“Effects of urbanization on the diversity, life-history traits and fluctuating asymmetry of odonates (Odonata: Zygoptera and Anisoptera)”

“Efeitos da urbanização sobre a diversidade, traços da história de vida e assimetria flutuante de odonatos (Odonata: Zygoptera e Anisoptera)”

Abstract

Urbanization has grown progressively and changing drastically and rapidly natural habitats, threatening the viability of sensitive groups. Little is known about the diversity and taxonomy of dragonflies from urban areas of the Cerrado, although some studies show that this environment can contribute to filling Linnean and Wallacean gaps. In addition, studies on the plastic responses of odonates under urbanization and extreme climate events are still emerging and rare in the Neotropical region. In this thesis, we investigated how urbanization can affect diversity and plastic responses of odonates, both for local urban conditions and future climate events. To achieve these objectives, we first performed an extensive inventory of the group in various ecosystems and phytophysiognomies of the Cerrado in urban and non-urban areas between 2018 and 2020 in Uberlândia, Minas Gerais. This inventory composed the first chapter. From these samples we separated two damselflies species (*Acanthagrion truncatum* Selys, 1876 and *Argia reclusa* Selys, 1865), representing different ecosystems, and that are abundant among urbanization gradients and within urban areas. These samples were part of the second chapter, which aimed to evaluate the morphometric and stress responses (evaluated by fluctuating asymmetry) of the group's wings in under urbanization, more specifically to fragmentation, and local preservation of urban fragments. Finally, in the third chapter, we conducted an experiment with larvae to verify the effect of future heat waves on *A. truncatum* life history traits, sampled in urban pons. In the first chapter, we described the female of *Forcepioneura machadorum* Vilela, Venâncio & Santos, 2020 (Coenagrionidae: Protoneurinae) and sampled 101 species in urban and non-urban areas

of Uberlândia, eight of these were new records for Minas Gerais. In the second chapter, we helped to fill knowledge gaps about the effects of urbanization on morphological traits and asymmetry of damselflies along urbanization gradients. For *A. truncatum*, we observed a negative effect on wing size, while the preservation of urban fragments proved to be an important factor for the size and shape of this trait for *A. reclusa*. Finally, we demonstrate in the third chapter that exposure of larvae to heat waves results in phenological advance and reduction in the size of urban adults of *A. truncatum*, a pattern that can affect the future viability of this species in this type of land use. Thus, the results of this thesis showed that we still know little about how urbanization can affect diversity and plastic and ontogenetic responses of odonates. Especially in the Neotropical region, where urbanization and climate change come too much and quickly growing, there is the urgency of further studies of the group.

Keywords: Wallacean shortfall, Linnean shortfall, Cerrado, Morphometry, Climate change, Urban gradients, Environmental stress

Resumo

A urbanização tem crescido progressivamente e alterando de forma drástica e rápida habitats naturais, ameaçando a viabilidade de grupos sensíveis. Pouco se sabe sobre a diversidade e taxonomia de libélulas de áreas urbanas do Cerrado, apesar de alguns estudos mostrarem que esse ambiente pode contribuir a preencher lacunas Linneanas e Wallaceanas. Além disso, estudos sobre a respostas plásticas de tratos de vida de libélulas perante a urbanização e eventos climáticos extremos desse ambiente ainda são emergentes e raros na região Neotropical. Nesta tese, nós verificamos como a urbanização pode afetar a diversidade e as respostas plásticas de libélulas, tanto para alterações locais do meio urbano quanto para eventos climáticos futuros. Para alcançar esses objetivos, nós primeiramente realizamos um extenso inventário do grupo em diversos ecossistemas e fitofisionomias do Cerrado em áreas urbanas e não urbanas entre 2018 e 2020 em Uberlândia, Minas Gerais. Esse inventário compôs o primeiro capítulo. A partir dessas coletas nós separamos duas espécies de donzelinhas (*Acanthagrion truncatum* Selys,

