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REVIEW
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# A Review of the Factors That Determine Whether Stormwater Ponds Are Ecological Traps And/or High-Quality Breeding Sites for Amphibians

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Stormwater ponds were originally constructed to control the quantity and quality of runoff on urban roads and highways before it was released to the environment. Often, stormwater ponds were designed in a technical feat of civil engineering, with no particular ecological or landscape objective in mind. Nevertheless, they are colonized spontaneously by diverse species, including amphibians. Through an initial review of the scientific literature, the objective of this study was to understand which factors determine whether a pond can be considered as an ecological trap or a valuable breeding site for amphibians. The first step was to question the role of the pond environment as a major factor in its colonization by amphibians, demonstrating that not all ponds are colonized by the same variety of species. The internal factors in the ponds that define them as ecological traps or sustainable breeding sites for amphibians was also considered. After confirming the functional and structural similarity between highway and urban stormwater ponds, 25 publications were compared, with study sites mostly located in Europe and North America, which concern the colonization of stormwater ponds by amphibians in urban or highway areas. Several factors were identified that may affect the ecological viability of these basins: (1) the factors related to the shape of the ponds (inclination of the banks, materials used, etc.,); (2) the biotic factors (aquatic vegetation, presence of predators, etc.,); (3) the abiotic factors (luminosity, water level in the ponds, etc.,); and (4) water pollutants. The low number of publications on this subject, as well as the low variety in the location of study sites, only allow cautious conclusions to be drawn. In particular, stormwater ponds located in highly anthropogenic landscapes can be both ecological traps and suitable habitats for amphibian breeding. This depends on the species that colonize each pond, many internal factors, and the environmental context in which it is embedded. Additional research is therefore needed in other parts of the world—particularly in amphibian biodiversity hotspots—as well as other impact factors such as the effects of different maintenance practices.

**Keywords: stormwater ponds, amphibians ecology, transport infrastructures, urban ecology, ecological management**

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## INTRODUCTION

There is no doubt that there is an increase of the extension of the urbanized land and transport infrastructure. The World Urbanization Prospects report notes that "among 233 countries or areas, just 24 per cent had levels of urbanization greater than 50 per cent in 1950 and only 8 per cent were more than 75 per cent urban. By 2014, 63 per cent of countries were more than half urban and one-third was more than 75 percent urban" (United Nations, 2014). This trend is accompanied by a rise in the number of stormwater ponds in the urban landscape. This has resulted in the creation of a vast network of wetland micro-zones and ecological spaces, which have been quickly colonized by a wide variety of organisms (Scher, 2005), including various amphibian species (Le Viol et al., 2009, 2012; Simon et al., 2009; McCarthy and Lathrop, 2011).

The main role of stormwater ponds is to reduce the environmental impact of water pollution by controlling the quantity and quality of water that is discharged into the receiving environment (Skriabine et al., 2004; Andrews et al., 2015). They are defined in literature as moderately-open surfaces and deep-water systems, initially built to control water runoff and pollution (Scher, 2005; Fayoux and Pelletier, 2009; Le Viol et al., 2009, 2012; Tixier et al., 2011). As Geai et al. (1997) clearly explain, the traditional design of highway ponds is essentially based on technical recommendations from civil engineering, which favors the construction of ponds with regular geometric shapes and varying slope inclination, made of artificial materials (often concrete) that often do not take into account the pond's aesthetic or ecological quality. Two types of stormwater ponds may be distinguished: those located in urban areas and those located on the edge of highways. When the biotic and abiotic characteristics of highway and urban stormwater ponds are compared (see Table in Supplementary Materials), similarities can be found. Although both tend to have a similar average size, the size of stormwater ponds can vary from 173 to 7,000 $m^2$ for highways ponds (Scher, 2005; Simon et al., 2009; Pohl et al., 2015) and from 49 to 14,784 $m^2$ for urban ponds (Bishop et al., 2000; Simon et al., 2009; Brand and Snodgrass, 2010; Scheffers and Paszkowski, 2013). Aquatic vegetation generally covers part of the pond water surface, with an average of 55% for highway ponds (Le Viol et al., 2009) and 38% for urban ponds (Bishop et al., 2000; Gledhill et al., 2008; Scheffers and Paszkowski, 2013; Holzer, 2014). Fish are found in 28% of the highway ponds (Le Viol et al., 2009) and 25% of urban ponds (Holzer, 2014). Water features are often similar, with temperatures in temperate regions hovering around 16°C in March (Scher, 2005; Gallagher et al., 2014), a slightly basic pH and a conductivity of around 0.80 mS/cm (e.g., Scher, 2005; Gledhill et al., 2008; Le Viol et al., 2012; Pohl et al., 2015). Whether on highways or in urban areas, a similar proportion of each category of ponds can be found, characterized by the variation of the water level. On highways, Le Viol et al. (2012) found 58% of permanent ponds and 42% of temporary ponds while Scher (2005) found 16% of permanent ponds, 66% of semi-permanent ponds and 18% of temporary ponds. In urban areas, Gallagher et al. (2014) found 36.5% of temporary ponds, 20.6 % of seasonal ponds and 42.8 % of quasi-permanent ponds while Holzer (2014) found 43.5 % of temporary ponds and 56.4% of permanent ponds. Dissolved oxygen levels are quite different. In highway ponds, Pohl et al. (2015) and Scher (2005) found 108% on average. In urban ponds, Gledhill et al. (2008) found 50% but this difference can be due to the fact that only one publication mentions this rate for urban ponds. Finally, in urban ponds, (Scheffers and Paszkowski, 2013; Gallagher et al., 2014; Holzer, 2014) found on average 54 mg/kg of chromium, 29.6 mg/kg of nitrate, 51.3 mg/kg of copper, 212.5 mg/kg of zinc, 0.3 mg/kg of cadmium, 30.1 mg/kg of lead and 662 mg/kg of carbon-hydrogen. There is no data on highway ponds. Although they were not built to host biodiversity, stormwater ponds are colonized by many species, both flora and fauna, common or rare (e.g., Bishop et al., 2000; Ackley and Meylan, 2010; Le Viol et al., 2012; Moore and Hunt, 2012). In some conditions, stormwater ponds biodiversity has been considered equivalent to that of semi-natural wetlands (Hassall and Anderson, 2015).

