Urban Wetlands

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Wetlands are a critical part of natural environments that offer a wide range of ecosystem services. In urban areas, wetlands contribute to the livability of cities through improving the water quality, carbon sequestration, providing habitats for wildlife species, reducing the effects of urban heat islands, and creating recreation opportunities.

wetland | urban wetland | green-blue infrastructure | sustainability | ecosystem services

1. Introduction

According to the United Nations, 55% of the world's population currently lives in urban areas. This number is also projected to grow to 68% by 2050 [1]. This growing tendency of urbanization, both in terms of area and density, is affecting the natural infrastructure and disrupting its natural process of sustainability [2]. It also severely affects the health and ecological functions of the urban environment, leading to vegetation degradation, water pollution, and biodiversity loss [3]. Moreover, urban areas, in most cases, have less vegetation and water compared with the surrounding areas, and existing green and blue infrastructure is often threatened by increased population density [4].

Preserving and creating these infrastructures in the urban context can also be used to control the adverse effects of climate change. Therefore, there is a need to study the impact of urban natural infrastructures, such as green-blue infrastructure (GBI), on the climate of urban areas. Using GBI, this impact of climate change can be adopted in urban areas. In cities, GBI enables water treatment, reduction of urban runoff, and the provision of psychological and social ecosystem services. For example, water ecosystems, such as ponds and other urban wetlands, which are two elements from GBI, contribute to hydrological cycles in the cities [5].

Wetlands are considered as one of the excellent natural resources in urban areas. Wetlands are one of the most important green-blue infrastructure components with their wide range of services. The optimal use of wetlands increases the social and environmental sustainability of urban areas [6]. In particular, wetlands situated in urban areas are a fundamental element of urban ecosystems. Urban wetlands provide various ecosystem services and vital suppliers to the human communities [7]. These include coastal area conservation [8], water quality rectification [9][10], reducing air pollution, carbon sequestration [11], and recreation and leisure [12].

The other positive effects of blue infrastructure, such as wetlands and ponds in the urban area include controlling the effect of urban heat islands (UHI). This effect is mainly due to changes in the surface properties that lead to a greater absorption of solar radiation, reduced convection cooling, and reduced water evaporation [2]. In addition, it is known that urban wetlands show their own microclimate and are usually cooler than the surrounding areas [4][13]. Thus, they help to improve the quality of life and the environment, which leads to sustainable urban development [14].

Wetlands also play an essential role in the protection of global biodiversity. Accordingly, wetlands are known as hot spots of biodiversity [15]. However, they are the most endangered ecosystems on the globe [16] since they are ecologically sensitive yet compatible systems [17]. This characteristic has caused wetlands to offer great diversity due to their origin, geographical location, water and chemical regime, dominant species, and soil and sediment features [18].

Many cities consider the conservation and restoration of urban wetlands as a strategy in urban planning that can make cities more resistant to climate change [19]. However, while wetlands play an essential role in cities and offer various services, these services are drastically under pressure due to rapid urban expansion [20]. In fact, the urbanization and the development of cities have presented wetlands with many challenges, such as (i) direct habitat loss due to land reclamation and dredging, (ii) changed water regime by barriers, (iii) contamination by wastewater, garbage, and pesticides, and (iv) biodiversity loss due to the introduction of alien species [6].

Therefore, wetland preservation has been seriously threatened by the surrounding urban development and expansion processes. It is necessary to preserve wetlands in cities to helps reduce climate change impacts. Therefore, the need to study wetlands and their effects on urban areas and their inhabitants is required.

This article aims to investigate the role of wetlands in urban areas by answering how urban wetlands contribute to the values in urban environments. The considered values in this article include *sustainability*, *biodiversity*, *urban heat islands*, *social perception*, and *recreation*. Each of these values benefits urban environments by reducing the impacts of climate change, enhancing the sustainability and livability of the cities, and easing accessibility of nature and water resources in urban environments, which offers diverse recreational benefits.