1876 e *Argia reclusa* Selys, 1865), representantes de diferentes ecossistemas, além de serem abundantes entre gradientes de urbanização e dentro de áreas urbanas. Essas coletas fizeram parte do segundo capítulo, o qual teve o objetivo de avaliar a respostas morfométricas e de estresse (avaliado pela assimetria flutuante) das asas do grupo perante a intensidade de urbanização, mais especificamente à fragmentação, e preservação local de fragmentos urbanos. Por fim, no terceiro capítulo, nós realizamos um experimento com larvas para verificar o efeito de ondas de calor futura sobre os tratos de vida e assimetria flutuante de *A. truncatum*, amostradas em lagoas urbanas. No primeiro capítulo, nós descrevemos a fêmea de *Forcepsioneura machadorum* Vilela, Venâncio & Santos, 2020 (Coenagrionidae: Protoneurinae) e inventariamos 101 espécies em áreas urbanas e não urbanas de Uberlândia, sendo oito desses novos registros para o Estado de Minas Gerais. No segundo capítulo, nós ajudamos a preencher lacunas sobre o conhecimento dos efeitos da urbanização sobre a morfologia de traços e assimetria de libélulas ao longo de gradientes de urbanização. Para *A. truncatum*, observamos um efeito negativo para o tamanho da asa, enquanto a preservação de fragmentos urbanos se mostrou como um fator importante para o tamanho e forma dessa estrutura em *A. reclusa*. Por fim, nós demonstramos no terceiro capítulo que a exposição de larvas a ondas de calor resulta em avanço fenológico e redução do tamanho de adultos urbanos de *A. truncatum*, o que pode afetar a viabilidade futura dessa espécie nesse tipo de uso do solo. Dessa forma, os resultados dessa tese mostraram que ainda sabemos pouco de como a urbanização pode afetar a diversidade e as respostas plásticas e ontogenética de libélulas. Especialmente na região Neotropical, onde a urbanização e a mudança climática vêm demasiadamente e rapidamente crescendo, há a urgência de mais estudos do grupo.

Palavras-chave: Déficit Wallaceano, Déficit Linneano, Cerrado, Morfometria, Mudança climática, Gradiente urbano, Estresse ambiental

Introduction

Urbanization is one of the main antrhropic causes of global biodiversity loss, as a result of drastic and sudden changes in natural environments (McKinney 2008). The progressive expansion of urban areas and the consequent demand for food and fuel could dizimate several natural areas by 2050 (Seto et al. 2012). Consequently, local communities are homogenized due to low diversity, which is mainly caused by the exclusion of sensitive taxa and the predominance of tolerant groups to these changes (McKinney 2008; Alberti et al. 2017). Therefore, especially in the tropics, where expansion is increasing (Seto et al. 2012), studies are needed to assess how urbanization affects sensitive groups.

Odonata compose a small portion of aquatic insects, totaling 6,300 species (Paulson and Schorr 2020) that occupy freshwater habitats associated with different types of vegetation at almost all continents (Corbet 1980). Brazil holds about 15% of this diversity, with approximately 900 described species, with more than 20% of this number in endemism (Pinto 2020). It is known that many species of odonates are threatened with extinction with overexploitation and urban expansion in many regions of the country (ICMBio 2018). Modifications generated by urbanization replace native vegetation with exotic species and impervious surfaces, resulting in local microclimatic changes and other aquatic and terrestrial physical-chemical characteristics of riparian zones (McKinney 2008; Brasil et al. 2021). These effects convert natural environments into areas with homogeneous biotic and abiotic characteristics that also affect the diversity and composition of odonates (Villalobos-Jiménez and Hassal 2016; Prescott and Eason 2018; Sganzerla et al. 2021). Commonly, sensitive species are excluded and replaced by generalist groups with tolerant characteristics (eg, greater dispersion), often simplifying communities of odonates (Dutra and De Marco 2014; De Marco et al. 2015; Dalzochio et

al. 2018; Oliveira- Junior and Junior 2019). Considering the vulnerability of many odonate species to environmental degradation, further studies are needed to fill knowledge gaps on diversity in urban areas.

Beside the effect on diversity, urban and anthropic environments harbour odonates that are still poorly sampled in Brazil, despite the various inventories carried out in the country (Miguel et al. 2017). This gap is even more worrisome in regions that are highly threatened by the expansion of land uses, such as Minas Gerais. Currently, more than 304 species of dragonflies are known in the state, with more than 20 new records and new species recently reported (Vilela 2022). Most of this new data was obtained in underexplored areas, such as Uberlândia, in the Triângulo Mineiro region, western Minas Gerais state, a place threatened by urban sprawl and agriculture (Barbosa et al. 2019). Three inventories in this municipality found more than 60 species of adult dragonflies in degraded areas (Vilela et al. 2016, Barbosa et al. 2019, Vilela et al. 2020a). Thus, it is necessary to carry out more inventories that include urban areas, which are poorly inventoried in the region. In addition, some new species were also discovered in the region, opening new opportunities for taxonomic studies. This is the case of *Forcepsioneura machadorum* Vilela, Venâncio and Santos, 2020, recently discovered within a green urban area, but the species description was based only on males (Vilela et al. 2020b), remaining a taxonomic description of the female.

