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MASTER THESIS

DISTRIBUTION OF AVOIDER, NEUTRAL AND EXPLOITER BIRD SPECIES IN RELATION TO NDVI

AUTHOR: LINDA CARRASCO MENDEZ, B.A.

SUPERVISOR: YANINA BENEDETTI, PHD

CONSULTANT: FEDERICO MORELLI, PHD

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DIPLOMA THESIS ASSIGNMENT

B.S.B.A Linda Carrasco Mendez

Landscape Engineering
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Thesis title

Distribution of avoider, neutral and exploiter bird species in relation to NDVI

Objectives of thesis

The main goal of this study is to investigate the association of avoider, neutral and exploiter species richness with primary productivity – estimated as NDVI values – in three European cities.

Methodology

Data on urban bird species distribution in three European cities and NDVI values was available from an ongoing project. NDVI values were determined in a 60m buffer around the sample point. The data was collected during 2018 breeding season with a total of 300 sample point counts.

A classification based in urban tolerance categories applied in the bibliography to define birds as urban exploiter, neutral and avoider species was performed. Then, an estimation of the total number of bird species, richness of avoider, neutral and exploiter species in each sampling point was assessed.

A preliminary exploration and graphical representation of the data was done using R statistical software. Then, Kruskall-Wallis test was performed in order to evaluate the differences of bird categories and NDVI values among the three European cities.

In order to determine associations between NDVI values with avoider, neutral and exploiter, bird species, generalized linear models (GLM) were performed in each city separately. The NDVI represented the predictor variable, while that avoider, neutral and exploiter species richness represented the response variables.

The proposed extent of the thesis

50

Keywords

NDVI, biotic homogenization, adapters, exploiters, urbanization

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Recommended information sources

Filloy J., Zurita G.A., Bellocq M.I. Bird Diversity in Urban Ecosystems:The Role of the Bioma and Land Use along urbanization gradients. Ecosystems. (2019), 22(1), 213–227. https://doi.org/10.1007/s10021-018-0264-y

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The Diploma Thesis Supervisor

Yanina Benedetti

Supervising department

Department of Applied Geoinformatics and Spatial Planning

Advisor of thesis

prof. Federico Morelli, PhD

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doc. Ing. Petra Šímová, Ph.D.	**prof. RNDr. Vladimír Bejček, CSc.**
Head of department	Dean

Prague on 25. 03. 2020

AUTHOR'S DECLARATION

I hereby declare that I am the author of the entirety of this diploma thesis, titled "Distribution of avoider, neutral and exploiter bird species in relation to NDVI" and has been completed under the supervision of Dr. Yanina Benedetti. I have referenced all the data sources, literature, and publications which I have used in this study.

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Prague 2020 Linda Carrasco Mendez

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I dedicate this diploma thesis to all my loved ones, and to my supervisor.

ABSTRACT

Aim A deeper assessment of bird assemblages' features and more efficient methods to monitoring spatial patterns of bird species in urban areas are essential for a better understanding of the impacts of urbanization. As revealed in different studies, areas at higher values of NDVI - a surrogate mainly of primary productivity- was already related with areas of higher bird species richness. This study aims to explore further potential uses of NDVI in relation to bird assemblages and to highlight areas where bird species with different urban tolerance are distributed in urban areas.

Study area This study raises spatial patterns of bird diversity and urban tolerance in three different European cities: Athens and Ioannina in Greece and Granada in Spain.

Methods Bird composition data was collected by ornithologists from middle of April till the end of July during 2018. NDVI values were estimated considering the same period. Birds were classified as urban avoiders, neutrals and exploiters according to bibliographic urban tolerance categories.

Results Within the three cities, 14,667 bird individuals were observed in a total of 292 sampling points. Of the total of 59 breeding bird species identified, 16 were identified as urban avoider species, 26 as urban neutral species and 3 as urban exploiter species. NDVI values were positively related with the number of bird species and the number of urban avoiders in all cities. Urban neutrals were associated with NDVI values only within the city of Ioannina. There was no association among urban exploiters and NDVI values in all cities.

Conclusions This study concludes that NDVI can be used more efficiently as a proxy for occurrence and richness of bird urban avoider species within urban areas. It also supports the means of using NDVI as an estimate for primary productivity within urban areas, and for analyzing urbanization effects on urban birds. These findings provide essential information of monitoring easily bird assemblages at a large spatial scale to improve future urban planning that includes biodiversity conservation.

KEYWORDS: *NDVI, biotic homogenization, adapters, exploiters, urbanization*

ABSTRAKTNÍ

Cíl Pro lepší pochopení dopadů urbanizace je nezbytné hlubší porozumění vlastnostem seskupení ptáků a účinnější metody sledování prostorových vzorců druhů ptáků v městských oblastech. Jak bylo zjištěno v různých studiích, oblasti s vyššími hodnotami NDVI - náhrada hlavně primární produktivity - jsou spojovány s oblastmi s vyšší druhovou rozmanitostí ptáků. Tato studie si klade za cíl prozkoumat další potenciální využití NDVI ve vztahu k ptačí soustavě a upozornit na oblasti, kde jsou v městských oblastech rozšířeny druhy ptáků s odlišnou městskou tolerancí.

Studijní oblast Tato studie se zaměřuje na prostorové vzorce ptačí rozmanitosti a městské tolerance ve třech různých evropských městech: Aténách a Ioannině v Řecku a Granadě ve Španělsku.

Metody Údaje o složení druhů ptáků byly sbírány ornitology od poloviny dubna do konce července během roku 2018. Hodnoty NDVI byly odhadnuty s ohledem na stejné období. Ptáci byli klasifikováni podle bibliografických kategorií městské tolerance jako: městům vyhýbající se, neutrální a vykořisťovatelé.

Výsledky Ve třech městech bylo pozorováno 14 667 ptáků na celkem 292 sledovaných místech. Z celkového počtu 59 identifikovaných druhů chovných ptáků bylo 16 identifikováno jako městům vyhýbající se, 26 jako neutrální a 3 jako městští vykořisťovatelé. Hodnoty NDVI pozitivně souvisely s množstvím druhů ptáků a také s počtem druhů vyhýbajících se městům ve všech městech. Souvislost neutrálních druhů s hodnotami NDVI byla pozorována pouze ve městě Ioannina. Nebyla zjištěna žádná souvislost mezi městskými vykořisťovateli a hodnotami NDVI v žádném z pozorovaných měst.

Závěry Tato studie dochází k závěru, že NDVI lze efektivněji využít jako náhradu za výskyt a rozmanitost druhů ptáků vyhýbajících se městům v městských oblastech. Potvrzuje také způsoby využití NDVI jako odhad primární produktivity v městských oblastech a pro analýzu účinků urbanizace na městské ptáky. Tato zjištění poskytují základní informace o snadném monitorování ptáků ve velkém prostorovém měřítku za účelem zlepšení budoucího urbanismu, který zohledňuje ochranu biologické rozmanitosti.

Klíčová Slova: *NDVI, biotická homogenizace, přizpůsobení, vykořisťovatelé, urbanizace*

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1. INTRODUCTION

Research on biodiversity in urban landscapes, and especially on urban birds, has shown that in areas with native vegetation, the bird community was composed mostly by native species generally called “urban avoiders” (Blair, 1996). In urban areas with intermediate levels of urbanization, both native and non-native species named “urban neutrals” were the main community. In the highly urbanized areas, where buildings and pavement cover rises, a few number of species, mainly non-native ones, are named “urban exploiters” (Blair, 1996). The pattern in which a few well adapted species to human-dominated areas (urban exploiters) replace a broader range of native species has been called biotic homogenization (Blair, 2001; Crooks, Suarez, & Bolger, 2004; Lockwood & McKinney, 2002). As urbanization is the major cause of biotic homogenization, urban conservation and planning should focalize on the preservation and restoration of local indigenous species (McKinney, 2006). Accordingly, the conservation of natural environments, habitats, and overall primary productivity are a key essential to mitigating the negative effects of urbanization processes (impervious surfaces, high densities, pollution, etc.) and supporting biodiversity in highly urban areas as well (Shochat, Warren, Faeth, McIntyre, & Hope, 2006). Thus, understanding the spatial patterns of primary productivity will help guide sustainable land management and design more effective conservation strategies. Although measuring and monitoring environmental variables through field surveys can be expensive and logistically challenging (Seto, Fleishman, Fay, & Betrus, 2004), the availability of satellite imagery as NDVI data, which has already demonstrated its ability to be related to bird species richness spatial distribution (Seto et al., 2004), it has the potential to highlight other relevant features of birds species assemblages as urban tolerance. However, the association among NDVI and the urban tolerance of birds within urban areas remains unexplored.

2. AIMS

The main aim of this study was to explore the potential use of primary productivity – estimated as NDVI values – as a proxy for the spatial distribution of avoider, neutral and exploiter bird species richness in urban areas.

3. LITERATURE REVIEW

The purpose and goal of this literature review are to provide further details on the necessary keywords and concepts within this study. It will provide clarity on why it is useful and pertinent to investigate urban bird species and their characteristics in response to the Normalized Difference Vegetation Index (NDVI) and evidently urbanization. The literature review of this study is based on previous research (peer-reviewed articles and books) in order to understand what data and variables were collected, the location of the study areas, the bird species studied and the research questions and studied hypotheses. Therefore, this literature review will seek to 1) focus on the effects of urbanization on biodiversity, 2) discuss the importance of the urban tolerance classification consisting of avoider, exploiter, and neutral for urban bird species, and 3) discuss how NDVI could be a useful proxy to assess biodiversity distribution at a broad scale.

3.1 BENEFITS OF BIODIVERSITY IN CITIES

Biodiversity is a term used to describe all fauna and flora that live and coexist together, while their variability and diversity are also taken into consideration. According to Alvey (2006) biodiversity involves three different organizational levels which incorporates both richness and evenness, those levels are: genome, assemblages or species, and landscape. Urban biodiversity is then all living organisms and their corresponding variables and variability in an urban setting (Muller, Werner, & Kelcey, 2010). Defining biodiversity is complicated, as there are various definitions on what biodiversity is and what it encompasses; each researcher, author, scientist, etc. contain their own variables that define biodiversity. Nonetheless, it is crucial for each researcher to define their limits and variables for biodiversity in order to understand the objective of their study.

The aim for conserving biodiversity within cities ultimately falls within the planners and managers and often times they too face dilemmas regarding how to address biodiversity (Dearborn & Kark, 2010). However, biodiversity is essential and could provide many benefits in cities and the urban life in different ways (Table 1). In the point of view of the inhabitants, Muller et al. (2010) stated that rich biodiversity provides healthy environments and habitats to live in, due to how fauna and flora and green space contribute to natural medicines and foods, the interactions between society, and aesthetics. Inhabitants can have the opportunity to experience nature through the conservation of natural areas, further supporting the theory that biodiversity increases the quality of life (Fontana, Sattler, Bontadina, & Moretti, 2011). In the point of view of ecology and the environment, with more available area (ha) in parks and green spaces then it offers more biodiversity and more possible habitats for living organisms (Cornelis & Hermy, 2004). Parks can have multiple types of vegetation such as grassland, bushes, forests, and also contain some water features (Cornelis & Hermy, 2004); that variety leads to more habitats, species richness and diversity. In general urban green spaces, such as golf courses, and their management practices contribute greatly to biodiversity within urban areas (Threlfall, Williams, Hahs, & Livesley, 2016).