The 12th session of the Ramsar Convention on Wetlands, held in Uruguay in June 2015, estimated that the global extent of wetlands had declined between 64% and 71% in the twentieth century and that wetland losses and degradation continue worldwide (Gardner et al., 2015). According to Bateman (2014), wetland decline is accompanied by a significant decrease in the global population of amphibians, especially over the past few decades (Blaustein et al., 1994; Houlahan and Findlay, 2003; Dodd, 2010). Because of their biphasic lifestyles, amphibians are subject to both aquatic and terrestrial threats, including habitat loss and degradation (e.g., Berger et al., 1998; Dodd and Cade, 1998; Thomas et al., 2004; Todd et al., 2009; Becker et al., 2010; Bancroft et al., 2011). According to Hayes et al. (2010), death and reproductive failure are the two immediate causes of amphibian decline. Atmospheric change, environmental pollutants, habitat modification, and invasive species are considered as the 4 indirect factors contributing to amphibian decline caused by reproductive failure (Hayes et al., 2010). It is therefore not uncommon to notice the presence of several species of amphibians in urban or highway stormwater ponds. One of the first reactions of the pond managers to this spontaneous colonization was trying to prevent them from entering the ponds, particularly with nets or screens. Few studies have been done to confirm or refute their effectiveness. Another solution to be considered is the possibility to design and maintain these ponds to be viable sites for amphibian reproduction but it is first necessary to determine the features that have an influence on whether the ponds are ecological traps or valuable breeding sites for amphibians.

The concept of ecological trap was first described by Dwernychuk and Boag (1972), but has only been studied in recent years (Battin, 2004). According to Brand and Snodgrass (2010), considering the principle that organisms select high-quality habitats from environmental signals, an ecological trap occurs when environmental clues provide an inaccurate representation of a habitat's suitability for reproduction and survival (Schlaepfer et al., 2002; Battin, 2004; Robertson and Hutto, 2006). A stormwater pond could be defined as an ecological trap if it

leads to direct mortality of individuals or if, as a breeding site, reproductive success is not high enough to support a stable or growing population without immigration (Battin, 2004). Due to the proximity of roads that may cause an increase of water pollutants in the pond and also other impacts such as a barrier effect and an increased risk of mortality, highway stormwater ponds do not appear to be suitable breeding sites for amphibians. The presence of water during the breeding period (from spring to early summer) and of vegetation in the ponds may attract amphibians, thus turning these ponds into ecological traps (Schlaepfer et al., 2002; Battin, 2004; Robertson and Hutto, 2006; Brand and Snodgrass, 2010). The purpose of this literature review is to ascertain to which extent stormwater ponds are colonized by amphibians and to identify the factors that would make a stormwater pond an ecological trap vs. a viable breeding site.

## METHODS AND MATERIALS

The selection of papers to be evaluated in the study was undertaken using several databases specialized in ecology and geography (Science Direct, Springer, Jstor). Words used in the search were "*stormwater pond*" (1980 results) associated with "*amphibians*" (96 results), "*highways*" (390 results) and "*road*" (890 results). The publications studied cover all types of environmental contexts (agricultural, urban, and forest environments), though most of them are located in developed countries, in particular on the European and North American continents. Though the subject of this study concerns highway stormwater ponds and amphibians, the limited number of publications on this subject (5) resulted in a complementary search through other publications referring to "*urban stormwater ponds*". As highways and urban ponds show high similarities (see Table in Supplementary Materials), 25 publications were selected on both urban and highway ponds: 50% of these publications were from journals of biology, 36% from conservation ecology journals and 14% from environmental science journals, the categories of journals having been determined according to the keywords used. Then, using this bibliographic database from Science Direct, Springer, Jstor as well as a complementary panel of publications on the ecology of amphibians (46), several tables were built to compare the species identified in ponds and the factors influencing—both positively and negatively—the species richness present in the stormwater ponds. There are many factors that can influence the ecological viability of stormwater ponds as a breeding site for amphibians. The effect of 4 categories of factors has been analyzed according to the definitions proposed by Jumeau (2017): (1) the factors related to the design of the ponds (inclination of the banks, materials used, etc.,); (2) the biotic factors (aquatic vegetation, presence of predators, etc.,); (3) the so-called "immediate" factors (luminosity, winds, water level in the ponds, etc.,) and (4) water pollutants. This results in a total of 77 factors. However, some of these factors have not been studied in other research. Therefore, only 37 factors were included in the comparison as they were considered in at least 2 publications.

