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Review

How to Improve the Biological Quality of Urban Streams? Reviewing the Effect of Hydromorphological Alterations and Rehabilitation Measures on Benthic Invertebrates

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Abstract: Urbanisation alters the natural hydromorphology of streams, affecting aquatic communities and ecological quality. Increasing efforts have been put into the rehabilitation of urban streams due to their importance for urban sustainability. Despite these efforts, many projects fail to achieve the improvement of aquatic communities. This study aims to provide specific recommendations to enhance the biological rehabilitation of urban streams by reviewing: (i) the impacts of urbanisation and climate change on urban stream hydrology, (ii) the responses of invertebrate assemblages to alterations in the hydrology and morphology of streams, and (iii) the hydromorphological rehabilitation measures applied to streams and their effect on invertebrate communities. This review found that commonly employed measures of habitat heterogeneity enhancement (such as the addition of meanders, boulders, and artificial riffles) are not enough to improve invertebrate communities. On the other hand, the most effective measures are those leading to the re-establishment of natural hydrological patterns and good water quality. Ultimately, an integrated ecohydrological approach that considers the entire watershed and its interactions between ecosystems and anthropological activities is the key to managing and rehabilitating urban streams.

Keywords: urban water management; ecological assessment; river restoration; ecohydrology; aquatic habitats; hydrology; climate change

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1. Introduction

Urban streams are one of the most degraded aquatic ecosystems in the world [1–3]. These streams are highly impacted by the accumulation of anthropogenic actions in their catchments, such as direct alterations to their channels, banks, and riparian zones by construction, loss of space, and runoff from impervious areas such as roads, buildings, and parking lots, which ultimately affect stream condition [4]. The "urban stream syndrome" is a term used to describe such ecologically degraded streams located in urban basins. The symptoms are diverse and include flashier hydrographs, high concentrations of nutrients and pollutants in the water, altered channel morphology, and reduced biotic richness (with increased dominance of tolerant species) [5]. Consequently, recovering the ecological condition of urban streams is imperative.

When successfully recovered, these ecosystems have the potential to offer numerous important services to urban populations [6–11]. The restoration of streams enhances biodiversity and ecosystem services that are essential for human wellbeing and supports the achievement of several goals in the 2030 Agenda for Sustainable Development of the United Nations [12,13]. Indeed, the ecological integrity of freshwater ecosystems has become an important issue and is supported by many international, national, and regional plans and legislations [14]. Additionally, legislative measures, such as the Clean Water Act in the USA, the Water Framework Directive, and the Habitats Directive in Europe, continue to be major drivers for the increasing implementation of stream restoration [15–18].

Stream restoration involves several strategies and measures that target the mitigation of prior disturbance [5,19]. Additionally, several criteria should guide successful projects [20,21], such as: (i) clear ecological objectives exist, guided by good ecological knowledge of the systems to be restored; (ii) the ecological condition of the stream must be measurably improved, and pre- and postassessment must be carried out; (iii) good technical knowledge of current and relevant methods is used; (iv) during the construction stage of the project, no lasting perturbations should remain in the ecosystem; and (v) the river system should become self-sustainable and resilient to the point that minimal follow-up maintenance will be necessary.

In urban areas, the restoration of streams (i.e., the return to natural conditions) is most often not realistic due to the numerous unavoidable constraints brought by the urban environment (such as the existence of buildings and other constructions that cannot be removed). In addition, alterations to the environment may have started a long time ago and already caused dramatic changes in the structure and function of the stream [22–24]. Thus, from here on, the term "rehabilitation" is used instead of "restoration", which contemplates the reclamation of as many of the stream's natural (predevelopment) components and functions as possible [14,25–27].

Despite the increasing number of rehabilitation projects in urban rivers and streams, many continue to fail in achieving desired biological outcomes [21,28–31]. There are a series of plausible causes of project failure, such as the misunderstanding of habitat response to geomorphological alteration, non-native invasions, and undetected water quality impairments. Additionally, many projects fail due to the attempt to manage individual species or habitat characteristics rather than the ecosystem as a whole [32].

