Species richness in urban green spaces – Relevant aspects for nature conservation

Von der Fakultät für Architektur und Landschaft
der Gottfried Wilhelm Leibniz Universität Hannover
zur Erlangung des akademischen Grades

Doktorin der Naturwissenschaften (Dr. rer. nat.)

genehmigte Dissertation von
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geboren am 20.12.1981 in Norden

2018

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Tag der Promotion: 15.3.2018

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Abstract

Keywords: biodiversity, green infrastructure, urban ecology

Maintaining species richness became a main subject of nature conservation due to a decline in biodiversity on different scales. In cities high species richness can be found in urban green spaces. As German cities experience population increase in some places and population decrease in other places, green spaces are under threat or, respectively, could be developed. Both phenomena give rise to the need and the opportunity for nature conservation actions. Therefore, the study of the driving factors which lead to high species richness in urban green spaces becomes ever more important.

Species richness in urban green spaces is influenced by various driving factors. Factors known to be decisive for promoting species richness include patch size, patch shape, distance to the urban edge and to other urban green spaces, as well as habitat heterogeneity within urban green spaces and in the surrounding area. These factors are derived from species-area effect, distance effects, and effects due to habitat structure. As there are numerous variables which have an impact on species richness in urban green spaces, a current challenge is how to reduce the influencing variables to the smallest relevant set. This set could be adapted for different taxonomic groups, as species richness reacts differently to driving factors in urban green spaces. Reference to the value of certain species for nature conservation, subgrouping within taxonomic groups regarding species' first occurrence, conservation status or specific traits may all be useful.

A lack of research still exists regarding a combination of several response variables and a combination of influencing and response variables. Research gaps include an investigation of different taxonomic groups with different mobility abilities, of endangered species richness, of proportions of different species groups compared to numbers, and of an 'overall species richness' containing different taxonomic groups. In addition, not only single factors drive the occurrence of certain species in urban green spaces, but these are also driven by a combination of multiple, interacting factors. Therefore, multivariate analyses are very useful in the identification of driving factors of species richness in urban green spaces. As it is not necessarily the same factors which drive the species richness in urban green spaces located in cities in different climatic regions, the transferability of results and subsequent identification of robust driving factors is an additional aspect relevant for nature conservation.

There are various methods available which can be used to define species richness and to verify the capability of driving factors of high species richness. However, each of these survey methods is characterized by specific advantages and disadvantages and the effectiveness and efficiency of the different approaches also differ. Therefore, they each need to be explored for their suitability especially in urban green spaces, as these are usually very diverse habitats.

To address in part these research gaps, the aim of my thesis is to name relevant aspects for nature conservation related to high species richness in urban green spaces. The first objective is to detect driving factors of species richness in urban green spaces within and across taxonomic groups. Another objective is to test the transferability of driving factors to cities located in different climatic regions. Finally, a review of the suitability of different field assessments in urban green spaces to survey species richness is performed and the methods evaluated.

The thesis addresses the question, of which single and combined factors deriving from species-area effect, distance effects, and effects of habitat structure primarily drive species richness within and across taxonomic groups. After combining the species richness of all the studied taxonomic groups, I then test which combined factors drive overall species richness. The research presented in the thesis is based on an identification of vascular plant, bird and mammal species richness in 32 urban green spaces in Hannover, Germany. The investigated species groups were categorized to be total, native, non-native, endangered, ornamental, and nitrophilous species for vascular plants, as well as total, native and endangered species for birds and mammals. In the study influencing factor patch size was determined from species-area relations. The factors distance to the urban edge, distance to the nearest green space, as well as density, percentage, connectivity, and diversity of the green spaces in a 500 m buffer were checked describing distance effects. The patch shape, number of habitat types, and diversity of habitat types within green spaces described effects of habitat structure and tested to be driving factors as well. Additionally I examine, if the same factors drive species richness of vascular plants in urban green spaces of cities located in different climatic regions. For this, a colleague conducted vascular plant surveys in Haifa, Israel, a city located in a Mediterranean climate. The study results were compared to test transferability of results gained in Hanover to other climatic regions and to identify robust driving factors. Finally, I answer the question, of whether a nested plot method with the possibility to extrapolate species richness is an effective and efficient way compared to a complete field survey that surveys vascular plant species in forested urban green spaces. For this study, results from Modified Whittaker Plots were compared to complete field surveys.

In single factor analysis, I detected that the bigger the patch size, the higher is the species richness of vascular plants, birds, and mammals, as well as the proportion of endangered vascular plant species. Additionally, the number of ornamental and proportions of ornamental and non-native vascular plant species were found to higher when urban green spaces were more compact. In urban green spaces with numerous habitat types, high species numbers of all tested taxonomic groups were found. Similarly, the diversity of habitat types positively influenced the numbers of vascular plants and birds, but not mammals. Regarding distance effects, the distance to the nearest green space positively affected all tested species groups. A higher distance to the urban edge only decreased the number of ornamental vascular plant species, whereas a high connectivity of green spaces increased the number of native vascular plants and total mammals.

The analysis of multiple influencing variables revealed, that patch area, distance to the urban edge, patch shape, and habitat heterogeneity within an urban green space, measured by the number and the diversity of habitat types, best explained the total number of vascular plants. The number of native and endangered vascular plants, as well as total and native birds was best explained by the same selection of variables, however distance to the urban edge and patch shape were not significant. Patch area, distance to the urban edge as well as compactness defined the number of non-native and ornamental, as well as proportions of native, non-native, and ornamental vascular plant species. The results also revealed that the bigger the patch area and the smaller the distance to the urban edge, the higher was the number of nitrophilous vascular plant species. An increasing patch area was the only factor driving the number of endangered birds, total and native mammals, and also driving the proportion of endangered vascular plant species. None of the tested influencing variables affected the proportion of nitrophilous vascular plant species significantly. The overall species richness was best explained by patch area in combination with habitat heterogeneity.

In the different climatic regions of Hannover, Germany and Haifa, Israel we found that in both of these areas the total and native vascular plant species numbers increased with increasing patch size. However, no significant influence of the patch size on the proportion of natives was detected either for Hannover or for Haifa. Regarding the influence of distance to the urban edge we did not find any significant results for the total or native species number, or the proportion of native species for these two cities located in different climatic regions.

Finally, I compared the results derived from the Modified Whittaker Plot method to those from a complete field survey in different urban forest habitats in Hannover. The Modified Whittaker Plot method showed some limitations in the estimation of total and endangered species richness of vascular plants and as a result in the habitat evaluation, especially in large habitats. At the same time it was more time efficient to use the plot method instead of the complete field survey in larger habitats. Therefore one advantage is that the Modified Whittaker Plot method can be the source of basic information that can be used for further survey efforts.

My work shows that there are diverse relevant aspects for nature conservation that need to be considered regarding species richness in urban green spaces. The driving factors behind species richness of different taxonomic groups are - to some extent - the same. This observation is independent of whether the investigation is based on the analysis of single or multiple variables. Patch size and habitat heterogeneity are both driving factors that have an overriding importance for different species groups as well as for the aggregated measure of overall species richness. A relevance of distance effects was only confirmed for the distance to the next urban green space in the single variable analysis of my work. In the multivariable approach the relevance of this variable was probably too weak to be significant after accounting for the effect of patch size and habitat heterogeneity. The importance of patch size was also underlined in the analysis in the different climatic region of Haifa. The assignment of species numbers and a habitat evaluation based on the Modified Whittaker Plot method revealed important information on the potential value of an urban green space. It does not replace complete field surveys, as it cannot detect specific species that can be assigned to be for instance native or endangered.

From my results I draw the following implications for sustainable urban development for the tested taxonomic groups: green spaces should not vanish or be reduced in size; green spaces should be maintained, developed, and planned to include heterogeneous habitats; driving factors of overriding importance can be transferred to cities located in different climatic regions; an effective species monitoring and evaluating system is needed for urban green spaces, whereas the Modified Whittaker Plot method can be used for providing basic information; and finally urban development should place special importance on site specific traits.

The results from my studies contribute to closing some of the existing research gaps on relevant aspects of nature conservation. The research demonstrates that sustainable conservation as well as development of species rich urban green spaces is possible. Nevertheless, there is still a clear need for further investigations of effects on and mechanisms behind high species richness. Further studies could include additional response variables and influencing variables, a greater number of studies in similar climatic regions, further research on statistical analysis, and an assignment of a habitat value to urban green spaces. As species loss lasts differently over time in different environments, the maintenance and development of species richness in urban areas with sustainable conservations actions and the implementation of state of the art research in urban planning are both vitally important for promoting a sustainable future.

Zusammenfassung

Schlagworte: Biodiversität, Grüne Infrastruktur, Urbane Ökologie

Urbane Grünflächen wie Parks, Friedhöfe oder Kleingärten stellen wichtige Lebensräume für zahlreiche Tier- und Pflanzenarten dar. Der Erhalt und die Förderung der Artenvielfalt dieser Flächen rücken daher zunehmend in das Interesse des Naturschutzes. Neben einer generellen Erhöhung der Artenzahlen konzentrieren sich Managementansätze des Naturschutzes besonders auf naturschutzfachlich wertvolle Arten (z. B. gefährdete Arten). Das Vorkommen und die Ausbreitung von nicht einheimischen Arten in diesen Lebensräumen sollen hingegen verhindert werden, um damit verbundene Probleme zu vermeiden (insb. invasive Arten).