1.1. Motivation and Contributions

Recently, wetlands as part of the GBI, are mostly considered as nature-based solutions. They can provide many services of significant social, economic, and environmental value to human well-being [21]. At the same time, wetlands are known as ecologically sensitive systems. This knowledge clarifies why much attention has been paid in recent years to formulating and implementing sustainable management strategies for wetlands [22]. Concern about wetlands could connect ecology and society through science, partnerships, and ethics. This important step helps to realize a more integrated and interdisciplinary approach to environmental research [23].

Due to the increasing growth of cities, aquatic environments, such as lakes, wetlands, and ponds have been drawn from the outskirts of cities into the urban texture [24]. Fortunately, using this opportunity helps us meet the needs of fast-growing urban areas and adapt to climate change. Urban wetlands interact (**Figure 1**) with various parameters, including adverse effects of climate change, population growth and density, urban development, urbanization, social perception, sustainability, and help by improving health and well-being, bringing biodiversity to the city, and controlling the urban heat island effect.

Figure 1. Ecological and cultural values offered by urban wetlands.

2. Background on Urban Wetlands

According to the Ramsar Convention on Wetlands [6], urban and peri-urban wetlands are located inside and around urban areas and their suburbs. Wetlands can be either natural or artificial, i.e., constructed and can also be permanent or temporary, containing a low water depth of not more than 6 m of water. In principle, urban wetlands are classified as natural and constructed [25][26]. Natural wetlands (NWs) include rivers, lakes and their flood plains, swamps, estuaries, peatlands, tidal flats, coral reefs, and mangroves, while constructed wetlands (CWs) include artificially constructed canals, drains, reservoirs, artificial lakes, fish and shrimp farming ponds, ponds, rice fields, and stormwater treatment sites [27][28].

It is expected that, by 2050, the global population will increase to around 9.8 billion most of whom will live in cities [1]. Therefore, if urbanization is not planned and controlled, the increased population growth in urban areas will be a threat to urban wetlands. The effects will include draining, contaminating, and destroying wetlands by land construction for housing, agriculture, and industry [29]. Unfortunately, due to the impact of urbanization, urban wetlands have become unconnected/fragmented. They have become patchy and distributed in different areas, and they have lost connectivity with each other. This habitat fragmentation in urban wetlands has led to a decrease in biodiversity in urban areas.

Urban wetlands possess a variety of ecological functions that cannot be replaced by other urban ecosystems. Urban wetlands are natural GBI in cities that host a wide range of biodiversity. Urban wetlands, due to their special role in urban ecological infrastructure, are known as a “city’s kidneys” and “biodiversity library” [27]. In addition, the interaction with these valuable ecosystems in cities improves citizens’ physical and mental health [30]. Urban wetlands offer a wide range of socio-cultural services, such as creating a space for recreation and leisure for the city inhabitants [31].

Urban wetlands not only provide ecological and recreational services in cities but also improve water quality by natural water purification and perform climate regulation. In terms of climatic regulation, urban wetlands create their own unique microclimate and reduce the overheating of urban environments [32]. As a result, the protection of urban wetlands is essential for obtaining sustainable living environments [12].

2.1. Urban Wetlands as Part of Green-Blue Infrastructure

Green-blue infrastructures (GBI) is presented as a strategy to deal with climate change in urban areas [33]. In urban developments, the GBI helps to optimize the use of lands in urban areas and meet the needs of people and nature in a sustainable way. In fact, GBI complements urban areas by combining hydrological networks with green areas and the built environments [34]. Among the diverse functions and advantages, in cities, the GBI enriches biodiversity, reduces global warming effects, enhances connectivity among ecological networks, and improves people's health and well-being [35][36].

In the urban context, the presence of GBI, such as trees, rivers, and ponds can increase thermal acceptability and establish climate-resilient urban systems [37], by obtaining higher cooling effects from blue infrastructures than the green infrastructures [38]. Moreover, if the area of GBI is larger than one hectare, there is a higher cooling effect (especially in summer) [39]. In cities, the GBIs have a significant therapeutic effect on human health and enhance the positive psychological reaction of humans [2][40]. Accessible GBI encourages physical activities and social cohesion and facilitates healthier living environments [41].

