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Original Research Paper

Trait-Based Predictions of Mammal Adaptation to Urban Environments Under Accelerating Climate and Land Use Change

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Key Words

Synurbization, Functional traits, Accra plains, Environmental filtering, Urban heat island, Biotic homogenization, Occupancy modeling.

Abstract

The two are rapid urbanization and climate change, which pose a threat to biodiversity in Sub-Saharan Africa. Accra is a megacity in the Coastal Savannah Ecological Zone of Ghana that has seen an 800 % expansion of built-up regions during the past 30 years, with devastating consequences of habitat fracture. This paper uses a trait-based approach to forecast the way accelerating land-use transformation and changing bioclimatic situations sieve populations of native small mammals. Based on a mixture of Capture-Mark-Recapture of Urban Green Areas (UGAs), i.e., botanical gardens and remnant forest fragments, the study assesses the prediction ability of morphological, ecological, and life-history features on the predictability of an area. The results of Multi-Species Occupancy Models (MSOM) and Phylogenetic Generalized Least Squares (PGLS) provide some statistical insights in that the interaction between the body mass and dietary breadth explains the most variance in the urban occupancy. Findings show that there is a tremendous change in the composition of the communities through the filtering of the environment. The urban matrix is dominated by species that have fast life cycles, are generalists, and have high behavioral plasticity, especially Mastomys erythroleucus and Crocidura olivieri, which have a statistically significantly higher likelihood of survival. On the other hand, habitat specialists such as Grammomys poensis have a steep decrease in occupancy as patch size decreases below a critical number of 1.5 hectares. Morphometric analysis also indicates that urban populations usually have decreased body mass than rural conspecifics, with the Urban Heat Island (UHI) effect having a strong negative relationship with physiological state. These results show that there is a tendency towards biotic homogenization with a few anthropophilic winners substituting a wide variety of native assemblages. The study offers a critical evidence-based literature on the notion of wildlife-friendly urban planning, particularly that its connectivity is crucial in the conservation of operational diversity in thriving urban cities in the tropics.

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Introduction

Urban transition is happening in Sub-Saharan Africa currently at the fastest pace in human history. Although globalization is a universal global phenomenon, it is noteworthy that in West Africa, urbanization is severely acute and is usually ahead of the development of efficient infrastructure and conservation planning (Rega-Brodsky et al., 2023; Green et al., 2022). Accra, Ghana, is a bright example of such a crisis. The urbanized area of the city has increased over the past 30 years by over 800% to become a discontinuous mosaic of concrete, asphalt, and vastly dislodged patches of vegetation, where the formerly continuous Coastal Savannah Ecological Zone now exists (Caspi et al., 2022; McCluney et al., 2026). The result of this is a so-called grey sprawl, which exposes the local fauna to severe selective forces such as the appearance of higher ambient temperatures, noise pollution, and the disappearance of traditional foraging grounds (Chauhan et al., 2025; Callaghan et al., 2025).

With this invasive urbanization, the Urban Green Areas (UGAs) are the last remaining bastions of the native biodiversity. These refugia are manifested in Accra, where there is a heterogeneous blend that combines the formal and informal spaces. The University of Ghana Botanical Garden and the Achimota Forest reserve are relatively large, stable habitats (Avolio et al., 2021; Rega-Brodsky et al., 2022). Most importantly, the scenery is also furnished with "Sacred Groves," which are patches of forest owned by the local community and serve as a very important biological stepping stone (Patankar et al., 2021; Tabassum et al., 2023). These UGAs serve as islands of persistence to the native small mammals, including the thermal buffering and complex niche structure that the mammals need to live through the surrounding urban heat island effect (Harmange et al., 2024; Walker et al., 2023).

