*Across the continental U.S., landscape-scale urban pollinator occupancy rates are associated with among-city differences in natural habitat area and relative income.*

1. **Introduction**

**First intro paragraph:** Across the globe, the intensity and extent of urban land use is increasing (Seto et al., 2012) and by the year 2050 over 70% of the world’s population is projected to live in urban areas (United Nations, 2018). With potential negative consequences for biodiversity, urbanization is associated with changes in the abiotic and biotic environment and in the spatiotemporal composition and configuration of habitat and resources (McKinney, 2006; Grimm et al., 2008; spatial; Leong et al., 2016; Eichenberg et al. 2021). To develop strategies that reduce the loss of biodiversity and ecosystem services due to this ongoing global land use change process, it is necessary to understand the key drivers of urban biodiversity patterns and, further, the spatial and temporal scales at which these drivers operate. Identifying these key drivers as well as their spatiotemporal scale dependence is especially pressing for pollinators, a functional group that provides valuable ecosystem services in the urban environment (Chepdou et al, ; urban agriculture eg. LeBuhn, Philpott\_) but that is also widely facing global declines, in part due to global land use change itself (refs).

**Last Intro paragraph:** Focusing on bumble bees and hoverflies as representatives of urban pollinator biodiversity, we use NHC’s ~~natural history collections data~~ to test two core sets of related hypotheses that link among city differences to landscape-scale urban biodiversity conservation. First, we test the hypothesis that undeveloped natural habitats embedded in the urban landscape are favourable for pollinator population growth and, simultaneously, that increased area of favourable natural habitat in the broad landscape mediates species conservation by compensating for local subpopulation extinctions. Second, ~~while accounting for natural habitat area in the urban landscape,~~ we use relative income as a proxy measure to test the hypothesis that high plant diversity is favourable for pollinator population growth and, simultaneously, that higher average plant diversity across a landscape mediates species conservation by similarly promoting establishment of robust subpopulations that may compensate for local extinctions. If these sets of hypotheses are true, we predict that city-wide occupancy of urban areas within the distributional range of each pollinator species is positively associated with city-wide natural habitat area and city-wide average income. Further, by testing for a negative correlation between species-specific effects of natural habitat area and species-specific range wide occupancy rates, we assess the secondary hypothesis that rare species require more natural habitat to persist in an urban landscape.

**First Discussion paragraph:** While previous studies have identified drivers of locally observed urban pollinator biodiversity, we conducted the first study to our knowledge that incorporates data from multiple urban landscapes to test whether these drivers operate on pollinator biodiversity patterns that emerge at broad spatial and temporal scales. We found that individual bumble bee species show wide variation in their responses to city-wide natural habitat area, however, our results indicate that the landscape-scale occupancy rate of the average bumble bee species does not have a strong association with city-wide natural habitat area. On the other hand, our results identify a weak positive association between bumble bee occupancy rates and city-wide relative income (our proxy measure for plant diversity), emphasizing that potential investment in management of the vegetation in the matrix of the anthropogenic landscape itself, separate from inclusion of large areas of undeveloped habitat, is a key component of urban pollinator conservation. Interestingly, our study finds an opposite pattern for hoverflies. For this taxonomic group, our analysis suggests high certainty in a positive association between city-wide natural habitat area and landscape-scale occupancy. This result emphasizes that natural habitat remnants such as urban greenbelts and nature reserves remain essential for some pollinator taxa to persist. Together, these results indicate that drivers found to increase local pollinator abundance and diversity have a compounding effect as they increase in an urban landscape, mediating landscape scale urban pollinator conservation – although with different drivers and the strength of the effect varying among species and taxonomic groups. Here we discuss assumptions of our data and analysis as well as the implications of these results for urban biodiversity conservation applications and, moreover, for our understanding of the spatiotemporal scale dependence of biodiversity patterns.

**Last Discussion paragraph:** Much of urban ecology and conservation science, and indeed ecology more generally, is focused on quantifying biodiversity metrics at the local scale, assuming that local populations and communities are spatially closed and isolated (Leibold et al., 2004; Chase et al., 2020). With this study we examined relationships between the environment and species occupancy at multiple broader spatial scales to accomplish a novel test of the hypothesis that city-wide landscape quality mediates city-wide biodiversity. For hoverflies, urban landscapes with larger amounts of natural habitat area sustain groups of interconnected populations, while for bumble bees affluent urban landscapes with presumably more resources to invest in vegetation cover and management – including in the developed urban matrix itself – sustain groups of interconnected populations. Thus, the fate of a species in the landscape is mediated not just by the local demography of a subpopulation, but also by the broader environment collectively experienced by all subpopulations (as is suggested by metapopulation and metacommunity perspectives) (Leibold et al., 2004; Chase et al., 2020). The properties of the broader overall landscape may influence landscape-scale species persistence by moderating the degree to which subpopulations can compensate for local extinctions due to environmental or demographic stochasticity (Leibold et al., 2004; Chase et al., 2020). The conclusions from this cross-landscape analysis call for increased consideration of the interplay between local population and community dynamics with landscape to regional dynamics. In application, this demands that local urban habitat restoration and enhancements coordinate with city-wide policy and planning to ensure long-term success of species conservation.