Within the GBI, the blue infrastructure can be either natural or constructed. Blue infrastructures, such as wetlands, contain waters that are easily accessible to humans in cities [42]. Wetlands are infrastructures that are composed of different elements, such as shore vegetation, soil, and water. This leads to a complex structure between land and water, harboring great biodiversity. Wetlands are transition zones that are caused by surface flooding or soil water saturation [27]. In principle, wetlands provide mechanisms to restore some of the natural processes that are needed to manage and create vital urban environments [43].

With proper planning and management, the ecosystem services of wetlands can benefit a growing urban population. Sustainable development and well-planned cities can generate higher levels of social welfare and drive economic growth and prosperity [44]. In sustainable cities, wetlands provide a range of ecosystem services, for example, by increasing water efficiencies, improving biodiversity, managing stormwater and flood regulation, regulating the regional climate, and mitigating climate change [45][46][47]. Wetlands also enable water quality protection, coastal protection, groundwater level and soil moisture regulation, and carbon sequestration [21].

Wetlands provide a large number of ecosystem services and the potential to be used as nature-based solutions to meet a variety of environmental, social, and economic challenges [48]. Unfortunately, during past decades, urbanization has changed the types or land use of wetland [49]. As a result, the reduction of wetlands has become one of the main threats to the sustainable development of urban areas [50]. It is mandatory to improve wetlands by sustainable developments and by applying and adopting appropriate methods for maintaining and protecting the existing wetlands or by constructing artificial wetlands in cities [46].

2.2. Urban Wetlands and Stormwater Management

Increased urbanization and subsequent human activities, such as uncontrolled construction are changing the watershed landscape. These changes increase runoff in urban areas, which has adverse effects on runoff quality and quantity, such as increased stormwater runoff pollutants [51]. Wetlands, whether natural or constructed, play an important role in cities for managing stormwater runoff including reducing the impacts of floods, absorbing pollutants, erosion control, groundwater recharge/discharge, and improving water quality.

In fact, urban wetlands can be an effective system for improving water quality. The complex hydrological, biological, physical, and chemical interactions that occur in a wetland lead to the natural reduction and effective purification of pollutants [52][53]. In addition, wetlands have an effective role in receiving storm runoff due to the inherent water storage and subsequently create a process to improve stormwater runoff quality. The most important wetland processes that improve stormwater runoff quality are sedimentation, filtration, adsorption and retention, ion exchange, precipitation, and biodegradation [51].

When water enters a wetland/pond through a stream or surface runoff, the water flows and passes through dense vegetation. The water flow velocity drops, and the suspended material in the water gradually settles to the surface of the wetland. Wetland plant roots can bind and remove up to 90% of the accumulated sediment from runoff or stream flow [52]. In addition, wetlands with dense vegetation, by reducing the velocity of the water flow through them, improve sedimentation and promote the removal of more contaminants.

The removal of contaminants by filtration through soils is effective in removing organic matter, phosphorus, bacteria, and suspended material. As runoff passes through the wetland, excess nutrients are absorbed by the wetland plants and accumulate in less harmful chemical forms [54]. When wetland plants die and decay, nutrients are recycled within the wetland. Wetlands are so effective in remove excess nutrients from stormwater runoff that it has led to the construction of wetlands specifically to treat effluent wastewater treatment in cities. It should be noted that natural wetlands are not suitable for this purpose, since there is a limitation for each wetland to how much can be added before the natural plant and chemical processes are overloaded and break down [55].

2.3. Natural and Constructed Wetlands

This subsection presents the definitions of natural wetlands (NWs) and constructed wetlands (CWs) and compares them. According to the United Nations Environment Program-Centre on Water and Environment (UNEP-DHI) (https://www.unepdhi.org/, accessed on 15 September 2021), "Natural wetlands are ecosystems that are permanently or seasonally saturated in water and create habitats for aquatic plants and provide conditions that lead to the development of hydric soils" [28][56][57].

NWs are GBI systems that can be found in diverse geo-environmental settings around the world [46]. NWs consist of rivers, lakes, saltwater lake, estuaries, swamps, tidal flats, coral reefs, peatlands, and mangroves [27]. In all environmental settings, NWs refine and enhance the quality of water passing through the system, because they operate as ecosystem filters [35]. In the other word, NWs are understood as high-efficiency disinfecting ecosystems. In particular, in local environments, NWs provide ecological flood protection and clean water [58]. They also offer shelters for birds during breeding and feeding [59], and preserve more native plant species [55].