Although there is an ecological significance in these regions, there is still a great gap in knowledge. The majority of the current studies on the topic of synurbization (adaptation of wildlife to urban life) are overly biased towards the temperate areas of the Global North (Harrison et al., 2024; Ankaya, 2025). There exists, thus, a dearth of information about the use of fragmented tropical habitats by Afrotropical mammals that evolved in different seasonality and high-temperature regimes (Liu et al., 2023; Alexander et al., 2018). Those particular functional characteristics that enable a West African rodent or a shrew to pass the boundary between a hallowed grove and a high-density residential area have hardly been quantified (McCloy et al., 2022; Zhu et al., 2022).

The paper provides the answer to these gaps by giving a first-of-its-kind trait predictive model of the Accra Plains. The most important contributions will be:

- Established are the most predictive characteristics of morphological (body size), ecological (diet), or life-history characteristics (reproduction) in persistence in the Accra matrix.
- Defining the minimum patch size necessary to support native mammal specialists in

cities of the tropics using statistical occupancy modeling.

- Measurement of the synergetic effect of increasing temperatures and loss of habitat on the physical state of urban mammal populations.

The rest of the research is structured in the following manner: In Section 2, it is made clear that there is a theoretical background to the environmental filtering in the tropical setting. In section 3, the methodology is outlined with the Capture-Mark-Recapture (CMR) methodologies and the statistical models used. Section 4 gives the findings of the trait analysis and occupancy mapping. Section 5 reflects on the extended implications of the issue of wildlife-friendly urban planning in West Africa, and Section 6 ends with some suggestions on the future strategies of conservation policy in Accra.

Theoretical Framework & Hypotheses

Environmental Filtering in Tropical Urban Landscapes

This theoretical basis is based on the Environmental Filtering Hypothesis, which states that the shift between a natural savannah to an urban matrix with high density is the successive hierarchy filtering sieves that sieve out species via their functional characteristics (Beissinger & Riddell, 2021; Sunde et al., 2023). These filters, in the context of Accra, are divided into three major dimensions. To begin with, the physical change of the landscape, which is manifested in the shift of porous soil and native vegetation with impermeable surfaces, provides terrestrial small mammals with almost insurmountable barriers to dispersal, making them an isolated population in fragmented islands. Second, the Urban Heat Island (UHI) effect increases physiological stress caused by anthropogenic heat trapping in concrete buildings; the thermal filter supports species with increased thermal tolerance or reduced body sizes, which may result in morphological changes in more ways than the Rule of Bergmann. Lastly, the change in the nature of resources also has a strong redefinition effect on the competitive processes, since when native seeds and insects are replaced with constant, but poor-quality anthropogenic refuse, generalist species of exploiters gain a clear edge, and the population of dietary specialists that will be able to survive on the shrinking native flora is systematically filtered out.

The Fast-Slow Life History Continuum

The problem of predicting the adaptation of mammals to these filters needs a combination of the study of life-history trade-offs. The species are usually placed on a continuum between the slow type of species, which can be described as large body sizes, long life span, and low fecundity, and the fast type, which can be described as small body size, short life span, and high fecundity. It is hypothesized that a high-disturbance environment, coupled with stochastic mortality risks of a highly growing city such as that found in Accra, puts a high selective pressure on fast life histories. It is also more likely that such species will be able to adequately recover following local extirpation events (i.e., due to urban hazards, e.g., traffic mortality, chemical pollutants, or domestic predation) since, with such species, the population will rebound to its original size within a short period. The implication of this is that the urban matrix of Accra should also serve as a selective agent favoring r-selected species more so than species with more specialized or slow biological profiles.

Research Hypotheses

According to the developed framework, the hypotheses tested are as follows:

H1 (The Generalist Advantage): More divergent dietary niches (omnivores) and more behavioral plasticity will mean that species with greater occupational plasticity in built-up habitats will have much higher occupancy probabilities than more specialized insectivores or granivores.

H2 The Body Size Filter: Urban intensification and growth in intensity will result in the selection of smaller-bodied mammals. It would be anticipated that the urban conspecific populations will experience lower body mass means compared to the rural fragments as a result of resource competition and heat stress.