Große Kenntnisdefizite bestehen derzeit noch dahingehend, welche Faktoren ausschlaggebend für die Artenvielfalt städtischer Grünflächen sind. Vorliegende Studien deuten darauf hin, dass vielfältige Faktoren wirksam sind, die u.a. in der Arten-Areal-Beziehung, Distanzeffekten und der Habitatstruktur der Flächen begründet sind. Eine besondere Herausforderung besteht darin, diejenigen Faktoren zu identifizieren, die neben der Artenanzahl unterschiedlicher und für die Grünflächen charakteristischer Artengruppen (z. B. Vögel, Pflanzen) auch die Vielfalt der naturschutzfachlich besonders bedeutsamen Arten innerhalb dieser taxonomischen Gruppen erklären (z. B. gefährdete Arten, einheimische / nicht einheimische Arten). Entsprechende Kenntnisse wären bedeutsam für die Naturschutzpraxis und könnten sowohl bei der Planung neuer Grünflächen, als auch für das Management existierender Flächen genutzt werden.

Das übergeordnete Ziel dieser Arbeit war es, die wesentlichen Einflussfaktoren für die Artenvielfalt urbaner Grünflächen zu ermitteln. Als erstes Teilziel sollten sowohl die maßgeblichen Einflussfaktoren für die Artenzahlen ausgewählter Artengruppen, als auch die Einflussfaktoren für die darin enthaltenen, naturschutzfachlich besonders relevanten Arten identifiziert werden. Ein weiteres Teilziel war die Prüfung der Übertragbarkeit dieser Einflussfaktoren auf Städte unterschiedlicher klimatischer Regionen. Schließlich sollten geeignete Freilandmethoden zur Erfassung von Artenzahlen auf urbanen Grünflächen als Grundlage für naturschutzfachliche Bewertungen untersucht und evaluiert werden.

Die Untersuchung erfolgte am Beispiel von Gefäßpflanzen, Vögeln und Säugetieren in 32 urbanen Grünflächen in Hannover, Deutschland. Es wurde der Frage nachgegangen, welche Faktoren die Gesamtartenzahlen dieser drei Artengruppen auf den Flächen bestimmen. Hierbei wurde auch untersucht, welche Faktoren die einheimischen und gefährdeten Arten erklären. Bei

den Gefäßpflanzen wurden darüber hinaus die Einflussfaktoren für die Anzahl der vorhandenen nicht einheimischen, Zier- und stickstoffliebenden Arten untersucht. Abgeleitet aus der Arten-Areal-Beziehung wurde die Flächengröße als ein Einflussfaktor überprüft. Die Distanz der Grünflächen zum Stadtrand, die Distanz zur nächsten Freifläche, sowie die Dichte, der Anteil, die Konnektivität und die Diversität an Freiflächen in einem 500 m Puffer wurden genutzt, um Distanzeffekte zu beschreiben. Die Flächenform, die Anzahl an Habitattypen und die Diversität an Habitattypen innerhalb der Grünflächen beschrieben die Effekte der Habitatstruktur.

Die einfaktorielle Analyse zeigte, dass je größer eine Grünfläche war, desto höher waren die Artenzahlen von Gefäßpflanzen, Vögeln und Säugetieren, als auch der Anteil an gefährdeten Gefäßpflanzen. Zusätzlich wurden höhere Anzahlen und Anteile an Zierpflanzen und nicht einheimischen Gefäßpflanzen in kompakteren Flächen gefunden. In Grünflächen mit einer Vielzahl an Habitattypen wurden höhere Artenzahlen aller getesteten taxonomischen Gruppen belegt. Vergleichbar beeinflusste auch die Diversität an Habitattypen die Artenzahl von Gefäßpflanzen und Vögeln positiv, nicht aber die der Säugetiere. Bezogen auf Distanzeffekte, wurde ein positiver Effekt der Distanz zur nächsten Freifläche auf alle getesteten Artengruppen nachgewiesen. Eine große Distanz zum Stadtrand verringerte die Anzahl an Zierpflanzen, während eine hohe Konnektivität zwischen den Flächen die Anzahl an einheimischen Gefäßpflanzen und die Gesamtartenzahl der Säugetiere erhöhte.

Die mehrfaktoriellen Analysen zeigten, dass die Flächengröße, die Distanz zum Stadtrand, die Flächenform und die Habitatheterogenität, gemessen durch die Anzahl und die Diversität der Habitattypen, am besten die Gesamtartenzahl der Gefäßpflanzen erklärte. Die Anzahl an einheimischen und gefährdeten Gefäßpflanzen, als auch die Gesamtartenzahl und die Anzahl an einheimischen Arten der Vögel wurde am besten durch die gleiche Auswahl an Einflussfaktoren erklärt, wobei die Distanz zum Stadtrand und die Flächenform keinen signifikanten Einfluss zeigten. Die Flächengröße, die Distanz zum Stadtrand als auch die Flächenform beeinflussten die Anzahl an nicht einheimischen Gefäßpflanzen und Zierpflanzen, als auch den Anteil einheimischer Pflanzenarten und Zierpflanzen. Je größer die Freifläche und je geringer die Distanz zum Stadtrand, desto höher war die Anzahl an nitrophilen Gefäßpflanzen. Eine zunehmende Flächengröße war der einzige Einflussfaktor, der die Anzahl an gefährdeten Vogelarten, die Gesamtartenzahl und die Anzahl an einheimischen Arten der Säugetiere, als auch den Anteil der gefährdeten Gefäßpflanzen beeinflusste. Keine der getesteten Einflussfaktoren hatte einen signifikanten Effekt auf den Anteil an nitrophilen Gefäßpflanzen. Die übergeordnete

Artenvielfalt, d.h. die Gesamtartenzahl der Vögel, Gefäßpflanzen und Säugetiere zusammen, wurde am besten durch die Flächengröße in Kombination mit der Habitatheterogenität erklärt.

Um mögliche Unterschiede in verschiedenen Klimaregionen zu ermitteln wurden die Einflussfaktoren auf die Artenzahlen der Gefäßpflanzen in Hannover mit Daten aus Haifa in Israel verglichen. Für die unterschiedlichen klimatischen Regionen wurde festgestellt, dass sich die Gesamtartenzahl und die Artenzahl von einheimischen Gefäßpflanzen mit zunehmender Flächengröße erhöhen. Dennoch wurde keine signifikante Beeinflussung der Anteile von einheimischen Gefäßpflanzen durch die Flächengröße in Hannover oder Haifa nachgewiesen. Für den Einfluss der Distanz zum Stadtrand konnte ebenfalls kein Einfluss auf die Gesamtartenzahl oder die Anzahl oder den Anteil von einheimischen Arten für die beiden Städte nachgewiesen werden.

Abschließend wurde die Frage beantwortet, ob mehrere Erfassungsplots mit der Möglichkeit einer Hochrechnung von Artenzahlen eine effektive und effiziente Möglichkeit zur Bestimmung der Artenzahlen in bewaldeten Freiflächen ist. Hier wurden die Ergebnisse der Modified Whittaker Plot Methode mit den Ergebnissen einer Vollerhebung verglichen. Die Modified Whittaker Plot Methode zeigte Schwächen bei der Hochrechnung der Gesamtartenzahl und der Anzahl gefährdeter Arten der Gefäßpflanzen. Entsprechend wiesen auch die Einschätzung des Habitatwertes Schwächen, besonders für große Habitate auf. Allerding war diese Methode vor allem für die großen Habitate im Hinblick auf den zeitlichen Aufwand der Erfassung effizienter. Aus diesem Grund kann die Modified Whittaker Plot Methode grundlegende Informationen geben, welche für weitere Erhebungen genutzt werden können.

Insgesamt zeigt meine Arbeit, dass es verschiedene relevante Aspekte für den Naturschutz gibt, die beachtet werden müssen, wenn das Ziel einer hohen Artenvielfalt in urbanen Grünflächen verfolgt wird. Die maßgeblichen Einflussfaktoren für die Artenzahlen der untersuchten taxonomischen Gruppen sind zu einem gewissen Grad vergleichbar. Die Flächengröße und die Habitatheterogenität sind maßgebliche Einflussfaktoren für die Gefäßpflanzen und Vögel, aber auch für die übergeordnete Artenvielfalt aus allen hier betrachteten taxonomischen Gruppen. Beide Faktoren wurden bereits in vielen anderen vergleichbaren Studien als wichtig identifiziert. Trotzdem wird in anderen Studien oft die direkte Umgebung als ein weiterer, wichtiger Einflussfaktor benannt. In der vorliegenden Arbeit wurde nur ein relevanter Einfluss der Distanz zur nächsten Freifläche in der einfaktoriellen Analyse bestätigt. In der multivariaten Analyse war der Einfluss dieses Faktors vermutlich zu schwach, um ihn noch nach dem Einfluss von Flächengröße und Habitatheterogenität zu bestätigen. Die Relevanz der Flächengröße für die

Artenzahlen wurde in der Untersuchung der unterschiedlichen klimatischen Region von Haifa unterstrichen. Die Errechnung von Artenzahlen und die Zuweisung eines Habitatwertes auf Grundlage der Modified Whittaker Plot Methode zeigte wichtige Informationen über den potenziellen Wert von urbanen Grünflächen. Allerdings ersetzt die Methode keine Vollerhebungen, da sie keine einzelnen Arten identifiziert, die einem Gefährdungs- oder Einwanderungsstatus zugeordnet werden können. Trotzdem kann die Modified Whittaker Plot Methode genutzt werden, um grundlegende Informationen über den Wert von urbanen Freiflächen zu erheben.

Aus den Ergebnissen werden folgende Empfehlungen für eine nachhaltige urbane Entwicklung für die getesteten taxonomischen Gruppen abgeleitet: Grünflächen sollen nicht verkleinert werden oder verschwinden, die Flächen sollen mit heterogenen Habitaten erhalten, entwickelt und geplant werden, besonders maßgebliche Einflussfaktoren können auf Städte in anderen klimatischen Regionen übertragen werden, ein effektives Arten-Monitoring und Bewertungssystem wird für urbane Freiflächen benötigt, wohingegen die Modified Whittaker Plot Methode nur grundlegende Informationen liefern kann, und eine urbane Entwicklung soll spezielles Augenmerk auf die Flächencharakteristika legen.