	Major Motivations for Urban Biodiversity Conservation
Benefits to nature	Preserve local biodiversity in an urbanizing environment and protect important populations or rare species
↑	Create stepping stones or corridors for natural populations
	Understand and facilitate responses to environmental changes
	Connect people with nature and provide environmental education
	Provide ecosystem services
↓	Fulfill ethical responsibilities
Benefits to humans	Improve human well-being

Table 1. Dearborn & Kark (2010) list major motivations for conservation of urban biodiversity and explain benefits in the point of view of nature and humans.

3.2 URBANIZATION EFFECTS ON BIODIVERSITY

3.2.1 URBANIZATION PROCESS

Urbanization is the process that cities, towns, or areas undergo when they are becoming more urban; in other words, they are transitioning from a rural community to an urban community. That can lead to land cover and land use change, higher densities due to urban development and thus greater amounts of impervious surfaces, multimodal transportation, population growth, land fragmentation and other characteristics of an urban area. The end results are significant effects on the surrounding natural environment (Mcdonald, Kareiva, & Forman, 2008). With urbanization being such a global trend in both developed and undeveloped countries (Pauchard, Aguayo, Peña, & Urrutia, 2006), there have been plenty of studies proving correlations between urbanization and the effect it has on the environment and local biodiversity.

Thus, urbanization is a continuous process where these approaches can lead to high density or urban sprawl, both of which have further impacts on the surrounding ecology (Figure 1). Urbanization leads to land fragmentation (York et al., 2011), impervious surfaces (Aronson et al., 2014), high amounts of anthropogenic noise (Cardoso, Hu, & Francis, 2018), and other significant effects which then lead to habitat loss and general alterations of the existing biomes (Hagen et al., 2017). For example, in the case of the metropolitan area of Concepcion, Chile, urbanization has greatly affected wetlands and other peri-urban ecosystems through fragmentation or introducing non-native invasive species (Pauchard et al., 2006). In countries where urbanization is significantly high and undergoing large-scale urbanization, like China, land cover change is the main issue since the amount of impervious surfaces increases as development increases, affecting local biodiversity and habitats (Güneralp, Perlstein, & Seto, 2015). Indonesia, like China in containing high urbanization rates, has also undergone compelling land use changes that have affected their terrestrial and marine ecosystems (Elmqvist et al., 2013). One of the most problematic consequences of urbanization is urban sprawl, and in many cases, it leads to habitat fragmentation and an overall loss of species diversity and eventually degrades biodiversity (Gordon, Simondson, White, Moilanen, & Bekessy, 2009). It has been studied that residential and housing development, specifically low density like single family housing, is more threatening for species since it negatively impacts vegetation cover and land cover (Sushinsky, Rhodes, Possingham, Gill, & Fuller, 2013; Tratalos et al., 2007).

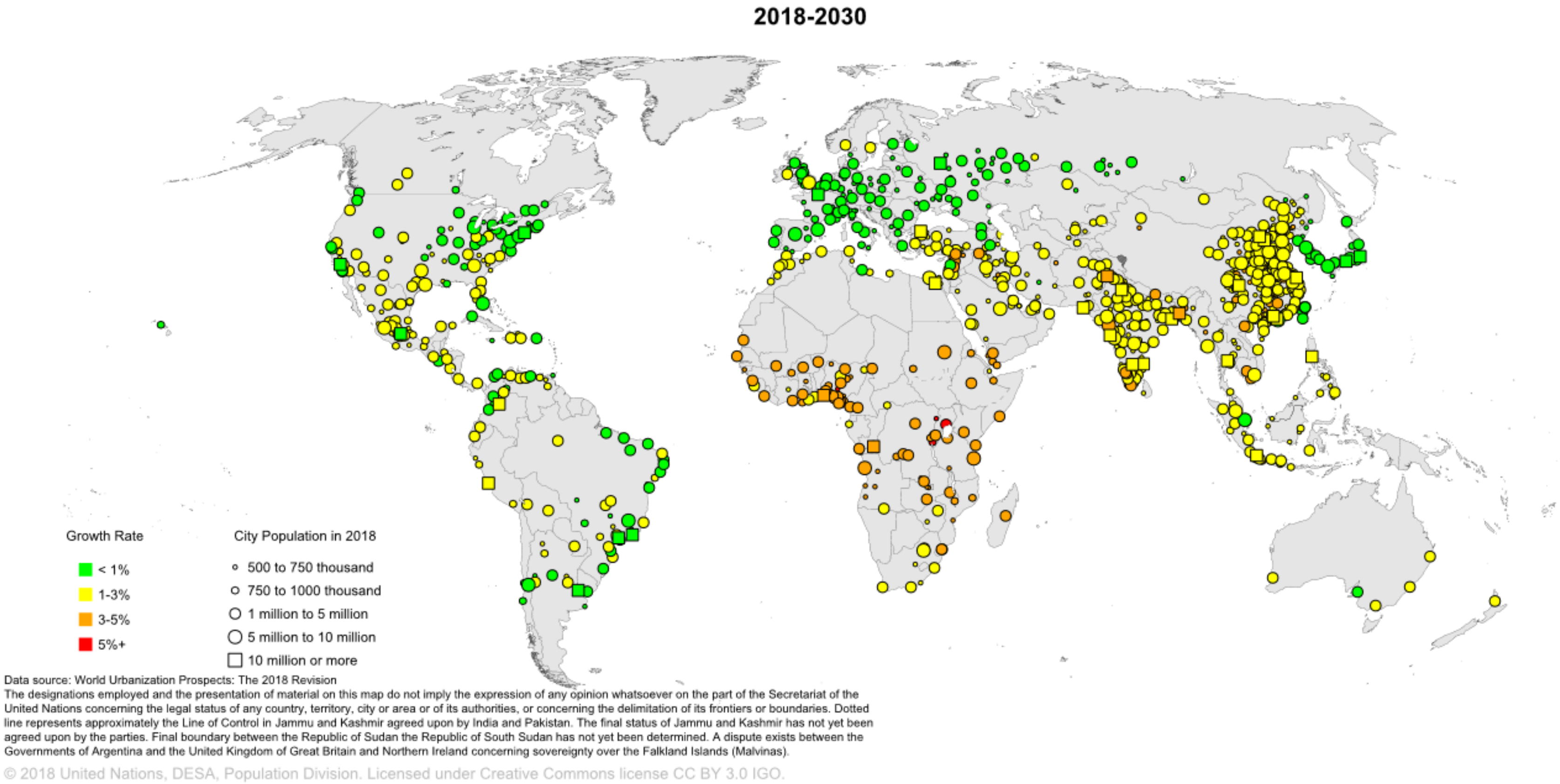

Figure 1. City growth rate for the years 2018-2030, where green is <1%, yellow is 1-3%, orange is 3-5%, and red is 5% and more. ("United Nations Convention on Biological Diversity," n.d.)

3.2.2 BIODIVERSITY LOSS AND BIOTIC HOMOGENIZATION

According to Shochat et al. (2010) there has been supportive evidence in recent years for the idea that, for some species, urban environments may be safer in comparison to rural habits and wildlands (Figure 2). Although it seems ironic and a conundrum that some species do prefer anthropogenic habitats, it is possible mainly depending on the taxa. Nonetheless it is clear that urbanization has a severe impact not only on human health and community wellbeing (Leon, 2008), but to biodiversity and ecological stability as well (Aronson et al., 2014; Filloy, Zurita, & Bellocq, 2019; Morelli et al., 2017).

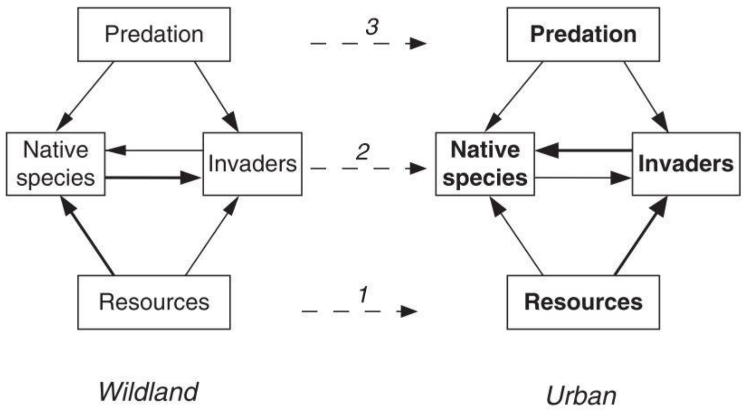

Figure 2. Shochat et al. (2010) describes the urban bird communities in wildland and urban settings: (1) Urbanization increases food resource and availability, which supports higher bird densities and invasive bird species, (2) The difference between the wildland and urban birds is the competition between the native and non-native (invasive) species, where in urban areas the non-native species dominate, and (3) predation as a mediate in urban areas is not as important as it is in wildland areas.

Biotic homogenization is perhaps one of the most unique and interesting results from urbanization for urban biodiversity. It refers to when biomes or communities have an increase in the abundance of common species and a decrease in rare species, or no to very few dominant species (Kühn & Klotz, 2006; Morelli et al., 2017). It is when an area has biotic similarity between species, mainly due to native species being replaced by non-native species or the invasion from non-native species (Alvey, 2006; Olden, Poff, & McKinney, 2006; Schwartz, Thorne, & Viers, 2006). This is possible because non-native species are often imported into urban areas both intentionally and unintentionally, and although that does not always guarantee biotic homogenization (McKinney, 2006), it can limit species richness. In other words, the non-native species are introduced by humans and can be invasive to where they decrease the richness of local native species. The effect that biotic homogenization has on biodiversity, which can lead to species loss, is that it limits the possible habitats for local fauna and flora by having homogenous communities and biomes, and thus leading distinct biota to become more similar (Kühn & Klotz, 2006). When any of these impacts occur, it fundamentally promotes biotic homogenization. Therefore, consequences and impacts of biotic homogenization are simple: less species richness and biodiversity. Figure 3 demonstrates all the possible consequences from urbanization and anthropogenic influences as discussed in this section, and how that can lead to increased urbanization and/or lower species diversity (Simberloff, 2001).

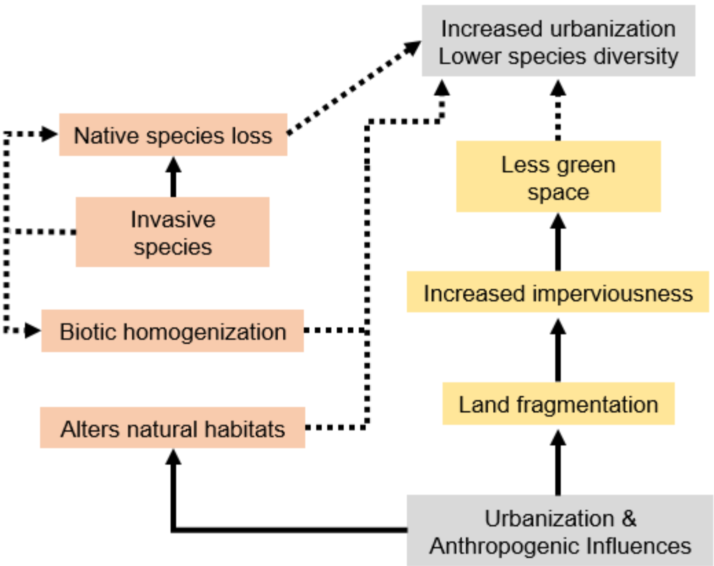

Figure 3. Using Shochat, Warren, Faeth, McIntyre, & Hope (2006) diagram as a reference, this displays some of the relationships and links between the impacts of urbanization on biodiversity, where the dashed lines are indefinite consequences and the solid lines are definite consequences.