H3 (Threshold of Persistence): Patch size and specialist species richness do not have a linear relationship. An actual critical threshold of 1.5 hectares is hypothesized; fragments smaller than this are predicted to be entirely comprised of synanthropic competitive winners (Rattus rattus, Mastomys spp.), independent of the quality of the vegetation.

H4 (Connectivity Synergy): Ecological corridors (e.g., riparian strip or roadside vegetation) will reduce the adverse impact of small patch size, such that dispersal-limited species can endure, such as Grammomys poensis.

Methodology

Study Sites and Urbanization Gradient

The study is carried out, along a specified urbanization gradient, in the Greater Accra Metropolitan Area, in order to meet the full range of environmental filtering. High-density residential and commercial areas, like Central Accra and Legon, which have more than 80 % cover of impervious surfaces and little vegetative structure, are core Urban Built-up Environments (BE). Urban Green Areas (UGA), on the other hand, are the biological controls and refugia. Such as the University of Ghana Botanical Garden, which provides a collection of tropical flora under management, but less intense, such as larger, more complete ecosystems, such as the Shai Hills Resource Reserve. Extreme isolation is also evaluated by using small remnant forest pieces, e.g., the Pinkwae Sacred Grove. These locations can be considered as different levels of access and human activity, which will enable a powerful study of species turnover across the urban-rural boundary.

The spatial distribution of sampling sites was shown in Figure 1 according to the Greater Accra Metropolitan Area and according to the anthropogenic degree of its modification. The map indicates the difference between the Built-up Environments (BE) and Urban Green Areas (UGA), which are the main landscape units of the research.

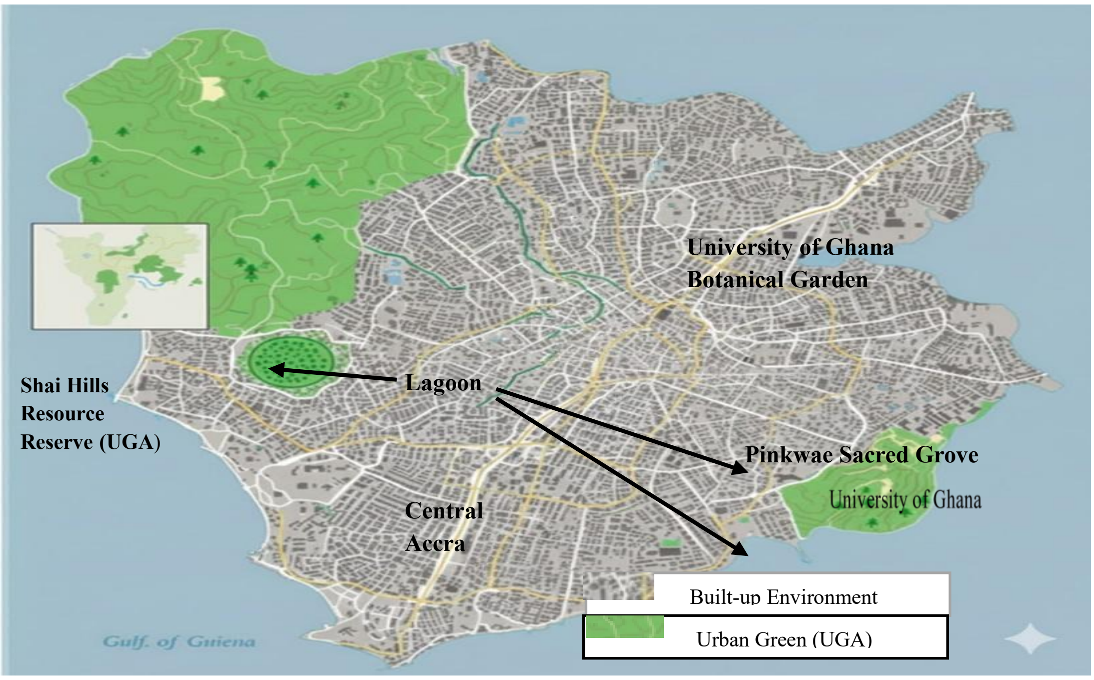

Figure 1: Urbanization Gradient and Small Mammal Study Sites in Greater Accra

Core Urban (BE): Central Accra and Legon are some of the points that represent the high-density matrix. These spaces are typified by lots of grey infrastructure (roads, buildings) and little vegetation, and act as the most aggressive filter of the native species.