In addition to diversity, exposure to the effects of urbanization can cause phenotypic variations during development in organisms. Some studies show that this plasticity occurs in urban populations of some species, and in some cases it is characterized by morphological adaptations in different life history traits (Alberti et al. 2017). Some urban insect species have wings with shapes that allow greater movement in urban areas or in highly fragmented places in this environment (Tüzün et al. 2017;

Wilk-da-Silva et al. 2017). However, characters that allow greater dispersive capacity is not universal among urban residents (Villalobos-Jiménez and Hassal 2019; Beasley et al. 2019). And in some cases, maladaptive plasticity of traits important for dispersal can lead to future local extinction of species as a result of inbreeding, for example (McDonnell et al. 2015). This effect of urbanization on the morphometry of dispersive tracts of adult odonates (i.e., wings) is still poorly explored and has mixed results (e.g.; Tüzün et al. 2017a; Villalobos-Jiménez and Hassal 2019). Thus, it is necessary that studies verify how urbanization affects dispersive tracts of communities and populations of sensitive organisms.

Adaptations to urban environments allows some species to be tolerant to the adverse effects of climate change (Diamond and Martin 2021). However, heat waves in urban areas are predicted to be more frequent and intense in the future (Dosio et al. 2018), and this may negatively affect the survival and fitness of urban dragonflies (Tüzün et al. 2017b), despite this tolerance. Odonates that develop under heating have lower survival, advanced phenology, smaller size and morphometry of dispersive traits (McCauley et al. 2015; Aramborou et al. 2017; Villalobos-Jiménez and Hassal 2017). These phenological and morphological changes can also result in negative effects in urban adults, such as changes in the interaction with environmental conditions and lower dispersive capacity (Aramborou et al. 2017; Starr et al. 2019). These effects were observed in temperate dragonflies, but little is known about the effects of heat waves on urban populations of tropical species.

The various anthropic effects present in urban areas and resulting from climate change are stressful to some species. Theoretically, organisms that are in ideal environments for development have measurements between bilateral traits that are similar to each other (Palmer and Strobeck 1986). However, the constant exposure of individuals

to stressful conditions throughout development causes deviations in bilaterally symmetrical structures through the process known as developmental instability (ID) (Palmer and Strobeck 1986; Beasley et al. 2013). A commonly used index in ID studies is fluctuating asymmetry (FA) (Graham 2010; Beasley et al. 2013). FA has been shown to be an effective, fast, low-cost method, and widely used to measure the level of environmental stress in populations, as there is a positive relationship between the degree of population stress and FA (Beasley et al. 2013). Because of this, the use of this biometer enables early analysis of populations under stressful conditions before the widespread disappearance of individuals from populations (Beasley et al. 2013). Although studies indicate high levels of PA in populations in urban environments and at different temperatures (Chang et al. 2007; Magura and Lövei), other recent studies have not found differences for these same stressful effects (Beasley et al. 2017; Symanski et al. 2021). In addition, the literature is quite scarce when evaluating FA in urban dragonflies.

Thus, the main objectives of the thesis were to evaluate the relationship between urbanization and the diversity, plasticity and treatment of Odonata's life history traits. More specifically: (i) conduct a faunal survey of dragonflies in urban and non-urban areas, in addition to describing the female of *Forcepsioneura machadorum* Vilela, Venâncio and Santos, 2020; (ii) verify the plastic response of the flight path morphometry and the AF of dragonflies from different ecosystems (lotic and lentic) along a gradient of urbanization and preservation of urban fragments; (iii) to test the effect of heat waves on the plasticity of life history tracts and on the FA of urban odonate populations.

Conclusions

Our study showed that urban environments have a diversity of dragonflies still little known, which can help to complement the Wallacean and Linnean shortfalls of the group in the Cerrado. Despite the negative effects of urbanization often reported for

Odonata, much of the diversity found in this study, including the new occurrences for Minas Gerais and the taxonomic description of a female, were the result of collections in urban green areas. Furthermore, this study also found that urban environments result in plastic variations in urban dragonflies' ways of life. Some of the responses occurred in dispersive traits, more specifically in the morphology of the wings, in view of the fragmentation and preservation of urban environments. We showed that these factors have negative or neutral effects on damsel populations from different ecosystems (i.e., lotic and lentic). We also show that urbanization allows urban dragonfly populations to present plastic responses that allow for greater tolerance to extreme weather events, such as heat waves. However, this plasticity of ways of life can make it difficult for populations to persist within the urban environment. Finally, these plastic responses cannot always be expressed in the form of stress through the deviation of symmetry between bilateral structures, more specifically by fluctuating asymmetry. Thus, this thesis showed that we still know little about how urbanization can affect the diversity and plastic or evolutionary responses of dragonflies. Especially in the Neotropical region, where urbanization and climate change are increasing rapidly and exceedingly, there is an urgent need for further studies of Odonata.

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