Es konnten einige der existierenden Forschungslücken bezogen auf die Artenvielfalt urbaner Grünflächen geschlossen werden. Trotzdem sind weiterführende Untersuchungen wichtig. Diese könnten zusätzliche beeinflusste Artengruppen und Einflussfaktoren, eine höher Anzahl an Studien in gleichen klimatischen Regionen, den Test weiterer statistischer Analysen oder eine Bestimmung des Wertes von Habitaten beinhalten. Da der Verlust an Arten in verschiedenen Lebensräumen anhält, sind der Erhalt der Artenvielfalt und die Umsetzung des aktuellen Forschungstandes in der Stadtplanung von größter Wichtigkeit.

1 Introduction

1.1 Background

Due to an observed decline in biodiversity, maintaining species richness has become a main concern of nature conservation on global (CBD 1992), national (BNatSchG 2010) and regional levels (NAGBNatSchG 2010). Cities can hold high species richness, although large man-made impacts also may have a great effect (cf. Hope et al. 2003). Even in cities there are areas with less severe negative human impacts that offer greater more near-nature characters (Sukopp et al. 1995). These areas are found in particular in urban green spaces. Urban green spaces provide habitats for numerous animal and plant species (Cornelis & Hermy 2004; Angold et al. 2006; Knapp et al. 2008; Kühn et al. 2004; Meffert & Dziock 2012; Melles et al. 2003) and therefore, contain high species richness. Urban green spaces within a city such as parks, forests, allotments, cemeteries, and wastelands all are a part of urban green infrastructure (EC 2013). Urban green infrastructure provides numerous ecosystem services, for instance climate regulation and recreation that are crucial to human well-being in the present and in the future (MEA 2005; Derkzen et al. 2015; Feyisa et al. 2014). As negative human impacts increase in other habitats, e.g. agricultural landscapes, severe species losses have been documented (Stoate et al. 2001; Benton et al. 2002). Some research studies have already shown that species richness in urban environments is greater than in cultivated landscapes (Wania et al. 2006; Kühn et al. 2004; Meffert & Dziock 2012). Nevertheless, cities, for instance German ones, experience many current challenges including population increase, which leads to more dense cities with green spaces under thread (e.g. Schinkel 2011) or population decrease, which may offer greater opportunities to develop urban green spaces (e.g. Schetke & Haase 2008, but also cf. Haase & Rink 2015). Therefore, the maintenance of species richness in urban green spaces has gained in importance and become a prominent and widespread public issue (e.g. Angold et al. 2006; Husté et al. 2006; La Sorte et al. 2014; Nielsen et al. 2014).

Species richness in urban green spaces is influenced by various driving factors. Variability in the physical environment (e.g. temperature, humidity, soil type, nutrition, salinity, oxygen concentration) affects plants and thus the animals living in and upon them (cf. Kuttler 1993; Kunick 1974; Blume 1993; Schuhmacher 1993; Guntenspergen & Levenson 1997). Habitat disturbance and human use affects biodiversity in such a way that the highest diversity is found in habitats with average disturbance (cf. Townsend et al. 2009; Guntenspergen & Levenson 1997; Mörtberg 2001; Drayton & Primack 1996; Shwartz et al. 2008; Platt & Lill 2006). Biotic interactions, e.g. predation and herbivory, increase or decrease species richness (cf. Townsend et al. 2009; Ricklefs & Miller 2000). Another relevant factor for species richness is the age of habitat, whereas, for example, old patches developed from (semi-)natural habitats and patches at the intermediate stage of succession most often show high species richness (cf. Blair 1996; Blair & Launer 1997; Zerbe et al. 2002; Drayton & Primack 1996). Of the mechanisms working in urban green spaces and resulting in changes in species richness, the species-area relationship is most likely one of the strongest and best investigated (e.g. MacGregor-Fors et al. 2011). The species-area effect with its origin in island biogeography suggests that larger areas usually facilitate greater species richness (MacArthur & Wilson 1967). For urban green spaces an increasing number of species with increasing patch area have been found for vascular plants (Angold et al. 2006; Li et al. 2006), birds (van Heezik et al. 2013; Carbó-Ramírez & Zuria 2011; Chamberlain et al. 2007; Husté et al. 2006; Husté & Boulinier 2007; Bolger et al. 1997; Mörtberg 2001; Meffert & Dziock 2012; but cf. also Platt & Lill 2006), and mammals (Hodgkison et al. 2007). In contrast, no significant species-area relationships have been found for butterflies and carabid beetles in urban green spaces (Bräuniger et al. 2010; Lizée et al. 2016). In addition to specifying the species-area relationship, taking into account the distance effect also works in urban green spaces. The distance effect describes how species richness is affected by immigration and emigration rates of species, which are influenced by the distance of an island from a source habitat (MacArthur & Wilson 1967; cf. Crooks et al. 2001; Opdam 2002; Uezu et al. 2005). It refers to connectivity and isolation, respectively (cf. Drayton & Primack 1996; Platt & Lill 2006; Zipperer et al. 2000). Species richness in green spaces is positively affected by a decreasing distance to the surrounding landscape, as the surrounding landscape is a potential source habitat (e.g. Guntenspergen & Levenson 1997; Mörtberg 2001; Niemelä 1999; MacGregor-Fors & Ortega-Álvarez 2011; Sandström et al. 2006; Saito & Koike 2013; cf. also Hope et al. 2003; Husté & Boulinier 2007). In addition, the area of green infrastructure surrounding the urban green space is considered to be an influencing factor for species richness in urban green spaces, as it is potential source habitat as well (e.g. Mörtberg 2001; Ferenc et al. 2014a; Melles et al. 2003; Saito & Koike 2013; Guntenspergen & Levenson 1997; Čepelová & Münzbergová 2012; Tonietto et al. 2011; but also cf. Meffert & Dziock 2012). Finally, the habitat structure of urban green spaces is an important factor for species richness (Bell et al. 1991). An increasing proportion of edge habitat compared to core habitat leads to increases in species richness (Ricklefs & Miller 2000; Li et al. 2006; but also cf. Soga et al. 2013). Increasing habitat heterogeneity in urban green spaces also increases species richness (e.g. Blair 1996; Cornelis & Hermy 2004; Garden et al. 2007; Hodgkison et al. 2007; Husté et al. 2006; Pellissier et al. 2012;

Sandström et al. 2006; Mörtberg 2001; Shwartz et al. 2008; Tonietto et al. 2011; Meffert & Dziock 2012; but cf. also van Heezik et al. 2016; González-Oreja et al. 2012). Therefore, numerous influencing variables affect species richness in urban green spaces. A current challenge is to confirm in a first step the relevance of the most important driving factors. And, in a second step, to test if the same factors are relevant in their interaction with other driving factors in order to reduce the driving factors to the smallest possible relevant selection of factors.

Response variables of species richness react differently to the driving factors in urban green spaces described above. Some taxonomic groups are intensively studied, for instance vascular plants (e.g. Pyšek et al. 2004; Schmidt et al. 2014; DeCandido 2004; Wania et al. 2006; Kühn et al. 2004) and birds (e.g. Shwartz et al. 2008, Platt & Lill 2006; Meffert & Dziock 2012), while other taxonomic groups like certain invertebrates (Tonietto et al. 2011; Vilisics & Hornung 2009; Knapp et al. 2008, Bräuniger et al. 2010), fungi (MacGregor-Fors et al. 2016), amphibians (MacGregor-Fors et al. 2016), reptiles (Knapp et al. 2008, Bräuniger et al. 2010) and mammals (Hodgkison et al. 2007; Saito & Koike 2013) are studied to a lesser extent. To refer to the value of certain species for nature conservation, subgrouping regarding the first occurrence is useful. This includes the assignment to native and non-native/alien/exotic species, as well as a subdivision into archaeophytes and neophytes for plants (Pyšek et al. 2004; La Sorte et al. 2014; DeCandido 2004; Schwartz et al. 2008; Platt & Lill 2006; Tonietto et al. 2011; Vilisics & Hornung 2009; McKinney & Lockwood 2001; Kühn et al. 2004; Bräuniger et al. 2010). Conservation status, for instance referred to as endangered species, also assigns a value to certain species and which has rarely been investigated (cf. Meffert & Dziock 2012). Species with specific traits that occur in certain patterns in the urban environment can be used for successful nature conservation. For plants, specific traits have been classified for instance in the form of Ellenberg indicator values (Pyšek et al. 2004; Schmidt et al. 2014), synanthropic species (McKinney 2006) or herbaceous and woody species (DeCandido 2004). Birds were for instance subgrouped as urban exploiters, urban adapters, and migrants (Shwartz et al. 2008; cf. also MacGregor-Fors & Ortega-Álvarez 2011). Additionally, studies of different feeding guilds (cf. Bräuniger et al. 2010) and breeding guilds (cf. Bräuniger et al. 2010) have been conducted and have identified the need for specific nature conservation actions. In addition to absolute species numbers, proportions of species also describe the species richness in urban green spaces more specifically (Schmidt et al. 2014; La Sorte et al. 2014; Wania et al. 2006). Even though a great number of response variables have already been investigated, some research gaps still remain. These research gaps include a further investigation of taxonomic groups, e.g. mammal species richness, of endangered species richness, of proportions of different species groups, and of an ‘overall species richness’ containing different taxonomic groups. As taxonomic groups and subgroups within taxonomic groups react differently to driving factors in urban green spaces, it is important to investigate driving factors within and across different taxonomic groups, as well as an aggregated measure of overall species richness of different taxonomic groups.