In contrast to NWs, the constructed wetlands (CWs) are defined as "man-made complexes of the saturated substrate, emergent and submerged vegetation, animal life and water that simulate natural wetlands for human use and benefits" [60]. CWs contain stormwater basins, constructed canals, drains, reservoirs, artificial lakes, fish, and shrimp farming ponds, constructed ponds, rice fields, and sewage treatment sites [27][57]. CWs are ecologically engineered systems that have similar functions to NWs. CWs are used as an alternative cost-effective approach to conventional wastewater treatment [61][62].

CWs are affordable and sturdy systems that are low cost, easy to maintain, and easy to operate systems that only need periodic on-site labor [35]. In general, CWs are the repetition of the natural process of NWs that pursue a beneficial purpose. This means that CWs are constructed to emulate and improve the function of NWs [63]. Sometimes CWs can be constructed for specific purposes (such as flood control and surface water management) to support a specific environmental concern and provide sustainable environments [64][65].

In living environments, CWs are accepted as a practical and effectual approaches to improve the environmental quality of cities by having a key role in revitalizing urban ecology [66]. For example, CWs utilize natural processes that are suitable to remove pollutants from contaminated water within a more controlled environment [67]. Moreover, CWs provide habitat and biodiversity, support recreational activities (such as bird watching), storing water during periods of drought and saturation, and adding aesthetic value in urban areas [68].

Both NWs and CWs can be considered as an alternative to conventional systems for wastewater treatment. Both systems contain vegetation, substrates, soils, microorganisms, and water. They use multiple processes, including physical, chemical, and biological mechanisms, to eliminate different contaminants and subsequently enhance the quality of the outlet water. Indeed, comparative studies considering the ecological operations of natural and constructed wetlands indicate that both accomplish relatively similar ecological functions [35][69].

Despite containing similar constructing elements, NWs and CWs have significant differences in their intended use and functions. For example, while CWs are used for the purifying of contaminated wastewater in urban areas [70]. NWs are normally not used for wastewater treatment purposes as this can yield irreparable detriment to the ecosystem of these wetlands [71].

A study by Rooney et al. [55] introduced three structural and biophysical differences between NWs and CWs. First, while CWs are usually steep-sided, the shores of NWs have much gentler slopes. Second, NWs are usually more strongly connected to both surface and groundwater streams compared with CWs. This is due to the fact that CWs are often covered with clay to prevent any connection to the groundwater, and their water levels are often maintained at constant depths. The third difference is related to the difference in landscape positions of NWs and CWs. While NWs are naturally created in different environments, CWs are constructed in peri-urban areas with higher population density, locations with higher exposure to roads and contaminants, and locations with impervious beds.

Another difference between CWs and NWs refers to the hosting biodiversity, as NWs have considerably more habitat types than CWs [72]. Indeed, while NWs are commonly a habitat for native species, CWs often host non-native species and have the potential to increase the number of undesirable species [55]. Still, due to the diverse benefits offered by natural and constructed wetlands, both need to be preserved and have their functionality improved. This could be done by preserving natural wetlands and stopping their loss as well as constructing new wetlands in urban areas.

Along with urbanization, the number of CWs have increased by 233% from the year 1970 to 2014 [73]. However, due to diverse human activities, including the expansion of urbanization, agriculture, and aquaculture which has taken place over the last decades, the majority of NWs have been significantly manipulated, destroyed, fragmented, or totally lost [74]. A research report that more than half of the world's NWs have disappeared during the last century [75]. Another study supported this finding by considering more than 2000 wetlands around the world and reported that the number of NWs decreased by an average of 35% from the year 1970 to 2015 [73].

3. Urban Wetlands and Biodiversity

Wetlands are biologically diverse systems that improve water quality and sequester carbon [76]. As significant biodiversity sources, wetlands provide habitats for groups of species from micro-organisms to mammals [77]. Examples of these species include amphibians, insects, reptiles, birds, and mammals (e.g., beavers) that are uniquely adapted to aquatic environments [78][79]. Indeed, wetlands increase the biodiversity in urban areas by acting as networks of fragmented habitat to facilitate the movement of species in the environments [80][81].