Thus, it is essential to analyse the main factors influencing the integrity and ecological quality of an urban stream ecosystem and their main constraints. Among the factors that influence aquatic communities, poor water quality, high concentrations of pollutants and nutrients, fine sediment deposition, low rates of dissolved oxygen, and low pH levels have been shown to lead to the loss of sensitive taxa and increase in the abundance of tolerant species, altering their structure, composition, and functional diversity [23,33–39]. Organic pollution can occur, for example, due to nonpoint source pollution from agricultural fields within the urban watershed [40] or from the wastewater drainage system, such as drainage of sewage spills, sanitary sewer overflows during storm events, leaky septic systems, and sewer exfiltration [41]. The improvement of water quality has been shown to be a key aspect for the recovery of aquatic communities (e.g., [42–44]).

Another important aspect that influences the aquatic biota is the hydrology of a stream and its profound effects on the ecosystem [4]. Lotic systems present high variability in the quantity, timing, and temporal patterns of streamflow. However, the amount of water should always be enough to fulfil ecological needs in order to sustain the biological community [45]. Stream geomorphology is another key factor in the ecosystem functioning. It is based on the interplay between streamflow and landscape. Channel features such as sinuosity (or meandering), riffles, pools, runs, and the actual floodplain depend on cycles of erosion and deposition, which, in turn, are determined by supplies of both water and sediments. This dynamic mosaic of geomorphological traits provides a wide variety of habitats to biological communities, including benthic invertebrates, fish, and aquatic plants [45–48]. Among these, benthic invertebrates are considered a key indicator of the ecological quality of rivers. Their high diversity of species, their key role in ecosystem processes (such as organic matter breakdown and transference of energy and matter to other trophic levels), and their known sensitivity to different stressors are what make them useful bioindicators [23,33–39,49,50].

The composition and structure of benthic macroinvertebrate assemblages will therefore be affected by urbanisation, including hydrological and habitat alteration, as well as water quality degradation.

Considering the importance of urban streams for achieving urban sustainability, the relevance of benthic invertebrates in these ecosystems, and their key role as bioindicators of ecological quality, this paper reviewed recent literature to retrieve insights and recommendations for recovering aquatic invertebrate communities. Particularly, it focused on hydromorphological alterations and rehabilitation measures and their subsequent effects on the stream's benthic macroinvertebrate communities [51]. To achieve the intended aims, this study first analysed the impacts of urbanisation and climate change on urban stream hydrology; then, the responses of invertebrate assemblages to alterations in the hydrology and morphology of streams; and finally, the effect of hydromorphological rehabilitation measures that have been applied to streams in invertebrate communities.

2. Impacts of Urbanisation and Climate Change on Urban Stream Hydrology

Land cover change, particularly urbanisation, has several effects on the hydrology of natural streams. Small streams are particularly sensitive to land cover change due to their small catchment areas. Hydrological processes are altered as a result of the removal of vegetation from hillslopes, stream channelisation, surface levelling, and construction of impervious surfaces, such as roads and buildings. These actions reduce interception, infiltration, subsurface flow, aquifer recharge, evapotranspiration, stormwater storage on hillslopes, and overall time for stormwater to reach a stream. As impervious cover increases, the percentage of water that flows as surface runoff increases too. This translates into more frequent stormflow events with high peak discharge and rapid stormflow recession (flashiness). Urbanisation brings about the redistribution of water from periods of baseflow to periods of stormflow, as well as increased daily variation in streamflow [4,38,52–59]. Impervious surfaces in immediate riparian zones also increase the risk of stream impairment (due to the decrease in buffer capacity for filtering impaired surface and groundwater) [60].

The "urban stream syndrome" identifies streams that suffer from a set of symptoms that include altered hydrographs and channel morphology, water pollution, and reduced biotic richness with increased dominance of tolerant species [5]. Recurrent characteristics of the urban stream syndrome include [61,62]: (i) increase of frequency and magnitude of high flow events and flashiness; (ii) increase in channel cross section due to higher discharge and, therefore, increased bed and bank erosion, leading to the enlargement of streams; (iii) increase in conductivity and overall decrease in water quality due to pollution drainage into streams (such as polycyclic aromatic hydrocarbons (PAHs), which result in combustion and petroleum products, and insecticides used for pest control); and (iv) declines in aquatic species due to the degradation of ecosystems.