## RESULTS

### The Number of Colonizing Species Depends on the Pond's Environment

44 amphibian species were identified colonizing stormwater ponds in the 25 publications included in the analysis (**Table 1**). Three publications on highway ponds referred to 13 amphibian species. 22 publications on urban ponds referred to 37 amphibian species and 17 of these species are cited in at least 2 publications. 6 species were found to be the most common to both urban and highway ponds: the green frog (*Rana clamitans*) and the pickerel frog (*Rana palustris*), which were identified in 5 studies; the American toad (*Bufo americanus*) and the green frog (*R. clamitans*) identified in 6 studies; the spring peeper (*Pseudacris crucifer*) and the wood frog (*Rana sylvatica*), which were identified in 7 studies.

Despite these findings, several articles have reported that species richness depends on the pond's environment and can therefore vary from one site to another. The importance of the landscape matrix for amphibians is regularly examined in the literature, within a radius of up to 500 m around the ponds (e.g., Semlitsch and Bodie, 2003; Simon et al., 2009). The species richness of amphibians is often correlated with a small impervious surface, the proximity to woodlands (Dodd and Cade, 1998; Le Viol et al., 2009, 2012; McCarthy and Lathrop, 2011) and the presence of a dispersal corridor in the case where the breeding site is not directly connected with woodlands (Semlitsch and Bodie, 2003; Ouellet and Leheurteux, 2007; Hamer and McDonnell, 2008; McCarthy and Lathrop, 2011). A terrestrial suitable habitat also provides food and the necessary overwintering sites for amphibians to survive (deMaynadier and Hunter, 1995).

Many studies point out that the density of forest cover has a moderate influence on the presence of amphibians in ponds (Bishop et al., 2000), but this influence varies according to species (e.g., Simon et al., 2009; Birx-Raybuck et al., 2010; Le Viol et al., 2012; Holzer, 2014). As shown by Gallagher et al. (2014), sensitive species such as the wood frog (*R. sylvatica*) occupy only ponds surrounded by a high proportion of forest cover, contrary to more tolerant species such as toads (Scher and Thièry, 2005; Simon et al., 2009). Thus, the literature review shows a correlation between the decrease in forest cover in the surrounding landscape and the decrease in the amphibian species richness identified in the ponds (Le Viol et al., 2009, 2012; Simon et al., 2009). Conversely they demonstrate that species richness and the occurrence of individual species were negatively related to impervious built surface cover (Scher and Thièry, 2005; Simon et al., 2009). The surrounding agricultural matrix is also identified as having a negative influence on species richness, particularly where intensive farming is practiced, probably due to the release of fertilizers and pesticides (Beja and Alcazar, 2003; Le Viol et al., 2012) and/or because it creates a break in the connectivity of the pond and the natural habitat that amphibians depend on (Trenham et al., 2003; Parris, 2006).

Stormwater ponds therefore host a wide variety of amphibian species, but species richness may vary depending on the

