Effets de l'urbanisation sur la biodiversité des plaines alluviales : en quoi les bases de données mondiales peuvent-elles nous renseigner ?

Urbanisation effects on floodplain biodiversity: what can we learn from globally aggregated field data?

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RÉSUMÉ

Les plaines d'inondation font partie des écosystèmes les plus menacés au monde, en raison de leur attractivité pour les sociétés humaines et des nombreux services écosystémiques qu'elles soutiennent. Malgré leur faible étendue, elles fournissent des habitats favorables à une grande diversité d'espèces, dont beaucoup sont rares ou menacées. La forte urbanisation des plaines alluviales s'accompagne de l'altération de la dynamique de débordement naturel des cours d'eau et de la construction d'obstacles à l'écoulement, de l'altération de la qualité de l'eau, etc. induisant une raréfaction et une simplification des habitats avec des conséquences délétère sur le maintien des communautés animales et végétales aquatiques et terrestres. Dans cette étude, nous visons à quantifier l'impact de l'urbanisation des plaines d'inondation sur la richesse spécifique de douze groupes d'espèces (8 d'invertébrés, 4 de vertébrés), en nous concentrant sur 1062 agglomérations urbaines de plus de 300 000 habitants, réparties dans le monde entier. Nous utilisons des données biologiques en libre accès, bancarisées à l'échelle mondiale, pour comparer la richesse spécifique des communautés urbaines à celle au bassin versant (en limitant à 300 km en amont et en aval des villes) qui leur est associé, en utilisant des techniques de raréfaction et d'extrapolation. Les résultats montrent une dégradation significative, à l'échelle mondiale, de la richesse spécifique des communautés urbaines pour huit de ces groupes.

ABSTRACT

Floodplains are among the most threatened ecosystems in the world, due to their attractiveness by human societies and the many ecosystem services they support. Despite their small extent, they provide favorable habitats for a great diversity of species, many of which are rare or threatened. The strong urbanisation of alluvial plains is accompanied by the alteration of the dynamics of natural overflow of watercourses and the construction of obstacles to flow, the alteration of water quality, etc. inducing a scarcity and simplification of habitats with deleterious consequences on the maintenance of aquatic and terrestrial animal and plant communities. In this study, we aim to quantify the impact of floodplain urbanisation on the species richness (R) of twelve groups of species (8 invertebrates and 4 vertebrates), focusing on 1062 urban agglomerations with more than 300,000 inhabitants, distributed around the world. We use open access biological data, aggregated at a global scale, to compare the species richness of urban communities (R_{up}) to that of its associated catchment (R_{cp} - 300 km up and downstream cities) using rarefaction and extrapolation techniques. The results show a significant degradation in the species richness of urban communities for eight of these groups on a global scale.

MOTS CLÉS

Erosion de la biodiversité, large échelle, plaines alluviales, richesse spécifique, urbanisation

Biodiversity loss, global scale, floodplains, species richness, urbanisation

1 INTRODUCTION

By 2050, 68% of the world's 11 billion people will live in cities (United Nations, 2019). Along with climate change, urbanisation represents one of the major threats to biodiversity worldwide. Urban systems have generally developed close to rivers and their floodplains. These specific landscapes, which cover less than 3% of the Earth's surface, represent 'attractors' and 'fixers' of global urbanisation because of the many ecosystem services they provide (Schindler et al., 2014). Though, floodplains are the most vulnerable ecosystems to human activity (MEA, 2005). Main alterations to floodplain biodiversity result from (1) the degradation of water quality and habitat availability, (2) the alteration of the longitudinal connectivity, (3) the limitation of flood expansions and the resulting alteration of the nutrient cycle (Waite, 2019, Foubert et al., 2020). Many regional case studies have shown that an increase in urban pressures affects every phylum and is associated with a significant decrease in the species richness of macroinvertebrates (Cuffney et al., 2010), fishes (Morgan et al., 2005), birds (Fuller et al., 2008; Santos et al., 2024) or plants (Cao et al., 2020). In contrast, studies that analyse this phenomenon at a global scale are scarce, generally lack methodological uniformity (Gál et al., 2019) or are derived from extrapolations based on abiotic variables, with few validations (Kuiper et al., 2014).

The unprecedented increase in the quantity of globally distributed biological data over the last decade (Heberling et al., 2021) and the development of database initiatives (GBIF, PREDICTS, GenBank, etc.) offer perspectives to assess the impact of urbanisation on species richness, yet unexplored at a global scale. The initiative that stands out for the quantity of biological data available in open access is the Global Biodiversity Information Facility (GBIF), which includes more than 3 billion observations, contributed by more than 2,000 publishing institutions (available at https://www.gbif.org [21 November 2024]). Even if the availability of such a database offers major perspectives, there are however several limits to their use, related to taxonomic biases, heterogeneity in protocols (Isaac et al., 2015), societal preferences (Troudet et al., 2017) and countries' awareness or resources (Boakes et al., 2015).