3.2.3 IMPACT OF URBANIZATION ON BIRD COMMUNITIES

Environmental indicators (also known as bio-indicators or species indicators) have been analyzed for decades, as established by the Convention on Biological Diversity, to study biodiversity (Bibby, 1999; Feld, Sousa, da Silva, & Dawson, 2010). One of the more outdated but ecologically significant studies, states a conclusive definition and explanation for an environmental indicator: an "indicator [is] meant to quantify and communicate complex phenomena, in this case, biodiversity trends and patterns, in a simple manner" (Bibby, 1999). Research has leaned towards birds as being the ideal taxa and species indicator for the purpose of monitoring, analyzing, gathering data, and studying biodiversity (e.g. Elmqvist et al., 2013; Fontana et al., 2011; R. Gregory et al., 2003; Morelli et al., 2017; Sol et al., 2014). The following reasons stated by Gregory and Strien (2010) are what justify birds as species indicators: they are found in most biomes making them mobile, widespread and diverse, they are sensitive to anthropogenic and natural environmental changes, they are easy to collect data from, identify and conduct surveys, and they are at higher trophic levels in food chains, respectively.

After discussing the complexity between urbanization and biodiversity, as well as the importance of environmental indicators and how birds are appropriate for exploring the correlations between urbanization and biodiversity, it is now pertinent to discuss how bird communities are impacted specifically. It is understood that urbanizing an area changes the landscape and land cover, and the bird communities respond to the change in their environments by categorical natural selection of avoiders, exploiters, and neutrals (Kark, Iwaniuk, Schalimtzek, & Banker, 2007; McKinney, 2002). Before discussing each category of avoiders, exploiters and neutrals in the following subsection, the terms adaptedness and adaptation are relevant and crucial to understand.

In general, the environmental changes that urbanization introduces into an area affect organisms differently. Adaptedness refers to when organisms possess traits that enable them to tolerate urban environments based on their unique phenotypic traits; in a sense they are preadapted to the urban change of their local environments. The more complex term of adaptation refers to when organisms essentially adapt to urban environments over extensive periods of time, possibly changing their phenotype to ensure a high probability of survival through urbanization. Understanding adaptedness and adaptation is relevant background information to how the categories of avoiders, exploiters and neutrals came to be within bird communities. Furthermore, urbanizing areas will continue to develop on natural ecosystems making the local organisms choose among potential pathways of (i) migration, (ii) potential for adaptedness, (iii) potential for adaptation, or (iv) extinction within the local urban environment. Figure 4 displays the potential pathways in respect to urban ecosystems. (McDonnell & Hahs, 2015)

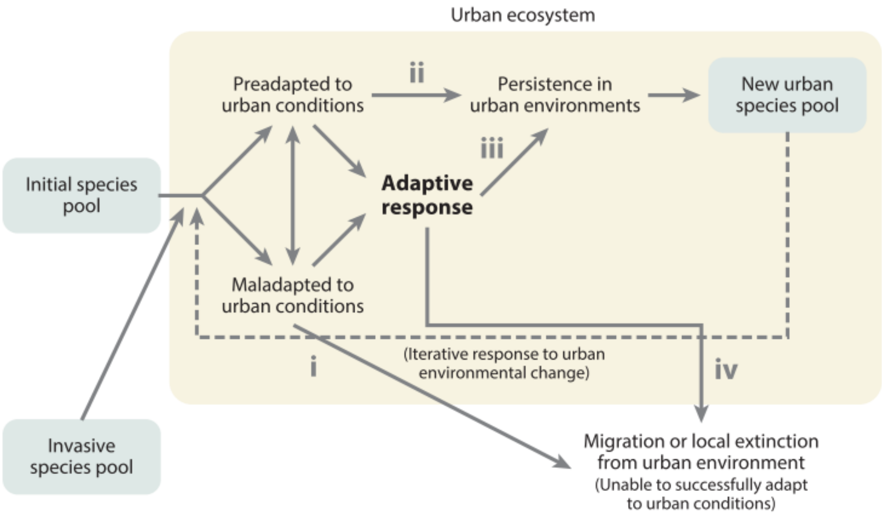

Figure 4. Potential pathways for organisms in urban ecosystems (McDonnell & Hahs, 2015).

3.3 URBAN TOLERANCE CLASSIFICATION: AVOIDERS, EXPLOITERS, AND NEUTRALS

The impact of urbanization on overall biodiversity is clearly due to the modification and alteration of the natural land as already mentioned. But more precisely, human-induced alterations of landscapes and land cover force species, like birds, to test their tolerance and adaption to urbanization (Callaghan et al., 2019; Sol et al., 2014).

Bird communities can be categorized by either avoiders, exploiters or neutrals based on urbanization and an increasing urban gradient (Kark et al., 2007). Urban avoiders are defined as those bird species that prefer native vegetation and areas that are outside the urban centers (Kark et al., 2007). They are sensitive to anthropogenic disturbances and influences (McKinney, 2002), prefer dense vegetation like old forests (Pauchard et al., 2006), and are most abundant and rich in areas of lower densities, i.e. natural areas (Fischer, Schneider, Ahlers, & Miller, 2015). Urban exploiters can easily be described as the opposite of urban avoiders. Exploiter species can adapt well to anthropogenic and urban environments (Kark et al., 2007) and are strongly dependent on those anthropogenic resources potentially reaching great densities (Fischer et al., 2015; McKinney, 2002). They are simply the bird species that are most able to thrive in dense, urban environments (Dearborn & Kark, 2010). The third classification are those species that are neutrals. Although there is not much information regarding how intensely urbanization impacts this group (Sol et al., 2014), neutrals are those that are neither avoiders or exploiters, meaning they do not prefer dense urban areas nor rural natural areas.

Throughout the years, ecologists have been studying these classifications in relation to urban tolerance (Conole, 2014). Urban tolerance is also related to that of how well can bird species adapt to urbanization and anthropogenic influences (Conole, 2014). Sol et al. (2014) explains their urban tolerance hypothesis as to what kind of biological traits do bird species (that occur in cities) contain in order for them to be able to either use anthropogenic resources or to avoid them. This is similar and understandable as to the terms adaptedness and adaption. In a study by Bonier et al. (2007), it was discussed that urban birds indeed contain broader environmental tolerance in comparison to other similar rural organisms, and that can be justified by their behavioral, physiological and ecological flexibility.

3.4 NDVI AS A PROXY FOR BIODIVERSITY

The efficient planning and management of cities are crucial in order to properly dedicate and establish land for urban green spaces which can essentially lessen the impact of urbanization (Leveau, Isla, & Bellocq, 2018). The fields of ecology, preservation and conservation studies and other environmental studies, as well as urban planning, landscape planning, etc. need to be integrated in order to address the impacts of urbanization on biodiversity to a full scale. In order to adequately conduct research on such topics of urbanization and biodiversity other fields like satellite remote sensing are vital for data analyses, just like how one of the widely applicable remote sensing spectral index is in fact the Normalized Difference Vegetation Index (NDVI) (Robinson et al., 2017). It is complex to be able to analyze ecological and environmental variables like climate, land cover, primary production, or habitat heterogeneity simultaneously to determine species distribution modelling, but NDVI has made that possible through remote sensing data (Ding et al., 2019; Shirley et al., 2013).

According to several studies, one of the more useful indices for monitoring biodiversity variables (Seto et al., 2004) and analyzing land cover types and species' behavior through satellite sensors is NDVI (Pettorelli et al., 2011; Shirley et al., 2013). With advancing technology especially in the field of remote sensing, the potential of satellite data for ecological and environmental research has been high (Leyequien et al., 2007). Since the introduction of NDVI in the early 1970's many more studies have been made regarding biomass estimation (Pettorelli et al., 2011), plant productivity or annual primary production (Nieto, Flombaum, & Garbulsky, 2015), the complexity and richness of vegetation and its relationship with bird species richness (Ding et al., 2019), and the relationship between urbanization and biodiversity (Shirley et al., 2013). NDVI has made a detrimental impact on ecological studies and research in the last decades.

NDVI is a ratio between the values of near-infrared (NIR) and red bands (Red), where they are divided between the differences of their respective sums (Leyequien et al., 2007; Seto et al., 2004):

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

With many other remote sensing vegetation indices and ratios, NDVI has gained popularity and became widely used throughout environmental research (Bonthoux, Lefèvre, Herrault, & Sheeren, 2018; Seto et al., 2004). It is adequate for analyzing large-scale primary production throughout time (Pettorelli et al., 2011) as well as predicting species richness and ecosystem productivity (Bonthoux et al., 2018). In connection with biodiversity, NDVI is stated to be best in autumn due to how the seasons affect the landscape mosaic throughout the year (Bonthoux et al., 2018).

Although there are some of ecological and environmental studies using NDVI to determine: species richness patterns (Bonthoux et al., 2018), spatial variance within species richness (Seto et al., 2004), or functional, taxonomic and phylogenetic diversity (Bae et al., 2018), few have focused specifically on birds within natural and urban areas (Bino et al., 2008; Leveau et al., 2018; McFarland & van Riper, 2013; Nieto et al., 2015; St-Louis et al., 2014). With NDVI being able to estimate primary productivity (Pettorelli et al., 2011), it can serve as an adequate tool for analyzing urban areas and its natural characteristics. Furthermore, knowing the amount of vegetation in an urban environment is useful for being able to adequately conduct studies regarding the effect of urbanization on bird diversity (Nieto et al., 2015), and overall biodiversity as well. In this case, using urban birds as a species indicator leads to NDVI as a potential proxy for not only biodiversity, but more specifically bird species richness within urban areas (Bino et al., 2008).

4. METHODOLOGY

4.1 STUDY AREAS AND THEIR CHARACTERISTICS

In this study three different European cities were surveyed: Athens and Ioannina in Greece, and Granada in Spain (Figure 5). All cities are located in the southern region of Europe.

4.1.1 ATHENS, GREECE

Athens is the capital of Greece, located within 8 kilometers of the Bay of Phalaeron from the Agean Sea (Vanderpool & Ehrlich, 2020). The climate consists of hot and dry summers, while little to no snow during the colder seasons (Vanderpool & Ehrlich, 2020). Minimum temperatures could be 0° C with a maximum of 37° C (Vanderpool & Ehrlich, 2020). The total population as of the 2011 census is 664,046, with Athens having a total area of 39.0 km^2 and a density of 17,027 people per km^2 (Brinkhoff, n.d.-a).

4.1.2 GRANADA, SPAIN

Granada is a city in southern Spain and the capital of Granada province (Britannica, n.d.-a). In the year, July is the warmest month with temperatures around 25.5° C and January being the coldest month with temperatures around 7° C (Climate-Data.org, n.d.-a). The total population for the city of Granada is 241,003 as of the 2011 census (Brinkhoff, n.d.-b). The total area is 81.1 km^2 with a density of 2,972 people per km^2 (Brinkhoff, n.d.-b).

4.1.3 IOANNINA, GREECE

Ioannina is a city located in northwestern Greece and is adjacent to Lake Ioannina (Britannica, n.d.-b). The climate in this city is generally warm, with more wet winters than summer (Climate-Data.org, n.d.-b). July is the warmest month of the year with temperatures averaging at 22.5° C and January is the coldest month with temperatures averaging at 4.2° C (Climate-Data.org, n.d.-b). The population as of the 2011 census is 65,574 (Brinkhoff, n.d.-c). Ioannina's total area is 17.4 km^2 with a density of 3,768 people per km^2 (Brinkhoff, n.d.-c).