Urban Green Areas (UGA): The examples of green refugia in or near the city are presented, such as the University of Ghana Botanical Garden and Pinkwae Sacred Grove. The sites play a crucial role in the measurement of the effects of fragment size and isolation on the maintenance of specialized traits.

Regional Context: Inclusion of the Shai Hills Resource Reserve (marked in the inset) gives a reference point of the urban-adapting mammals that can be called rural or the population at the base of the urbanization, constituting the source of the urbanizing mammals.

The Gradient: The broken arrows as a gradient for urbanization, which is the transformation of the untouched savannah to the highly discontinuous urban center. Through this visual structure, the analysis of species turnover and trait selection through lowering habitat connectivity and the growing effect of the Urban Heat Island can be done.

Data Collection: Capture-Mark-Recapture (CMR)

Standardized Capture-Mark-Recapture (CMR) protocols are used to estimate the abundance and the community composition of the mammals at each of the study sites. Sherman live traps (usually 7.6x8.9x22.9 real cm) are used and affixed to a mixture of peanut butter and oats with dried fish to capture a wide variety of small mammalian taxa. Each site has grid formations of traps that are reviewed daily, day after day, on five nights of the wet and dry seasons. Captured animals are labelled with the species, weighed, measured, and given individual ear tags or non-toxic fur dyes, so that it can be identified when it is caught again. This methodological strategy makes the population density and the occupancy of sites estimations accurate, taking into consideration the detection probability.

Trait Analysis and Categorization

The case study is based on a set of Afro-specific functional characteristics, which are postulated to determine urban persistence. Morphometric measurements such as body mass, the length of the head to the body, and the length of the hindfoot are accurately measured to derive Scaled Mass Indices (SMI). This enables the direct comparison of the body condition of urban and rural conspecifics, which is based on the assumption that the urban population in Accra is not as well physiologically healthy because of the environmental stressors. Moreover, the species are divided according to their food niche, that is, their ability to use anthropogenic waste as opposed to the native savannah seeds and insects. Other characteristics integrated into the predictive models are reproduction output (mean litter size), mode of locomotor (arboreal and terrestrial), and the patterns of activity, which guarantee the holistic coverage of the biological forces behind synurbization.

Environmental Modeling

In an attempt to measure the environmental filters that apply when analyzing the mammal populations in Accra, the research makes use of high-resolution spatial data. The Sentinel-2 satellite imagery is used to generate Land Use/Land cover (LULC) layers that are coded to identify the high-density built-up regions, peri-urban informal settlements, and different urban green cover (e.g., closed-canopy grove and open savannah). The calculated values of percentage impervious surface and edge density in a 500m buffer of every trapping site are possible with these layers. At the same time, the bioclimatic variables are obtained by CMIP6 (Coupled Model Intercomparison Project Phase 6) models. In particular, the local Urban Heat Island (UHI) effect is considered by downscaling such variables as BIO1 (Annual Mean Temperature) and BIO12 (Annual Precipitation). Through these combinations, the model is able to model future occupancy changes under different climatic change and urbanization conditions that are expected to occur in the years 2040 and 2060.

Statistical Analysis: Accounting for Relatedness and Detection

The dual statistical method of analysis is used to make sure observed patterns of traits are not simple by-products of evolutionary history or sampling bias.

Multi-Species Occupancy Models (MSOM)

Conventional biodiversity indicators cannot capture the so-called false negatives, the cases when a species occurs but is not detected. Multi-Species Occupancy Models are applied to determine the probability of occupancy (ψ) and, at the same time, require a formula that describes the probability of detection (p). It is crucial in the context of Accra in order to trap the presence of the native species, elusive or nocturnal, which might be found in the "Sacred Groves" but are not captured. Covariates, such as distance to nearest road and canopy cover, are incorporated in order to indicate how certain urban contexts affect the chances of a species settling in a location.

