Chapter 14
Urban Aquatic Insects

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Abstract The increasing growth of urban areas on natural ecosystems has seriously affected wetlands. Aquatic insects, as key components of urban wetlands, are critically impacted by human environmental changes and practices. The main threats are those derived from the lost, replacement, or fragmentation of natural habitats, ecosystem homogenization, and modification of hydrological, sedimentological, and thermal wetland characteristics due to the surrounding urban matrix. Therefore, understanding the mechanisms by which urbanization processes affect biodiversity, and in particular how the biota responds to alteration of their habitats, is crucial for integrating the environment in proper urban planning. In this chapter we analyze the relationships between aquatic insects and environmental factors, including human influences and threats in urban wetlands. For this purpose, we compiled studies from around the world, especially from the neotropical region, addressing biological patterns and associated environmental processes in urban areas and endeavors. We discerned the main environmental threats and clues for the maintenance of the increase of the insect biodiversity, including the creation of new, man-made, wetlands. In addition, we focus on the importance of insect knowledge as indicators of environmental health in urban wetlands and the promotion of the citizen science to improve their conservation.

Keywords Urbanization · Biodiversity · Ecology · Freshwater · Colonization

14.1 Introduction

An urban area can be defined as a cultural landscape where people live at high densities, and extensive impervious surface areas are occupied by built structures and infrastructure, forming a dynamic patch mosaic whose structure, function, and

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dynamics are determined by coupled human-environment interactions (Pickett et al. 2011; Wu 2014). The process by which urban ecosystems are created is the urbanization (McIntyre 2000), and it has as a consequence transformed pristine natural landscapes to agricultural and suburban, and finally to urban landscapes. These impacts hinge on spatial scales from global and regional (e.g., mosquito population changes in response to global warming (Martin and Lefebvre 1995)), through landscape (e.g., electric lights, fast-moving traffic, replacement of mangroves by docks) down to highly local (e.g., water butt communities, unburied organic matter, wood stored in a warehouse). Yet the highly local is related to the regional and global; for example discarded vehicle tires encourage the spread of mosquitos and transported goods from harbor to harbor carry biota with specific habitat requirements. In addition, a worldwide increasing of infectious diseases associated with wetlands has been related, among other causes with a high human encroachment of natural environments, reductions in biodiversity, and changes in the number of vector breeding sites or in reservoir host distribution (Niemelä and MacDonnell 2011).

The Ramsar Convention's 10th meeting of the Conference of the Contracting adopted Resolution X.27 on Wetlands and urbanization (RAMSAR 2008) recognized that wetlands in urban and peri-urban areas can provide a range of important ecosystem services—benefits to people—but also that in many countries wetlands are increasingly becoming degraded because of spreading urbanization. As a complement of cities' green spaces, wetlands are also considered as blue spaces (Wu 2014). There are several papers dealing extensively with urban wetland ecology, as for example Chadwick et al. (2006), Meyer et al. (2005), Urban et al. (2006), and Walsh et al. (2005) for streams and Hassall (2014) for ponds.

Urban wetlands are ecosystems seriously threatened by the increase of the human population which, in the last decades, have been inclined to favor the growing of urban centers instead of rural areas; in addition, Latin America is one of the regions with the highest projected growth of urban population (De Sherbinin et al. 2009). This trend increases the pressure over the remaining green and blue spaces, as large parcels of land are deeply modified due to the real state pressure. At the same time the increase of the impervious surfaces which locally modify the evapotranspiration regime or increase of air and water pollution is a main driver to reduce availability, quality, and size of urban wetlands.

On the other hand, remaining wetlands are modified in order to fit human uses, practices, and preferences or new ones are made by man for different purposes, as drainage systems, garden, and ornamental and industrial ponds (Hassall 2014). The main threats are those derived from the lost or replacement of natural habitats (by filling, drainage, and excavation), ecosystem homogenization (i.e., decreasing microhabitat diversity through simplification of wetland coasts, reduction of riparian vegetation), and modification of hydrological, sedimentological, and thermal wetland characteristics due to the surrounding urban matrix and the introduction of alien species. These modifications impact negatively all levels of biodiversity and the ecosystem services they provide, implying an amelioration of life quality.