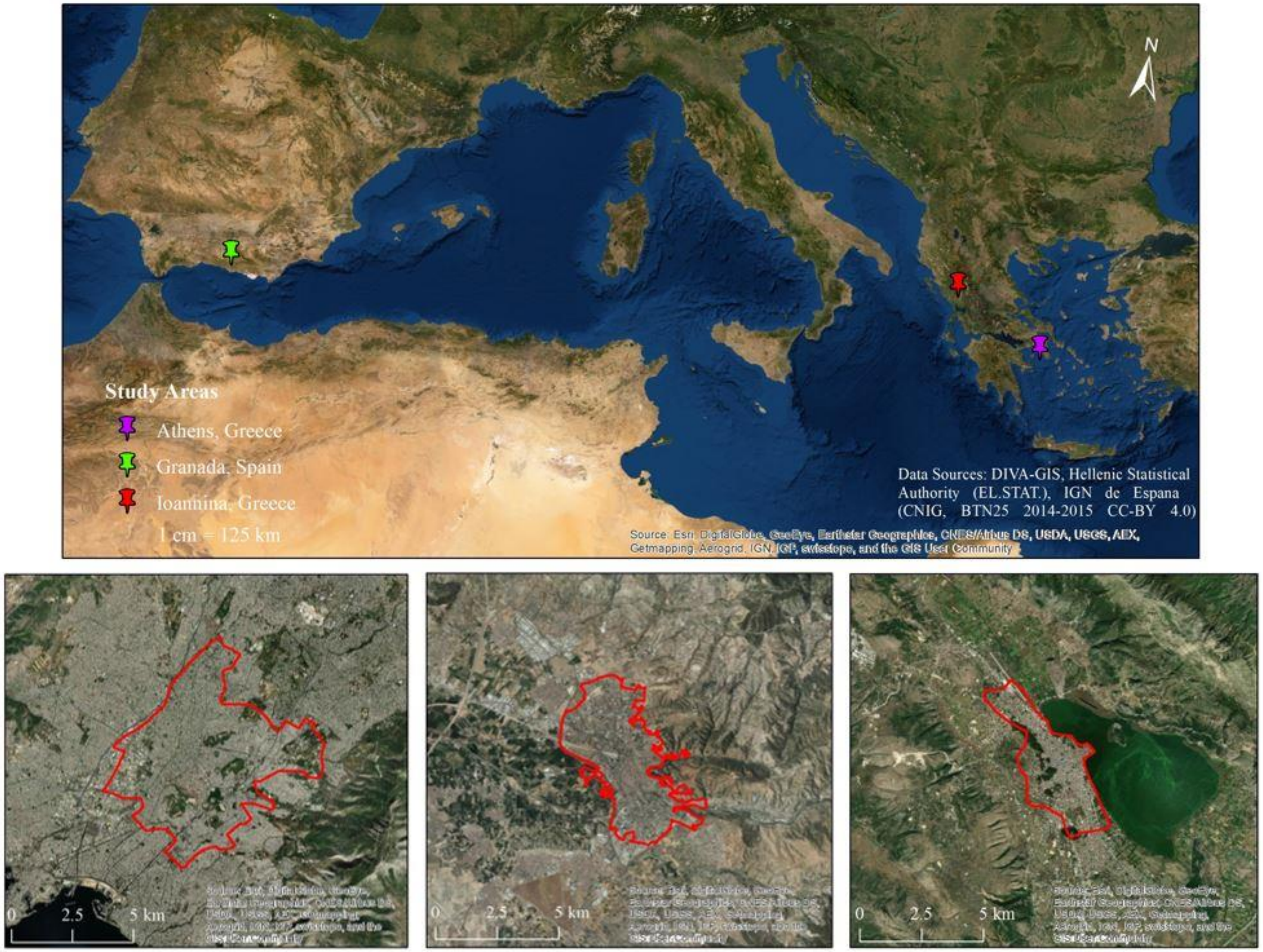

Figure 5. Location of the three cities surveyed: Athens, Greece (bottom far left), Granada, Spain (bottom middle), and Ioannina (bottom far right) where the red outlines are the respective city boundaries. GIS data was retrieved from the following sources: Hellenic Statistical Authority (EL.STAT.), 2011 for Greece and the Centro Nacional de Informacion Geografica y Direccion General del Instituto Geografico Nacional (IGN) (CC-BY 4.0) for Spain.

4.2 BIRD DATA SURVEY

Data on bird presence and abundance was collected in each city during the 2018 breeding season (mid-April to end of June) and was supported by the Czech Science Foundation GAČR (project number 18-16738S). Every observer selected 100 sampling sites per city, following a gradient of urbanization, roughly described as: a) high urban density = e.g. city center, historical center, commercial center (shops), b) medium urban density = e.g. residential areas with small gardens and c) low urban density = e.g. residential areas with large gardens, green areas, parks.

Each sampling point was surveyed once between 06:00 and 10:00 for 10 minutes, only under favourable weather conditions. All points were separated by at least 200 meters (m) and provide highly reliable estimates of relative population density, representing a standardized method in ecology (Bibby, Burgess, & Hill, 1992). All diurnal bird species detected visually and acoustically were recorded by the observer in a radius of 100 m.

4.3 AVIAN TAXONOMIC DIVERSITY

To assess avian diversity the following was estimated: a) bird abundance (AB) and b) bird species richness (BSR). Both metrics were assessed considering each bird community in a sampling site. The abundance was assessed as the number of bird individuals surveyed while the bird species richness as the number of recorded bird species. (Magurran, 2004)

4.4 URBAN TOLERANCE CLASSIFICATION

The bird species identified in all cities were classified based in the urbanization tolerance categories applied by Sol et al. (2014) with modifications. Sol et al. (2014) classified urban birds as “avoider” whether the observed bird abundance was equal to or lower than the 5th percentile of the random abundances in the urban habitat, whereas they classified urban birds as “exploiter” whether the bird abundance was equal to or higher than the 95th percentile. The classification of urban birds as "neutral" was determined in the range of higher than 5th percentile and lower than 95th percentile. The classification of neutral species is not very reliable due to the scarce information concerning how intensely urbanization affects neutral species. For that reason, many studies have excluded the neutral species from formal analyses (Sol, González-Lagos, Moreira, & Maspons, 2013). However, in this study, it was modelled as a response variable to compare the different associations of urbanization tolerance with NDVI values. This does not guarantee that every species with a formal classification contain an equal response to urbanization, that is not achievable and cannot be assumed (Evans, Chamberlain, Hatchwell, Gregory, & Gaston, 2011). Therefore, to lessen this assumption the analysis was restricted to urbanized environments only. This metric measures species in the aspect of being able to sustain, withhold and tolerate habitats that have undergone heavy human alterations and modifications. What is excluded are those exploiter species that pursue urban environments only to scout and exploit areas of more natural habitats such as backyards or parks (Sol et al., 2014). Finally, an estimation of the total number of avoider (ASR), neutral (NSR) and exploiter (ESR) bird species richness in each sample point was assessed.

4.5 Normalized Difference Vegetation Index (NDVI)

Rouse, Hass, Schell, & Deering, (1973) introduced this index as a method for evaluating the conditions of vegetation, and their normalized vegetation ratio has impacted remote sensing greatly since then (Seto et al., 2004). NDVI is computed by dividing the difference of near-infrared (NIR) and red bands (Red) by the sum of NIR and Red respectively (Pettorelli et al., 2011; Seto et al., 2004).

Because this index is calculated through NIR, any vegetation with green leaves would be highly reflective, which would result in positive NDVI values while land covers such as bare soil, snow or concrete would result in NDVI values close to zero; negative NDVI values lead to water as the land cover (Pettorelli et al., 2011). This is possible due to how NDVI is responsive to photosynthetically active biomass and active radiation (Seto et al., 2004). Considering the season and the stage at which the vegetation would be in is necessary to mitigate potential "flaws" in NDVI values (Bonthoux et al., 2018).

For each city, the mean NDVI values were calculated from beginning of April 2017 to end of June 2017 to assure full coverage. The Google Earth Engine archive: LANDSAT/LC08/C01/T1_32DAY_NDVI was the database for NDVI values, which consisted of a 32-day composite. The archive was created from Landsat 8 satellite and are Top of Atmosphere Reflectance, orthorectified scenes. Each sample point NDVI value was extracted from the NDVI raster with 60 m resolution.

4.6 STATISTICAL ANALYSIS

We tested differences among cities in the following variables: AB, BSR, ASR, NSR, ESR and NDVI values using the non-parametric Kruskal-Wallis test with the 'kruskal.test' package in R (Hollander & Wolfe, 1973). Then, we explored the nature and strength of the associations between NDVI values and each avian diversity and urban tolerance class to understand if NDVI can predict the spatial distribution of each class of urban tolerance. These associations were examined using generalized linear models (GLM) (McCullagh & Nelder, 1989). Each diversity and urban tolerance parameter were established as a dependent variable and modelled separately. The variable NDVI was entered as the predictor in the full models. Models were fitted assuming a Poisson distribution for bird species richness and each type of urban tolerance class, while it was considered a Gaussian distribution for the bird abundance after determining their distribution (Box & Cox, 1964) with the package "MASS" (Venables & Ripley, 2002).

All statistical tests were performed with R software (R Development Core Team, 2019) and considered results statistically significant if p-value was lower than 0.05.

5. RESULTS

5.1 AVIAN DIVERSITY IN ATHENS, GRANADA AND IOANNINA

During breeding season, three European cities were surveyed for a total of 292 sampling sites. The total amount of bird individuals recorded in all cities was 14,667 (Athens: 7,718, Granada: 4,763 and Ioannina: 2,186) (Table 2). The highest values of average number of individuals was recorded in Athens with 77.20 over Granada (48.10), and Ioannina with 23.50 individuals respectively (Table 2, Figure 6). The cities differed significantly in the number of individuals ($p < 0.05$) (Table 2).

In this study, 59 breeding bird species were identified during the 2018 breeding season (Appendix A, Table 6). Athens contained the most bird species (37 total) while Ioannina the least bird species (31 total) as seen in Table 2. The bird species richness in sampling sites varies from a minimum of 2 species in Athens and Ioannina to a maximum of 24 species in Granada (Table 2, Figure 7). The highest values of average species richness was recorded in Granada (Table 2, Figure 7), while the lowest values were obtained for Ioannina (Table 2, Figure 7). The cities differed significantly in the number of bird species ($p < 0.05$) (Table 2).

Table 2. Summary of bird abundance (AB) and bird species richness (BSR) from the three cities focused in this study.