Not only single factors drive the occurrence of a certain species in an urban green space, but also these are driven by a combination of multiple, interacting factors. Therefore, multivariate analyses are needed for the identification of driving factors of species richness in urban green spaces (Garden et al. 2006; Nielsen et al. 2014). The combined analysis of several influencing variables, for instance by multiple regressions, is well studied: for example, the investigation of urban structure, habitat and environmental conditions by Schmidt et al. (2014) or the investigation of park size, isolation, and urban landscape surrounding by Lizée et al. (2012). The list of investigated variables is diverse and includes different variables of up to 83 in a study by Bräuniger et al. (2010; cf. also Knapp et al. 2008; MacGregor-Fors & Ortega-Álvarez 2011; Jokimäki 1999). The combined analysis of several response variables has been studied to a far lesser extend (cf. Nielsen et al. 2014; Garden et al. 2006). Nevertheless, some studies that included several taxonomic groups at the same study sites give the opportunity to compare the results for single taxonomic groups with each other (e.g. Knapp et al. 2008; MacGregor-Fors et al. 2016; Bräuniger et al. 2010). Jokimäki (1999) showed that groups of bird species react differently from each other, since species with lower area demands were found closer to the city center than species with greater area demands. Bräuniger et al. (2010) investigated lichens, mosses, vascular plants, birds, butterflies, carabid beetles, and snails together after normalizing and summing up species numbers. Finally, the investigation of several influencing and response variables at the same time has rarely been studied. Only Bräuniger et al. (2010) has investigated overall species richness with a multiple influencing variables approach. Beyond this promising statistical method, the approach solely refers to protected areas where species numbers were taken from already existing published lists from literature, observations, and mapping. With respect to the use of multivariable analysis there is a lack of research which studies the combination of several taxonomic groups and the combination of several taxonomic groups with several potential driving factors.

The transferability of results and by this the naming of robust driving factors are additional relevant aspects of nature conservation (cf. Ferenc et al. 2014b). In prior studies for instance either one green space has extensively been studied (e.g. Shwartz et al. 2008) or a specific type of urban green space, for instance urban forests (Platt & Lill 2006), green roofs (Tonietto et al. 2011), or urban wastelands (Meffert & Dziock 2012). Different types of green spaces like forests, gardens, public parks, and botanical gardens have also been investigated (Vilisics & Hornung 2009, cf. also González-Oreja et al. 2012; Sandström et al. 2006). Some studies were conducted within standardized assessment plots or lines within the urban area (e.g. Zerbe et al. 2002; Saito & Koike 2013). Nevertheless, former research studies suggest that not necessarily the same factors drive the species richness in cities in different climatic regions. For example, habitat heterogeneity had no significant effect on bird species richness in Mexico, but was most relevant in Sweden (cf. González-Oreja et al. 2012 with Sandström et al. 2006; Nielsen et al. 2014). Additionally, the impact of single driving factors can change over time and space (cf. for e.g. patch size Bräuniger et al. 2010; Angold et al. 2006; Li et al. 2006). Regarding research studies in similar climatic regions, Ferenc et al. (2014b) studied macro-ecological patterns of bird communities in 41 cities in central Europe and Säumel et al. (2010) investigated local floras in 11 urban parks along a gradient from Central to Southeastern Europe. Urban floras in 101 cities in different climatic regions world-wide were investigated by La Sorte et al. (2014). However, these studies did not necessarily focus on an investigation of the driving factors of species richness in urban green spaces. Therefore, the need to test the transferability and robustness of driving factors of species richness in urban green spaces of cities located in different climatic regions remains.

Various assessment methods are available to define species richness and to assess the capability of driving factors to impact on high species richness (Rich et al. 2005; Sutherland 2006). However, each of these methods is characterized by specific advantages and disadvantages. There are some standard methods for specific taxonomic groups. For the assessment of vascular plants in urban green spaces most often relevés of different size and repetitions are used (Pyšek et al. 2004; Čepelová & Münzbergová 2012; MacGregor-Fors et al. 2016; Hermy & Cornelis 2000). Studies on the landscape level often use grid cells for plants (e.g. Kühn et al. 2004; Schmidt et al. 2014) or for birds (Ferenc et al. 2014a). Point counts are used for the assessment of birds in urban green spaces (Schwartz et al. 2008; MacGregor-Fors & Ortega-Álvarez 2011; MacGregor-Fors et al. 2016), and also for bats, beetles and fungi (MacGregor-Fors et al. 2016), as well as in the form of camera traps for mammals (Saito & Koike 2013). The use of transects for the assessment of species richness is most common for birds (e.g. Platt & Lill 2006; Hodgkison et al. 2007), but has also been used for ants, grasshoppers, and butterflies (MacGregor-Fors et al. 2016). Some of these methods (points, transects, quadrat-based and nested plots) encompass sample based techniques which presents the possibility to compare results and also to extrapolate species numbers for larger areas (Palmer 1990; Rich et al. 2005; Stohlgren 2006). A more accurate, but time intensive method to define species richness is a complete field survey (cf., true census, systematic total count). Complete field surveys in urban green spaces are rare, but have been conducted by Meffert & Dziock (2012) for birds and by MacGregor-Fors et al. (2016) for butterflies as well as amphibians. These aim for a comprehensive detection of all, for instance, plant species in a given area (Krebs 1989; Chiarucci & Palmer 2005). Nevertheless, the effectiveness and efficiency of those different survey approaches differ and need to be explored especially in urban green spaces, as these are most often very diverse habitats.

Even though a lot of research on species richness in urban areas has already been conducted since the 1980s (e.g. Sukopp 1990; Sukopp & Weiler 1988; Kowarik 1986; Kowarik 1985), there are still knowledge gaps for successful nature conservation that need further research. These knowledge gaps can be assigned on a superordinate level to driving factors of species richness, investigations of species groups within and across taxonomic groups, multivariate analyses concerning driving factors and response variables, naming of robust driving factors and testing of the transferability of results, as well as an identification of suitable assessment methods for species richness in urban environments (cf. Nielsen et al. 2014).

1.2 Objectives and research questions

With respect to the existing research gaps, the aim of my thesis is to identify relevant aspects for nature conservation related to high species richness in urban green spaces. My thesis focuses on three overall objectives. The first objective is to detect driving factors of species richness in urban green spaces within and across taxonomic groups. The second objective is to test the transferability of driving factors in cities located in different climatic regions. And finally, the third objective is to evaluate suitable field assessment methods for surveying species richness in urban green spaces.

More specifically, I will answer the following research questions to narrow related research gaps:

1. Which *single* factors associated with species-area effect, distance effects, and effects of habitat structure drive species richness within and across taxonomic groups?

2. Which *combined* factors associated with species-area effect, distance effects, and effects of habitat structure drive species richness within and across taxonomic groups?

3. Which combined factors drive overall species richness, if species richness of all investigated taxonomic groups is combined?

4. Do the same factors drive species richness within a taxonomic group in cities located in different climatic regions?

5. Is a nested plot method an effective and efficient method to survey species richness in urban green spaces compared to a complete field survey?

1.3 Approach and structure of thesis

To answer theses research questions surveys on vascular plants, birds and mammals were conducted in 32 urban green spaces in Hannover, Germany. Almost complete species lists were generated by full field surveys on vascular plants, transect counts on birds and point counts on mammals. Objectives were tested within and across taxonomic groups. The total species richness and groups of native, non-native, endangered, ornamental, and nitrophilous species for vascular plants, as well as total, native and endangered species for birds and mammals were investigated. Based on the species-area relation the effect of patch size was checked as an influencing factor. The distance to the urban edge, distance to the nearest green space, as well as density, percentage, connectivity (Proximity Index), and diversity (Shannon Diversity Index) of the green spaces in a 500 m buffer were used to describe distance effects. The patch shape (as a measure of the proportion of edge to core habitat), number habitat types, and diversity (Shannon Diversity Index) of habitat types within green spaces was used to describe effects of habitat structure. In addition to the study in Hannover, a colleague conducted vascular plant surveys in Haifa, Israel, a city located in a Mediterranean climate. The study results from Hannover were compared to those from Haifa to test transferability and to identify robust driving factors. To gain insight into a possibly precise and cost-efficient survey method to investigate vascular plant species richness in urban forest habitats, results from Modified Whittaker plots were compared to complete field surveys.

The detailed research approaches and methods as well as the answers to my research questions are presented in one book chapter and three papers. The thesis is structured as follows:

Chapter 2.1 (paper 1) addresses research questions 1 and 2 for the influence of patch size, patch shape and distance to the urban edge on total species number, as well as the numbers and proportions of native, non-native, endangered, ornamental, and nitrophilous vascular plants.

Chapter 2.2 (book chapter 1) addresses research question 4. Vascular plant species richness patterns in urban areas of Hannover, Germany and Haifa, Israel are investigated. The influence of patch size and distance to the urban edge were tested on total and native numbers, as well as the proportion of native vascular plant species.

Chapter 2.3 (paper 2) addresses the research questions 1, 2 and 3 for vascular plants, birds, and mammals.

Chapter 2.4 (paper 3) addresses the research question 5 for vascular plant species surveyed by Modified Whittaker plots as well as by complete field surveys in forested urban green spaces.

Chapter 3 presents the summarized results and Chapter 4 the summarized discussion with special attention to the closed research gaps. Finally, in Chapter 5 conclusions are drawn and an outlook given for further research.

2 Publications

2.1 Factors driving the vascular plant species richness in urban green spaces: Using a multivariable approach

Matthies SA, Rüter S, Prasse R, Schaarschmidt F (2015) Factors driving the vascular plant species richness in urban green spaces: Using a multivariable approach. Landscape and Urban Planning 134: 177-187.
doi: 10.1016/j.landurbplan.2014.10.014

Author contributions: Conceived the study: SM, SR, RP. Conducted the field surveys: SM. Analyzed the data: SM, FS. Wrote paper: SM, SR, FS, RP.