**TABLE 1 |** Species identified in highway and urban stormwater ponds.

| Species | Urban Ponds (references) | Highway Ponds (references) |
|---|---|---|
| Agile frog (*Rana dalmatina*) | | Le Viol et al., 2009, 2012 |
| Alpine newt (*Ichthyosaura alpestris*) | | Le Viol et al., 2009, 2012 |
| American Bullfrog (*Lithobates catesbeianus)* | Simon et al., 2009; Birx-Raybuck et al., 2010; McCarthy and Lathrop, 2011; Bateman, 2014 | |
| American Toad (*Bufo americanus*) | Bishop et al., 2000; Massal et al., 2007; Snodgrass et al., 2008; Simon et al., 2009; Brand and Snodgrass, 2010; Bateman, 2014 | |
| Boreal chorus frog (*Pseudacris maculata*) | Scheffers and Paszkowski, 2013 | |
| Common eastern froglet (*Crinia signifera*) | Parris, 2006; Hamer and Parris, 2011 | |
| Common frog (*Rana temporaria*) | Gledhill et al., 2008 | Le Viol et al., 2009, 2012 |
| Common toad (*Bufo bufo*) | Gledhill et al., 2008 | Le Viol et al., 2009, 2012; Pohl et al., 2015 |
| Cope's gray treefrog (*Hyla chrysoscelis*) | Massal et al., 2007; Simon et al., 2009; Birx-Raybuck et al., 2010; Brand and Snodgrass, 2010 | |
| Eastern Newt (*Notophthalmus viridescens*) | Simon et al., 2009 | |
| Edible frog (*Pelophylax esculentus*) | | Le Viol et al., 2009, 2012 |
| Emerald-spotted tree frog (*Litoria peronii*) | Parris, 2006 | |
| European Fire Salamanders (*Salamandra salamandra*) | | Le Viol et al., 2009, 2012 |
| Fowler's Toad (*Bufo fowleri*) | Simon et al., 2009; Birx-Raybuck et al., 2010; McCarthy and Lathrop, 2011; Bateman, 2014 | |
| Gray Treefrog (*Hyla versicolor*) | Bishop et al., 2000; Massal et al., 2007; Simon et al., 2009; McCarthy and Lathrop, 2011; Bateman, 2014 | |
| Green frog (*Rana clamitans*) | Bishop et al., 2000; Massal et al., 2007; Simon et al., 2009; Brand and Snodgrass, 2010; McCarthy and Lathrop, 2011; Bateman, 2014; | Scher and Thièry, 2005 |
| Growling grass frog (*Litoria raniformis*) | Parris, 2006 | |
| Haswell's froglet (*Paracrinia haswelli*) | Parris, 2006; Hamer and Parris, 2011 | |
| Long-toad salamander (*Ambystoma macrodactylum*) | Holzer, 2014 | Le Viol et al., 2009, 2012 |
| Mediterranean Tree Frog (*Hyla meridionalis*). | | Scher and Thièry, 2005; Le Viol et al., 2009, 2012 |
| Natterjack Toad (*Bufo calamita*) | | Scher and Thièry, 2005 |
| Northern crested newt (*Triturus cristatus*) | Gledhill et al., 2008 | |
| Northern crocket frog (*Acris crepitans*) | Simon et al., 2009 | |
| Northern Leopard Frog (*Lithobates pipiens*) | Bishop et al., 2000; Bateman, 2014; Gallagher et al., 2014 | |
| Northern red-legged frog (*Rana aurora*) | Holzer, 2014 | |
| Northwestern salamander (*Ambystoma gracile*) | Holzer, 2014 | |
| Pacific chorus frog (*Pseudacris regilla*) | Holzer, 2014 | |
| Palmate newt (*Triturus helveticus*) | | Scher and Thièry, 2005; Le Viol et al., 2009, 2012 |
| Parsley frog (*Pelodytes punctatus*) | | Scher and Thièry, 2005 |
| Pickerel Frog (*Rana palustris*) | Massal et al., 2007; Simon et al., 2009; Brand and Snodgrass, 2010; McCarthy and Lathrop, 2011; Bateman, 2014 | |
| Pobblebonk (*Limnodynastes dumerilii*) | Parris, 2006 | |
| Rough-skinned newt (*Taricha granulosa*) | Holzer, 2014 | |
| Smooth newt (*Lissotriton vulgaris*) | Gledhill et al., 2008 | Le Viol et al., 2009, 2012; Pohl et al., 2015 |
| Southern brown tree frog (*Litoria ewingii*) | Parris, 2006; Hamer and Parris, 2011 | |
| Southern bullfrog (*Lithobates grylio)* | Hamer and Parris, 2011 | |
| Southern leopard frog (*Rana sphenocephala*) | Simon et al., 2009; Birx-Raybuck et al., 2010; McCarthy and Lathrop, 2011 | |
| Spotted marsh frog (*Limnodynastes tasmaniensis)* | Parris, 2006 | |
| Spring Peeper (*Pseudacris crucifer*) | Bishop et al., 2000; Massal et al., 2007; Simon et al., 2009; Birx-Raybuck et al., 2010; Brand and Snodgrass, 2010; McCarthy and Lathrop, 2011; Bateman, 2014 | |
| Striped marsh frog (*Limnodynastes peronii*) | Parris, 2006; Hamer and Parris, 2011 | |

*(Continued)*

**TABLE 1** | Continued

| Species | Urban Ponds (references) | Highway Ponds (references) |
|---|---|---|
| Victorian smooth froglet (*Geocrinia victoriana*) | Hamer and Parris, 2011 | |
| Western chorus frog (*Pseudacris triseriata*) | Bishop et al., 2000; Gallagher et al., 2014 | |
| Western tiger salamanders (*Ambystoma mavortium*) | Scheffers and Paszkowski, 2013 | |
| Whistling tree frog (*Litoria verreauxii)* | Parris, 2006; Hamer and Parris, 2011 | |
| Wood frog (*Rana sylvafica*) | Bishop et al., 2000; Massal et al., 2007; Snodgrass et al., 2008; Simon et al., 2009; Brand and Snodgrass, 2010; Scheffers and Paszkowski, 2013; Bateman, 2014 | |

presence of more or less appropriate amphibian habitats in their surroundings.

## Factors That Positively or Negatively Influence the Ecological Viability of Stormwater Ponds as Breeding Sites

The factors that can affect the viability of stormwater ponds as good breeding sites for amphibians cannot be overlooked. Indeed, although they host many amphibians, stormwater ponds are not necessarily favorable habitats for the species that breed there.