Unfortunately, due to the urbanization and the development of urban areas, wetlands as habitats have been fragmented. Fragmentation of wetlands indeed damages the habitat and has become a major challenge in urban environments [82]. Although the fragmentation of wetlands is a major threat to their existence, they remain important and are highly functional for wildlife species [83]. Therefore, identifying the importance of wetlands, preserving them, and possibly increasing the connectivity between them would considerably support the protection of biodiversity in urban areas [84].

Even preserving wetlands that are considered of lower quality (in terms of reduced biodiversity) and polluted (in terms of water quality) has numerous advantages compared to the situation of totally lacking wetlands or having fewer of them [85]. This is because, when fragmentation of urban wetlands occurs, low-quality habitats can play an important role by supporting connectivity between good patches. In this way, a sub-optimal habitat network structure can support a higher level of biodiversity on a landscape level [82].

Due to the significance of wetlands for providing habitats and supporting biodiversity in urban areas, in the following, we provide a review on this topic and summarize the objectives, methodologies, and findings of the reviewed articles in **Table 1**.

Table 1. Urban wetlands and biodiversity.

Reference	Objective	Methodology	Findings
Melbourne, Australia (Hale et al., 2019) [82]	Highlighting the potential ecological effects of stormwater wetlands to manage the unintended consequences for urban biodiversity	Investigated 67 urban wetlands with pollutant concentrations to specify storm wetlands could be ecological traps for native amphibian and fish in the studied areas	The stormwater wetlands often become habitats for animals, which is beneficial for the persistence of species in cities
Vihti, Finland (Wahlroos et al., 2015) [69]	Designing two wetlands with slightly different and monitored them for 5 years	Studied the vegetation establishment, water quality improvement, animal settlement, as well as people's recreation	In the second year, vegetation was self-established and wetlands became successful breeding grounds for amphibians and birds and offered recreation values to people
Netherlands and New Zealand (van Roon, 2012) [86]	Investigating the role of wetlands in carbon sequestration and evaluating biodiversity loss in the urbanization process	Used the literature review and case study investigation in a period from 2002 to 2010	There are problems in creating suitable conditions for a variety of rare and vulnerable wetlands near urban use
Melendugno, Italy (Semeraro et al., 2015) [87]	Assessing the role of multifunctional CTW in terms of biodiversity and enhance ecosystem services	Monitored fauna and flora, preparing habitat map by GIS	CTW's ability to provide side benefits beyond the main purpose of water treatment, conservation of wildlife habitats and biodiversity
Helsinki, Finland (Liao et al., 2020) [88]	Examining how urbanization influences the diversity of diving beetles	Sampled diving beetles in 25 urban ponds using the GLMM model	The model revealed that urbanization reduced the richness of diving beetle species but had little effect on their abundance
Catalonia, Spain (Gascon et al., 2009) [89]	Conducting conservation biology by prioritizing sites based on high biodiversity	Regression tree models were used to identify key factors affecting biodiversity, including water, wetland, and landscape features as explanatory variables	The biodiversity criteria used in this study were significantly related to some explanatory variables. Significant positive relationships were found between some biodiversity criteria and wetland habitat conditions
Guapore, Brazil (da Silva et al., 2015) [90]	Investigating development targets and planning tasks for the area between the Pantanal	Used the (DPSIR) framework to evaluate	Planning and management in this wetland in three ways: (1) Business as usual (2)

Reference	Objective	Methodology	Findings
	and the Amazon as an important ecotone or transition zone	cause-and-effect relationships	Conservation actions (3) Integrating biodiversity objectives into other policies and planning strategies
Meli et al., (2014) [91]	Presenting a meta-analysis to evaluate the effectiveness of ecological restoration and identify what factors influence	A literature review was conducted to identify quantitative studies on the effects of ecological restoration	The meta-analysis study showed that ecological restoration increases biodiversity and ES supply
Lombardy, Italy (Morganti et al., 2019) [92]	Studying the bird communities of inland wetland	Environmental variables were collected at the two different spatial scales of Natura 2000 sites and point counts respectively	The extent of the reedbeds/mires was positively associated with the occurrence of all species of conservation concern at the site scale
Andalusia, Spain (Guareschi et al. 2015) [93]	Exploring the relationships between community composition and species richness of waterbirds and aquatic macroinvertebrates in 36 Ramsar wetlands	Waterbird data surveys, as part of an official monitoring program, were performed by the Regional Government	The collection of waterfowl was more affected by climatic variables and water levels, while conductivity was the most important factor affecting large vertebrate communities

