



Linking management to biodiversity in built ponds using metacommunity simulations



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ABSTRACT

In urban and other built environments, management decisions serve as a prominent feedback between biodiversity patterns and human-controlled environmental variables. In this study, we used the metacommunity concept to assess the mechanisms that link zooplankton biodiversity to different management regimes in urban water bodies associated with the Baltimore Ecosystem Study Long-Term Ecological Research site (USA). In the summer of 2011, we sampled zooplankton in 21 ponds built for stormwater management. Ponds were classified as either unmanaged ($n=9$) or actively managed ($n=12$) for recreation and aesthetic value, where managed ponds received multiple chemical and algicide applications to improve water clarity. We found managed ponds had higher local (alpha) diversity and lower spatial turnover in community composition (beta-diversity), and thus greater biotic homogenization than ponds that were unmanaged. We developed a lottery-based metacommunity simulation (MCSim) to assess how niche and dispersal dynamics could create the observed biodiversity patterns, and to assess whether biotic homogenization was related to management. A comparison of empirical and simulated diversity patterns suggests the zooplankton pond metacommunity was influenced by both dispersal and niche-based community assembly dynamics. Simulations showed that the observed biotic homogenization effect was expected based on the spatially aggregated distribution of managed ponds, but pond management was not likely exacerbating biotic homogenization in this system. Such insight is essential to understand how environmental management can affect biodiversity at local and regional scales.

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1. Introduction

Humans have managed natural ecosystems for 40–50 millennia (Bird et al., 2008), yet strategies of ecosystem management continue to evolve as a rapidly growing human population places accumulating demands on natural systems (Wilkinson et al., 2013). Fortunately, our understanding of the functioning of communities and ecosystems is also evolving, allowing for more effective management of natural systems (Farber et al., 2006). One recent advance in our understanding of the structure and dynamics of ecological communities is the multi-scale perspective of metacommunity theory (Leibold et al., 2004). As a result, modern community ecology acknowledges that the movement of organisms across landscapes may have as large an effect on community

structure and dynamics as environmental tolerances and species interactions (Leibold et al., 2004).

Urbanization is a leading cause of biotic homogenization (McKinney, 2006), which describes a pattern of increasing similarity (or decline in beta diversity) among ecological communities across a region, or even globally (McKinney and Lockwood, 1999). This trend is caused by both local extirpations of indigenous taxa and the increased dispersal and introduction of “winner” taxa that become widely established (McKinney and Lockwood, 1999; Olden, 2006). A growing recognition among land managers and policy makers of the value of ecosystem services associated with biodiversity is reflected in municipal sustainability plans that guide conservation and natural resource management in U.S. towns and cities (e.g., Baltimore City, 2009). Therefore, it is important that we understand links between management and biodiversity in the built ecosystems that make up human dominated landscapes.

A rapid expansion of the human presence on the landscape has resulted in the increase of built ecosystems (Alig et al., 2004),

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including stormwater detention basins (Fairchild et al., 2012). Built ponds collect stormwater and reduce the impact of a flashy hydrograph resulting from high impervious surface cover that is characteristic of urban landscapes (Plumb et al., 2013). Some detention ponds are also actively managed for recreational and aesthetic purposes when they occur in green spaces set aside for recreational use (Ferguson, 1991). Alternatively, unmanaged built ponds (e.g., Bishop et al., 2000) are relatively free from human alteration following construction except for routine structural maintenance.

Ponds represent sentinel ecosystems that integrate the landscape and are closely tied to local land use decisions (C er ghino et al., 2008; De Meester et al., 2005), and thus may provide a multi-scale perspective on how management practices affect biodiversity. Here, we focus on zooplankton biodiversity because zooplankton represent an intermediate trophic guild and zooplankton community composition integrates a suite of abiotic and biotic influences, including local physiological constraints, bottom-up and top-down trophic interactions, and pond trophic status (Jeppesen et al., 2011).

Our aim was to address the following two questions regarding built ponds in the Baltimore Ecosystem Study (BES), Long Term Ecological Research (LTER) site (Baltimore, Maryland, USA): does management for common aesthetic and recreational purposes throughout the region result in a homogenization of local habitats, and thus biodiversity? How important are local niche-based and regional inter-pond dispersal dynamics for understanding how biodiversity will respond to management decisions?

The first step in addressing the above questions was to assess whether we could detect a difference in zooplankton biodiversity between actively managed and unmanaged built ponds using field survey methods. We performed these surveys in collaboration with the local homeowners' association (Columbia Association, Columbia, Maryland, USA), which is responsible for management of both stormwater runoff and water quality of these detention features.