Bird Abundance								
City	Sampling sites	Bird abundance	Mean	SD	Min	Max	Kruskal-Wallis H test	*p-value*
Athens	100	7,718	77.20	75.80	15	438	115.77	p < 0.05
Granada	99	4,763	48.10	18.90	16	109		
Ioannina	93	2,186	23.50	21.10	4	177		
Bird species richness								
City	Sampling sites	Bird species richness	Mean	SD	Min	Max	Kruskal-Wallis H test	*p-value*
Athens	100	37	9.34	3.71	2	18	82.01	p < 0.05
Granada	99	33	11.70	4.24	3	24		
Ioannina	93	31	6.23	2.98	2	15		

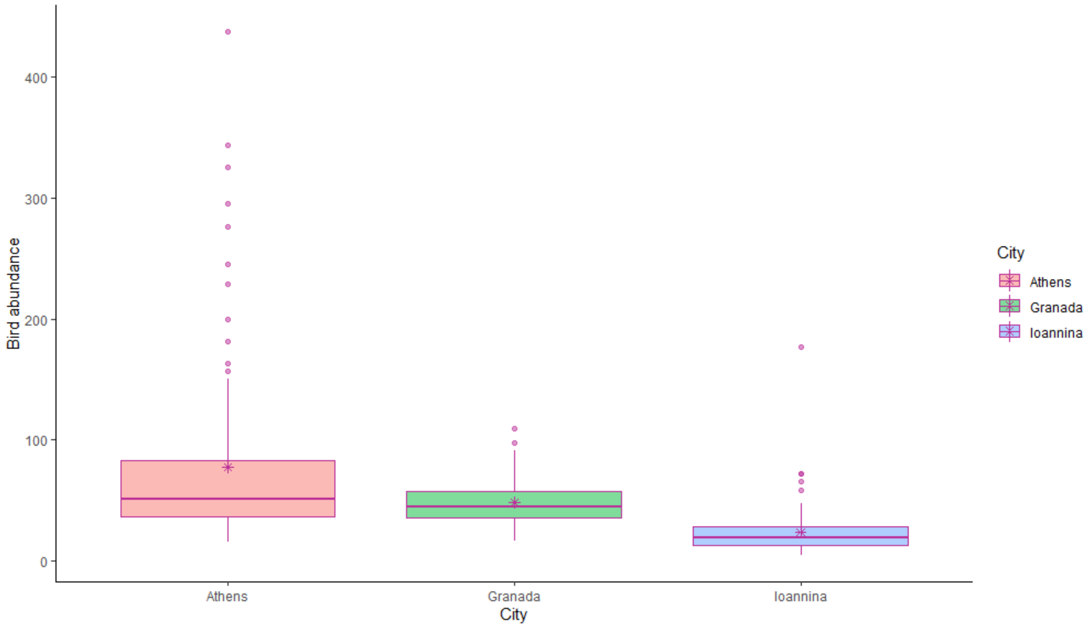

Figure 6. Comparison among the number of bird individuals (Bird abundance) recorded in the three cities focused in this study. The box plots show medians, mean values (violet star), quartiles, 5- and 95-percentiles and extreme values.

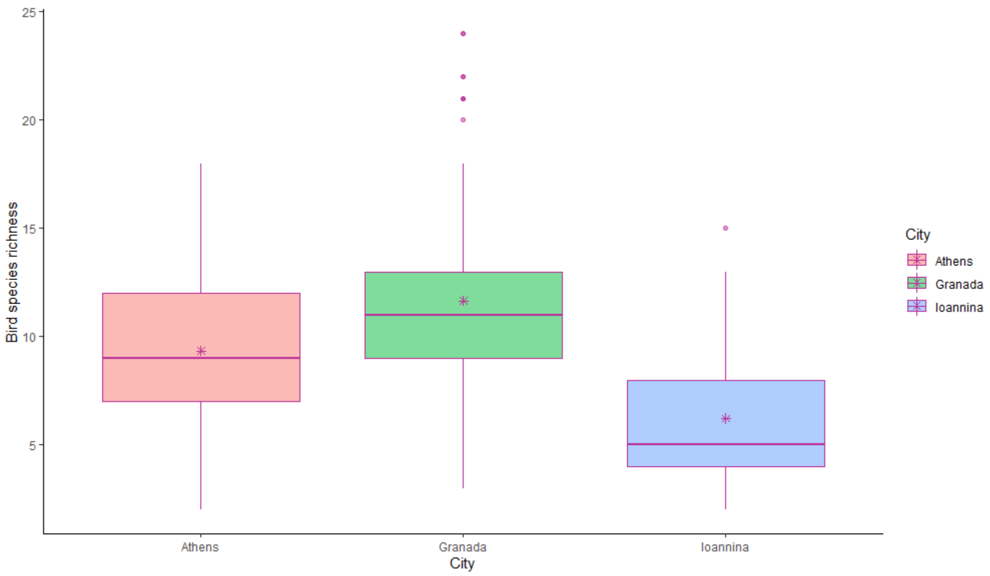

Figure 7. Comparison among the bird species (BSR) identified in the three cities focused in this study. The box plots show medians, mean values (violet star), quartiles, 5- and 95-percentiles and extreme values.

5.2 URBAN AVOIDER, NEUTRAL AND EXPLOITER BIRD SPECIES IN ATHENS, GRANADA AND IOANNINA

From a total of 59 bird species identified in this study, 16 bird species were classified as urban avoiders, 26 as urban neutrals and 3 as urban exploiters (Appendix B, Table 7). In average, the city harboring the most avoider species was Granada with 1.84 species, while the cities of Athens and Ioannina harbored an average of 1.44 and 0.40 avoider species respectively (Table 3, Figure 8). The Kruskal-Wallis test confirmed the differences observed in the number of avoider species among the cities ($p < 0.05$) (Table 3). Regarding the number of neutral species, Granada also contained the most species with an average of 5.39, followed by Athens with 3.22 and Ioannina with 2.58 average species (Table 3, Figure 9). The differences in the number of neutral species among each city were confirmed by the Kruskal-Wallis test ($p < 0.05$) (Table 3). In terms of exploiter species, the city of Granada contained the most with an average of 2.42, while the city of Athens contained an average of 1.98 exploiter species and the city of Ioannina with an average of 1.76 exploiter species (Table 3, Figure 10). The Kruskal-Wallis test was able to confirm the exploiter species differences among the cites ($p < 0.05$) (Table 3).

Table 3. Summary of urban avoider species (ASR), urban neutral species (NSR) and urban exploiter species (ESR) from the three cities focused in this study.

Bird avoider species								
City	Sampling sites	Total species	Mean	SD	Min	Max	Kruskal-Wallis H test	*p-value*
Athens	100	12	1.44	1.30	0	4	75.25	$p < 0.05$
Granada	99	10	1.84	1.17	0	5		
Ioannina	93	3	0.40	0.63	0	3		
Bird neutral species								
City	Sampling sites	Total species	Mean	SD	Min	Max	Kruskal-Wallis H test	*p-value*
Athens	100	12	3.22	1.95	0	8	72.25	$p < 0.05$
Granada	99	17	5.39	2.47	0	12		
Ioannina	93	7	2.58	1.67	0	7		
Bird exploiter species								
City	Sampling sites	Total species	Mean	SD	Min	Max	Kruskal-Wallis H test	*p-value*
Athens	100	3	1.98	0.89	0	3	39.40	$p < 0.05$
Granada	99	3	2.42	0.62	1	3		
Ioannina	93	3	1.76	0.63	0	3		

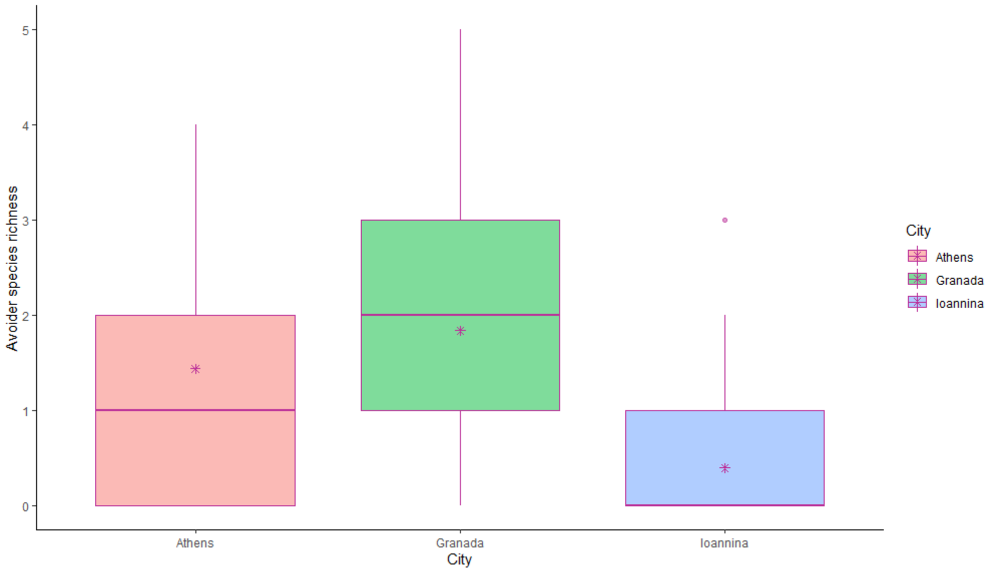

Figure 8. Comparison among the number of avoider species (ASR) classified in the three cities focused in this study. The box plots show medians, mean values (violet star), quartiles, 5- and 95-percentiles and extreme values.

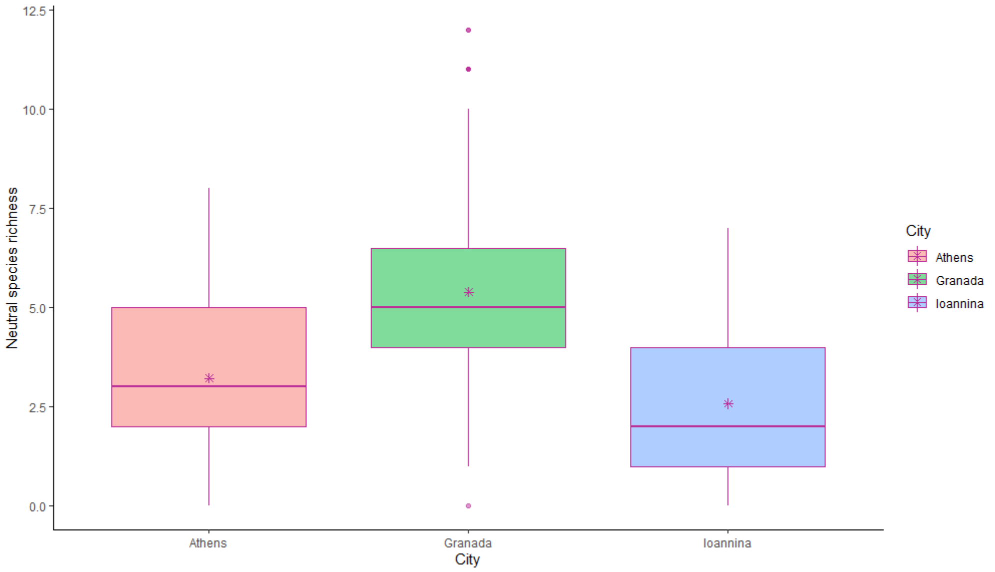

Figure 9. Comparison among the number of neutral species (NSR) classified in the three cities focused in this study. The box plots show medians, mean values (violet star), quartiles, 5- and 95-percentiles and extreme values.

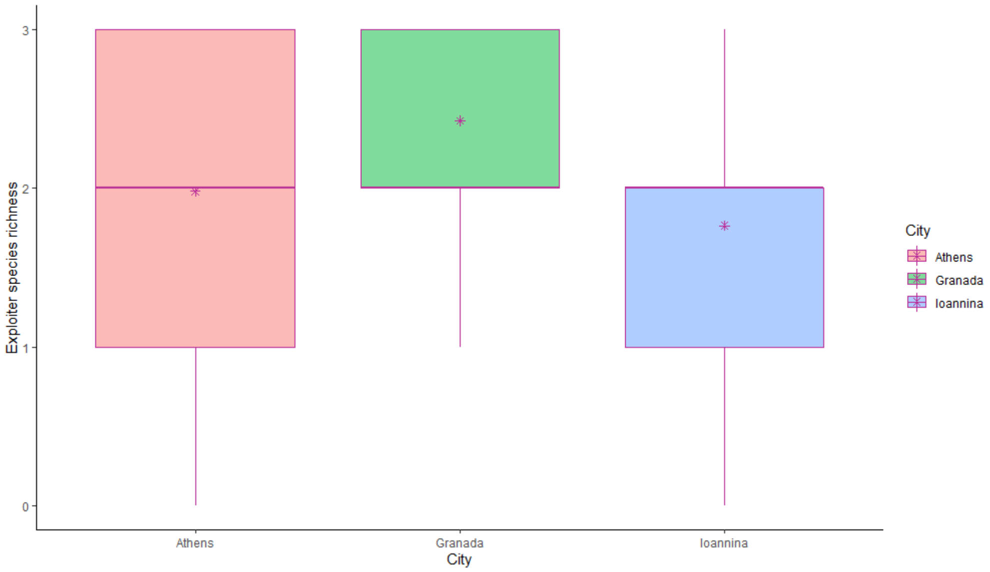

Figure 10. Comparison among the number of exploiter species (ESR) classified in the three cities focused in this study. The box plots show medians, mean values (violet star), quartiles, 5- and 95-percentiles and extreme values.