However, streams around the world respond differently to urbanisation. Feasible reasons for the divergence in response are [61]: (i) climate—frequency of high flow events and droughts (urbanisation radically affects the frequency–magnitude–duration balance in streamflow, which leads to major ecological modifications); (ii) sediment delivery—urbanisation usually decreasing the delivery of sediments due to streambank armouring and stabilisation of hillslopes (so in regions that would naturally yield high loadings of sediments, this shortage of sediment delivery can affect channel morphology as much as increased discharge); and (iii) urban infrastructure—age, timing of development, and history of land cover.

Such regional and local divergences reinforce the complexity of urbanisation and its influence on natural streams. Therefore, to set realistic and feasible management goals, it is crucial to understand how and why urban streams differ from one another and how they will respond differently to the same rehabilitation measures. This requires an understanding of the relationship between watershed and urban traits, the regional ecological composition, and the social and economic practicability of management approaches. For this reason, it is difficult to state a list of measures that will rehabilitate urban streams worldwide. However, some common recommendations to deal with urbanisation are [53,61]: (i) disconnecting impervious areas from streams by improving infiltration and retention/harvesting (these actions will show varying efficiencies according to regional storm characteristics) and (ii) addressing the main water quality issues first, such as sewage disposal and other sources of pollution.

Conventional stormwater management approaches attempt to reduce pollutant loads and peak flow rates. The most common measure in this approach includes end-of-catchment stormwater wetlands. These prove to be efficient at reducing pollutant loads and peak flows, but their retention capacity and ability to reduce volumes through infiltration and evapotranspiration are limited, which often results in outflow rates that exceed channel erosion thresholds, degrading geomorphic and ecological conditions [63,64]. Additionally, constructed wetlands can reduce baseflow, altering hydrological patterns even further; they are unable to protect upstream waters from pollutants since they are located at the end of the catchment; and finally, they replace lengths of the stream with a dissimilar ecosystem, disrupting the stream's longitudinal connectivity [64–66]. Other load reduction approaches, such as dispersed biofiltration systems, have the ability to protect upstream water quality. However, these systems exhibit low hydrological retention capacities and are connected to the stormwater drainage system, minimising the potential for volume reduction through evapotranspiration and exfiltration to surrounding soils [64]. Finally, the successful rehabilitation of urban streams can only be achieved once hydrological processes and the spatial distribution of water storage are re-established throughout the urban basin [4].

Walsh et al. (2016) proposed five principles for urban stormwater management [67]:

1. Ecosystems to be protected must be identified, and objectives for their ecological state must be set.
2. The resulting interplay between evapotranspiration, infiltration, and streamflow should resemble predevelopment conditions. This usually entails keeping significant runoff volumes from reaching the stream.
3. Stormwater control measures (SCMs) should yield flow regimes that resemble the predevelopment regime in both quality and quantity.
4. SCMs should be able to store water from high flow events so that the frequency of disturbance to biota does not increase in comparison with predevelopment conditions.
5. SCMs should be implemented on all impervious surfaces in the catchment of the target stream.

Examples of SCMs are rainwater tanks, infiltration systems that receive overflow from tanks and impervious surfaces, and biofiltration systems. These tools can be applied at several scales, such as residential, public, and commercial buildings; streetscapes; and blocks. Such tools, however, are only effective when employed at a large-enough scale to re-establish hydrological patterns [7,64].

Urbanisation, apart from hydrology, also affects channel geomorphology, which in turn, can degrade the overall ecological integrity of a stream. Many urban streams are channelised [68,69], impacting channel geomorphology and streambed sedimentological characteristics through the reduction of riffle habitat frequency, increased streambed substrate embeddedness, frequency of fine substrate, and streambed siltation [70]. Projects should thus also aim to restore geomorphology to a new equilibrium that enhances the health and ecological integrity of the stream [14]. Some channel rehabilitation practices include the replacement of concrete or riprap streambed with a more natural substrate, such as gravel and sand [71,72], and, in cases where banks cannot be renaturalised, the incorporation of engineering-based methods, such as porous concrete that allows the development of riparian vegetation [73].