Following the field survey of BES ponds, our second step was to test hypotheses about how observed biodiversity patterns could be linked to metacommunity and hydroscape (i.e., a "landscape" of aquatic features) characteristics using process-based metacommunity simulations (Gravel et al., 2006; Hubbell, 2001; Mouquet and Loreau, 2003; Sokol et al., 2011). Specifically, we designed simulations to identify a set of metacommunity characteristics that could effectively reproduce *in situ* biodiversity patterns *in silico*. This approach can be used to identify a best-fit simulation scenario that represents a well-informed hypothesis describing zooplankton metacommunity dynamics in the built-pond hydroscape of the BES based on our current understanding of metacommunity theory and the empirical characteristics of the system (Fig. 1). We then used the best-fit simulation scenario as a reference for null model hypothesis testing to determine if observed differences in biodiversity between managed and unmanaged ponds could be explained by exogenous factors, i.e., properties of the hydroscape not affected by management (e.g., pond size and spatial connectivity, Frisch et al., 2012; Steiner et al., 2013), or if biodiversity patterns should be attributed to active pond management.

2. Methods

2.1. Empirical data collection and analysis

We chose 21 stormwater detention ponds in and around the cities of Columbia and Baltimore, Maryland, USA within the BES LTER for sampling. Site selection was based on pond proximity, management history, and accessibility. Unlike naturally occurring ponds, managers often restrict human access to private built ponds for safety and/

or privacy concerns (e.g., by building fences around the ponds). Therefore, we were only able to sample ponds that were unfenced or where we had permission to visit from the local homeowners' association. We designated ponds as either "managed" ($n=12$) or "unmanaged" ($n=9$) based on whether algal management was taking place (Table A1). Management classification was based on information acquired by the Columbia Association Department of Open Space Management, which actively manages algal blooms in built ponds with Aquashade  (pers. comm.). Aquashade  is an acid-based, light-attenuating dye designed to inhibit the wavelengths of light necessary for photosynthesis.

All ponds were sampled once during 6–15 June 2011. An 11 cm diameter, 63 μm mesh plankton net was used to collect a sample from the littoral zone in a 30 m long horizontal tow at 1 m depth. Samples were concentrated on a 63 μm sieve, then immediately preserved in 70% ethanol. To estimate zooplankton density (Table A2, A3), samples were brought to a total volume of 500 ml using distilled water, homogenized by stirring with a plastic pipette, and 10 subsamples (2 ml each) were viewed from each sample with a compound microscope using a 1 mm² gridded Sedgewick Rafter at 40 \times magnification. A total of 200–400 zooplankton were identified to the lowest practical taxonomic level for each sample.

Phytoplankton biomass and conductivity were used to characterize environmental variation among ponds. Phytoplankton biomass was estimated as chlorophyll *a* by collecting a 500 ml surface grab sample from the littoral zone of each pond. We filtered the sample onto a 47 mm Whatman GF/F, and froze the filters until they were analyzed via ethanol extraction and absorbance via spectrophotometry (ISO, 1992; Sartory et al., 1984). Conductivity was measured at the water's surface in the field with a YSI Model 30M Conductivity Probe (YSI Inc., Yellow Springs, Ohio, USA). Dissolved oxygen (mg l^{-1}) and temperature were measured on site with a YSI Model 700A Probe (YSI Inc., Yellow Springs, Ohio, USA). The concentrations of phosphorus (PO_4 , mg l^{-1}) and nitrate (NO_3 , mg l^{-1}) were measured via ion chromatography following filtration through 47 mm Whatman GF/F filters. We used Welch's two-sample *t*-test to compare means and the robust Brown–Forsythe Levene-type test in the lawstat package (Gastwirth et al., 2013) to compare variances. All analyses were conducted using R v3.1.1 (R Core Team, 2014).

For all estimates of biodiversity in this study, we focused on occurrence rather than relative abundance because occurrence-based metrics will be less sensitive to seasonal fluctuations in zooplankton abundances, which reflect local dynamics that are beyond the scope of this study. We used the vegetarian package (Charney and Record, 2012) to conduct multiplicative diversity partitioning based on order $q=0$ Hill numbers (Jost, 2007) to estimate D_α , D_β , and D_γ for managed and unmanaged ponds, where D_α , D_β , and D_γ represent alpha, beta, and gamma diversity, respectively. For diversity partitions based on order $q=0$ Hill numbers, D_α and D_γ represent local and regional richness, respectively, and D_β represents the number of "distinct" communities in the metacommunity.

The difference in diversity between managed and unmanaged ponds (dD) was estimated by subtracting Hill number diversity estimates for the unmanaged group of ponds from the managed group (e.g., $dD_\alpha = D_{\alpha, \text{managed}} - D_{\alpha, \text{unmanaged}}$). To test if shifts in diversity were significant, we calculated a null-distribution of dD_α , dD_β , and dD_γ for 10,000 random permutations of the observed data set (see Appendix). This test provided an estimate of the distributions of dD_α , dD_β , and dD_γ that would be expected if ponds were randomly assigned to a management group (managed vs. unmanaged). Estimates of dD for alpha, beta, and gamma diversities were considered significantly different than 0 if they were outside the 95% CI of their respective null distributions.

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