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Effects of management intensity, function and vegetation on the biodiversity in urban ponds

Blicharska Malgorzata[a,b,*], Andersson Johan[c], Bergsten Johannes[d], Bjelke Ulf[e], Hilding-Rydevik Tuija[a], Johansson Frank[c]

[a] Swedish Biodiversity Centre, Swedish University of Agricultural Sciences, Box 7016, SE-750 07 Uppsala, Sweden
[b] Department of Earth Sciences, Uppsala University, Villavägen 16, 75 236 Uppsala, Sweden
[c] Department of Ecology and Genetics, Uppsala University, Norbyvägen 18D, 752 36 Uppsala, Sweden
[d] Department of Zoology, Swedish Museum of Natural History, Box 50007, SE-10405 Stockholm, Sweden,
[e] The Swedish Species Information Centre, Box 7007, SE-750 07 Uppsala, Sweden,

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ABSTRACT

Ponds are important elements of green areas in cities that help counteract the negative consequences of urbanization, by providing important habitats for biodiversity in cities and being essential nodes in the overall landscape-scale habitat network. However, there is relatively little knowledge about the impacts of pond management intensity, function and environmental variables on urban pond biodiversity. In this study we addressed this gap by investigating which factors were correlated with the level of biodiversity in urban ponds, indicated by species richness of aquatic insects, in Stockholm, Sweden. Our study did not confirm any direct link between the perceived intensity of management or function of ponds and overall biodiversity. However, it seems that management can influence particular groups of species indirectly, since we found that *Trichoptera* richness (Caddisflies) was highest at intermediate management intensity. We suggest that this is caused by management of vegetation, as the amount of floating and emergent vegetation was significantly correlated with both the overall species richness and the richness of *Trichoptera* (Caddisflies). This relationship was non-linear, since ponds with an intermediate coverage of vegetation had the highest richness. Interestingly, the amount of vegetation in the pond was significantly affected by pond function and pond management. The overall species richness and richness of *Trichoptera* were also positively correlated with pond size. Since we found that the pattern of relations between species richness and environmental variables differed between the insect groups we suggest that it will be difficult to provide overall design and management recommendations for ponds in urban green areas. Therefore, it is recommended that to provide high aquatic diversity of species in urban areas one should aim at promoting high diversity of different types of ponds with differing management and environmental factors that shape them.

1. Introduction

The on-going global trend of urbanisation has important consequences for biodiversity, leading to the increasing fragmentation of natural environments and habitat loss (McDonald et al., 2008; Miller and Hobbs 2002). Even though some plant and animal species are able to inhabit urban areas, most are sensitive to the effects of urbanisation (Ghert and Chelsvig, 2003; Riley et al., 2005). However, detrimental influences of urban environments can be alleviated by the presence of green areas that may offer important habitats for biodiversity in cities and provide essential nodes in the overall landscape-scale habitat network (Angold et al., 2006; McKinney 2006). In some cases, these areas provide habitats for species that are decreasing elsewhere (e.g. Carrier and Beebee, 2003).

Ponds in cities are often classified as "green-space areas", because they are usually located within parks or other urban green zones and constitute important components of these areas (Harrison et al., 1995). Growing recognition of the importance of ponds and other small water bodies for maintaining biodiversity in cities (Colding et al., 2009; Fuyuki et al., 2014; Hassall and Anderson 2015) extends to conservation programmes for endangered species (Vermonden et al., 2009). Hassall and Anderson (2015) revealed that urban storm water management ponds can provide a similar level of biodiversity as urban wetlands in Ottawa, Canada.

* Corresponding author at: Department of Earth Sciences, Uppsala University, Villavägen 16, 75 236 Uppsala, Sweden.
E-mail address: malgorzata.blicharska@geo.uu.se (M. Blicharska).

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Similarly, Le Viol et al. (2009) investigated the diversity of macroinvertebrates in highway storm water ponds and concluded that these ponds supported communities at least as rich and diverse as pond communities in the surrounding landscape. Goertzen and Suhling (2013) showed that urban ponds may have great value for biodiversity but are threatened by various urban disturbances and lack of suitable design.

During the past decade, there has been an increase in the number of studies examining biodiversity of urban ponds (e.g. Gledhill et al., 2005; Hamer et al., 2012; Noble and Hassal, 2014). The majority of studies have focused on how ecological and land-cover variables or water chemistry affects the biodiversity of ponds (e.g. Biggs et al., 2005; Lamy, 2013; Leibold, 1999; Oertli et al., 2002). There remains, however, a lack of knowledge on how the intended primary function and management of ponds affects biodiversity in cities (Biggs et al., 2005; Hassall et al., 2011). Ponds in cities can have different primary functions, e.g., their purpose can be treatment of urban run-off, maintenance of natural value for biodiversity, or delivery of aesthetic experiences to citizens (Hassal, 2014). Each function may involve specific kinds of management activities that influence pond vegetation. In one of the few studies on pond management and biodiversity, Noble and Hassal (2014) identified a possible conflict between human and wildlife interest in pond management in Bradford District, UK, because many ponds were managed primarily for their aesthetic function such that removal of vegetation to keep the pond "neat" for people potentially decreased their ecological value. However, there is little research on how environmental factors and function and management of ponds are correlated and how this influences biodiversity of urban ponds.