[82] unintended consequences for urban biodiversity. The study investigated 67 urban wetlands with pollutant concentrations to specify whether storm wetlands could be ecological traps for native amphibians and fishes in the studied areas. The findings of this study stated that the stormwater wetlands often become habitats for animals, which is beneficial for the persistence of species in cities. Another important finding is that the animals that colonise the stormwater wetlands suffer from the accumulated pollutants.

Based on these findings, this study highlighted the following key considerations for stormwater wetland management to reduce its negative effects on biodiversity. The accumulation of pollutants and adverse effects on amphibians and other animals is one of the main aspects of habitat quality in relation to storm wetlands. Therefore, it is suggested that inspection and maintenance programs be considered to ensure the function of storm wetlands. Another consideration pertains to the ecological consequences of changes in wetland quality.

Changes in the quality of wetlands can cause ecological traps, which are recognized as an unintended consequence of management activities. Ecological traps are usually a serious situation, but they remain hidden and unknown.

Wahlroos et al. [69] evaluated the design of two urban wetlands with slightly different designs in urban parks. The two wetlands were designed to adapt open water areas for habitat and recreation at the cost of densely vegetated areas. The two wetland parks were designed to have sufficient wetland space for amphibian habitats. Larger open water areas, as well as islands, were designed as habitats for both wetland parks to provide waterfowl habitats and attract people. The study showed that, in the second year, the vegetation was self-established.

The vegetation establishment reached 102 species with 97% native plants after 5 years. Furthermore, the results of wildlife observation showed that breeding of amphibians and water birds was successful after constructing the wetlands. These wetlands also became successful breeding grounds for spawning amphibians and nesting birds. Thus, the wetlands succeeded in creating high biodiversity at the habitat scale in the center of a residential community. Moreover, the study reported the recreation values of peoples' everyday visits due to the increase of biodiversity and vegetation in these parks in the city of Vihti.

Van Roon [86] investigated the role of wetlands, such as bogs, fens, and swamps in carbon sequestration and evaluated the biodiversity loss in the urbanization process. This study reviewed the literature related to historical degradation, current maintenance, and management of wetlands, including bogs, fens, and swamps. Additionally, Van Roon investigated these sites in the period from 2002 to 2010, analyzed the documents related to the site, and interviewed staff from the site information centers as well as municipal planners.

Based on the literature review, this study concluded that creating suitable conditions for the reconstruction and maintenance of vulnerable wetlands is very difficult for swamps to fens to bogs near urban areas. Creating these conditions requires minimizing air emissions and manipulating groundwater flows, protecting springs, and minimizing nutrient depletion through the surface or groundwater. For instance, bogs survive in the lowest-density urban development areas.

Ecological corridors that contain fen wetland remnants can survive in development areas only with high biodiversity. In fact, fens survive throughout the ecological corridors near high-density urban areas, but the results showed that they are chemically and hydrologically degraded, and their contribution to stopping biodiversity loss is limited. Furthermore, achieving these conditions helps water-centric development and corridor reservations and is beneficial to all stakeholders.

Semeraro et al. [87] aimed to assess the role of constructed treatment wetlands (CTW) in terms of biodiversity and enhanced ecosystem services. This study used annual monitoring of fauna and flora to identify national and international species strongly related to available new habitats. In the first stage, to identify the CTW wetland habitat, a habitat map was prepared by taking photos and orthophotos and then classifying the habitat using the Commission of the European Communities, 1991 (CORINE) habitat classification.

The habitat map was validated and updated through inspections and field surveys at GIS. The second stage was done by describing the vegetation to identify different types of plant communities in the basins and canals, along the beaches, in artificial soils, and in the garrigue. The outcomes of the study confirmed CTW's ability to provide side benefits beyond the main purpose of water treatment, such as the conservation of wildlife habitats and biodiversity at local and international scales, as well as its ability to create recreational and educational value.