5.3 NDVI values assessed in Athens, Granada and Ioannina sampling sites

This study assessed NDVI values from a total of 292 sampling points in the cities of Athens, Granada and Ioannina. In average, the city of Ioannina showed higher values of NDVI (0.284) than Granada and Athens which showed values in average of 0.277 and 0.25 respectively (Table 4, Figure 11). The maximum values were registered in Ioannina (0.678) and Granada (0.678) while the minimum values were recorded in Athens (0.07) (Table 4, Figure 11). According to the Kruskal-Wallis H test, the NDVI values in the cities do not differ significantly ($p > 0.05$) (Table 4).

Table 4. Range of NDVI values and differences in the three cities focused in this study.

NVDI values							
City	Sampling sites	Mean	SD	Min	Max	Kruskal-Wallis H test	*p-value*
Athens	100	0.25	0.10	0.07	0.678	3.44	p > 0.05
Granada	99	0.277	0.12	0.10	0.56		
Ioannina	93	0.284	0.13	0.11	0.678		

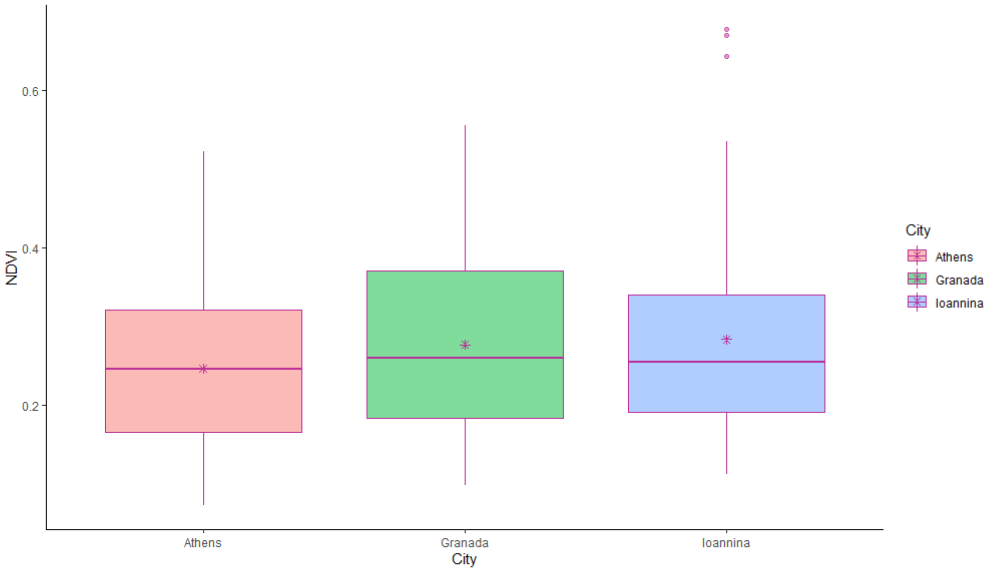

Figure 11. Comparison among the NDVI values assessed in the three cities focused in this study. The box plots show medians, mean values (violet star), quartiles, 5- and 95-percentiles and extreme values.

5.4 Association between NDVI values and urban avoider, neutral and exploiter bird species

In all cities, the NDVI values were associated differently with bird species richness and each urban tolerance class. NDVI values were positively related with the number of bird species and the number of urban avoiders in all cities. (Table 5, Figures 12 and 13). On the other hand, the number of urban neutral species was associated with NDVI values only in Ioannina (Table 5, Figure 14) and the number of urban exploiter species was not significantly associated with NDVI in any city (Table 5, Figure 15).

Table 5. Results of the generalized linear model (GLM) performed in this study, accounting for variations between number of urban avoider species (ASR), number of urban neutral species (NSR), number of urban exploiter species (ESR) as response variables in relation to NDVI values as predictor. Abbreviations: ES = estimate; SE = standard error, t/z = z-score. Significant results are in bold.

Predictor variable	**ES**	**SE**	**t/z**	***p-value***
		Response variable: ASR – Athens		
Intercept	0.008	0.227	0.035	> 0.05
NDVI	1.560	0.791	1.973	**< 0.05**
		Response variable: ASR – Granada		
Intercept	0.147	0.199	0.737	> 0.05
NDVI	1.541	0.621	2.480	**< 0.05**
		Response variable: ASR – Ioannina		
Intercept	-2.382	0.441	-5.404	< 0.05
NDVI	4.151	1.093	3.799	**< 0.05**
		Response variable: NSR – Athens		
Intercept	0.985	0.148	6.661	< 0.05
NDVI	0.955	0.528	1.810	> 0.05
		Response variable: NSR – Granada		
Intercept	1.496	0.113	13.218	< 0.05
NDVI	0.601	0.368	1.634	> 0.05
		Response variable: NSR – Ioannina		
Intercept	0.395	0.161	2.454	< 0.05
NDVI	1.735	0.467	3.713	**< 0.05**
		Response variable: ESR – Athens		
Intercept	0.745	0.186	3.996	< 0.05
NDVI	-0.146	0.692	-0.211	> 0.05
		Response variable: ESR – Granada		
Intercept	0.869	0.165	5.261	< 0.05
NDVI	0.037	0.551	0.068	> 0.05
		Response variable: ESR – Ioannina		
Intercept	0.622	0.196	3.172	< 0.05
NDVI	-0.272	0.645	-0.422	> 0.05

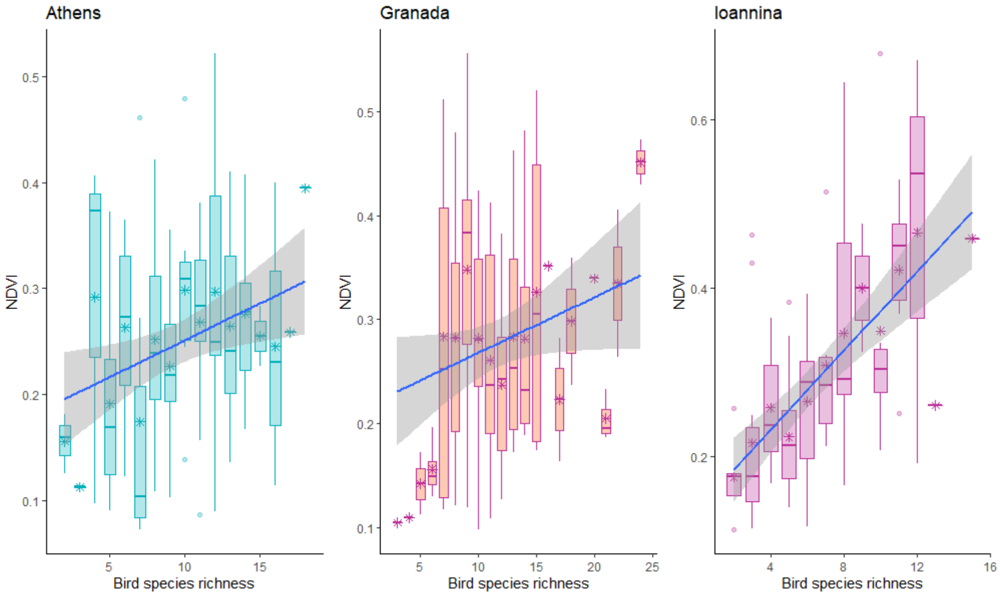

Figure 12. Comparison among the three cities focused in this study about the associations between the number of bird species (BSR) and NDVI values. The box plots show medians, mean values (violet star), quartiles, 5- and 95-percentiles and extreme values.

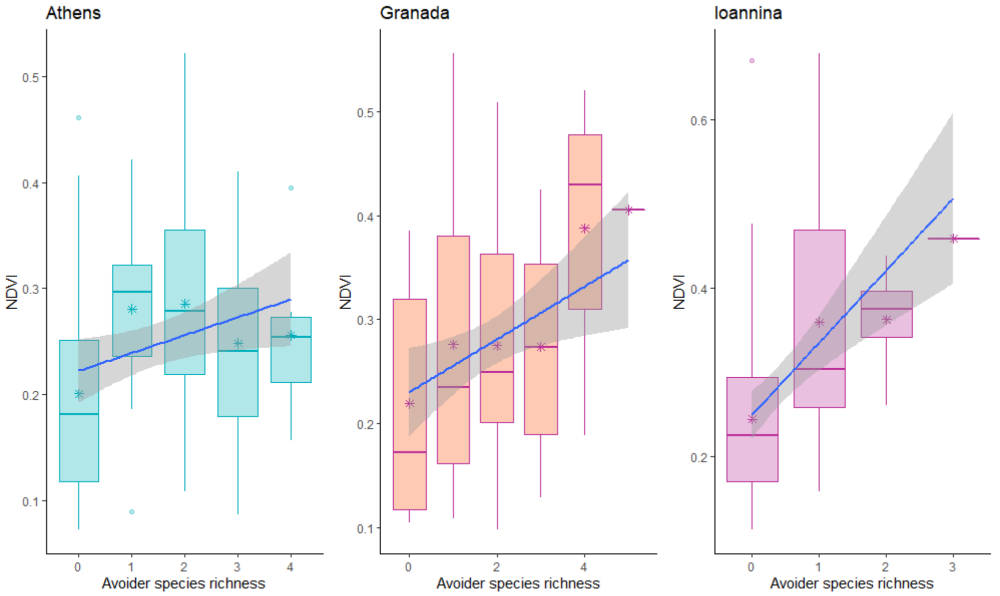

Figure 13. Comparison among the three cities focused in this study about the associations between the number of urban avoider species (ASR) and NDVI values. The box plots show medians, mean values (violet star), quartiles, 5- and 95-percentiles and extreme values.

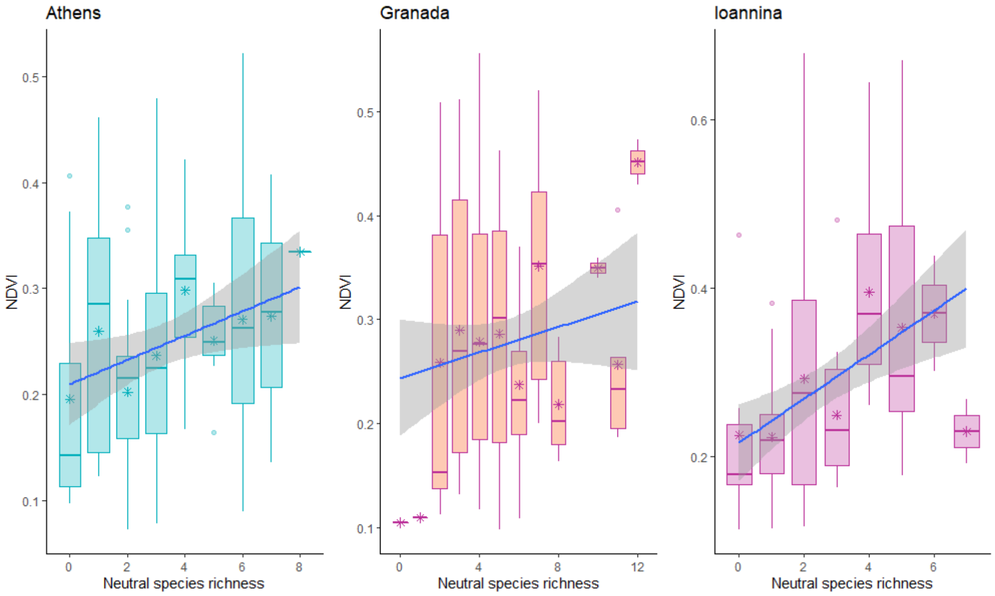

Figure 14. Comparison among the three cities focused in this study about the associations between the number of urban neutral species (NSR) and NDVI values. The box plots show medians, mean values (violet star), quartiles, 5- and 95-percentiles and extreme values.