Climate change affects urban areas by altering air temperature and precipitation patterns, exacerbating both the magnitude and duration of climate extremes [7]. Warmer temperatures intensify the hydrological cycle because of the increased vapour in the atmosphere and consequential precipitation [74]. Projections point to the increase in flood frequency and intensity, being that half of the globe will experience increased flood hazards, particularly in central and eastern Siberia, parts of Southeast Asia, India, tropical Africa, and northern South America, but decreases are projected in parts of Northern and Eastern

Europe, Anatolia, Central and East Asia, central North America, and southern South America [75,76]. Whilst climate change will have a strong effect on runoff increase, land use change will exacerbate it. Urban areas are particularly vulnerable to floods because of higher flood peaks and increased runoff volumes due to impervious cover [75–77].

Simultaneously, warmer climate causes heat stress, which translates into deficit of runoff and soil moisture, exacerbating droughts by making them more intense and long-lasting, whether because of reduced rainfall, increased evaporation, or both [74,76]. The hydrological cycle is affected by reduced groundwater levels and streamflow [78]. Flow regime modification due to such events is expected to lead, for instance, to the transition of perennial rivers to intermittent rivers due to extreme drying periods [77]. Droughts are projected to intensify in Southern Europe and the Mediterranean region, Central Europe, central and southern North America, Central America, Northeast Brazil, and Southern Africa [76].

Increased water temperatures will finally result in altered species distribution, survival rates, and phenology. It is estimated that approximately 50% of global freshwater species are threatened by climate change [79].

3. Response of Aquatic Invertebrate Assemblages to Alterations in the Hydrology and Morphology of Streams

It is well known that macroinvertebrate assemblages are conditioned by streamflow characteristics [80,81]. Different taxonomic groups respond in opposite directions, depending on their biological traits, such as body form, fixation ability, capacity to escape into sediments, and type of locomotion (e.g., active or passive swimming), resulting in modifications in communities' structure due to flow alterations [69,80]. For example, in an urban stream, Serra et al. (2019) found that the months with poorer biological quality, poorer communities, and lower functional diversity corresponded to those with higher peaks of discharge and worst water quality [69]. On the other hand, Mor et al. (2019) found that streams with low discharge present reduced dilution capacity and point to a "threshold" of water level that should be maintained, particularly during dry periods, to mitigate the effects of inevitable point-source pollution [82]. Indeed, streamflow metrics seem to limit the maximum richness/abundance of sensitive taxa, whilst for tolerant taxa, they act as the minimum for their relative richness/abundance [80]. Benthic macroinvertebrate assemblages are directly affected by altered hydrology through the removal of organisms by high flows that drag them downstream or that even kill them [69]. High flows can also reduce habitat, by increasing the rate of bed scour and turbidity, disturbing streambed sediments, and change the distribution of aquatic plants (an important refuge and food resource for benthic invertebrates) [4,69,83]. Flow reduction, on the other hand, reduces available habitats, feeding resources, and dilution capacity, increasing the concentration of nutrients and other pollutants in the water and reducing oxygenation [84].

Another recurrent hydrological characteristic that influences macroinvertebrates is flow permanence, which can overwhelm other environmental and hydrological factors, such as habitat size and typology (riffles or pools), seasonal precipitation, and connectivity to upstream reaches [85,86]. A higher flow permanence increases functional richness, evenness, and taxonomic richness [85,87]. Parker et al. (2019) found that calibrating hydrological models according to flashiness and flow permanence provides models better suited to describe biotic condition variability, even if they do not accurately represent flow regimes [88]. Additionally, streamflow variability influences aquatic communities, namely, through changes in their taxonomic and trait composition [89].