In many countries the potential of urban ponds to deliver both biodiversity and ecosystem services such as water purification, flood control, or aesthetic experiences has been recognized. Many ponds and small water bodies have been filled during the past few decades, but there is now an increasing trend to restore and even to create new water bodies in many European cities (e.g., Åstebøl et al., 2004; Segaran et al., 2014; Starkl et al., 2013; Gledhill and James, 2012). In Sweden, ponds have been increasingly included in urban landscape planning since 1990, both for the purpose of water runoff management and to increase aesthetic appeal of nearby housing areas (Personal communication with representatives of municipalities in the city of Stockholm, 2014). Recently, the focus in Sweden has been to increase the value of these ponds for biodiversity, and some projects to restore ponds with the intention of improving their ecological value have been initiated (e.g. Ohlin, 2013). However, to our knowledge there are no studies that have focused on the relationships between the intended primary function of a pond, how intensively a pond is managed, and pond biodiversity. We use the example of a large Swedish city, Stockholm, to investigate this relationship. Such knowledge is important because it can help with pond design and management to enhance their ecological value and thus provide biodiversity rich habitats in the urban matrix.

The purpose of our study was to investigate which factors are responsible for determining biodiversity in Stockholm urban ponds with a focus on management. We selected environmental variables that were shown to affect biodiversity in a pilot study as well as variables associated with pond function and management that were identified during interviews.

2. Methods

2.1. Study area and selection of ponds

Our study was conducted in the city of Stockholm, capital of Sweden. The city has ca. 900 000 residents (Stockholm Stad, 2013) and is characterised by many waterways and high coverage of green areas (Andersson et al., 2009). Stockholm is a city where environmental considerations are high on the political agenda. It was the first city to be awarded the European Green Capital by the EU Commission in 2010, because of its holistic vision to combine economic growth with sustainable development (European Commission, 2010).

In the present study, we considered 43 ponds in central Stockholm covering seven municipalities (Fig. 1). We define ponds as natural or man-made water bodies having an area between 1 m^2 and 2 ha and holding water for at least 4 months of the year (Pond Conservation, 2002; Biggs et al., 2005). Ponds were selected from maps and by using information from municipal officials. We focused on densely populated areas in the city. We divided Stockholm into 1 × 1 km squares and only considered squares where >75% of the area was occupied by build-up land uses as defined in Terrain map (Terrängkartan^{TM}) of the Swedish mapping, cadastral and land registration authority (Lantmäteriet). Therefore, we excluded ponds located in golf courses, most often situated outside the populated areas, even if they have shown a great potential for fostering biodiversity in urban areas (Colding et al., 2009).

2.2. Selection of variables and data collection

We defined biodiversity as species number, and we measured it as richness of aquatic insects, in the taxa dragonflies (*Odonata*), aquatic beetles (*Coleoptera*), aquatic true bugs (*Hemiptera*) and caddisflies (*Trichoptera*). Although former studies have shown that also other taxonomic groups significantly contribute to the biodiversity of urban ponds (Hassall and Anderson, 2015; Hill et al., 2015), the taxa selected for the purpose of this study provide an accurate proxy of general biodiversity, because these invertebrates represent different functional groups and their biodiversity is correlated with biodiversity of plants, vertebrates and other invertebrate groups (Hassall et al., 2011; Oertli et al., 2010). As species richness was significantly correlated with Shannon index for species ($p < 0.000$, $r = 0.82$) and species abundance ($p = 0.005$, $r = 0.42$) we did not include these variables in the analysis, because adding variables decreases statistical power of the models.

We collected information on environmental variables that were previously found to be correlated with aquatic insect diversity. In a pilot study conducted using 26 ponds in north and central parts of Stockholm (Andersson, 2014) that investigated the effects of environmental variables on the aquatic insect diversity, it was found that species richness is significantly correlated with the amount of aquatic vegetation (both floating and emergent) in ponds and their distance to the nearest building. We therefore included these variables. Similar effects of vegetation on species richness in ponds have been found in other studies (Biggs et al., 2005; Goertzen and Suhling, 2013; Hassall et al., 2011). However, we did not sample submerged vegetation. In addition, we added pond size as a potential variable that could affect biodiversity, because it has been shown to be important in studies of rural ponds (Biggs et al., 2005; Oertli et al., 2002), even if studies considering pond size have yielded conflicting results (Hassall et al., 2011).

Vegetation cover of the ponds (i.e. floating plants and plants growing in the ponds) was estimated by eye in August 2013 and 2014 in tenths and described in percentage ranging from a total cover of no vegetation (0%) at all to full cover (100%). Vegetation was recorded into two separate categories; floating leaf vegetation and emergent vegetation. Pond size and distance to nearest building was estimated with the software ArcGIS 9 and the Terrängkartan^{TM} map from Lantmäteriet.

Information on the ponds' main function, age and perceived intensity of management was collected through interviews. First, an open-ended interview (Kvale, 1996) lasting about 2.5 h was