Water pollution is one of the most studied factors in the relationship between stormwater ponds and amphibians (**Table 3**). Pollutants such as road salt may have sub-lethal effects on amphibians, which could lead to death in the long term (e.g., Bishop et al., 2000; Sanzo and Hecnar, 2006; Karraker et al., 2008; Snodgrass et al., 2008; Collins and Russell, 2009). However, some authors point out that road salt remains a factor that can slow down the development of the larvae but that it is not decisive in assessing the viability of the ponds as amphibian breeding sites (Scher and Thièry, 2005; Brand et al., 2010; Hassall and Anderson, 2015). Moderate levels of nitrogen in ponds appear to have little or no direct risk on the development of amphibian embryos and larvae identified on site (Mayer et al., 1996; Bishop et al., 2000; Massal et al., 2007). Snodgrass et al. (2008) point out that the impact of pollution on the populations of amphibians present in the ponds studied depends on the tolerance of each species to each of the pollutants. For example, nitrate ($NO_3^-$) emissions from cars may be an important nutrient for aquatic vegetation (Camargo et al., 2005 in Holzer, 2014). Conversely, high levels of nitrate may have detrimental effects on amphibian larvae due to its toxicity or due to anoxia resulting from eutrophication (Marco et al., 1999; Hatch and Blaustein, 2003; Holzer, 2014). The impact of the nitrate levels also varies positively (Scheffers and Paszkowski, 2013) or negatively (Houlahan and Findlay, 2003) according to the species considered. In fact, stormwater ponds containing moderate nitrate levels may be suitable for the breeding and development of amphibian larvae because it contributes to the development of algae, micro-organisms, and decaying material which amphibian larvae feed on (Duguet et al., 2003; Pohl et al., 2015). Neighboring agricultural areas can also contribute to the development of algae in ponds through the runoff of nitrate-rich fertilizer (Beja and Alcazar, 2003). The odors produced by algae proliferation attract frogs when they're on a reproductive migration (Savage, 1961; Grubb, 1973, 1975; McCarthy and Lathrop, 2011). Algae also nourish amphibian larvae (Bateman, 2014; Holzer, 2014). However, nitrates may also be harmful when present in high concentration, as excessive algae growth can lead to eutrophication (Bishop et al., 2000). In conclusion, agricultural land-use near ponds can have a variable impact, depending on agricultural practices and the sensibility of amphibian species to euthophication (Le Viol et al., 2012).

Some studies point to hydroperiod (**Tables 2**, **3**) as a factor affecting species present on studied sites (Hamer and McDonnell, 2008; Chester and Robson, 2013). Hydroperiod is defined as the time of inundation during which the soil becomes saturated in water, resulting in anoxia (Bonis, 2014). These alternations of flood and wet stages can lead to the coexistence of species with a wide range of tolerance and ecological requirements (Bonis, 2014). The literature has shown that a too short hydroperiod can be harmful to species that have a long developing period, which are unable to reach metamorphosis before the pond dries. Those species die from dehydration (Ostergaard et al., 2008; Brand and Snodgrass, 2010; McCarthy and Lathrop, 2011). Conversely, a too long hydroperiod (i.e., a prolonged duration of submersion) is often associated with the presence of fish, which represent a significant risk of predation for the communities of amphibians present in ponds (e.g., Hamer and Parris, 2011).

A comparison of both **Tables 2**, **3** shows a divergence of opinions on the predation issue. The absence of fish is considered a positive factor in five studies (Beebee, 1996; Petranka et al., 2004; Porej and Hetherington, 2005; Vasconcelos and Calhoun, 2006; Chester and Robson, 2013) and a negative factor in three other studies (Sredl and Collins, 1992; Bishop et al., 2000; Brand and Snodgrass, 2010). The presence of fish has direct and indirect negative impacts on frog larvae (e.g., Porej and Hetherington, 2005; Hamer and Parris, 2011) but some species show resistance to fish predation (Kats et al., 1988; Gunzburger and Travis, 2005; McCarthy and Lathrop, 2011). Brand and Snodgrass (2010) recommend a seasonal hydroperiod, natural or artificial, with a late drainage (i.e., at the end of summer), to increase the suitability of stormwater ponds as amphibian breeding sites. In addition, this practice can be adopted in the maintenance of highway and urban ponds in temperate areas where spring and autumn periods show high levels of rainfall while in summer they have less precipitation.

The pond banks inclination is cited in the literature as a characteristic that can make ponds traps for amphibians

**TABLE 2 |** Factors identified in the literature review that have a positive effect on the use of stormwater ponds as breeding sites for amphibians.