In this study, we therefore seek to determine (1) to what extent such database can inform on the effects of urbanisation on floodplains' species richness worldwide, (2) for which phylum such trends can be identified, and (3) whether urbanisation has a greater impact on certain groups of taxa.

2 MATERIALS AND METHODS

2.1 Site selection

We considered urban agglomeration exceeding 300,000 inhabitants as urban sites (UN 2019). The city centre was spatially defined as the "High Density Cluster", proposed in GHS-SMOD R2023A (Schiavina et al., 2023). For the purpose of our study, we retained those sites that intersected rivers larger than 30-60 m resulting in a total of 1062 study sites overlapping the GFPLAIN250m data extent (Nardi et al., 2018). For each site, clipping the GFPLAIN250m layer to the WWF HydroSHEDS Basins (Lehner & Grill, 2013) at the 6th level basin subdivision (Strahler order) and extending downstream within a 300 km buffer at level 9th basin subdivision provided the "catchment scale" (further named catchment). Further clipping the GFPLAIN250m layer to the GHS-SMOD R2023A "High Density Cluster" provided the "urban scale" (further named urban).

2.2 Biological data

Biological data were extracted from the GBIF (GBIF.org, 2024) on May 30th, 2024, considering the occurrences of animals and plants between January 1st, 2020, and December 31st, 2023. Those occurrences with a spatial coordinate uncertainty > 250 m were excluded to match the resolution of the GFPLAIN250m raster layer. From this extraction and the scales defined above, we were able to further establish an expected pool of species (catchment) and a pool of species filtered by urbanisation (urban) at each site. In the following, we present those results concerning Animalia species only.

2.3 Data analysis

To ensure the comparison of species richness between the urban and the catchment pools for a given group of species, we computed the revised sample coverage index for both scales computed from the entropart R package (Marcon & Hérault, 2015). The selected sites were the ones where both urban and catchment pools reached a minimum sample coverage of 0.9, a threshold commonly applied (Chao et al., 2014). The same procedure was applied for each group of species.

To make the pools comparable, we further applied rarefaction and extrapolation methods (Chao et al., 2014) using the iNEXT R package (Hsieh et al., 2024). The urban pool effort (i.e number of occurrences in the urban pool, E_{up}) is always lower than the catchment pool effort (i.e number of occurrences in the catchment pool, E_{cp}) as the previous one is nested into the latter. We further defined the target sample size (until which to rarefy and extrapolate) for a given combination of pools as two times the E_{up} (if $E_{cp} > 2^* E_{up}$) or as equal E_{cp} (if $E_{cp} < 2^* E_{up}$). The iNEXT method returned an extrapolated species richness (R_{ext_up}) for each urban pool and a rarefied (R_{rar_cp}) species richness for each catchment pool and each group of species. We computed the differences between R_{ext_up} and R_{rar_cp} to quantify the species richness loss at each urban site. We then computed the R_{ext_up} to R_{rar_cp} ratio allowing us to assess how close the species richness of the urban pool compared to the species richness of the catchment pool (our "reference" pool) for each site.

Average differences between R_{ext_up} and R_{rar_cp} were computed for each group of species. Student's t-Test was performed in case of normality (Shapiro-Wilk Normality Test, $p > 0.05$) and a Wilcoxon Rank Sum and Signed Rank Tests if not ($p<0.05$). We used non parametric ANOVA to test for differences in the R_{exst_up} to R_{rar_cp}ratio across the groups of species allowing us to assess the impact of urbanisation on the species groups.

3 3. PRELIMINARY RESULTS

The continent with most cities located in floodplains is Asia (n=596 out of 1062 sites), then comes Europe (n=165), North America (n=131), Africa (n=91), South America (n=73) and Oceania (n=6). The total number of floodplain occurrences retained for the study equalled 3,033,097 (E_{cp}), including 530,426 at the urban scale (E_{up}). According to the rules of their associated occurrences being located in floodplains embedded in their catchment area, the final number of retained sites included various group of species and phyla: Clitellata (n=13 sites), Trichoptera (n=18), aquatic Gastropoda (n=25), Bivalvia (n=44), Malacostraca (n=78), Lepidoptera (n=312), Fishes (n=147), Amphibia (n=156), aquatic macroinvertebrates (n=175), Odonata (n=216), Mammalia (n=100), and Aves (n=441). The threshold of 0.9 for coverage index in the catchment and urban pools was reached for 3 sites for Trichoptera, 6 for Clitellata, 10 for aquatic Gastropoda, 11 for Bivalvia, 20 for Malacostraca, 28 for Lepidoptera, 30 for Fishes, 49 for Odonata, 52 for aquatic macroinvertebrates, 73 for Amphibia, 100 for Mammalia, and 136 for Aves.