Alterations to the morphology of streams also have negative effects on the assemblages of aquatic invertebrates [90–92]. The inorganic substratum that makes up streambeds provides habitats and refugia for benthic macroinvertebrates [92,93]. Additionally, the riparian zone provides streams with structures that enhance and diversify habitats, such as woody debris, root formation, and overall organic matter [91,94]. Therefore, anthropological actions that impair the morphology of streams, such as bank and channel modifications, result in the decline of invertebrate communities, presenting lower taxonomic variety and abundance [90,91,95]. Such actions include channel stabilisation through armouring, resectioning, culverts, fords, weirs, and sluices [90,91]. Riparian vegetation is often removed or confined to streambanks, and banks are resectioned or reinforced to avoid flooding [91]. These alterations often lead to the limitation of riparian function, loss of lateral connectivity, and decreased heterogeneity of riparian and benthic habitats, thus leading to smaller niches and refuge availability [91,96]. Erba et al. (2020) showed that invertebrate communities respond to morphology impairment even when alterations are not severe [90].

4. Effect of Hydromorphological Rehabilitation Measures on Benthic Invertebrate Communities

The physical structure of water bodies has been degraded for decades now, in favour of urban development, agriculture, and navigation. This has been done through channelisation, obstruction of streambeds, dredging of banks, construction of weirs, disconnection of streams from the floodplain, and so on [97]. As such, rehabilitation efforts often take the hydromorphological route, implementing actions that aim to restore the natural hydrology and geomorphological structure of an impaired stream. For example, of 178 stream rehabilitation projects in FL, USA, 73% involved hydromorphological measures, such as stream reclamation, flow modification, bank stabilisation, channel reconfiguration, floodplain reconnection, and in-stream habitat heterogeneity improvement [98].

However, such measures do not always have the intended effect on macroinvertebrate assemblages. Hydromorphological rehabilitation efforts in urban streams may be successful at stabilising streambanks, preventing bank sloughing and further incision, but in biological terms, these measures may not be sufficient [99]. For instance, Turunen et al. (2017) found that the addition of wooden structures enhances hydraulic retention and, in turn, re-establishes a more natural flood regime. The implementation of boulders proves to be effective in improving habitat heterogeneity. These measures combined were thought to have improved the benthic macroinvertebrate communities in forestry impaired streams, but instead, there was no response [100]. Accordingly, Ernst et al. (2012) found that natural channel design restoration has little change on the macroinvertebrate community, even though it can benefit the stream habitat and its fish assemblages [101]. Through the evaluation of failed hydromorphological rehabilitation projects, Verdonschot and Nijboer (2002) found that such occurred due to the employment of nonpriority measures and neglect of pressing issues, such as poor water quality [102].

Some studies have explored the possibility of enhancing benthic macroinvertebrate assemblages as a result of structural rehabilitation projects that targeted other species, such as salmonids, or that simply did not target invertebrate communities per se. However, these measures were also ineffective with benthic invertebrates [103,104], maybe because new habitats are not being created at scales that are relevant to the assemblages, or perhaps regional/watershed scale factors over-ride any structural restoration efforts [105].

These measures can be included in what is regarded as the habitat heterogeneity paradigm [28]. This paradigm considers that increasing the structural diversity of a habitat, by adding structures, such as boulders, and artificial riffles and meanders, will restore biodiversity by enhancing structural heterogeneity [28]. However, an extensive evaluation of 78 independent rehabilitation projects by Palmer et al. (2010) led to the finding that, although habitat heterogeneity was improved, only 2 projects resulted in a significant increase in biodiversity, therefore suggesting that projects should prioritise the mitigation of stressors, such as source pollution and hydrological alteration, and only then should move to measures such as increasing physical complexity [28]. Another issue that seems to be recurrent with rehabilitation projects is not addressing or prioritising watershed-scale issues, such as source pollution and land use management practices. Hydromorphological rehabilitation actions as stand-alone measures are insufficient to improve the ecological status of a stream as long as water and sediment quality remain impaired [28,97,102]. Reach-scale rehabilitation actions are not enough to promote improvement in the invertebrate community if watershed-scale problems such as land use and hydrological regime disturbance persist [101,106].