Nowadays, there are an increasing number of studies focusing on the improvement of management practices for urban wetlands and strategies for biodiversity conservation. One of the main objectives of those studies is to improve environmental quality and increase the ecosystem services they provide. Taking into account that insects represent one of the main taxa in any terrestrial or aquatic ecosystem, concurrently studies about the ecological role of the aquatic insects in these ecosystems and their value as biological indicators are ramping.

14.2 Aquatic Insects in Urban Wetlands

Modern cities tend to harbor different kinds of wetlands, natural, modified, and artificial, from rivers, streams, rivulets to ponds, lakes, ditches, dams, and phytotelmata (Fig. 14.1). Almost all main orders of aquatic insects can be potentially inhabitants of urban wetlands, excluding probably those extremely sensitive to environmental impacts as chemical pollution, habitat homogenization, or highly estenoic (i.e., aquatic Mecoptera). Nevertheless, as mentioned before, urbanization generates ecosystem homogenization and we could assume that a particular urban wetland exhibits less species richness than a similar one, non-anthropized, in the same region (Fig. 14.1a, b). Even though cities negatively affect natural wetlands, reducing their number, size, and heterogeneity, there is also a positive effect of human developing, the availability of new artificial wetlands which partially mitigate adverse impacts (Fig. 14.1c) (Schnack et al. 2000; Kadoya et al. 2004; Fontanarrosa et al. 2009; Holtmann et al. 2018). On the other hand, if these new artificial wetlands offer habitat for autochthonous species, we could expect an increase of more generalist or synanthropic species.

Fig. 14.1 Urban wetland diversity. (**a**) Pergamino stream crossing Pergamino city (Buenos Aires province, Argentina), (**b**) Pergamino stream downstream the city (Buenos Aires province, Argentina), (**c**) highway ditch in Avellaneda city (Buenos Aires province, Argentina), (**d**) artificial pond, Japanese Garden (Buenos Aires city), (**e**) artificial pond in a public park (Buenos Aires city, Argentina), artificial shoreline, (**f**) artificial pond in a public park (Buenos Aires city, Argentina), artificial shoreline

Fig. 14.1 (continued)

As aquatic insects mostly have complex amphibiotic life cycles (Fig. 14.2), urbanization impacts on aquatic and terrestrial ecosystems could affect the success of their populations. Interrelation between aquatic, semiaquatic, and terrestrial/aerial developmental stages, as for example adult emergence and maturation, mating, oviposition, and pupae survival, could be seriously affected by urbanization, leading to population losses (Smith et al. 2009). Also for those insects with a complete aquatic life cycle (e.g., several Nepomorpha as Belostomatidae, Corixidae, or Notonectidae) that eventually can fly and disperse through the terrestrial environment (Fig. 14.2a), it is necessary to consider for its conservation the structure of the surrounding terrestrial matrix.

Moreover, several management activities and/or urban infrastructure can act as ecological traps for many animals, especially for insects (Hale et al. 2015) (Fig. 14.3). Ecological traps are structures that can attract adult insects, especially those in dispersal or reproductive movements, as for example several species of Ephemeroptera which are attracted by higher polarization of reflected light of dark and shiny asphalt roads, probably because they use horizontally polarized light to identify ponds as potential oviposition sites (Smith et al. 2009; Malik et al. 2010; New 2015).