| Factors with positive effects | References of the studies |
|---|---|
| Ecological connectivity | Prunier et al., 2014 |
| Connectivity with other bodies of water or between ponds | Gledhill et al., 2008; Birx-Raybuck et al., 2010; Chester and Robson, 2013; Hassall and Anderson, 2015 |
| Connectivity with surrounding amphibian populations site | Hamer and McDonnell, 2008 |
| Proximity to terrestrial habitat | Semlitsch, 1998; Guerry and Hunter, 2002; Rubbo and Kiesecker, 2005; Trenham et al., 2005; Van Buskirk, 2005; Babbitt et al., 2006; Rittenhouse and Semlitsch, 2007; Gledhill et al., 2008; Hamer and McDonnell, 2008; Le Viol et al., 2009, 2012; McCarthy and Lathrop, 2011; Chester and Robson, 2013; Holzer, 2014 |
| Possibility of dispersal and/or possibility of colonization of new area | Semlitsch and Bodie, 2003; Ouellet and Leheurteux, 2007; Hamer and McDonnell, 2008; McCarthy and Lathrop, 2011 |
| Proximity to habitat that provides food and wintering site | deMaynadier and Hunter, 1995 |
| Proximity to a wet forest | Baldwin et al., 2006; Holzer, 2014 |
| Appropriate management | Chester and Robson, 2013 |
| Appropriate variations of hydroperiod | Hamer and McDonnell, 2008; Chester and Robson, 2013 |
| Water quality | Hamer and McDonnell, 2008 |
| Low nitrate level | Holzer, 2014 |
| Absence of fish or other predators | Beebee, 1996; Petranka et al., 2004; Porej and Hetherington, 2005; Vasconcelos and Calhoun, 2006; Chester and Robson, 2013 |
| Aquatic vegetation (providing refuge against predators, nesting site, shade and production of oxygen) | Sredl and Collins, 1992; Hamer et al., 2002; Egan and Paton, 2004; Pearl et al., 2005; Skidds et al., 2007; Hamer and McDonnell, 2008; Hamer and Organ, 2008; Hamer and Parris, 2011; Chester and Robson, 2013; Holzer, 2014 |

(**Table 3**). For example, Parris (2006) registers, on the basis of a predictive model, a decrease of more than 40% in the species richness measured in stormwater ponds due to the presence of a vertical wall. Other factors are mentioned as having an effect on the amphibian presence in stormwater ponds, but do not appear to be conclusive. This is the case for the age of ponds (e.g., Birx-Raybuck et al., 2010; Pohl et al., 2015). Although Birx-Raybuck et al. (2010) identified the presence of amphibians in recent ponds, some species may be slower to colonize new wetlands and are therefore likely to occupy older ponds. The presence of aquatic vegetation within the pond studied is also mentioned as a factor favorable for amphibian development (**Table 2**), without being defined as a determining factor (Brand and Snodgrass, 2010; Hamer and Parris, 2011; Scheffers and Paszkowski, 2013). Similarly, the connectivity of the ponds studied to the surrounding wetlands (**Tables 2**, **3**) is also correlated to the species richness and abundance (Gledhill et al., 2008; Birx-Raybuck et al., 2010; McCarthy and Lathrop, 2011; Hassall and Anderson, 2015).

## Certain Negative Factors May be Modified by Stormwater Pond Managers to Make Them Ecologically Viable for Amphibian Breeding

As previously mentioned in the results, some factors influencing the suitability of stormwater ponds as amphibian breeding sites can be modified during pond maintenance operations (e.g., the presence of predators, hydroperiod or pollution accumulation) (e.g., Snodgrass et al., 2008; Birx-Raybuck et al., 2010; Brand and Snodgrass, 2010; Hamer and Parris, 2011). The connectivity between the ponds and suitable natural habitats in the surroundings can be enhanced by vegetation management (Hamer and Parris, 2011; McCarthy and Lathrop, 2011). Similarly, the connectivity of the studied ponds to other wetland habitats (including other stormwater ponds) can be enhanced by vegetation management (Gledhill et al., 2008; Birx-Raybuck et al., 2010; Chester and Robson, 2013; Hassall and Anderson, 2015) in order to support the creation of a dispersal corridor and form a network (Hamer and McDonnell, 2008; Le Viol et al., 2009; Hamer and Parris, 2011). Bateman (2014) suggests that ponds be managed in groups rather than individually to ensure that the habitat requirements of the different species are respected, while improving the species richness on a regional scale.

Finally, other authors Geai et al. (1997); Chang et al. (2011), and Scheffers and Paszkowski (2013) recommend the construction of gently sloping banks, which facilitate the growth of aquatic and semi-aquatic vegetation, as is already the case in many ponds. Chang et al. (2011) recommend that ponds with vegetated banks have slopes $\leqq 45°$, those designed with concrete subtract $\leqq 60°$ and those designed with clay $\leqq 30°$ in order to allow amphibians to climb more easily. In addition to facilitating the entry and exit of amphibians, a structure covered by vegetation provides shelter against predators (Geai et al., 1997; Scheffers and Paszkowski, 2013) and facilitates access for maintenance (Geai et al., 1997).