Despite all these drawbacks, there are also examples where the hydromorphological rehabilitation of streams resulted in improved invertebrate assemblages [97,107]. Szita et al. (2019) found that urban Hungarian streams had a good biological condition due to the preservation of near-natural hydromorphological and riparian conditions that significantly reduced urbanisation effects and preserved water status [108]. Li et al. (2018) proved the successful improvement of benthic macroinvertebrate assemblages of a rehabilitated agricultural headwater stream by implementing different hydromorphological measures (such as boulder placement and artificial drops) close to each other along a 1000 m long segment, allowing them to complement each other, and by analysing the results after a sensible time frame (in this study, 2 to 6 years after the implementation of the project). This is an example of rehabilitation prioritisation: they tackled the main issue related to agricultural streams, substratum degradation, by placing dense instream measures [109].

In conclusion, hydromorphological actions are effective at improving the quality of stream habitats, but these actions alone may not be sufficient to rehabilitate biological communities. An integrated ecological approach to stream restoration is required, in which ecological concepts, threats, and former experiences are combined [102]. As seen in the literature, macroinvertebrate communities and, therefore, stream ecosystems will not improve unless more important stressors are taken care of first. Sometimes, habitat heterogeneity may not even be a limiting factor to begin with [103]. In those cases, stressors such as point-source pollution, sediment deposition, and modified hydrological patterns need to be prioritised.

Scale and time are also challenges for rehabilitation projects. Reach-scale actions are often inefficient if the rest of the watershed is impaired [110,111]. Time is also an important variable in the evaluation of the effect of rehabilitation measures [107]. In fact, benthic biodiversity generally drops right after rehabilitation actions are employed [105]. This can be attributed to the fact that rehabilitation represents a disturbance to the invertebrate community, since it unnaturally modifies the stream habitat. Thus, it is necessary to let the stream recover naturally after the construction phase before expecting improvements in the biological condition. Resilience of the biota to such disturbances can be facilitated by the existence of refugia. Refugia are locations that are not as affected by disturbance as their surrounding areas. Organisms that manage to seek refuge have a higher probability of surviving the period of disturbance and later recolonising the restored habitat. Bryophytes can act as refugia for benthic invertebrates after the first impact of rehabilitation. Since rehabilitation actions leave the streambed unstable for a long period of time, invertebrates take refuge in stable stones that are covered in bryophytes. These increase the structural complexity of the substratum, decrease water velocities, and accumulate detritus and epiphytic algae, providing food and shelter for invertebrates. Rehabilitation projects should thus leave patches of stream bottom intact in order to facilitate recolonisation after conditions settle [112].

Another important refuge for benthic invertebrates, especially during early development phases, is the hyporheic zone [113]. This area constitutes a transition between the surface stream and groundwater [114,115]. Hydrologically, the hyporheic zone can also be defined as the interstitial spaces adjacent to the streambank and below the streambed, spaces that are saturated and contain some of the channel water [116]. Both the hyporheic zone and superficial sediments of the streambed show a capacity to act as a refuge for invertebrates whilst conditions are unstable right after rehabilitation [117]. Sediments with large-enough interstices may be a morphological trait to preserve/restore in streams that suffer from drying periods, considering that climate change will exacerbate these types of events.

The hyporheic zone also contributes to maintaining water quality through biological filtration, and porous sediments adjacent to the stream act as buffers to rising water levels, reducing, delaying, or even preventing flooding. A few management measures can rehabilitate the hyporheic zone, such as the removal of impervious surfaces in the streambed, periodic release of environmental flows to flush silt and reoxygenate sediments, planting and maintenance of riparian buffers, effective land use practices, and suitable groundwater and surface water extraction policies, and in terms of sediments, the careful introduction of gravel, the loosening of existing gravel by mechanical methods, and the reintroduction of bends, large boulders, and logs to induce downwelling and sediment deposition [113].