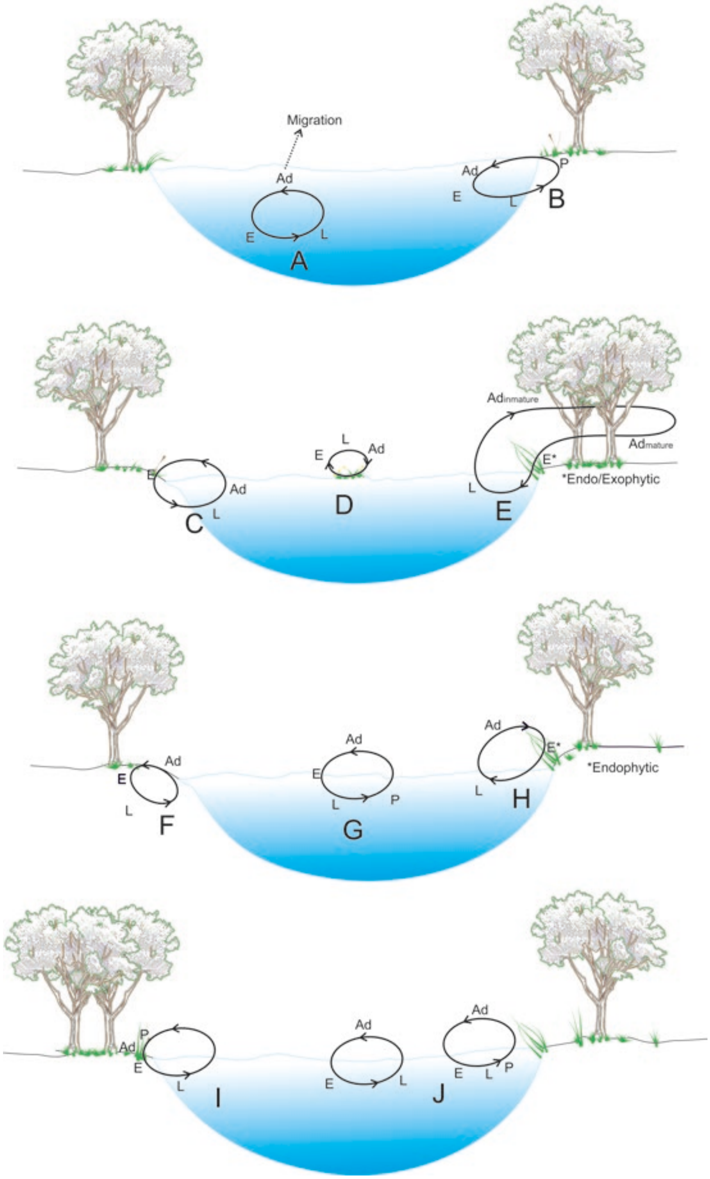

Fig. 14.2 Diagram of general types of aquatic/semiaquatic insect life cycles. E: eggs, L: larvae, P: pupae, Ad: adults. (**a**) Fully aquatic, eventually with migration flights (e.g., Corixidae, Notonectidae, Belostomatidae), (**b**) aquatic with terrestrial/riparian pupae (e.g., Dytiscidae, Gyrinidae, Elmidae), (**c**) aquatic or semiaquatic with riparian/aerial eggs (e.g., Hydrometridae, Gerridae, Belostomatidae only genus *Lethocerus*), (**d**) semiaquatic pleustonic (e.g., Orthoptera), (**e**) aquatic with terrestrial/aerial adults with prereproductive phase flying far from wetland (e.g., several Odonata), (**f**) fully riparian (e.g., Gelastocoridae, Ochteridae, Saldidae), (**g**) aquatic larvae and pupae with eggs over the water surface and terrestrial/aerial adults (e.g., Diptera Culicidae), (**h**) aquatic larvae with endophytic eggs on riparian plants and terrestrial/aerial adults (e.g., several Odonata), (**i**) terrestrial with aquatic larvae (e.g., Megaloptera), (**j**) aquatic with terrestrial/aerial adults (e.g., Odonata Anisoptera with exophytic oviposition, Trichoptera, several Diptera)