Liao et al. 2020., [88] examined how urbanization influences the diversity of diving beetles (Dytiscidae) and the effect of pond margin steepness, as well as the presence/absence of fish in the pond on urban diving beetles. In this study, diving beetles were sampled using activity traps in 25 urban ponds (14 ponds without fish and 11 ponds with fish). In the study, various characteristics were considered, such as the pond water depth, pond size, shoreline length, and proportion of impermeable surface in a buffer zone.

The results reveal that urbanization reduced the richness of diving beetle species but had little effect on their abundance. This indicates that urbanization does not diminish the capacity of ponds to support diving beetle species, as their numbers are unchanged; however, some species react negatively to urbanization. The presence of fish in the ponds compared to the absence of fish has a very significant and negative effect on species richness.

The presence of fish had a stronger effect on the richness of diving beetle species compared with urbanization and the pond margin steepness. Furthermore, the pond margin steepness had no statistically meaningful effect on the richness of diving beetles in ponds without fish. However, the interaction between the pond margin steepness and the presence of fish had a very notable and negative effect on diving beetles.

A study by Gascon et al. [89] aimed to identify the key factors affecting the biodiversity in wetlands to find a relationship between biodiversity metrics, conservation status, and habitat conditions. The objectives of the study were:

(*i*) comparing the reactions of different biodiversity metrics,

(*ii*) recognizing key environmental factors for different biodiversities, and

(*iii*)investigating whether wetlands with high biodiversity also have good habitat conditions and high protection status.

In this study, 91 wetlands (such as ponds, lagoons, and marshes) were sampled at the assemblage level (crustaceans and insects). The study used regression tree models to identify key factors affecting biodiversity. Thus, the study used variable factors, including the dissolved inorganic nitrogen, soluble reactive phosphorus, total nitrogen, total phosphorus, chlorophyll-a, conductivity, water permanence (temporary vs. permanent), water body size, wetland isolation, and water body density. The study calculated eleven biodiversity metrics, such as the assemblage structure, rarity, and taxonomic distinctness for each (crustacean and insect) sample. Among the eleven metrics, three metrics were related to the structure of the assemblage, including:

(*i*) the number of species in each sample,

(*ii*) the species diversity obtained using the Shannon–Wiener diversity, and

(*iii*)Pielou's evenness (species evenness) based on Shannon's index.

Analyzing the key factors determining the biodiversity of wetland aquatic invertebrates, the results showed that five of the eleven biodiversity metrics used in this study were significantly related to some explanatory variables. Moreover, the results obtained from the comparison of the two sampled seasons (winter vs. spring) showed that conductivity was the main factor influencing biodiversity metrics. Significant positive relationships were found between certain biodiversity metrics and wetland habitat conditions, while there was no case for conservation status, indicating the inadequacy of conservation policies to protect aquatic invertebrate biodiversity.

A study by da Silva et al,. [90] investigated the development targets and planning tasks for the Guaporé–Paraguay wetland, which is an area between the Pantanal and the Amazon as an ecotone with high biodiversity importance. It is worth noting that an ecotone indicates a transitional area of vegetation between two different plant communities, such as forests and wetlands. The study used a framework named the driver pressure state impact response (DPSIR) to evaluate cause and effect relationships between the interrelated components of social, economic, and environmental systems.

These interrelated components include the driving forces of environmental change; pressures on the environment; state of the environment; impacts on population, economy, ecosystems; and the response of the society, e.g., policy response. Note that the DPSIR approach was originally derived from the social sciences and later became extensively accepted as a general framework for organizing information about the state of the environment.

This research utilized a database of plant and animal species including the presence/absence information, abundance, and diversity index for different scales. Then, they analyzed the existence and distribution of plants, mammals, birds, fish species, macrophytes, peri-phytons, and zooplankton in order to assess the biodiversity status of the region. As a result, the research proposed the following three strategies for planning and management of the Guaporé–Paraguay ecotone:

(*i*) Business as usual, which refers to a further decrease of natural areas. The court of justice decided that Guaporé–Paraguay does not require special protection in the state planning system. Thus, this strategy will result in ongoing forest and river fragmentation.

