be initiated by identifying the current socio-ecological situation of a community or society concerning their human–river relationships. Different authors have identified phases during the societal development of living with European rivers (Rhine: Wolf et al., 2021; Seine: Lestel et al., 2022) or identified general, global patterns (Di Baldassarre et al., 2013). In a schematic comparison between the Global North and Global South, Wantzen, Tharme, et al. (2022) identified five phases (Figure 4):

- I River dynamics control human activities in river floodplains (early civilisations);
- II Local dikeing, damming, and overuse of riverine resources;
- III Industrial phase: coalescing stressors degrade biocultural diversities;
- IV Post-industrial phase: attempts to restore socio-environmental quality; and
- V Bioculturally diverse future perspectives of respectful, sustainable human–river relationships.

These authors sustain that in the Global South, phases I, II, and III are prevailing, while the Global North displays a transition between phases III and IV, indicating that in the latter, a kind of ‘catharsis’ is taking place, resulting in attempts to restore life-support functions by river ecosystems (Vörösmarty et al., 2018). In Global South countries, multiple environmental ‘stressor ensembles’ (Simmons et al., 2021; Wantzen et al., 2019) affect the hydrosystems that have already partially been overcome in the Global North. However, the Global South still displays active human–river relationships,

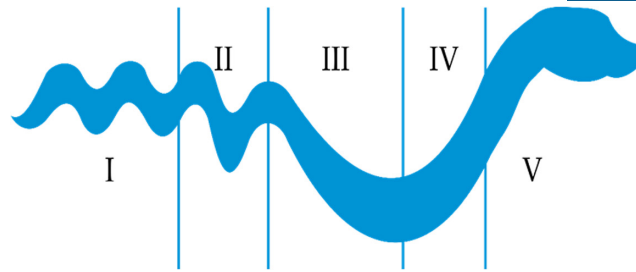


FIGURE 4 The 'River Snake Model' of human–river relationships over time (see text). From Wantzen, Tharme, et al. (2022)

some of which may deliver essential information for sustainable management for the North, where the human–river intergenerational memory has been widely interrupted. The stepwise losses of the specific human linkages to river rhythms (described in the previous section) occur during phases II and III of these human–river relationships.

The River Culture Concept (Wantzen, Ballouche, et al., 2016) proposes different fields of action to restore the linkages between human societies and the nature of rivers, including the re-appreciation of the values of the riverine nature. Especially in cities, this awareness is often hampered by the fact that the aquatic ecosystems have simply been covered by concrete or have been drained to make place for construction (see below). Good documentation with excellent use of diverse media is needed to convey this memory back to the current generation. Water museums (<https://www.watmuseum.net/>), NGOs, and digital strategies, such as using iterative design in social media to raise awareness/engage communities (e.g., the JC-WISE project initiated by Hong Kong University; <https://www.jcwise.hk/>) or creating participatory GIS platforms for spatial decision support (e.g., Khirfan et al.'s interactive map of global daylighting projects: <https://uwaterloo.ca/stream-daylighting/interactive-map>) may play important roles here. Support for the re-establishment of the memory of disappeared water bodies may come from sources that are not very common for restoration scientists and engineers, such as ancient street names, interviews with older people, historical maps, or novels. In the context of daylighting (i.e., deculverting) of urban streams, this approach has proven to be very useful to rediscover the original course of the streams (Wantzen et al., [under revision](#); Khirfan et al., 2020) and to re-establish memory. In analogy to the 'Stolpersteine' (stumbling stones, small bronze plaques embedded in the pavements) bringing back the memory of Jewish people that used to live in European cities before the Holocaust (Drozdowski, 2018), memorials to the physical existence and the ancient cultural linkages to water bodies may help the *de-novo* development of a sense of place and become a driver for future restoration projects.

Further tenets of the River Culture Concept include living in the rhythm of the natural flows, and transforming forgotten, sustainable use forms into modern applications, and/or copying solutions from observation of nature (Wantzen, Ballouche, et al., 2016). With their concept of 'river time', Jackson et al. (2022) underline the tenet 'living in the rhythm of the waters' of the River Culture Concept by highlighting the lived (and experienced) time rather than periodicity as such as an important determinant for rhythm. The temporal connectedness of socio-cultural activities to specific events of the annual water cycle has been and still is a strong determinant in some societies; however, once it is lost, it is very difficult to re-establish in modern societies. The safety and the comfort provided by the absence of hydrological rhythms (floods and droughts) prevail over connectedness to nature, but it may also result in loss of collective flood memory, which leads to an underestimation of flood risks (Fuchs et al., 2017).