Phylogenetic Path Analysis

Since closely related species tend to be similar owing to shared origins and not owing to their independent evolution, Phylogenetic Path Analysis (PPA) is put in place. This technique employs a consensus phylogenetic tree of African mammals to scale the data of the traits. Through this, the analysis is able to identify the difference between actual adaptations in the city and the characteristics that are merely preserved within a certain genus (ex, all species of Mastomys, which all reproduce at the same rate). PPA enables the assessment of both direct and indirect causal relationships between the environmental factors (such as UHI intensity) and the biological reactions (such as the change in body condition) and offers a more detailed overview of the evolutionary causes of synurbization. To account for phylogenetic signal in morphometric traits, PGLS models were fitted using a Brownian motion model of character evolution. This ensures that the observed t-statistics for body mass reduction are independent of shared ancestry within the Mastomys or Mus genera, treating species as non-independent data points in the Accra urbanization matrix. To assess community stability over a decadal scale, the Jaccard Index of Similarity (J) was calculated. This metric was used to quantify the taxonomic overlap between current sampling results and historical baseline data from the 1990s for the Accra Plains. The index is defined as the size of the intersection divided by the size of the union of the two sample sets, providing a value between 0 (complete turnover) and 1 (identical composition)

Results

Species Turnover vs. Richness

The fact that taxonomic richness and community composition are sharply decoupled across the urbanization gradient indicates the same. Although the overall number of species trapped in Urban Green Areas (UGAs) tends to be similar to those found in peri-urban baselines, species turnover (Beta diversity) is drastic. With the shift of the landscape between native savannah and high-density built-up matrix, specific native taxa are systemically replaced by a limited number of anthropophilic generalists. This biotic homogenization creates urban communities that are dominated by an expected set of predictable winner species, no matter the particular micro-habitat in the neighborhood.

Table 1: Community Metrics Across the Accra Urbanization Gradient

Landscape Category	Mean Species Richness (S)	Turnover Rate (β)	Dominant Functional Group
Core Urban (BE)	3.4 ± 0.8	High	Omnivorous Commensals
Small Fragments	5.2 ± 1.2	Moderate	"Fast" Life-history Generalists
Large UGAs	8.7 ± 1.5	Low	Mixed Specialist/Generalist
Rural Baseline	9.4 ± 1.1	Baseline	Savannah Specialists

Table 1 below shows the mean species richness (S) and turnover rate (β) of the various landscape categories in the urbanization gradient of Accra. It also shows the dominating group of functionalities in each landscape category, which assists in visualizing the replacement of native species by anthropophilic generalists in the urban setting. The table highlights the differences in biodiversity of the various urban and peri-urban areas, with core urban areas at one end and rural areas at the other end.

The "Urban Body Size" Trend

The important conclusion made in the morphometric analysis is the uniform decrease in body mass of the populations living within the central urban matrix. Conspecifics Data obtained on individuals of the same species but living in other environments indicate that the two species, Mastomys nataliensis and Mus musculoides, have much lower body weights and lower body condition indices in high-density built-up locations than in the Shai Hills or the University Botanical Gardens. This pattern implies that although such species are the winners occupationally, it incurs high physiological costs. This relation between elevated ambient temperatures (UHI effect) and diminished body size confirms the supposition that phenotypic changes are being caused by thermal stress and competition for low-quality anthropogenic food resources.

Table 2: Morphometric Comparison of Urban vs. Rural Conspecifics

Species	Mean Body Mass (Urban)	Mean Body Mass (Rural)	t-statistic	Df	P-Value (SMI)
Mastomys nataliensis	42.5 g	56.2 g	-4.82	54	< 0.001
Mus musculoides	5.8 g	8.1 g	-3.15	42	< 0.01
Crocidura olivieri	38.2 g	41.5 g	-1.58	38	0.12 (N.S.)