(*ii*) Conservation actions that calls for the restoration of riparian deforested or degraded areas and protecting wetlands in both basins. The development of conservation actions can lead to the expansion of current protected areas and management plans in the region; therefore, regional protected areas can be identified to preserve a large area of river forests to survive the priority species of the Guaporé–Paraguay ecotone.

(*iii*) Integrating biodiversity objectives into other policies and planning strategies, which refers to the restoration of riparian deforested or degraded areas and the protection of wetlands in the basin. This strategy integrates biodiversity goals in the planning and implementation of hydroelectric dams and agricultural management.

A study by Meli et al. [91] reviewed 70 experimental studies to identify quantitative studies on the effects of ecological restoration on the biodiversity and ecosystem services of degraded aquatic and semi-aquatic wetlands. A meta-analysis identified the factors influencing restoration. The study compared the performance factors of the selected ecosystems between (1) the destroyed and restored wetlands; and (2) between the restored and natural wetlands using response ratios and stratified modeling of random effects.

The meta-analysis showed that ecological restoration increases biodiversity and ecosystem services supply in degraded wetlands and, thus, benefits the human communities that interact with them. The exact effects of wetland restoration strongly depend on the underlying factors, thus, emphasizing the need for specific habitat planning and evaluation of restorations. Furthermore, biodiversity demonstrates good recovery, although the exact recovery strongly depends on the species.

Restoration wetlands showed 36% of ES supply, regulation, and support levels compared to degraded wetlands. The biodiversity recovery and ecosystem services also positively showed a correlation, which represents an effective restoration result. Moreover, the restored wetlands showed a level of ecosystem services similar to natural wetlands.

Morganti et al. [92] studied the bird communities of an inland wetland. This study aimed to:

(*i*) understand the landscape-scale variables affecting the biotope level occurrence of conservation birds,

(*ii*) identify the habitat variables related to the occurrence of a set of target reedbed-dwelling species, and

(*iii*) achieve practical management recommendations for the protection of bird communities and populations in the inland wetlands.

The results showed that the extent of the reed beds/mires was positively associated with the occurrence of all species of conservation concern at the site scale. At the field scale, the reed bed extent positively predicted the species' occurrence but only in the presence of patches of clear shallow water. Species-specific MARS models qualitatively demonstrated similar results for some species but were generally outperformed by multi-species.

Guareschi et al. [93] explored the relationships between the community composition and species richness of waterbirds and aquatic macroinvertebrates in 36 wetlands. As core objectives, this research aimed to:

(*i*) test the congruence of the patterns of species composition and richness among waterbirds and aquatic macroinvertebrates, and

(*ii*)

investigate which environmental variables were associated with the biodiversity patterns of waterbirds and macroinvertebrates in order to identify the key factors explaining potential discordance in these patterns.

The study demonstrated that climatic variables and water levels mostly affected the collection of waterbirds; while conductivity was the most important factor affecting large vertebrate communities. The results depict a slightly inverse relationship in the richness patterns, where wetlands that are rich in waterbird species are less rich in Hemipetra families and macroinvertebrates. The results of the linear models also demonstrate that, in general, different environmental variables were related to the richness patterns of different classification groups. In addition, the analysis of different biological communities revealed that using datasets of different classification groups is an essential prerequisite for successful policies and monitoring of wetland conservation. The research concluded that there is a need for creating a diverse and complete network of protected sites, which can maintain multiple biodiversity components in wetlands.

To conclude the section, wetland biodiversity has been severely disrupted as a result of urbanization, as urban development is a primary factor in reducing the biodiversity of wetlands. In the literature, the studies explain that, when natural or human factors destroy wetlands, ecological restoration is often performed to preserve biodiversity and ecosystem services. Consequently, the preserved wetlands become a breeding ground for wildlife and strengthen the biodiversity in wetlands.

Wetlands create a network of fragmented habitats and provide feeding, spawning and nursing areas for many species, such as invertebrates, amphibians, birds, and fish. Preserving biodiversity in wetlands is essential to maintaining the vital functions of wetland ecosystems and preserving the values they provide to their environment. The maintenance of biodiversity in wetlands also can be achieved by raising public awareness, which requires continuous guidance and learning at the public level.

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