The group of species were differently impacted by floodplain urbanisation. Birds were the most impacted group with an average estimated R_{ext_up} to R_{rar_cp} ratio of 0.65 ($p = 3.24e-23$), and Gastropoda were the least impacted with a ratio equal to 0.72 ($p = 0.01$). The ratios of four groups (Clitellata, Bivalvia, Trichoptera, Malacostraca) showed no evidence for being impacted by urbanisation (Fig. 1).

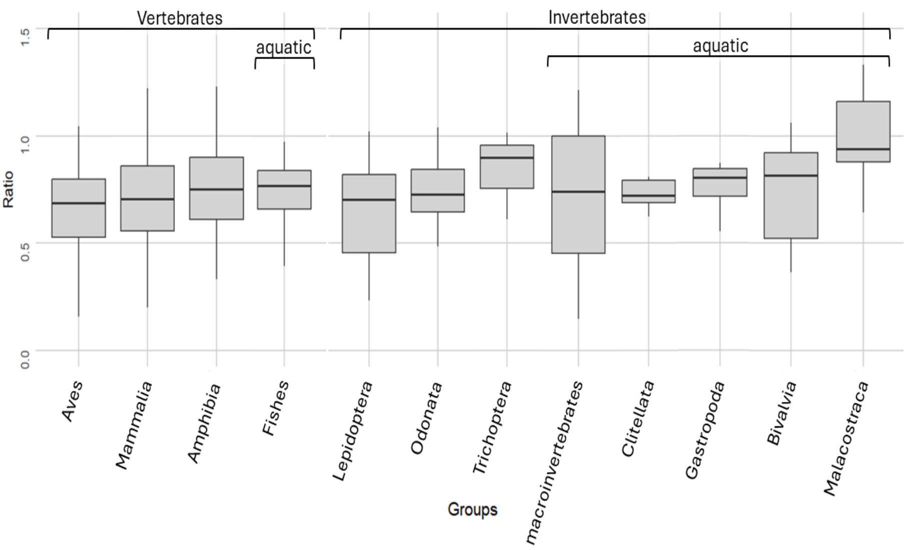

Fig. 1 Extrapolated urban to rarefied catchment species richness ratio in each group of species retained in the study. Within each larger grouping (Invertebrates, Vertebrates, Aquatic) ratios are ordered by ascending median. The taxonomy of species strictly aquatic was extracted from the freshwaterecology.info database (Schmidt-Kloiber et al., 2019).

4 DISCUSSION

The findings of our study clearly show that (1) data aggregated through international initiatives shows major taxonomic and spatial biases. For example, urban/catchment-aggregated occurrences could be compared for only 3 sites for Trichoptera and for 136 sites for birds, and almost all of them located in the northern countries. Furthermore, a dissymmetry occurred in the amount of data collected within and outside urban centers, which makes the comparison of pools challenging. One explanation for these heterogeneities lies in the societal preferences, differences in the completion of monitoring network, difficulties of setting up the study device for observation/identification (Amano et al., 2016 ; Knapp et al., 2021), as well as countries' wealth, security or education level (Amano & Sutherland, 2013) and on a still low attention to urban biodiversity (Isaac et al., 2015 ; Martin et al., 2012) ; (2) our results show a significant decrease in species richness for 8 groups, regardless of whether they are vertebrates or invertebrates, aquatic or terrestrial. The replacement of vegetation by impervious surfaces, which result in a loss of habitats, represents a common threat for all animal groups. (3) Among the 12 groups studied, birds experience the most significant alteration in species richness. This can be explained by their needs for larger home ranges and for some species by the decline of the density of native trees in urban areas (Reis et al., 2012). In addition, we found that the average loss of species facing urbanisation was comparable for birds and Lepidoptera. Our findings are in accordance with previous studies that have highlighted that trends in the species richness of Lepidoptera followed those of birds (Blair 1999). In contrast, gastropods' richness showed a weak response to urbanisation, probably because their dominance in urban streams is most likely a result of the increased availability of algae and macrophytes linked to the increased input of nutrients (Wiederkehr et al., 2020).

Our study sheds important light on the erosion of biodiversity associated with urbanisation and is encouraging for further analyses, which will aim at (1) assessing the effects of competition by invasive species within urban environments; (2) comparing the species ecological preferences or specialisation/adaptation to urbanisation; (3) inferring the loss or degradation of ecosystem services through functional traits; and (4) assessing links between the responses of selected taxa and urbanisation pressures (e.g. urban sprawl, demographic growth, pollutants).

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