Living in the rhythm of the waters also includes public acceptance of the pulse-shaped occurrence of windows of opportunity and of sustainability (Wantzen, Ballouche, et al., 2016). Practically speaking, this means that people may (re-) integrate the seasonal occurrence of resources (which also means their absence during the rest of the year). In terms of nutrition, the current practice is that almost all food items are available throughout the year, except for very few items such as asparagus, but even these are now produced in a way that the season could be expanded from a few weeks to several months. Seasonal food consumption may contribute to more sustainable practices in agriculture (Macdiarmid, 2014). In a wider sense, an increased seasonality in resource use, driven by river rhythms and other seasonal events, may be supported by periods of plentifulness or abstinence and thereby support not only the sense of place but also the sense of time, both of which are relevant for human wellbeing (Schweitzer et al., 2021). At the cultural level, events that are directly or indirectly linked to the rhythm of the water, such as celebrations of a fish migration period, may become re-issued as calendar marks in the annual schedule (even if the fish populations have meanwhile become too rare and are no longer exploited as a food source). These events have the potential to get closer to nature by perceiving elements of nature and to rediscover sustainable practices such as sharing of resources, which have become rare in the postmodern world.

At the socio-economic level, revitalisation of traditional use forms that are bound to river rhythms is difficult as they are not intrinsically sustainable. Management options that have existed in the past need to be critically revised as to their applicability in modern, sustainable use concepts (Wantzen, Tharme, et al., 2022). Even if the techniques are still applicable today, they are often unable to compete on the market, as they are too labour-intensive. However, traditional cultural heritage related to rivers can be integrated into today's promotion of sustainable production. A first approach to cope with the lack of market competitiveness of these products (e.g., artisanal fishery, agricultural products from sustainably managed floodplains) can be to create niche markets, such as by specific eco-labelling (Grunert et al., 2014). With increasing popularity and valuing among consumers, and through integrated pricing (i.e., if environmental costs of products are considered), these products may be stepwise integrated into 'normal' markets. Activities that used to be of commercial value, such as river navigation in traditionally built ships for the transport of goods and persons, may receive new functions and be integrated into eco-tourism and leisure activities, such as on the Loire and Vistula rivers (Angiel & Angiel, 2015; Wantzen, Berton, et al., 2022).

Concerning the windows of susceptibility occurring with riverine rhythms, acceptance of a flood season or drought periods may help to improve urban resilience against climatic imponderables. Stronger integration of the notion of hydrological seasons may improve the preparedness and self-sufficiency of citizens in general, especially during periods when extreme events are more likely (Fuchs et al., 2017). A 'flood culture', including the avoidance of placing valuable objects in areas of risk or the preparedness to seek shelter, as well as a 'drought culture', avoiding excessive use of resources at a given moment as claimed by scientists and planners (La Jeunesse & Larrue, 2019), can both be triggered by a growing awareness of the river and its rhythms in the public mind. This also includes that the environmental flow patterns become accepted as a 'normal' phenomenon, and not as a 'catastrophe', as is currently reported in the media. In native communities in large natural and sparsely colonised river systems, e.g., the Saskatchewan and the Amazon River basins (Jackson et al., 2022), even extensive expansions of flood space are not considered catastrophic because people are culturally and technically prepared for the water rhythm. In modern societies, this adaptedness can be re-appraised, e.g., by the construction of floating houses (Strangfeld & Stopp, 2014) or the 'abandonment of the ground floor' in urban planning strategy for flood-prone districts (elevated, flood-proof architecture; Cao and Wantzen, unpublished manuscript).

Living with, not against, riverine rhythms by accepting natural flow regimes also means that previously lost flood space needs to be provided again, both in the vertical and the lateral dimensions, as claimed by river ecologists and restoration experts for decades (e.g., Tockner & Stanford, 2002); that dams need to be managed in a way that their flow patterns are more similar to the natural hydrology (Arthington et al., 2018); and that obsolete barriers are identified and removed (Belletti et al., 2020). Practically speaking, the negative hydrological effects of damming and canalisation (resulting in an elimination of the sponge effect) need to be replaced by natural flows and natural habitat dynamics. Landscape and urban planners have neglected (unintentionally or deliberately) to integrate the values of nature (apart from water as a resource) into the process of place-making. The re-establishment of designer flow regimes alone – e.g., in dam management – is generally not sufficient to re-establish human–river relationships of traditional human riparian communities (for discussion, see Jackson et al., 2022). Approaches such as rural participatory appraisal workshops (e.g., Ricaurte et al., 2014) can help to reveal and give value to these practices (Anderson et al., 2019).

7 | HOW TO ACCOMODATE THE RHYTHM OF THE RIVER IN CITIES?

Here, I make a plea for a more radical form of 'watery place-making', precisely, to make place by restoring physical space that used to be a riparian zone of a river combining benefits for nature and humans alike. This would include a substantial redesign of urban space, including the deconstruction (dilapidation in the original sense of the word) of concrete buildings in the floodplain. In cities, huge parts of the riparian zones that had been covered by parking places for cars will become available for re-use – car-sharing and transport drones will make most individually owned cars obsolete (Lee et al., 2022). In the context of climate change, adaptation to urban heatwaves makes it necessary to substantially increase evapotranspiration surfaces (Gunawardena et al., 2017), and cities need more space for storing and percolating flood water resulting from extreme rain events (Tang et al., 2018). The recent (July 2021) devastating flood events in Central Europe, with more than 120 dead (CNBC, 2021), provide evidence for the need for watery place-making to avoid flood risk.