# DISCUSSION

This literature review demonstrates that the viability of stormwater ponds as breeding sites depends largely on

**TABLE 3 |** Factors identified in the literature review that have a negative effect on the use of stormwater ponds as breeding sites for amphibians.

| Factors with negative effects | References of the studies |
|---|---|
| Lack of connectivity | Ostergaard et al., 2008; Birx-Raybuck et al., 2010 |
| Changes in the hydrological cycle | Hamer and McDonnell, 2008; Brand and Snodgrass, 2010 |
| Long or permanent hydroperiod facilitating fish presence | McCarthy and Lathrop, 2011 |
| Seasonality | Stebbins and Cohen, 1995; Babbitt, 2005 |
| Presence of fish or other predators | Sredl and Collins, 1992; Bishop et al., 2000; Brand and Snodgrass, 2010 |
| Water pollution (affecting survival and reproduction) | Phillips, 1990; Blaustein et al., 1994; McCarthy and Lathrop, 2011 |
| Toxicity of pollutants | Campbell, 1994; Rouse et al., 1999; Gillespie, 2001; Hatch and Blaustein, 2003; Houlahan and Findlay, 2003; Kats and Ferrer, 2003; Massal et al., 2007; Otto et al., 2007; Wik et al., 2008 |
| Oil | Neff et al., 2005 |
| High level of nitrate | Snodgrass et al., 2008 |
| Conductivity and heavy metal | Hatch and Blaustein, 2003; Le Viol et al., 2012 |
| Pesticides and herbicides | Beja and Alcazar, 2003; Le Viol et al., 2012 |
| Salinity | Marsalek and Marsalek, 1997; Bishop et al., 2000; Marsalek, 2003; Karraker et al., 2008; Snodgrass et al., 2008; Denoel et al., 2010; Gallagher et al., 2014 |
| High level of nutrients (causing aquatic eutrophication) | Paul and Meyer, 2001; Johnson et al., 2007 |
| Decrease of algae quantity | Paul and Meyer, 2001 |
| Proximity to urban areas | Hitchings and Beebee, 1997; Gagné and Fahrig, 2007; Hamer and McDonnell, 2008 |
| Woody species too close to the pond (causing shade and decreasing water temperature) | Thurgate and Pechmann, 2007 |
| Human disturbance | Rodríguez-Prieto and Fernández-Juricic, 2005 |
| Artificial light affecting amphibians calls and reproduction cycles | Baker and Richardson, 2006 |
| Noise pollution affecting calls | Sun and Narins, 2005; Bee and Swanson, 2007 |

characteristics of ponds and their surroundings but also on the ecology of the colonizing species. While water pollution seems to be one of the main characteristics for defining stormwater ponds as ecological traps for amphibians (Bishop et al., 2000; Collins and Russell, 2009; Gallagher et al., 2014), many studies show that its effect varies depending on species and pollution levels, (McCarthy and Lathrop, 2011; Bateman, 2014) even though some pollutants do not directly threaten the development of amphibian embryos and larvae (Massal et al., 2007). We could therefore conclude that stormwater ponds may constitute suitable additional or alternative breeding sites for pollutant-tolerant species (Snodgrass et al., 2008; Holzer, 2014; Pohl et al., 2015). A low level of water pollution, such as a low presence of nitrate, may also be positive for amphibians because it contributes to the development of microorganisms that larvae feed on. However, there is a need to establish which levels of pollution can be tolerated, and by which species.

Thus, for several factors such as pollution levels or hydroperiod, it is difficult to make precise recommendations because of the heterogeneity of evaluation criteria presented in the publications, which limits the comparisons. A good example of this heterogeneity is the characterization of ponds in terms of hydroperiod variations. Stormwater ponds can be divided into two categories: *temporary* or *permanent* (Le Viol et al., 2012; Holzer, 2014); or *seasonal* or *semi-permanent* (Brand and Snodgrass, 2010). However, the classification may be more subtle and may include three categories based on annual observations of ponds. Scher and Thièry (2005) suggest a classification of highway ponds according to whether they are always full (*permanent*), have submerged depths (*semi-permanent*), or have a total drying phase exceeding 1 month (*temporary*). Similarly, Gallagher et al. (2014) define three categories of urban ponds according to the duration of flooding, which can be considered *temporary* (<50% of the time), *seasonal* (50–90% of the time) or *quasi-permanent* (>90% of the time) ponds. Thus, the categories of hydroperiods show a high variation in stormwater ponds (Scher and Thièry, 2005; Brand and Snodgrass, 2010; Le Viol et al., 2012; Gallagher et al., 2014; Holzer, 2014) and is probably the determining factor in the suitability of ponds as habitats for amphibians. Nevertheless, the lack of homogeneity within the hydroperiod classification does not allow the comparison of the results published.

Concerning the surrounding land, the negative influence of the adjacent intensive agricultural areas on the presence of amphibians in stormwater ponds can be explained by a strong tendency of these species to avoid these areas (Joly et al., 2001; Rothermel and Semlitsch, 2002). These agricultural land appear to be obstacles to species dispersal. In addition, they can cause a high concentration of pesticides in the water, which can be lethal for some species (Sparling et al., 2001). On the other hand, the positive influence of the presence of other wetlands near the ponds can be explained by the fact that the size of the regional population is often small. Consequently, the persistence of these populations depends on functional metapopulations composed of a network of different ponds (Semlitsch and Bodie, 2003). Finally, the positive influence of a forest environment

can be explained by the fact that many species require habitats covered by natural vegetation where they can find refuge and food, such as forests. The close proximity of the pond to a forest environment leads to a lower cost of dispersal for amphibians during seasonal migration phases (Bonte et al., 2012). Otherwise, most of the data presented in the publications analyzed here concerning the pond environment are studied within a radius of 500 m, considered as the distance of influence of an environment in relation to a pond (Simon et al., 2009). This distance is justified by the fact that dispersal movements may range from several hundred meters to one kilometer (Joly and Grolet, 1996; Denoel, 2005; Kovar et al., 2009). Nevertheless, the area studied should be adapted regarding the dispersal ability of each species.