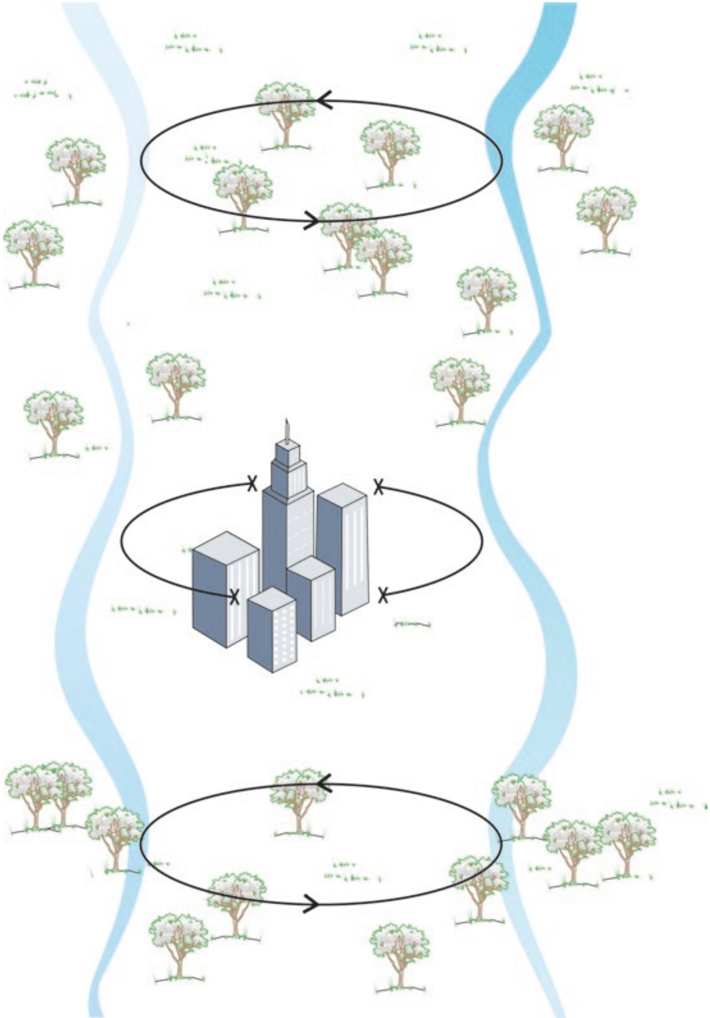

Fig. 14.3 Cities acting as an ecological trap. Diagram showing biota relationship between two different streams and the interference of urban infrastructure. Modified from Smith et al. (2009)

14.3 Main Threats and Impacts

There are a series of common characteristics or processes in urban centers proposed as threats for aquatic insects:

- Habitat fragmentation: Fragmentation reduces wetland size and connectivity and could affect negatively diversity. Wetland fragmentation in cities may be due to different types of human constructions or infrastructure (e.g., roads and buildings). Lost, replacement, or size reduction can be mentioned as a first impact on wetlands and its communities. There are some infrastructure, as bridges or road culverts, that also can act as barriers, mainly for lotic insect migration (Blakely et al. 2006). In addition, loss of connectivity between aquatic and terrestrial habitats, as for example modification of shorelines, could have a critical impact on those taxa with amphibiotic cycles with eggs and/or pupas in an aquatic/terrestrial interphase (Fig. 14.1e, f) (Smith et al. 2009).

- Nevertheless, there are no conclusive evidences about negative effects of wetland fragmentation on insects (Kadoya et al. 2004; Goertzen and Suhling 2013; Talaga et al. 2017). Suitability of habitats is assumed as more relevant than size and connectivity in some studies, perhaps due to the fact that most aquatic insects have a high dispersion capacity (Goertzen and Suhling 2013; Ramos et al. 2017). Whether wetland size could or could not influence insect diversity, there are some indirect environmental characteristics that could be primarily affected by size and shape, as for example shoreline longitude and heterogeneity of riparian vegetation (Samways and Steytler 1996; Kadoya et al. 2004) (Fig. 14.1d–f). Artificial man-made wetlands, as for example dams and road ditches, can host a significant specific diversity (Schnack et al. 2000; Goertzen and Suhling 2013; Ramos et al. 2017; Holtmann et al. 2018) counterbalancing negative impacts of other human constructions (Fig. 14.1c, d). On the other hand, an increase of ß diversity was positively correlated with habitat fragmentation in urban areas because fragmentation increases habitat heterogeneity and promotes edge species (Jones and Leather 2012; Talaga et al. 2017).
- Chemical pollution: Including diffuse, extensive, and continuous emissions deposited through atmospheric pollutants (from industry, traffic-related emissions, etc.) and point sources (as industry deposits, waste deposits, landfills, sewer, etc.). In addition, wetlands can receive pollutant inputs, through stormwater runoff and treated wastewater effluents (Niemelä and MacDonnell 2011; Turpin-Nagel and Vadas 2016). Unlike soil, pollution negative impacts on wetlands are fast and harder to contain, both on running and standing waters. Aquatic insects are negatively affected not only by the chemical itself, but also by alteration produced by it (e.g., changes in oxygen demand, conductivity, pH). Other important sources of water pollution are insecticides, commonly used in cities mostly for pest and mosquitoes' control. Some special ecosystems, as phytotelmata, are greatly threatened by insecticide spraying (Talaga et al. 2017).
- Light pollution: Artificial light is a new stressor for biotic components, recently incorporated by humans in the last 150 years. The attraction potential that artificial lights have over insects is recognized albeit not well known because light does not affect uniformly species and sexes; cities' light pollution can modify photoperiod responses and reduce nightime drift of larval aquatic insects in urban streams by disrupting their circadian rhythms (Henn et al. 2014). These impacts can modify inter- and intraspecific interactions and communities' structures, implying the disruption of ecosystem functioning, for which the term ecological light pollution was coined (Longcore and Rich 2004).
- Resource disruption: Habitat fragmentation, exotic vegetation, and human water consumption can affect negatively resource availability for many insect groups.