This space could become transformed into 'multiple-use urban floodplains' (Prominski et al., 2017) and 'human–river encounter sites' (Zingraff-Hamed et al., 2021; fig. 5).

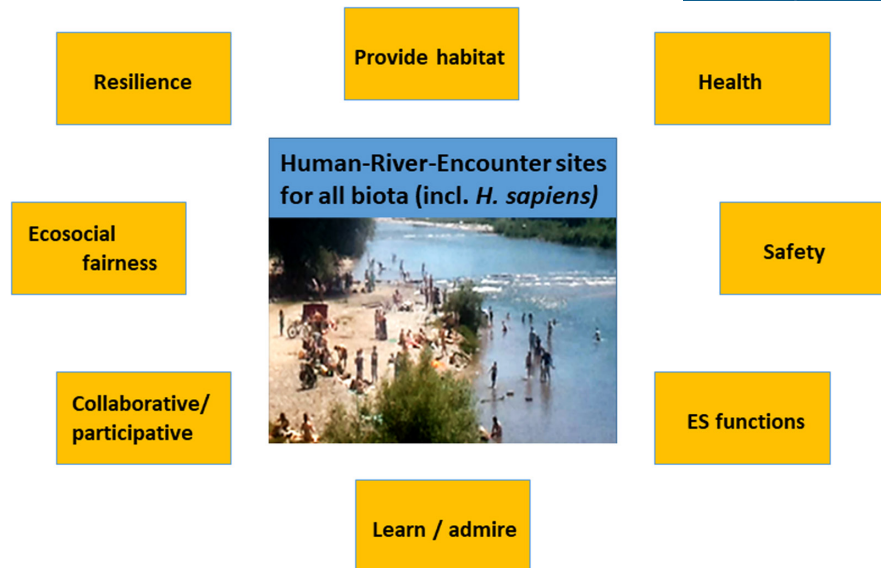


FIGURE 5 Elements to be included in the design of human–river encounter sites (modified after Zingraff-Hamed et al., 2021)

Practically speaking, these sites need to fulfil several different purposes, which have to be carefully balanced. The dwindling biodiversity, insufficient ecosystem functions, and the fast-paced invasion of riverine ecosystems by exotic species require a form of management that reintegrates habitat space for the biota and hydromorphological dynamics (sediment transport, floods) that enables recovery of a substantial portion of the original biotic community and re-establishes their capacity to adapt and evolve (Schindler et al., 2016). Also, the cultural diversity needs to be supported and re-established. In more natural riverscapes, a ‘two-eyed approach’ by combining the views of ecologists with those of traditional people seems to be the most straightforward approach to assess these human needs (see, e.g., Jardine et al., 2022, for the Saskatchewan River Delta). In cities, historical studies and participatory processes need to be combined with ethological and physiological studies to identify the ‘best-fitting solution’. Humans, especially urbanites, need ‘therapeutic landscapes’ in which they can recover from stressors such as dry, polluted air, noise, and optical pollution (Bell et al., 2018), especially near the water (Völker & Kistemann, 2011). This can be provided by park-like riparian zones that are pleasant soundscapes for recreation and playing (Jeon et al., 2012). Perceived happiness increases with the biodiversity of urban blue-green spaces (MacKerron & Mourato, 2013). Social components of equality need to be considered when planning those spaces, such as participatory processes and the avoidance of ecosocial disparities (gentrification). Lastly, these ‘human–river encounter sites’ should be ‘enchanted places to marvel at nature’, places to find inspiration, to intensify relationships with nature, and to develop human care for the environment. The creation of these places, in combination with a redesign of artificial flow patterns according to environmental flow principles (Arthington et al., 2018), could become important for the reintegration of riverine rhythms in human life in cities.

Motivating the population to support such endeavours (which may include change or abandonment of generally accepted features) remains a large problem. Examples from the Netherlands show how it is possible to convince citizens to move out of flood risk zones (Hegger et al., 2017). Water quality is of central importance for motivating people to develop a positive relationship to natural or near-natural rivers, and there is a positive feedback-relationship: the cleaner the water, the higher the motivation to take care of the river (including measures to improve water quality; Cho et al., 2021). Common activities such as the European River Network’s Big Jump initiative (www.bigjump.org), incentivising people to take a bath in the river at different locations, or the promotion of drinkable water (www.drinkablerivers.org), may create the motivation to have a clean, naturally flowing river nearby. Social engineering is needed to connect bottom-up motivation (i.e., driven by the initiatives of citizens) with top-down approaches (i.e., policy-driven actions) and with additional drivers of motivation, such as economic trends or public health care and wellbeing.

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