It is important to underline the low number of publications and their restricted location as a large majority of the articles relate to studies conducted on sites located in Europe and North America. Stormwater ponds are used around the world in a variety of forms and environmental contexts that are currently difficult to evaluate in a review article as the literature does not provide information about functionality, maintenance practices and environment features surrounding the pond. Additional studies are needed, including multi-factorial studies to investigate the influence of the combination of factors listed in this article on amphibian development.

It is also necessary to conduct more targeted studies on the different types of stormwater ponds whose operational objectives and management methods may vary. It might be relevant to include a wider range of factors in the analysis and to make comparative studies between different types of ponds. The difficulty in drawing accurate conclusions also comes from the lack of homogeneity in the few publications concerning this subject as shown with the example of the term "hydroperiod."

Therefore, it is difficult to state on the basis of this review, that stormwater ponds are or are not ecological traps, insofar as this depends on many criteria that vary according to the type of pond, its design, the climate and the land uses in the areas adjacent to the pond's location. The ecology of the species that colonize it is also an important factor. However, it is interesting to note that several authors point out that stormwater ponds could be beneficial breeding sites for amphibian species (Bishop et al., 2000), especially in man-made landscapes where aquatic habitats are increasingly rare (Le Viol et al., 2009, 2012; Gallagher et al., 2014). If so, they could make a substantial contribution toward enhancing local and even regional biodiversity (Gledhill et al., 2008).

It is important to remark that many factors that can affect the sustainability of stormwater ponds to provide quality habitat for amphibians have not been studied. This review of the scientific literature raises the question of whether or not stormwater pond maintenance practices can play a role in the adaptation of the ponds as breeding sites for amphibians (Hamer and Parris, 2011; Gallagher et al., 2014; Hassall and Anderson, 2015).

In **Tables 2**, **3**, pond maintenance is only noted as a potential positive factor and is absent from the negative factors (Chester and Robson, 2013). The different maintenance practices include dredging the pond (i.e., removing the sludge that accumulates at the bottom of the ponds) and clearing vegetation (IFSTTAR-LCPC., 2006; Le Viol et al., 2009). Dredging can have a deadly impact on amphibian populations present in the pond if the activity is carried out during the breeding season. Nevertheless, it can also have other potential benefits because it prevents the pond from being filled by mud and consequently from drying out (Duguet et al., 2003; Ruban et al., 2003). In addition, it prevents the pond from the proliferation of invasive species. The management of stormwater ponds also involves vegetation control in and around the ponds. Although aquatic vegetation plays a positive role in spawning and providing refuges against predators (Duguet et al., 2003), an excessive development can result in eutrophication as well as difficulties in water circulation (Hamer and Parris, 2011). There is a need to find a balance between ecological and technical management in order to support the development of amphibian populations without hindering the functioning of the ponds. Further studies are needed to reconsider pond management and to identify the best practices to reduce the negative factors and to enhance positive ones for amphibian development in stormwater ponds.

This literature review suggests a possible compatibility between a purely technical management and ecological management of ponds that can benefit amphibians while maintaining the functionality of the pond. In addition, this review highlights the importance of a proper vegetation management to link these ponds to a terrestrial habitat, which is necessary for the lifecycle of amphibians. Finally, it seems important to consider the temporality of the process in the analysis of the suitability of stormwater ponds as habitats for amphibians. Whether it be short-term because of a variable hydroperiod, or long-term because of the need to be cleaned regularly to avoid filling, the question remains: Can stormwater ponds be considered temporary wetlands, such as the natural temporary Mediterranean pools mentioned by Babbitt and Tanner (2000); Beja and Alcazar (2003); Jakob et al. (2003); Bagella et al. (2010); Ruhí et al. (2012) or the continental pools mentioned by Lukács et al. (2013)? If so, should these ponds be included in local or regional plans to enhance biodiversity?

However, it is possible to conclude that stormwater ponds located in highly anthropogenic landscapes, as is the case in Europe and North America, can be both ecological traps and suitable habitats for amphibian breeding, depending on a number of factors, including the species that colonize them, pond design, and the environmental context in which they are embedded. Additional studies are therefore needed in other parts of the world, particularly where amphibian biodiversity hotspots are located, but also on possible management and maintenance practices and how to link stormwater ponds to quality terrestrial habitats through the creation of ecological corridors.

## AUTHOR CONTRIBUTIONS

LC, CC and PP: Contributed conception and design of the study; LC: Organized the database; LC: Performed the statistical

analysis; LC: Wrote the first draft of the manuscript; LC: Wrote sections of the manuscript. All authors contributed to manuscript revision, read and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2018.00040/full#supplementary-material

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