For example, differences in the composition of the riparian vegetation can produce changes in leaf litter decomposition, thus modifying the relative abundance among functional feeding groups, or oviposition substrate availability (Frankie and Ehler 1978; Smith 2007; Talaga et al. 2017).

- Urban heat island effect: It has been observed in most cities of the world that air temperatures are significantly higher than in the surrounding rural areas; this alteration of the climate is known as heat island effect. It can be a very complex phenomenon, showing a mosaic of different temperatures according to city design, distribution, and abundance of green spaces and wetlands (New 2015). These differences are not restricted to a specific season in the year, and vary according to the characteristics of the city, such as size and type of buildings (Niemelä and MacDonnell 2011). The causes of this effect are the supplanting of vegetation by impervious surfaces, which reduces evaporation and evapotranspiration (Niemelä and MacDonnell 2011; New 2015). There are several effects of the heat island effect on general urban biodiversity including aquatic communities. Higher temperatures affect the periods of growth and flowering of plants that affect or suppress ecological successions, which modifies the structures of the communities. In addition, the heat island favors the settlement of thermophilic species and alien species from warmer climates.
- Invasive species: Urban populations are fundamental in trade and transport plants and animal alien and/or invasive species and provide opportunities for a range of different introduction pathways (Hassall 2014). There are several examples of deliberated fish introduction in cities' ponds both as ornamental and sports fishing species. These invasive species could have a direct impact on aquatic insects' diversity and abundance, modifying their taxocoenosis (Muzón et al. 2005; Buria et al. 2007). On the other hand, invasive aquatic plants have a negative impact on wetlands, modifying water courses, reducing runoff, replacing native species, etc. (Howard 1999). Nonetheless, the effect of invasive exotic plants is not always detrimental to endemic biodiversity, since many of these plants behave ecologically similar to native plants (Samways 2005). Some species of dragonflies are excluded when invasive exotic trees provide a lot of shade in the habitat, but if the indigenous species are mixed with the native ones, the species do not seem to be affected (Kinvig and Samways 2000).

14.4 Aquatic Insects as Target Taxa for Urban Wetland Restoration and Conservation

As urban wetlands are nowadays considered key ecosystems to improve life quality and cities' sustainability, there are increasing studies focusing on evaluating and monitoring its environmental health, and evaluating the efficiency of recovery and/or conservation practices (Kadoya et al. 2004; Blakely et al. 2006; Hassall 2014; New 2015; Nieto et al. 2017).

Systematic and ecological knowledge of insects from urban wetlands is a major input for monitoring ecosystem health and evaluating best practices to improve biodiversity levels in cities (Morley and Karr 2002). On the other hand, urban insects' knowledge helps the promotion of the citizen science which in turn improves their conservation (Dickinson et al. 2010; Buldrini et al. 2015; Code 2017; Dumakude and Graham 2017).

Aquatic insects have been proposed as a reliable bioindicator group, both in natural and anthropogenic ecosystems. A bioindicator is a species or a group of species, whether animals, plants, or microorganisms, that can live under relatively specific environmental conditions under a narrow range of tolerance to one or more environmental factors of biotic or abiotic origin (Segnini 2003). Their presence in a habitat is informative of a particular state of its environment; they have been used to evaluate the magnitude of the disturbance produced by the human being, to monitor population trends in other species, and to identify and locate areas of high regional biodiversity.

Aquatic macroinvertebrates, particularly insects, are the most used bioindicators to assess environmental health. Many countries have a long history of using macroinvertebrates to monitor the environmental health of aquatic ecosystems. Benthic macroinvertebrates are key components of aquatic food webs that link organic matter and nutrient resources (e.g., leaf litter, algae, and detritus) with higher trophic levels. With the sensitive life stage and relatively long life span, they have the ability to integrate the effects of short-term environmental variations. Besides, these assemblages are made up of many species among which there is a wide range of trophic levels and pollution tolerances, therefore providing strong information for interpreting cumulative effects. Community structure of the assemblages frequently changes in response to environmental disturbances in predictable ways, which is the basis for development of biocriteria to evaluate anthropogenic influences (Li et al. 2010). Since different taxa are found in different geographical areas, biotic indices must be regionally specific.