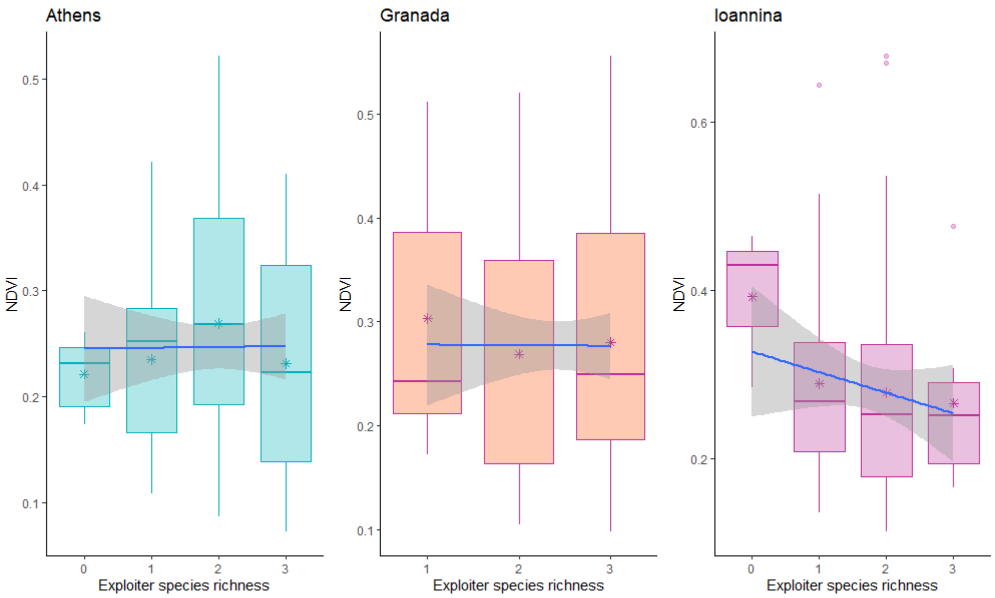

Figure 15. Comparison among the three cities focused in this study about the associations between the number of urban exploiter species (ESR) and NDVI values. The box plots show medians, mean values (violet star), quartiles, 5- and 95-percentiles and extreme values.

6. DISCUSSION

6.1 THE RELEVANCE TO HIGHLIGHT AVIAN DIVERSITY IN URBAN AREAS

The findings of this study are showing the relevance of an NDVI assessment as a tool to discover more detailed features of bird assemblages than taxonomic diversity through highlighting the spatial distribution of urban avoider species in urban areas. The study and deeper knowledge of avian diversity, and to determine the urban tolerance classification, can be the initial step to: a better understanding about the effects of urbanization on biodiversity (Sol et al., 2013), lead to adequately planning cities (Gordon et al., 2009; Sushinsky et al., 2013), preserve natural habitats, and ultimately strengthen the interaction between nature and people (Fischer et al., 2015; McKinney, 2006; Shwartz, Turbé, Simon, & Julliard, 2014).

6.2 TRENDS IN URBAN AVOIDER, NEUTRAL AND EXPLOITER SPECIES FOUND IN THIS STUDY

The cities focused in this study shared four urban avoider species, four urban neutral species and all three urban exploiter species (Appendix B, Table 7). The urban avoiders are bird species characterized to elude the highly urbanized areas (Fischer et al., 2015). They constitute the most valuable feature in bird assemblages which promotes lower biotic homogenization (van Rensburg, Peacock, & Robertson, 2009). For that reason, the presence of avoider species within urban cities is a paradox but it can insinuate positive assumptions regarding the city's composition and biodiversity. One of the common avoider species observed in this study is the European Goldfinch *(Carduelis carduelis)* (Figure 16), which Croci, Butet, & Clergeau (2008) interestingly identified as an indicator species of urban areas. According to "BirdLife International IUCN Red List for birds" (2019) this species inhabits a variety of woody environments, as well as orchards, parks and gardens. However this does not necessarily invalidate European Goldfinch

(Carduelis carduelis) as an avoider species; it leads to the conclusion that it may be an urban species which finds those natural areas in urbanized environments to dwell in, and that could be the case as to why all three cities shared this species. The other shared avoider species was Chaffinch *(Fringilla coelebs)* (Figure 17), and in Palomino & Carrascal (2006) study it was observed to be abundant in gardened urban areas. Like the European Goldfinch *(Carduelis carduelis)* this species also contains the same preferred habitats of woody environments, orchards, parks and gardens ("BirdLife International IUCN Red List for birds.," 2019), which is consistent with how large urban green spaces are able to sustain a significant abundance of bird species (Threlfall et al., 2016). Observing avoider species and their distribution within cities is a useful method for monitoring biodiversity and, to a larger extent, facilitate and improve the environmental planning of urban environments, adding to the significance and value of avoider species.

Figure 16. European Goldfinch *(Carduelis carduelis)* is an avoider species observed in Athens, Granada and Ioannina. According to Croci et al. (2008) this is an indicator species for urban areas. Photo by Aidanos via Flickr.com.

Figure 17. Chaffinch *(Fringilla coelebs)* is an avoider species observed in Athens, Granada and Ioannina. According to Palomino & Carrascal (2006) study this species was abundant in gardened areas. Photo by Bruno Casals via Flickr.com.

As expected in our study, all cities showed higher number of urban neutral species. Neutral species are a classification which need further research regarding how urbanization affects them (Sol et al., 2014), and many urban bird species are not effectively classified making this a critical limitation. However, the higher abundance of neutral species contributes to demonstrate the effect of urbanization, where species will need to adapt to modified environments and therefore cannot be species requiring all natural environments but a combination of both (Bonebrake, 2013; Sol et al., 2013). That can explain why all cities demonstrated a clear abundance for neutral species, because of their variability of preferred habitats. Of the shared neutral species was the Eurasian Magpie *(Pica pica)* (Figure 18) and the Eurasian Blackbird *(Turdus merula)* (Figure 19), which interestingly enough, Palomino & Carrascal (2006) identified as a species which avoid more urbanized environments in their study. However, the Eurasian Blackbird *(Turdus merula)* was also observed to have a noticable abundance within urban parks (Bino et al., 2008); furthermore in Luck & Smallbone, (2011) this species resulted to be able to inhabit a variety of environmental conditions, which coincides with its urban tolerance classification of neutral. Previous studies and their findings can validate the need for more evidence and descriptions regarding urban neutral species. With continuing research in urban tolerance classifications for urban birds it can be hypothesized for future studies that these neutral species be reclassified, and could become exploiter species who dominate heavily urban environments.

Figure 18. Eurasian Magpie *(Pica pica)* is classified as a neutral species that is known to avoid more urban environments and habitats (Palomino & Carrascal, 2006). Photo by Liu K (bazazga) via Flickr.com.

Figure 19. Eurasian Blackbird *(Turdus merula)* is classified as a neutral species, which has been observed within urban parks (Bino et al., 2008) but on the contrary is also a species that avoids urban environments (Palomino & Carrascal, 2006). Photo by Joan Rigo Arnavat via Flickr.com.

On the other hand, urban exploiters are most abundant in areas of high urbanization and human-altered habitats (Fischer et al., 2015), characterized alongside higher biotic homogenization, which occurs when species of small numbers (i.e. urban exploiters) dominate and overpower native species in highly urban areas (Kark et al., 2007). Furthermore, the few exploiter species observed in this study can also explain how not many bird species have the specialization and willingness to exploit heavily urbanized environments (Kark et al., 2007), thus keeping the tolerance classification of exploiter quite strict.

Of the shared exploiter species is the Common Swift *(Apus apus)* (Figure 20) and in a study completed by Fontana et al. (2011) this species dominated urbanized areas, where they are able to have abundant food resources and use buildings as a substitute for rocky habitats. The other is the House Sparrow *(Passer domesticus)* (Figure 21), which is known to be an aggressive competitor leading to biotic homogenization in many cities globally (McKinney, 2006). Although these exploiter species were present in the three cities, the observations for exploiter species was minimal (total of three species for all cities). The overall minimal observations of exploiter species in Athens, Granada and Ioannina supports the fact that exploiter species are somewhat rare (Kark et al., 2007). Perhaps this can lead to exploiter species also being valuable, but in opposition to the value of avoider species, where it will indicate the severity of urbanization instead of possible biodiversity (Kark et al., 2007). Knowing the bird community composition and its tolerance classifications can lead to the advantage of monitoring the ongoing effect of urbanization among not only the cities within this study, but for urban cities globally.

Figure 20. Common Swift *(Apus apus)* is an exploiter species known to be able to properly exploit the urban environment, with having an abundance in food and benefiting from buildings (Fontana et al., 2011). Photo by Anthony Minvalla (minvallaa) via Flickr.com.

Figure 21. House Sparrow (*Passer domesticus*) is an exploiter species known to dominate cities globally and enhance biotic homogenization (McKinney, 2006). Photo by Jlcummins via Flickr.com.

6.3 NDVI VALUES AS A PROXY FOR URBAN AVOIDERS

NDVI values were positively related with the number of bird species and the number of urban avoiders in all cities. The positive association of NDVI values and bird species richness was highlighted previously in different studies (Bae et al., 2018; Bonthoux et al., 2018; Leveau et al., 2018; Nieto et al., 2015; Pettorelli et al., 2011; Seto et al., 2004). Several studies have also demonstrated that higher NDVI values are related with higher primary productivity (Bae et al., 2018; Nieto et al., 2015; Seto et al., 2004), since higher NDVI values indicate the presence of vegetation and greenery (Pettorelli et al., 2011). Thus, the previous studies already verified not only the significance of NDVI values as a proxy, but that more vegetation and natural elements within urban areas calls for a greater abundance in bird species, simultaneously leading to greater biodiversity. However, no study so far has previously tested NDVI's relationship with more detailed aspects of bird assemblages beyond species richness in urban areas. In that sense, our results showing that higher number of urban avoider species in all cities were associated with higher NDVI values.

It has been discussed that urban avoiders reach their greatest abundance in areas located outside of the main urban centers. Tryjanowski et al. (2017) revealed how parks and cemeteries are adequate habitats for urban avoiders, making these areas a place of refuge within cities. Thus, the main characteristic within urban areas that are suitable for avoider species are native habitats with native plant species and overall native vegetation, to serve as natural resources for them (McKinney, 2002; Sol et al., 2013). This signifies that NDVI values for urban cities with these characteristics should be relatively high (Bino et al., 2008). This can explain how avoider species were the most abundant following neutral species, leading to how avoider species within the three cities could have been observed within patches of the upmost natural areas, like gardens, parks, or even cemeteries; further research within the urban characteristics and features of each city would be able to clarify that. This also explains that if an urban city contains high NDVI values, it should be linked positively to avoider species richness. Additionally, in urban areas where the presence and richness of urban avoider species is higher, biotic homogenization is known to be lower (McKinney, 2006). With that, it is reasonable to infer that urban cities with high NDVI values can highlight patches of natural vegetation dispersed throughout the city and may not only contain greater avoider species richness but overall bird species richness and greater biodiversity (Bino et al., 2008) which mitigates biotic homogenization. This all concludes that NDVI values are able to predict and possibly be an adequate proxy not only for bird species richness, but even to reveal the spatial distribution of avoider species richness in the cities and on the other hand, to discover potential areas at higher risk of biotic homogenization.