Abstract

Many studies have shown high vascular plant species richness in urban areas and, especially, in its green spaces. However, little is known about the factors driving the numbers and proportions of different species groups. The aim of our study was to test for the effects of patch size, patch shape, and distance to the urban edge as well as the combined effects of these factors on the numbers and proportions of total, native, non-native, endangered, ornamental, and nitrophilous vascular plant species. We conducted vascular plant surveys in 32 urban green spaces in the city of Hannover, Germany. We detected positive correlations between patch size and total, native, non-native, endangered, ornamental, and nitrophilous vascular plant species numbers and the proportion of endangered species by Spearman's rank correlations and linear regressions. A more compact patch shape, calculated by the shape index, affected the proportion of native, non-native, and ornamental species positively. Testing combined effects of factors with multiple linear regressions underlined the importance of patch size in combination with distance to the urban edge, and in combination with distance and patch shape. We conclude that in the context of recent urbanization processes, it is most important to create and conserve large urban green spaces (> 6 ha) in order to maintain vascular plant species richness. As species groups were affected most by different combinations of driving factors, our study highlights the importance of using multivariable approaches for detecting effects more precisely.

2.2 Vascular plant species richness patterns in urban environments – Case studies from Hannover, Germany and Haifa, Israel

Matthies S, Kopel D, Rüter S, Toger M, Prasse R, Malkinson D (2013) Vascular plant species richness patterns in urban environments – Case studies from Hannover, Germany and Haifa, Israel. In Malkinson D, Czamanski D, Benenson I (Eds.), Modeling of Land-Use and Ecological Dynamics. Cities and Nature Springer, Berlin, Heidelberg, pp. 107-118.
doi: 10.1007/978-3-642-40199-2_6

Author contributions: Conceived the study in Hannover, Germany: SM, SR, RP. Conducted the field surveys in Hannover, Germany: SM. Analyzed the data for Hannover, Germany: SM. Wrote paper: SM, SR, DM, DK, RP, MT.

Abstract

The continuous expansion and growth of urban and settled areas result in a mosaic of open spaces which provide important habitat for species. Species richness within the urban matrix has been commonly studied in relation to urban- rural gradients, where the richness in open-space patches has been evaluated with respect to their location along this gradient. In this study we propose that additional factors may drive richness properties, namely patch size. We established a comparative study, where species richness patterns were compared between Haifa and Hannover, with respect to two driving factors: open-area patch size and its distance from the urban edge. These relationships were assessed for the overall number of vascular plant species and for native species only. Patches were identified by classifying aerial photographs of the cities, and surveying 32 patches in Hannover and 37 patches in Haifa which were randomly selected from the delineated patches. Results indicate that in both cities distance from the urban edge was not a significant factor explaining either the total vascular plant richness in the patches, or the native species richness. In contrast, both classes of species richness were significantly related with patch size. R^2 values for total richness were 53 % in Hannover and 45 % in Haifa. With respect to native species richness, patch size explained a higher proportion of the variance in Hannover where R^2 = 73 %, and a lower proportion of the variance in Haifa (R^2 = 33 %). These preliminary results indicate strikingly similar driving factors in two urban landscapes which are characterized by fundamentally different histories and environments.

2.3 Determinants of species richness within and across taxonomic groups in urban green spaces

Matthies SA, Rüter S, Schaarschmidt F, Prasse R (2017) Determinants of species richness within and across taxonomic groups in urban green spaces. Urban Ecosystems 20: 897-909.
doi: 10.1007/s11252-017-0642-9

Author contributions: Conceived the study: SM, SR, RP. Conducted the field surveys: SM. Analyzed the data: SM, FS. Wrote paper: SM, SR, FS, RP.

Abstract

Urban green spaces provide habitat for numerous plant and animal species. However, currently we have little knowledge on which determinants drive the species richness within and across taxonomic groups. In this paper we investigate the determinants of total, native, and endangered species richness for vascular plants, birds, and mammals within and across taxonomic groups. We examined a stratified random sample of 32 urban green spaces in Hannover, Germany. Species inventories for plants and birds were generated on the basis of line transect surveys. Mammals were surveyed by means of point counts using camera traps. Using a principal component analysis and multiple regression models, we tested 10 explanatory variables for species-area effects, distance effects and the effects of habitat structure of green spaces on species richness. When analyzing single explanatory variables, we determined that the species richness of all groups was significantly positively correlated to patch area, number of habitat types, and a short distance to the nearest green space. Testing combined effects of variables showed that patch area in combination with habitat heterogeneity was most important for plants (total, native, and endangered), birds (total and native), and overall species richness. This emphasizes the importance of the species-area effect and the effects of habitat structure on species richness in urban green spaces. We conclude that, in the context of urban planning, it is important to conserve large green spaces that include a high diversity of habitats to maintain high species richness.

2.4 Applicability of Modified Whittaker plots for habitat assessment in urban forests: Examples from Hannover, Germany

Rüter S, Matthies SA, Zoch L (2017) Applicability of Modified Whittaker plots for habitat assessment in urban forests: Examples from Hannover, Germany. Urban Forestry and Urban Greening 21: 116-128.
doi: 10.1016/j.ufug2016.11.008

Author contributions: Conceived the study: SR, SM, LZ. Conducted the field surveys: LZ, SM. Analyzed the data: SR, LZ, SM. Wrote paper: SR, SM, LZ.

Abstract

In ecological planning, cost-effective but accurate methods for the assessment of habitats and species are needed. In this study we investigated whether the multi-scale Modified Whittaker plot (MWP) method is suited for vascular plant surveys as a basis for habitat assessment. We measured total and endangered species richness in ten urban forests in Hannover, Germany. The MWPs´ time efficiency and effectiveness in capturing species richness were quantified and compared to complete field surveys. The MWP method estimated both greater and lower species numbers per habitat, the absolute deviation ranged from +60 to -15 species. It generally captured fewer endangered plant species than the complete field survey. In particular, the method did not detect species with a high category of endangerment. Regarding time efficiency, the MWP method took an average of 186 minutes per habitat, while the complete field surveys were more time consuming (average=265 minutes). In small habitats (< 1.0 ha) the full survey took less time than the MWP method. To determine the applicability for nature conservation and ecological planning, we evaluated the species data derived from the two methods by using common habitat evaluation criteria. In most cases, the species data received from the MWP method resulted in lower habitat values compared to the use of data from the full surveys. We conclude that comprehensive habitat evaluation exceeds the applicability of the MWP method which may miss locally rare species. However, the MWP method provides an opportunity to efficiently estimate plant species richness patterns in urban forests and, thus, holds the potential to convey basic information for an overall monitoring of species diversity and may lead to specific habitat assessment efforts.

3 Synthesis of results

Which *single* factors associated with species-area effect, distance effects, and effects of habitat structure drive species richness within and across taxonomic groups?

This question is answered in Chapters 2.1, 2.2, and 2.3.

When analyzed as a single factor, the bigger the patch area, the higher are the number of total, native, non-native, endangered, ornamental, and nitrophilous vascular plant species, as well as total, native, and endangered bird species, and total and native mammal species. Additionally, the bigger the patch area, the higher is the proportion of endangered vascular plant species.

With higher compactness of urban green spaces, more ornamental and higher proportions of non-native and ornamental vascular plant species were found. The less compact, the higher was the proportion of native vascular plant species. Regarding the number of habitat types within urban green spaces, higher numbers positively affect total, native, and endangered vascular plant and bird species, as well as total and native mammal species. Therefore, more species were found in green spaces with numerous habitat types. The diversity of habitat types within urban green spaces showed similar results. The higher the diversity of habitat types within an urban green space, the higher were the numbers of total, native, and endangered vascular plant and bird species.

The distance to the nearest green space positively affected all tested species groups, namely total, native, and endangered vascular plant and bird species, as well as total and native mammal species. A higher distance to the urban edge only decreased the number of ornamental vascular plant species. A high connectivity of green spaces increased the number of native vascular plants and total mammals.

Which *combined* factors associated with species-area effect, distance effects, and effects of habitat structure drive species richness within and across taxonomic groups?

This question is answered in Chapters 2.1 and 2.3.

The patch area, distance to the urban edge, patch shape, and habitat heterogeneity within urban green spaces, measured by the number and the diversity of habitat types, best explained the total number of vascular plants. These results of the third paper supplemented the analysis from the first one. Here it was shown that the total vascular plant species richness increased in bigger and more compact urban green spaces, which are located closer to the urban edge. Nevertheless, no other influencing factors were tested. By including habitat heterogeneity to the final model the explained variance was increased from 58% to 76%. Therefore, the understanding of driving factors of total vascular plant species richness was advanced.

The patch area, distance to the urban edge (n. sig.) and patch shape (n. sig.), as well as habitat heterogeneity influenced the number of native and endangered vascular plants, as well as total and native birds. For the number of native and endangered vascular plants the initial analysis in the first paper revealed that species numbers increased with bigger patch area and smaller distance to the urban edge. Therefore, the second analysis supplemented the results of the first one by identifying more influencing variables and models with higher explanations of variance.

Patch area, distance to the urban edge as well as patch shape affected the number of non-native and ornamental, as well as the proportions of native, non-native, and ornamental vascular plant species. The bigger the patch area and the smaller the distance to the urban edge, the higher was the number of nitrophilous vascular plant species. An increasing patch area was the only factor driving the number of endangered birds, total and native mammals, as well as the proportion of endangered vascular plant species. None of the tested influencing variables affected the proportion of nitrophilous vascular plant species significantly.

All these results clearly underline the importance of patch area and habitat heterogeneity within urban green spaces for species richness, if combined influencing variables are tested.

Which combined factors drive overall species richness, if species richness of all investigated taxonomic groups is combined?

This question is answered in Chapter 2.3.