At present, aquatic macroinvertebrates are the most widely used organisms in the biomonitoring of wetlands impacted by human disturbance (Bonada et al. 2006). It has been shown that, among them, insects are good subrogates, reducing monitoring cost and time (Smith 2007; Simaika and Samways 2012). Furthermore, as mentioned before, several aquatic insects have complex amphibiotic life cycles that could make them good monitors simultaneously on aquatic and terrestrial ecosystems (Kietzka et al. 2016).

There are several insect groups proposed or used as good biomonitors (e.g., Ephemeroptera, Odonata, Plecoptera, Hemiptera, Coleoptera, Diptera, Trichoptera), both together and separately. There are many indexes considering several taxa at once as for example:

- Biotic index, which evaluates community structure and makes use of the indicator species concept without placing undue emphasis on species that do not appear in significant numbers (Hilsenhoff 1977).
- Family biotic index, which requires only family identifications (Hilsenhoff 1988; Pérez and Ramírez Restrepo 2008).

- EPT index, for Ephemeroptera, Plecoptera, and Trichoptera: This index works under the assumption that the higher the water quality of streams, the higher is the specific richness due to the low tolerance of these taxa (Lenat and Penrose 1996; Hepp et al. 2013).

Also, there are indexes that are not based on supra-specific taxa or multi-taxa groups, but rather consider the information at the specific level for a particular group. For example, Odonata species were successfully used to test habitat quality (Dias-Silva et al. 2010; Dutra and De Marco 2015; de Oliveira-Junior et al. 2015; Valente-Neto et al. 2016; Miguel et al. 2017). Also there are several indexes based on odonate species: the Dragonfly Biotic Index, DBI (Simaika and Samways 2009, 2012; Samways and Simaika 2016), the Dragonfly Association Index (Chovanec et al. 2015), and the Odonate River Index, ORI (Golfieri et al. 2016), and the synanthropy level of urban wetlands through the Nuorteva index (Ramos et al. 2017).

Finally, there are some indexes used to describe environmental conditions in order to evaluate taxa diversity, as for example the Habitat Integrity Index (HII), widely used in South America (Nessimian et al. 2008). This index considers a protocol of 12 items that describe several environmental conditions, assessing characteristics that include patterns of land use adjacent to the riparian vegetation, the width of the riparian forest and its state of preservation, the condition of the riparian forest within a radius of 10 m, a description of the type of sediment and presence of retaining debris, the structure and erosion of the banks, the characteristics of the substrate of the stream bed, the aquatic vegetation and debris, and the distribution of rapids, pools, and meanders. Each of these items is scored on a scale of four to six points, and these values are summed and divided by the maximum possible score to provide a final value of 0–1 for the HII, with the highest values indicating the greatest stream integrity (Nessimian et al. 2008; Miguel et al. 2017). Although originally used for birds, the index has been used for many aquatic insects such as Heteroptera (Dias-Silva et al. 2010), Odonata (Miguel et al. 2017), and Trichoptera (Pereira et al. 2012).

14.5 South American Background

Most studies done in urban ecosystems have to do with megacities. The landscape that these ecosystems form is more similar among the cities of the world, regardless of their location, than with the surrounding ecosystem. However, most neotropical cities do not have these characteristics, but they are smaller (Talaga et al. 2017); this can modify the relationship with the surrounding ecosystems and the response of biodiversity. Additionally, there are few studies dealing with the processes that act within urban plots over time, except in studies of environmental impact due to specific sources of contamination with a strong sociological/epidemiological content or in many cases economic.

In the Neotropics, most of the studies are developed in streams (Couceiro et al. 2007; Dias-Silva et al. 2010; Feitosa et al. 2012; Miguel et al. 2017; Hepp et al.

2013; Monteiro-Júnior et al. 2014, 2015; de Oliveira-Junior et al. 2015) and to a lesser extent temporary ponds (Fontanarrosa et al. 2009; Ramos et al. 2017) and phytotelmata (Talaga et al. 2017). These studies are mainly focused on comparison of insects' diversity between urban and rural or pristine environments. There are few studies dealing with the processes that act within urban plots over time, except in studies of environmental impact due to specific sources of contamination with a strong sociological/epidemiological content or in many cases economic.