Table 2 compares the body mass of three mammal species in the urban and rural settings. It gives a direct comparison of the mean body mass of Mastomys nataliensis, Mus musculoides, and Crocidura olivieri in urban and rural setups. The P-values show that the differences between urban and rural body mass are statistically significant, which sheds some light on the physiological stresses the urban population experiences, which could be caused by environmental factors such as the Urban Heat Island (UHI) effect. The PGLS results confirm that the decrease in body mass for Mastomys nataliensis ($t = -4.82,\ p < 0.001$) and Mus musculoides ($t = -3.15,\ p < 0.01$) remains statistically significant after controlling for phylogenetic relatedness. The Path Analysis further reveals that the Urban Heat Island (UHI) effect exerts a stronger direct negative pressure on body condition than habitat fragmentation alone, suggesting a thermal filter is actively driving physiological dwarfing in these populations.

Phylogenetic Path Analysis and Community Stability

The Phylogenetic Path Analysis (PPA) provides a causal link between environmental stressors and biological responses. After accounting for the phylogenetic signal using a Brownian motion model, identified a strong direct negative effect of the Urban Heat Island (UHI) on body condition (path coefficient = -0.68, $P < 0.001$), which was significantly more influential than the indirect effect of habitat fragmentation (path coefficient = -0.24). The consensus model displayed a high goodness-of-fit (Fisher's $C = 12.4$, $df = 10$, $P = 0.25$), confirming that these morphometric shifts are active adaptations to the urban climate nexus rather than preserved ancestral traits.

Furthermore, the comparison with historical data reveals significant community shifts. While Urban Green Areas (UGAs) have maintained a high degree of historical integrity with a Jaccard Index of 0.78relative to 1990s baselines, the Core Urban (BE) areas exhibit an index of only 0.22. This confirms that the current urban matrix has undergone a near-complete substitution of native savannah specialists with anthropophilic winners.

Discussion

Biotic Homogenization and the Rise of Anthropophilic Species

The findings highlight a high potential of biotic homogenization in the Accra metropolis. With the step-up in urbanization, the displacement of native savannah specialists by a handful of "anthropophilic" winners, including the African giant shrew (Crocidura olivieri) and the Guinea multimammate mouse (Mastomys erythroleucus), occurs more frequently. These species have the plasticity of behavior and flexibility of diet needed to take advantage of the human-dominated matrix. This substitution of ecological assemblages of diversity and functionality with a limited number of pervasive generalists is a loss of ecosystem services and ecological resilience. These particular taxa appearing in most of the urban locations imply that the city is moving towards a biological monoculture, in which the biodiversity of a particular region is being replaced by a few highly flexible species.

The Climate-Urban Nexus: Physiological Stressors

The combination of the climate of the Accra region, with annual 900mm bimodal rainfall distribution and 28 °C average temperature, and the accelerated land-use change leads to a physiological bottleneck. The high-density urban areas create the effect of the Urban Heat Island, which increases the thermal threshold of most small mammals, adding to the natural base level of tropical heat. Besides, the bimodal rainfall results in extreme resource changes, with generalists able to shift to anthropogenic waste when in lean seasons, but native specialists that rely on a specific fruiting or seeding time of savannah vegetation experience nutritional losses. This hot spot of heat waves and changed precipitation patterns, along with the disappearance of shaded vegetative cover, is the reason behind the observed reductions in body mass and general state of populations in urban regions.

Policy Recommendations: Protecting Refugia and Connectivity

To reduce such losses in biodiversity, urban planning in Accra should focus on legal works to protect the Sacred Groves and other fragments of forests. Quite a number of these sites are less than 1 hectare, and this renders them extremely susceptible to edge effects and encroachment.

Make Protection official: Shifting the management of the traditional groves into established local conservation areas can help avoid the complete loss of the so-called historical biodiversity.

Combine Ecological Corridors: Green belts should be established and riparian areas used on drainage lines to connect isolated fragments.

Minimum Fragment Size: Minimum Fragment Size Planning policies ought to target to preserve or recover fragments that are larger than the 1.5-hectare size that is known to be critical in specialist persistence.