The patch area in combination with the habitat heterogeneity, measured by the number and the diversity of habitat types, had significant impacts on the overall species richness. The influencing variables patch shape and distance to the urban edge were included in the model because of the analysis method that was used, but were not significant. Therefore, patch area and habitat heterogeneity were identified to be the most important driving factors for overall species richness.

Do the same factors drive species richness within a taxonomic group in cities located in different climatic regions?

This question is answered in chapter 2.2.

The total number of vascular plant species increased with increasing patch size in the two different climatic regions of Hannover, Germany and Haifa, Israel. Additionally, the number of native species increased significantly with increasing patch size in both cities. However, no significant influence of the patch size on the proportion of natives was detected either for Hannover or for Haifa. Regarding the influence of distance to the urban edge no significant results were found for the number of total or native species, as well as the proportion of native species for the two different climatic regions. All results for Hannover are in line with the results already described for the single variables analysis of driving factors. Overall, similar results were gained for Hannover, Germany and Haifa, Israel.

Is a nested plot method an effective and efficient method to survey species richness in urban green spaces compared to a complete field survey?

This question is answered in Chapter 2.4.

The Modified Whittaker Plot method overestimated as well as underestimated the species numbers in forested green spaces in a range of -37.1% to 44.1%. Regarding endangered species the tested method underestimated species numbers up to 100%. Using the Modified Whittaker Plot method resulted in better as well as worse time efficiency depending on patch size. A habitat evaluation based on the Modified Whittaker Plot method for the total species number resulted in four cases equal, two cases more and four cases less importance to the habitat; for the presence of endangered species it resulted in three cases equal and seven cases less importance to the habitat. The Modified Whittaker Plot method showed some limitations in the estimation of total and endangered species richness and accordingly in the habitat evaluation, especially in large habitats. At the same time it was more time efficient than the full field survey in larger habitats.

4 Synthesis of discussion

In a first step I answered the question, of which single factors drive species richness within and across taxonomic groups. My results in this context identify patch size as one of the most important driving factors for species richness in urban green spaces. My results confirm the results of prior research studies documenting a positive effect of patch size on total vascular plants (Knapp et al. 2008; Bräuniger et al. 2010; Angold et al. 2006; Cornelis & Hermy 2004; but cf. also MacGregor-Fors et al. 2016), endangered vascular plant species (Hill & Curran 2001), as well as total and endangered bird species richness (Meffert & Dziock 2012; Knapp et al. 2008; MacGregor-Fors et al. 2016; Bräuniger et al. 2010; Husté et al. 2006). The positive effect of patch size on the number of native, non-native, ornamental, and nitrophilous vascular plants species, native bird species, total and native mammal species, as well as the proportion of endangered vascular plant species had not been tested prior to my research and are new findings. My analysis of single driving factors showed a positive species-area relation for all tested species groups which works within and across taxonomic groups.

With respect to the habitat structure, three different influencing variables were tested; the patch shape (as a measure of compactness), the number and diversity of habitat types within urban green spaces. The patch shape significantly influenced the number of ornamental vascular plant species, as well as the proportion of native, non-native, and ornamental species. For all other tested species groups no significant influence of the variable was detected. My results indicate that compact urban green spaces hold high numbers of ornamental species as well as high proportions of non-native and ornamental vascular plant species. The results could be due to some regularly shaped cemeteries and parks with high numbers of ornamental plant species in the investigated green spaces. Knapp et al. (2008) investigated the perimeter as a similar measure of patch shape, but excluded this variable from further analyses for birds and plants, as it was autocorrelated to the total area. Therefore, no comparable results for the influence of patch shape exist. The second variable derived from habitat structure was the number of habitat types within investigated urban green spaces. When tested as a single variable in my work it significantly increased the number of all investigated species groups. Some studies have already demonstrated the relevance of habitat heterogeneity measures on species richness in urban green spaces (cf. Shwartz et al. 2008; Husté et al. 2006; Meffert & Dziock 2012; Knapp et al. 2010). Significant effects of habitat structure and on-site habitat characteristics have also been shown for small mammals (Garden et al. 2007; Hodgkison et al. 2007). A positive effect of a high diversity of habitat types within urban green spaces on the number of total, native, and endangered vascular plant and bird species in my work also confirms prior results of the importance of different habitat heterogeneity measures in urban green spaces on species numbers (cf. Husté et al. 2006; Shwartz et al. 2008). Therefore, the habitat structure, measured by different variables, is a driving factor in single variable analysis and positively affects almost all tested taxonomic groups.

For distance effects the distance to the urban edge, distance to the nearest green space, as well as connectivity of green spaces, green space density, percentage of green spaces, and diversity of green spaces within a 500 m radius was tested. In my single variable analysis the distance to the urban edge had a significant negative influence only on the proportion of ornamental vascular plant species. Therefore, the smaller the distance to the urban edge, the higher is the proportion of ornamental vascular plant species. Earlier studies have shown a decrease of native and an increase of non-native species due to increased urbanization (D'Antonio & Meyerson 2002; Thompson & Jones 1999; Zerbe et al. 2002), which indicates the distance from the center or urban edge, respectively. My results with higher proportions of ornamental species close to the urban edge indicate the opposite. This could be due to higher proportions of green space with a potentially higher variety of spreading ornamentals or neophytic species (cf. Kong & Nakagoshi 2006). Additionally, former studies proved significant effects of the distance to the urban edge for birds (MacGregor-Fors & Ortega-Álvarez 2011) and mammals (Saito & Koike 2013). City borders are very differently shaped (Czamanski et al. 2014) and the city matrix could inhabit a considerable amount of urban green space, implicating a less severe isolation effect (cf. Garden et al. 2010; Oliver et al. 2011). Therefore, it is possible that the distance to the urban edge and/or the surroundings, were inappropriate for the scale of the effect. The distance to the nearest green space showed significant negative effects on all tested species groups of my research. Significant effects of the surroundings were shown in former studies for birds (Ferenc et al. 2014a; Pellissier et al. 2012), mammals (Saito & Koike 2013), and plants (Čepelová & Münzbergová 2012). This is different to findings of Knapp et al. (2008), who did not detect significant effects of the mean distance to the nearest similar habitat on total plants or birds in multiple regressions. Additionally, my work showed that a high connectivity of green spaces in the surroundings of the investigated green space had positive effects on native plant and total mammal species (cf. Čepelová & Münzbergová 2012; Saito & Koike 2013). All other tested distance measures did not show any significant results on the tested species groups. Therefore, distance effects on species richness can be shown for only some tested species groups, whereas other groups were not affected.

In a next step I used multivariate analyses in order to describe the mechanisms with interacting driving factors more precisely and to reduce the number of driving factors (cf. Nielsen et al. 2014). For the total vascular plant species richness the patch area, patch shape, distance to the urban edge and habitat heterogeneity, measured by the number and the diversity of habitat types, were identified as driving factors. Compared to my own single variable analysis, the significance of patch shape and distance to the urban edge was new for total plant species richness, whereas the relevance of the distance to the next urban green space tested in combination with three other connectivity measures, was no longer confirmed. This implies for total vascular plant species richness that on-site characteristics are more important than that of the surrounding area. The relevance of the area of a patch for total vascular plant species richness in combination with other influencing variables, for instance the mean perimeter-to-area ratio of habitat and land-use patches within sites, has already been shown by Knapp et al. (2008) for protected areas in urban landscapes. In contrast to my findings, they detected no significant influence of the number of habitat and land-use patches of the site on the total vascular plant species richness (cf. Knapp et al. 2008). This difference could be due to the aim of the Knapp et al. (2008) study to detect driving factors of species richness in protected areas of urban and rural landscapes and, therefore, the inclusion of a variable accounting for the location of the site in the city or countryside in the models. Bräuniger et al. (2010) showed that the number of habitat and land-use types in a 100 m buffer zone around the urban green space was best able to explain total vascular plant species richness in protected areas in multivariate analysis after correcting for patch area. In this study a large number of influencing variables were investigated (cf. Bräuniger et al. 2010). For instance, the number of habitat types within the patch as well as the Shannon's Diversity Index of habitat types (the latter comparable to the driving factor of habitat heterogeneity in my research), and they found that the Mean Shape Index did not show significant results (Bräuniger et al. 2010). This is different to my findings. In the same study the distance to the nearest neighbor or the mean distance to the nearest similar habitat (comparable to distance to the nearest green space in my research), were also found not to be significant (Bräuniger et al. 2010), which is in agreement with my findings. The different results of Bräuniger et al. 2010 to my study could be due to the correction of species numbers and landscape variables for patch area prior to model building. Patch area is one of the most important driving factors in my study and is accounted for in the first position in the model. After accounting for the variance of all driving factors in the model (patch area, patch shape, distance to the urban edge, habitat heterogeneity) the effect of the surrounding area was possibly too weak to be detected in my analysis. In addition I used a 500 m buffer to define the number of green spaces per ha in the surrounding area. Bräuniger et al. (2010) used a 100 m and a 500 m buffer to define the number of habitat and land-use types, but identified the habitat types and land-use types in the 100 m buffer to best explain total plant species richness, therefore, differences between our studies could partly be due to different buffer distances. A study in Hamburg, Germany on the species richness in 1 km² grids revealed, that the total vascular plant species richness was best explained by the Ellenberg's indicator value for nutrients and habitat diversity, while climatic variables and the proportion of protected area were less important (Schmidt et al. 2014). The relevance of habitat diversity was also demonstrated by my investigations, whereas the additional driving factors differ from those tested in the Schmidt et al. (2014) Hamburg study. Despite these differences I advance scientific understanding by identifying driving factors of total vascular plant species richness for different type of unprotected urban green spaces, including highly altered ones like parks and cemeteries.