Surprisingly, studies of urban streams from an ecological point of view are scarce. Morley and Karr (2002) surveyed the world literature published between 1991 and 2001 and found that only 30 papers were concerned with the direct estimation of human effects on the biota in urban streams.

14.6 Wetlands as Promoters of Urban Biodiversity

As urban green spaces, wetlands (blue spaces) are main providers of many important ecological services to local communities (Wu 2014). In fact, among others they can act as flood control, groundwater replenishment, shoreline stabilization, storm protection, sediment and nutrient retention, water purification, and reservoirs of biodiversity. In addition, wetlands are key habitats for the development of educational programs aimed to the general public on natural sciences and also to initiate several citizen science programs. Hassall (2014) proposes a socio-ecosystem approach for the environmental management of urban ponds in order to minimize the arising conflicting priorities over ecological functions and services.

A sustainable urban design (including disciplines like architecture, landscape architecture, civil engineering, and urban planning) urgently needs information inputs from basic and applied research. Nevertheless, in a global context, the knowledge of urban ecosystems is far from being balanced between terrestrial and aquatic ones, being wetlands far less known than terrestrial, as well as their biota (Pickett et al. 2011). Hassall (2014) identifies three main research needs: the roles of design and location of urban ponds in influencing biodiversity, the function of urban wetlands for stormwater and pollution management, and the public perceptions of urban ecosystems and how those perceptions are influenced by interactions with natural systems.

Regarding aquatic insects, and in order to prevent major impacts or to better manage urban wetlands, we need to know not only species inventories, but also life cycle requirements, dispersal traits and patterns, ecological relationships, how species respond to the already urbanization threats, long-term consequences of changing landscapes on population genetics and species persistence, etc. (Smith and Lamp 2008). This kind of information is very uncommon for neotropical taxa, even though there are some important works published in Brazil (e.g., Feitosa et al. 2012; Monteiro-Júnior et al. 2014; Nicasio and Juen 2015; de Oliveira-Junior et al. 2017).

Considering that urbanization impacts on wetlands cause a decrease in their biodiversity, optimizing urban design is crucial for minimizing impacts and promoting biodiversity levels. Several requirements were proposed for the construction of new artificial ponds, which were summarized by Hassall (2014). Goertzen and Suhling (2013) suggest that conservation urban planning in urban centers must focus on a general improvement of habitat structure; for example, they proposed that moderate anthropogenic disturbance can increase habitat diversity and promote species of temporary and pioneer ponds especially at ruderal sites. Increasing biological value of urban wetlands through reduction of impact level, for example restoration of degraded shorelines and banks, removal of invasive alien trees, and recovering of riparian natural vegetation, can significatively increase specific richness, specially insects (Samways and Taylor 2004; Suren and McMurtrie 2005; Samways and Sharratt 2010; Goertzen and Suhling 2013). Also, Goertzen and Suhling (2013) have suggested at the city scale that different pond types regarding water level and succession stage would be beneficial for increasing biodiversity levels. In a similar way, a study carried out by Fontanarrosa et al. (2009) in temporary urban ponds in Buenos Aires found that seasonally irregular filling pattern due to local climatic conditions (humid temperate cities of the Southern Hemisphere) and physical characteristics of ponds (pool depth and area) were most significative to community structure.

Regarding minimizing of impacts, there are several studies around the world on how some threats affect aquatic biodiversity, especially aquatic insects. Management actions or best practices proposed in those studies must be considered for sustainable urban design; the region or the city the proposal is carried out does not matter (Walsh et al. 2005). For example, rehabilitate the natural heterogeneity of riparian ecosystems (Holmes et al. 2008); prevent and manage ecological traps (Hale et al. 2015); for those impacts produced by dark asphalt roads three mitigation measures have been proposed: to keep gravel roads in susceptible areas, to cover it with small-sized white gravel, or paint the asphalt with matte white stripes (Malik et al. 2010). Blakely et al. (2006) studied the effect of culverts as barriers for stream restoration and they found that the constriction of streams by culverts and associated physical barriers should be minimized in order to promote insect oviposition rates and sustain biodiversity levels.

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