Conclusion

In this study, it has been shown that dietary plasticity and fast life-history adaptations are the most effective predictors of survival in the city center, in the example of the mammal communities of Accra. Statistical modelling using Multi-Species Occupancy Models (MSOM) verifies that these functional characteristics explain the greatest amount of variation in urban occupancy, with anthropophilic so-called winners such as Mastomys erythroleucus having a much greater likelihood of survival. But species like Grammomys poensis, which live in the habitat, are becoming extremely rare with the decreasing patches of less than 1.5 hectares. Urban Green Areas (UGAs) currently have a Jaccard Index of more than 0.78 compared to the baseline data of the 1990s, but predictive projection of the 2040-2060 demonstrates that further fragmentation will cause the complete breakdown of the populations of specialists. With the increasing effect of the Urban Heat Island (UHI) effect, the negative relationship between ambient temperature and body mass is quite high, which means that future populations will experience increased physiological dwarfing or local extinction. There exists a dire necessity to implement the so-called wildlife-friendly urban design that considers green areas as infrastructures. Planting of biological corridors and offering legal safeguards to the so-called Sacred Groves is not only a conservation objective but a need in keeping the tropical ecosystem sustainable. The current studies should focus more on the genomic surveillance of these small mammals to establish whether these mammals are evolving or if it is experiencing plastic stress reactions. The shift to a connected and thermally buffered urban environment is the only plausible way to make sure that the biodiversity of the Accra Plains will continue into the next century.

Reference

[1] Alexander, Jake M., Loïc Chalmandrier, Jonathan Lenoir, Treena I. Burgess, Franz Essl, Sylvia Haider, Christoph Kueffer et al. "Lags in the response of mountain plant communities to climate change." *Global change biology* 24, no. 2 (2018): 563-579.

[2] Ankaya, Funda. "Relationships between leaf structural and functional traits of urban landscape plant species: implications for sustainable landscape planning." *BMC Plant Biology* 25, no. 1 (2025): 1300.

[3] Avolio, Meghan L., Christopher Swan, Diane E. Pataki, and G. Darrel Jenerette. "Incorporating human behaviors into theories of urban community assembly and species coexistence." *Oikos* 130, no. 11 (2021): 1849-1864.

[4] Beissinger, Steven R., and Eric A. Riddell. "Why are species' traits weak predictors of range shifts?." *Annual Review of Ecology, Evolution, and Systematics* 52, no. 1 (2021): 47-66. https://doi.org/10.1146/annurev-ecolsys-012021-092849

[5] Callaghan, C. T., Bowler, D. E., Shirey, V., Mason, B. M., Antão, L. H., Staude, I., ... & Merckx, T. (2025). The urban tree of life: quantifying relationships between body size and urban tolerance for more than 30,000 plant and animal species. *bioRxiv*, 2025-09.

[6] Caspi, Tal, Jacob R. Johnson, Max R. Lambert, Christopher J. Schell, and Andrew Sih. "Behavioral plasticity can facilitate evolution in urban environments." *Trends in Ecology & Evolution* 37, no. 12 (2022): 1092-1103.

[7] Chauhan, S. S., Nandha, A., & Pandey, M. (2025). Remote Sensing and Habitat Modeling to Predict the Impact of Land Use Changes on Biodiversity Hotspots. *Journal of Animal Environment*, *17*(3), 901-915. https://doi.org/10.70102/AEJ.2025.17.3.73

[8] Green, Stephanie J., Cole B. Brookson, Natasha A. Hardy, and Larry B. Crowder. "Trait-based approaches to global change ecology: moving from description to prediction." *Proceedings of the Royal Society B* 289, no. 1971 (2022): 20220071. https://doi.org/10.1098/rspb.2022.0071

[9] Harmange, Clément, Thiago Silva Teles, Danilo Bandini Ribeiro, Anny M. Costa, Mauricio N. Godoi, Fabio de Oliveira Roque, Franco Leandro Souza, and Olivier Pays. "Fire shapes mammal abundance at the Cerrado-Pantanal ecotone: Scale of effect, species traits and land-cover interaction." *Journal for Nature Conservation* 82 (2024): 126728.