For native and endangered vascular plant, as well as total and native bird species richness the most important driving factors were the patch area and the habitat heterogeneity. Additionally the distance to the urban edge and the patch shape were included in the model, though both of these were not significant. For all these species groups, the number of driving factors was reduced by the distance to the next green space with multivariate analysis. Additionally, the significance of the connectivity of green spaces in the surrounding for native vascular plant species was not confirmed. Bräuniger et al. (2010) identified the number of habitat and land-use types in a 100 m buffer zone as the driving factor for native vascular plant species richness in protected urban areas just as for the total plant species richness, which is again different to my findings. The number of habitat types, as well as the Shannon diversity index of habitat types within urban green spaces were not identified as significant for native vascular plants, even though this was tested (Bräuniger et al. 2010). Possible reasons for the differences between the results of Bräuniger et al. (2010) and my results were discussed above for total plant species richness and this discussion can be transferred to that for native plant species richness as well. A comparable study for endangered vascular plant species is not currently available. For total bird species richness numerous similar studies are available (cf. e.g. Knapp et al. 2008; Hodgkison et al. 2007). My findings are in line with those of Husté et al. (2006), who identified patch size and vegetation structure, measured by the diversity and abundance of trees and shrubs, as strong predictors of local bird species richness. Shwartz et al. (2008) identified lawn cover and woody plant richness, both measures of habitat heterogeneity, to drive total bird species richness. Additionally, the distance from nearest water source was relevant in the study that was carried out in Tel Aviv, Israel. The latter driving factor certainly gains weight in regions warmer than

Lower Saxony, where Hannover is located. In contrast, Knapp et al. (2008) detected only the patch area as a driver of total bird species richness in protected areas and found no significant effects of the number of different habitat types within patches in multiple regressions. Jokimäki (1999) named the area of a park as the best predictor of total bird species richness in combination with five other, though less important influencing variables. Four of them describe habitat heterogeneity, therefore fall in line with my findings; the last one was recreational activity, which was not addressed in my investigations (cf. Jokimäki 1999). Bräuniger et al. (2010) revealed very different driving factors, even though similar influencing variables as those tested by me were studied. In the Bräuninger et al. (2010) study total bird species richness was driven by the mean patch fractal dimension of hemeroby levels, distance to nearest neighbor among the protected areas, mean perimeter-area ratio of hemeroby levels, and the number of habitat and land-use types in a 500 m buffer zone. Though a correlation between patch area and species numbers was detected, it was not included in the model as species numbers and landscape variables were corrected for area (cf. Bräuniger et al. 2010). The number of habitat types and the Shannon diversity index of habitat types (which are similar variables to habitat heterogeneity in my analysis) were not significant (Bräuniger et al. 2010). The human impact on species richness for instance by investigating hemeroby levels was not investigated in my work. The minor relevance of connectivity measures, taking the surrounding of green spaces into account, for mobile species like birds, is surprising in my study. Nevertheless, patch size and the habitat heterogeneity best explained species richness and no further inclusion of driving factors was necessary. Again, my findings supplement the state of research for a larger number of green space types with recent data and for a city located in warm temperate climate.

For the number of non-native, ornamental, and nitrophilous, as well as the proportion of native, non-native, and ornamental vascular plant species richness the patch area, the distance to the urban edge, and for most of the species groups the patch shape were identified as driving factors. The only comparable study (Schmidt et al. 2014) identified the Ellenberg's indicator value for moisture and temperature, both correlated to the distance to the city center, as driving factors of the proportion of non-native vascular plant species richness. The patch area or patch shape was not investigated, as equally sized grid cells were investigated (cf. Schmidt et al. 2014). Because there are few comparable studies available, most of my findings for these species groups are new.

Area was the only driving factor of endangered bird, total and native mammals species richness, as well as the proportion of endangered vascular plants. Meffert and Dziock (2012) concluded that the occurrence of endangered birds depends on the area of urban wastelands and its vegetation structure, and only to a lesser extent on the composition of the urban matrix. Hodgkison et al. (2007) identified tree density in combination with hollows and area of vegetation connected to vegetation within a 2 km radius to be the driving factors for total mammal species richness. Significant effects of habitat structure and on-site habitat characteristics have also been proved for small mammals by Garden et al. (2007). The difference between these studies and my findings could be due to the different size of investigated target species and related habitat size. The proportion of endangered vascular plant species were driven in another research study (Schmidt et al. 2014) by the Ellenberg's indicator value for moisture and nutrients, as well as the proportion of protected area. As indicated above, the influence of patch size was not investigated in the Schmidt et al. (2014) study, as equally sized grid cells were investigated. Therefore, my findings partly underline and partly supplement the state of knowledge.

Finally the driving factors of overall species richness were investigated. For overall species richness my analysis confirmed patch area and habitat heterogeneity to be the most important driving factors. The only comparable study was conducted by Bräuniger et al. (2010) which used the concept of total richness with reference to lichens, mosses, vascular plants, birds, butterflies, carabids, and snails in protected urban areas. Driving factors in the Bräuninger et al. (2010) study were the percentage of woods and forests per protected area and the number of habitat and land-use types in a 100 m buffer zone, after variables were corrected for area. In this study the total investigated species richness was driven by a measure of habitat heterogeneity within the investigated green space and a measure of connectivity of green spaces in the surroundings (cf. Bräuniger et al. 2010). Therefore, habitat heterogeneity within the urban green space was identified as a driving factor in the Bräuniger et al. (2010) and my own research study, though measured by different variables. Additionally both studies identified the patch area as the most important driving factor, which in turn made it unnecessary to take the surrounding into account in my analysis. My results therefore support the existing results.

In a next step my focus was to answer whether it is the same factors that drive high species richness of vascular plant species in urban green spaces in Haifa, Israel and Hannover, Germany. We documented a strong relationship between the patch size and the total number as well as native number of vascular plant species for both cities. The relevance of patch size is in line with many other studies for different taxonomic groups (e.g. Knapp et al. 2008; Meffert & Dziock 2012; Mörtberg 2001; Bolger et al. 1997). Nevertheless, no comparative studies on urban green spaces in different climatic regions are available and a comparison of multiple studies is not constructive due to different survey approaches, variable definitions and analysis approaches. Our findings correspond with the concept of species-area relationship (Preston 1962). An impact of patch size on the proportion of native species was not detected. This could be due to the different types of urban green spaces investigated. Possibly our proportion of native vascular plant species is related to a lesser extent to ecological concepts than to human actions of actively increasing exotic species within settlements. The distance to the urban edge was not a factor explaining species richness in either of the cities. This is not in line with other studies, which investigated species richness patterns along a gradient from urban to rural (cf. McKinney 2008). Highest species richness at an intermediate level of urbanization was documented by many studies (cf. Hope et al. 2003; Husté & Boulinier 2007; Bolger et al. 1997). The lack of importance of immigration processes in cities from the landscape indicates that the urban matrix is more permeable to vascular plants than expected and that short distance dispersal is more important. Therefore, the immediate vicinity could be most essential (cf. Wania et al. 2006). Especially for plants, the presence of historic, respectively old sites is important (cf. Blair 1996; Blair & Launer 1997; Drayton & Primack 1996). The results show that there are driving factors of overriding importance, that are valid despite environmental differences with respect to climate, topography and composition of flora.

In the last part of my thesis I explored if the Modified Whittaker Plot method is suitable to survey vascular plant species richness in urban forest habitats in an effective and efficient way. The method showed limited accuracy in estimating vascular plant species richness. The deviation from observed species numbers became more prominent in large forest habitats (cf. Stohlgren et al. 1995), whereas the time efficiency increased with increasing habitat size. Species richness is the most commonly used measure of biodiversity (Gaston 1996). Nevertheless, high species richness does not necessarily imply a high conservation value at the same time. Species richness needs to be evaluated with regard to the completeness of species for a habitat and the spatial scale. Therefore, habitat evaluation can be performed on expected levels of species richness as benchmarks for habitats and, ideally, biogeographical regions (Bredemeier et al. 2015). An additional important factor is, whether a habitat supports endangered species. Complete field surveys support the detection of different species groups, like native or endangered species (Steward et al. 2009). To my knowledge very few research studies investigated the vascular plant species richness within urban green spaces with complete field surveys (cf. Knapp et al. 2008) or with a comparative study including complete field surveys and a plot/relevé assessment. The vascular plant species richness in urban green spaces has often been investigated by a comparison of species numbers in (large) single assessment plots (e.g. Pyšek et al. 2004;

Čepelová & Münzbergová 2012) or by an aggregation of species lists of multiple assessment plots (e.g. MacGregor-Fors et al. 2016; Hermy & Cornelis 2000). Both methods can cause limitations in the results, as especially urban green spaces are structured by diverse habitats. An extrapolation of species numbers based on assessment plots has not been conducted in urban green spaces so far. Therefore, no comparable studies are available. Nevertheless, the Modified Whittaker Plot method showed limitations in our study, as it missed a considerable number of endangered species. However, the Modified Whittaker Plot method gives the opportunity to identify habitats with potentially high conservation values for additional surveys focusing on endangered species.

5 Conclusions and outlook

The results of my work indicate that there are diverse relevant aspects for nature conservation that need to be addressed regarding maintaining and developing high species richness in urban green spaces. The driving factors of species richness within and across taxonomic groups are - to some extent - the same. There are driving factors that have an overriding importance: patch size and habitat heterogeneity within urban green spaces. At least for the patch size its importance was underlined in an analysis carried out in a city located in a different climatic region than Hannover. The assignment of species numbers and a habitat evaluation based on the Modified Whittaker Plot method gathered important information on the potential value of an urban green space. Nevertheless, it does not replace full field surveys, but will gain in importance, as comprehensive surveys in cities are more and more required.