Recolonisation of rehabilitated sites also depends on taxon pool occurrence rate and proximity to this pool. Barriers do not seem to impose a significant challenge, since only a few species appear to be susceptible to them. This being the case, an assessment of the pool's taxonomic composition and dispersal modes may be interesting to perform beforehand, assisting in the spatial prioritisation of rehabilitation [118]. Considering that restoration projects disturb communities at first, recolonisation happens from macroinvertebrates that take refuge whilst conditions are not stable, as well as from new species that migrate from other habitats. Thus, the ease with which this happens depends on the dispersal capacity of the community, distance, and connectivity from its source of colonisers [119].

To facilitate recolonisation, it seems imperative that refuge is available or provided for the existing macroinvertebrate assemblage so as to endure unstable conditions caused by restoration. This may be done by leaving a patch of streambed intact and close to a taxon pool with adequate dispersal capacity to recolonise the newly restored habitat.

5. Insights and Recommendations

The urban stream syndrome comprises a few commonalities, such as flashier hydrographs, high concentrations of nutrients and pollutants, altered channel morphology, and reduced biotic richness with increased dominance of tolerant species. Nevertheless, all urban streams are different and unique to their region; hence, it is impossible to prescribe a "universal recipe" for rehabilitating all kinds of urban streams. Nonetheless, a few common recommendations on the management of such streams could be extracted from the previous review.

First, an urban stream is a freshwater aquatic ecosystem and, therefore, must be regarded as so. Practitioners should familiarise themselves with the habitat components of natural streams in the region in question and aim to rehabilitate them, such as riparian vegetation, streambed composition, and natural discharge. A stream's flow rate must be enough to satisfy the ecological discharge of the ecosystem and, therefore, sustain its biological communities and functionality. Since invertebrate communities show development limits to hydrological characteristics (such as magnitude, duration, frequency, timing, and variation), the assessment of such limits could be performed beforehand, allowing practitioners to predictively model and procure optimal solutions to the implementation of measures that will regulate superficial runoff, such as disconnecting impervious areas from streams by improving infiltration and retention/harvesting.

No stream will ever be ecologically acceptable if its water remains polluted. Despite the lack of direct studies that assess biological communities after drainage infrastructure improvements, a universal approach to urban stream management is to prioritise water quality. It can be done by targeting the sources of pollution, including investing in the maintenance of urban wastewater treatment and drainage system infrastructures. In addition, rehabilitation projects need to consider the whole catchment and not be limited to reach scale. End-of-pipe treatments do not improve water quality upstream and, therefore, are not enough to improve the ecological condition of a watershed-scale stream system.

Another important aspect to consider is the disturbance caused by the physical rehabilitation actions. Refugia must be available or provided to facilitate recolonisation after conditions have settled. The hyporheic zone offers refugia and plays an important role in the regulation of water quality and in buffering floods. If needed, to rehabilitate and/or maintain the hyporheic zone, environmental flows can be periodically discharged to flush silt and reoxygenate sediments; riparian buffers must be planted and/or maintained; and effective policies for land use practices and groundwater and surface water extraction must be implemented. Superficial sediments also provide refuge for invertebrates that are not adapted to the hyporheic zone. To rehabilitate this aspect of the streambed, gravel can be loosened and further added, meanders reintroduced, and boulders and logs can be used to induce downwelling and sediment deposition. Bryophytes also prove to be a critical source of refuge, and therefore, patches of the stream bottom must remain intact to facilitate recolonisation after rehabilitation. Additionally, recolonisation depends on the composition of and proximity to a taxon pool, as well as the dispersal traits. An analysis of such traits is important before planning a rehabilitation.

Finally, another important shortcoming of rehabilitation projects is related to the motivation to restore. In fact, oftentimes failure happens in media/politically driven rehabilitation projects as rehabilitation actions that enhance the aesthetics of the site do not necessarily address pressing ecological issues [21]. Moreover, lack of communication between experts and practitioners and the local population often prevents the success of rehabilitation in urban areas [120]. Thus, including sensibilisation and education actions is essential.

This review pointed out some aspects that need to be further investigated to support effective rehabilitation projects in urban streams, including the definition of reference values for the streamflow metrics as limits for the maximum richness/abundance of sensitive taxa. This requires a great deal of experimental work covering different situations and the construction of large databases.

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