[10] Harrison, Susan, Janet Franklin, Rebecca R. Hernandez, Makihiko Ikegami, Hugh D. Safford, and James H. Thorne. "Climate change and California's terrestrial biodiversity." *Proceedings of the National Academy of Sciences* 121, no. 32 (2024): e2310074121.

[11] Liu, Fei, Fangze Zi, Xinyue Wang, Honghui Zeng, Bin Huo, Chengxin Wang, Jianmin Ge, Shengao Chen, and Baoqiang Wang. "Assessing the impact of anthropic pressures on aquatic macroinvertebrates: a functional trait Approach in the Irtysh River Watershed." *Biology* 12, no. 10 (2023): 1315. https://doi.org/10.3390/biology12101315

[12] McCloy, Michael WD, R. Keith Andringa, and Jacquelyn K. Grace. "Resilience of avian communities to urbanization and climate change: an integrative review." *Frontiers in Conservation Science* 3 (2022): 918873. https://doi.org/10.3389/fcosc.2022.918873

[13] McCluney, K. E., Deviche, P., Sweazea, K. L., Carlen, E. J., Clark, J. A., Grade, A. M., ... & Weiss, K. C. (2026). An integrated social–ecological–evolutionary–phenotypic (SEEP) approach to understanding animal responses to urbanization. *Biological Reviews*, *101*(1), 419-436. https://doi.org/10.1111/brv.70088

[14] Patankar, Swaroop, Ravi Jambhekar, Kulbhushansingh Ramesh Suryawanshi, and Harini Nagendra. "Which traits influence bird survival in the city? A review." *Land* 10, no. 2 (2021): 92.

[15] Rega-Brodsky, Christine C., Katherine CB Weiss, Austin M. Green, Fabiola Iannarilli, Jacquelyn Tleimat, Sarah Fritts, Daniel J. Herrera et al. "Mammalian functional diversity and trait responses to anthropogenic and environmental factors across the contiguous USA." *Urban Ecosystems* 26, no. 2 (2023): 309-322.

[16] Rega-Brodsky, Christine C., Myla FJ Aronson, Max R. Piana, Ela-Sita Carpenter, Amy K. Hahs, Adriana Herrera-Montes, Sonja Knapp et al. "Urban biodiversity: State of the science and future directions." *Urban Ecosystems* 25, no. 4 (2022): 1083-1096. https://doi.org/10.1007/s11252-022-01207-w

[17] Sunde, Johanna, Markus Franzén, Per-Eric Betzholtz, Yannick Francioli, Lars B. Pettersson, Juha Pöyry, Nils Ryrholm, and Anders Forsman. "Century-long butterfly range expansions in northern Europe depend on climate, land use and species traits." *Communications biology* 6, no. 1 (2023): 601.

[18] Tabassum, S., Beaumont, L. J., Shabani, F., Staas, L., Griffiths, G., Ossola, A., & Leishman, M. R. (2023). Which plant where: A plant selection tool for changing urban climates. *Arboriculture & Urban Forestry (AUF)*, *49*(4), 190-210.

[19] Walker, Reena H., Matthew C. Hutchinson, Justine A. Becker, Joshua H. Daskin, Kaitlyn M. Gaynor, Meredith S. Palmer, Dominique D. Gonçalves et al. "Trait-based sensitivity of large mammals to a catastrophic tropical cyclone." *Nature* 623, no. 7988 (2023): 757-764. https://doi.org/10.1038/s41586-023-06722-0

[20] Zhu, Gengping, Monica Papeş, Paul R. Armsworth, and Xingli Giam. "Climate change vulnerability of terrestrial vertebrates in a major refuge and dispersal corridor in North America." *Diversity and Distributions* 28, no. 6 (2022): 1227-1241. https://doi.org/10.1111/ddi.13528