The number of urban neutral species was associated with NDVI values only in Ioannina. This is in accordance and can be explained with how the city of Ioannina also contained the highest NDVI values. Since neutral species do not have a specified or preferred habitat, like avoiders and exploiters, they are able to survive within a greater range of environments which includes cities and their surrounding areas (Sol et al., 2013). If they are able to dwell in urban areas as well as some vegetative areas, then the NDVI values can contain a greater variability; this makes NDVI values as a proxy somewhat meaningless and not necessary for neutral species richness. Since our study only depicted Ioannina with this association, perhaps the neutral species richness have simply adapted to or prefer more areas of vegetation since Ioannina contains high NDVI values. Our study continues to show how neutral species are observed by chance and need further research to adequately classify them (Sol et al., 2014), understand their preferences and ultimately be used to understand the complexity of biodiversity within urban areas.

The number of urban exploiter species was not significantly associated with NDVI values in any city. This was expected, as exploiter species do not depend on vegetation but on more urban habitats and altered environments. Because the abundance in exploiter species peaks at the urban centers (McKinney, 2006), and assuming that urban centers do not contain as much greenery due to high densities, NDVI values should be relatively low within these areas. Based on that, it can be hypothesized that there exists some association between the number of exploiter species and low NDVI values. However, our study was not able to prove any significant association among those two variables. This disassociation and ambiguity on behalf of exploiter species, and perhaps the overall urban tolerance classification, can be due to how species populations are complex and include many categories in order to explain the responses to urbanization (Fischer et al., 2015).

7. CONCLUSION

This study was able to determine the association of primary productivity – estimated as NDVI values – with the distribution of urban avoider species in urban areas. Thus, utilizing NDVI as a proxy to determine the spatial distribution of urban avoider species in urban areas is useful to identify avian diversity hotspots characterized by lower biotic homogenization. This potential application is relevant in biodiversity conservation in urban areas considering that bird taxa is a useful ecological indicator to determine biodiversity status. Additionally the NDVI assessments can be useful for monitoring the impact of urbanization on biodiversity and to evaluate urban planning strategies more comprehensively and swiftly, while at large spatial scales compared to that of traditional methods.

The association of the distribution of avoider, neutral and exploiter bird species with NDVI will strengthen the argument that green spaces and urban greenery is critical for biodiversity conservation. Therefore, this study is very relevant to the continuing research on the environmental variables associated with the habitat selection of urban avoider species in urban areas.

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9. APPENDIX

APPENDIX A

Table 6. A list of the total identified bird species from the three cities focused in this study, which totaled to 59 species.

Identified bird species			
Order	**Family**	**Species name**	**Common name**
Passeriformes	Acrocephalidae	*Acrocephalus arundinaceus*	Great Reed-Warbler
Passeriformes	Acrocephalidae	*Acrocephalus schoenobaenus*	Sedge Warbler
Passeriformes	Aegithalidae	*Aegithalos caudatus*	Long-tailed Tit
Apodiformes	Apodidae	*Apus apus*	Common Swift
Strigiformes	Strigidae	*Athene noctua*	Little Owl
Accipitriformes	Accipitridae	*Buteo buteo*	Common Buzzard
Passeriformes	Alaudidae	*Calandrella brachydactyla*	Greater Short-toed Lark
Passeriformes	Fringillidae	*Carduelis carduelis*	European Goldfinch
Passeriformes	Hirundinidae	*Cecropis daurica*	Red-rumped Swallow
Passeriformes	Certhiidae	*Certhia brachydactyla*	Short-toed Tree-Creeper
Passeriformes	Scotocercidae	*Cettia cetti*	Cetti's Warbler
Passeriformes	Fringillidae	*Chloris chloris*	European Greenfinch
Pelecaniformes	Ciconiidae	*Ciconia ciconia*	White Stork
Columbiformes	Columbidae	*Columba livia*	Rock Pigeon
Columbiformes	Columbidae	*Columba palumbus*	Common Wood-Pigeon
Passeriformes	Corvidae	*Corvus corone*	Carrion Crow
Passeriformes	Corvidae	*Corvus monedula*	Eurasian Jackdaw
Passeriformes	Paridae	*Cyanistes caeruleus*	Blue Tit
Passeriformes	Hirundinidae	*Delichon urbicum*	Northern House-Martin
Piciformes	Picidae	*Dendrocopos syriacus*	Syrian Woodpecker
Passeriformes	Emberizidae	*Emberiza cirlus*	Cirl Bunting
Passeriformes	Emberizidae	*Emberiza melanocephala*	Black-headed Bunting
Passeriformes	Muscicapidae	*Erithacus rubecula*	European Robin
Falconiformes	Falconidae	*Falco peregrinus*	Peregrine Falcon
Falconiformes	Falconidae	*Falco tinnunculus*	Common Kestrel
Passeriformes	Fringillidae	*Fringilla coelebs*	Eurasian Chaffinch
Passeriformes	Alaudidae	*Galerida cristata*	Crested Lark
Passeriformes	Corvidae	*Garrulus glandarius*	Eurasian Jay
Passeriformes	Acrocephalidae	*Hippolais polyglotta*	Melodious Warbler
Passeriformes	Hirundinidae	*Hirundo rustica*	Barn Swallow
Passeriformes	Acrocephalidae	*Iduna pallida*	Eastern Olivaceous Warbler
Passeriformes	Laniidae	*Lanius senator*	Woodchat Shrike
Passeriformes	Fringillidae	*Linaria cannabina*	Eurasian Linnet
Passeriformes	Muscicapidae	*Luscinia megarhynchos*	Common Nightingale
Passeriformes	Emberizidae	*Miliaria calandra*	Corn Bunting

Passeriformes	Motacillidae	*Motacilla alba*	White Wagtail
Passeriformes	Motacillidae	*Motacilla cinerea*	Grey Wagtail
Passeriformes	Muscicapidae	*Muscicapa striata*	Spotted Flycatcher
Passeriformes	Oriolidae	*Oriolus oriolus*	Eurasian Golden Oriole
Strigiformes	Strigidae	*Otus scops*	Common Scops-Owl
Passeriformes	Paridae	*Parus major*	Great Tit
Passeriformes	Passeridae	*Passer domesticus*	House Sparrow
Passeriformes	Passeridae	*Passer montanus*	Eurasian Tree Sparrow
Passeriformes	Paridae	*Periparus ater*	Coal Tit
Passeriformes	Muscicapidae	*Phoenicurus ochruros*	Black Redstart
Passeriformes	Corvidae	*Pica pica*	Eurasian Magpie
Passeriformes	Paridae	*Poecile montanus*	Willow Tit
Passeriformes	Muscicapidae	*Saxicola rubetra*	Whinchat
Passeriformes	Fringillidae	*Serinus serinus*	European Serin
Columbiformes	Columbidae	*Streptopelia decaocto*	Eurasian Collared-Dove
Columbiformes	Columbidae	*Streptopelia turtur*	European Turtle-Dove
Passeriformes	Sturnidae	*Sturnus unicolor*	Spotless Starling
Passeriformes	Sturnidae	*Sturnus vulgaris*	Common Starling
Passeriformes	Sylviidae	*Sylvia atricapilla*	Blackcap
Passeriformes	Sylviidae	*Sylvia communis*	Common Whitethroat
Passeriformes	Sylviidae	*Sylvia melanocephala*	Sardinian Warbler
Apodiformes	Apodidae	*Tachymarptis melba*	Alpine Swift
Passeriformes	Turdidae	*Turdus merula*	Eurasian Blackbird
Bucerotiformes	Upupidae	*Upupa epops*	Eurasian Hoopoe

APPENDIX B

Table 7. Urban tolerance classification of bird species recorded in each city. From the 59 total breeding species observed in all the three cities, only 45 were able to be classified as an urban avoider, an urban neutral or an urban exploiter. That resulted in a total of 16 avoider species, 26 neutral species and 3 exploiter species. Bird species marked with a (*) are present in all three cities.

Avoider species			
Common name *(species name)*	**Athens**	**Granada**	**Ioannina**
1. Long-tailed Tit *(Aegithalos caudatus)*		X	
2. Little Owl *(Athene noctua)*	X	X	
3. European Goldfinch *(Carduelis carduelis)* *	X	X	X
4. Common Woodpigeon *(Columba palumbus)*		X	
5. Cirl Bunting *(Emberiza cirlus)*	X		
6. European Robin *(Erithacus rubecula)* *	X	X	X
7. Chaffinch *(Fringilla coelebs)* *	X	X	X
8. Crested Lark *(Galerida cristata)*	X	X	
9. Eurasian Jay *(Garrulus glandarius)*	X		X
10. Melodious Warbler *(Hippolais polyglotta)*		X	
11. Woodchat Shrike *(Lanius senator)*	X		
12. Common Nightingale *(Luscinia megarhynchos)*	X		X
13. Eurasian Golden-Oriole *(Oriolus oriolus)*			X
14. Eurasian Great Tit *(Parus major)* *	X	X	X
15. Whinchat *(Saxicola rubetra)*	X		
16. Sardinian Warbler *(Sylvia melanocephala)*	X	X	
Neutral species			
Common name *(species name)*	**Athens**	**Granada**	**Ioannina**
1. Common Buzzard *(Buteo buteo)*	X		
2. Short-toed Tree-Creeper *(Certhia brachydactyla)*		X	
3. Ceti's Warbler *(Cettia cetti)*		X	X
4. European Greenfinch *(Chloris chloris)* *	X	X	X
5. White Stork *(Ciconia ciconia)*			X
6. Carrion Crow *(Corvus corone)*	X		X
7. Eurasian Jackdaw *(Corvus monedula)*		X	X
8. Peregrine Falcon *(Falco peregrinus)*	X		
9. Common Kestrel *(Falco tinnunculus)*	X	X	
10. Barn Swallow *(Hirundo rustica)* *	X	X	X
11. White Wagtail *(Motacilla alba)*		X	
12. Grey Wagtail *(Motacilla cinerea)*			X
13. Spotted Flycatcher *(Muscicapa striata)*	X	X	
14. Eurasian Scops-Owl *(Otus scops)*	X		X
15. Eurasian Tree Sparrow *(Passer montanus)*			X
16. Coal Tit *(Periparus ater)*			
17. Black Redstart *(Phoenicurus ochruros)*		X	
18. Eurasian Magpie *(Pica pica)* *	X	X	X
19. European Serin *(Serinus serinus)*	X	X	
20. European Turtle-Dove *(Streptopelia turtur)*		X	

21. Spotless Starling *(Sturnus unicolor)*		X	
22. Common Starling *(Sturnus vulgaris)*			X
23. Blackcap *(Sylvia atricapilla)*		X	X
24. Common Whitethroat *(Sylvia communis)*			X
25. Eurasian Blackbird *(Turdus merula)* *	X	X	X
26. Eurasian Hoopoe *(Upupa epops)*	X	X	
Exploiter species			
Common name *(species name)*	**Athens**	**Granada**	**Ioannina**
1. Common Swift *(Apus apus)* *	X	X	X
2. House Sparrow *(Passer domesticus)* *	X	X	X
3. Eurasian Collared-Dove *(Streptopelia decaocto)* *	X	X	X