I draw the following implications for sustainable urban development

- Green spaces should not vanish or be reduced in size (e.g. in growing cities); where it is possible, green spaces should be enlarged (e.g. in shrinking cities, new developed urban districts). For vascular plants, our results show that large green spaces not only favor endangered and native species, but also numbers and proportions of non-native species. Therefore, while protecting native and endangered species in large urban green spaces, the importation of non-native species to urban areas should be discouraged as they can cause biotic homogenization by the replacement of native with non-native species (Olden et al. 2006).
- Green spaces should be maintained, developed, and planned to include heterogeneous habitats. Habitat heterogeneity refers in this case especially to the number as well as the diversity of habitat types. Additionally, a mosaic of different habitats between green spaces would allow for a high urban diversity, therefore, urban planning needs to counteract loss and fragmentation. Green spaces should be connected and have short distances to each other.
- More comparative studies of urban green spaces in cities located in different climatic regions should be encouraged in order to complete the picture of transferable driving factors of species richness. These studies need to address at least variables derived from the species-area effect, effects of habitat heterogeneity, and distance effects focusing on the habitat heterogeneity in the immediate surrounding of the green spaces.

- An effective species monitoring and evaluating system is needed for urban green spaces. Our results on the applicability of Modified Whittaker plots for habitat assessment in urban forests give first insights in a possible method and its limitations. The information gathered by the use of the Modified Whittaker Plot method can be used to locate green spaces or urban habitats that are valuable for intensive habitat assessments.
- Green space should not be used for further development in cities before the ecological value of the green space is defined. This value needs to address the green space value for different species groups, respectively target species. It needs to be calibrated to the addressed value of habitats in the surroundings, as biodiversity in the surrounding - especially in agricultural landscapes – decreases and at the same time the value of urban green spaces increases. Additionally, the green space's value for a habitat network within the city and to the surroundings needs to be taken into account.
- My results place special importance on site specific traits, rather than traits regarding the immediate surrounding. They assign lesser importance to immigration processes even for predominantly mobile species like birds and mammals. Therefore, historic green spaces should be assigned a special value.

Despite my findings on the relevant single and combined driving factors of species richness in urban green spaces within and across taxonomic groups, their transferability to cities located in other climatic regions, and suitable field assessment methods for species richness in urban green spaces, there still remain general knowledge gaps, whereas other, more specific research question devolve from my work. As I was able to close some of the existing research gaps on relevant aspects of nature conservation, further investigations on effects on and mechanisms behind high species richness could be advanced. These would improve the already existing data and support further development for maintaining high species richness in urban green spaces.

Further research needs to be conducted on additional response variables. In this context, additional investigations in other cities of the investigated species groups of vascular plants, birds, and mammals could be beneficial. For the taxonomic group of birds, additional subgrouping could be done, e.g. according to feeding or nesting guilds. Additionally, the investigation of birds in winter and the driving factors in this season could reveal different results. For the taxonomic group of mammals, additional information on small mammals like mice might be interesting. Due to the selected recording method in my research, small mammals are not included to my analysis. Whether or not small and large mammals have different driving

factors needs to be investigated. Therefore, for mammals an additional subgrouping could be interesting.
In addition, an investigation of additional taxonomic groups should be conducted. These taxonomic groups should include some with different moving abilities, for instance butterflies, and some with seasonally differentiating behavior and use of habitat, for instance bats, as driving factors might be different from those identified in my work.

Further research could also be conducted on influencing variables. These could include totally new variables, not investigated in the presented research, like (human) disturbance characteristics (e.g. Drayton & Primack 1996; Nagendra & Gopal 2012, Jokimäki 1999) and patch history (e.g. Bertoncini et al. 2012). From the discussion of my results compared with other research studies, it could be useful to correct for the influence of the patch size in order to define additional relevant variables (cf. Bräuniger et al. 2010). This could make it easier to study the influence of the immediate surrounding more clearly and determine what is best for different buffer zones from 100 m to 500 m. Nevertheless, the tested influencing variables of my work can be modified to some extent as well. For instance, regarding habitat heterogeneity, the definition of habitat types can be conducted differently. These could be defined for different taxonomic groups, for subgroups within taxonomic groups, or for specific species, as well as by addressing the whole area of green space or specific, relevant components (cf. Bräuniger et al. 2010; Hustè et al. 2006; Schwartz 2008; Jokimäki 1999; Hodgkison 2007). Additionally, the diversity of habitat types can be measured by various different diversity indices or, possibly even more desirably, by a combination of different diversity indices.

More study areas within the same environmental conditions should be investigated in order to define the transferability of results to all cities located within this specific climatic region. Additionally, cities located in other environments than the two climates tested here (warm temperate and mesic mediterranean) should be investigated. In this context regional development patterns of cities need to be taken into account and would make it possible to subgroup study areas even further. The tested number of 32 study sites within Hannover is regarded a suitable number for such research.

Further research should be done on the statistical analysis. This should include analyses on influencing variables in single variable and, additionally, in multivariable approaches, as we know, that the factors in nature act altogether. Nevertheless, the investigation of the impact of single variables can lead to important insights, as several variables can explain quite similar parts of differences in species numbers. If this is the case, often only the one variable with the highest

explanation value (in combination with other relevant variables) will be integrated in a multivariate analysis. However, as statistics in the first place describe patterns, this does not necessarily mean that the excluded variable has no or little influence.
The introduced combination of the species numbers of different taxonomic groups by a principle component analysis to overall species richness was an important step in the data analysis. If future principle component analysis reveals interpretable results, it is recommended to use these measures of overall species richness in further studies as well. By this, the number of relevant influencing variables can be reduced, which simplifies the communication of driving factors and the integration of driving factors to urban development.

An additional aspect of future research should be the further calibration of gathered information on species richness in cities to information on species richness in arable sites and in protected sites. The knowledge of species richness in urban green spaces and the habitat value of such green spaces are important information on biodiversity. This information should be gathered in different cities in order to define their contribution to the maintenance of biodiversity. Additionally, not only is this information important to allow comparison of several cities, but also to compare them to the value of the surrounding, not legally protected sites. Possibly financial support of biodiversity measures, for instance for agricultural sites, needs to be extended to similar supports for urban sites, especially in urban green spaces.

Finally, it is very important to implement state of the art research into urban planning and to introduce effective measuring and planning instruments (cf. Garden et al. 2006). This would guarantee the maintenance of and possibly allow the development of species-rich green spaces in urban areas. As species loss lasts differently over time and space in different environments, the maintenance of species richness and biodiversity in all environments, including urban areas, is becoming ever more important.

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Acknowledgements

Prof. Dr. Rüdiger Prasse danke ich recht herzlich für die Chance, diese Doktorarbeit zu schreiben, und für die gute wissenschaftliche Betreuung.

Prof. Dr. Ingolf Kühn danke ich für die recht kurzfristige Übernahme des Koreferats.

Prof. Dr. Christina von Haaren und Prof. Dr. Michael Reich gaben mir die Möglichkeit der Bearbeitung weiterer spannender Forschungsthemen am IUP und somit der Weiterfinanzierung in der Wissenschaft. Hierfür sei gedankt!

Ein riesiges Dankeschön geht an den gesamten Mittelbau des IUPs für die langwierige Unterstützung in wissenschaftlichen Fragen, aber natürlich auch die schöne private Zeit, aus der ich immer wieder Kraft geschöpft habe. Insbesondere seinen hier Frauke Lehrke, Birte Bredemeier, Janine Sybertz, Daniela Kempa, René Hertwig, Christiane Hausmann, Hilke Rühmkorf, Roland Schröder, Nana Wix und Christina Weiß genannt.

Lotta Zoch legte bereits als Studentin ein außergewöhnliches Engagement an den Tag. Vielen Dank dafür und mach so weiter!

Daniel Czamanski, Dan Malkinson, Marina Toger und Daniella Kopel waren die Projektpartner in Haifa, Israel. Ihnen sei für den wissenschaftlichen Austausch und den Einblick in die israelische Flora gedankt.

Martha Graf, Louise von Falkenhayn und Dennis Collentine halfen mit der englischen Sprache und machten somit die Arbeit einer breiten Öffentlichkeit zugänglich. Vielen Dank.

Den Vertretern der Stadt Hannover, der Region Hannover und einigen privaten Flächeneigentümern sei für die Möglichkeit der Durchführung meiner Untersuchungen gedankt. Namentlich H. Grebe, M. Bienek, G. Brunotte, L. Busse, I. Fischer, G. Garnatz, H. Geiges, S. Hallex, H. Illmer, B. Karrasch, C. Peter, H. Scharping, N. Voßler, A. Wenau und C. Wohnrade.

Des Weiteren danke ich meiner ganzen Familie, vor allem Urs Leyhe und Jacob Matthies, für die Unterstützung, die guten Worte und die Geduld mit mir.

Besonderer Dank gilt Frank Schaarschmidt für die Hilfe und Geduld bei statistischen Fragen, aber auch für seine nette Art und die hervorragende Fähigkeit, auch „Nicht-Statistikern“ dieses

Thema mit Freude und auf eine verständliche Art näher zu bringen. Mit deiner Hilfe ist die Arbeit ein gutes Stück besser geworden!

Schließlich danke ich ganz, ganz herzlich Stefan Rüter, ohne den diese Doktorarbeit sicherlich nicht existieren würde: Vielen Dank für den wissenschaftlichen Austausch, die vielen Stunden der tatkräftigen Hilfe und die Aufmunterungen, immer weiter zu machen. Vielen lieben Dank!

Allen, die mir geholfen haben, ganz herzlichen Dank!

Eidesstattliche Erklärung

Hiermit versichere ich, die vorliegende Dissertation selbständig angefertigt und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt zu haben. Die Arbeit wurde noch nicht als Dissertation oder als Prüfungsarbeit vorgelegt.

Teile der Dissertation wurden mit Zustimmung des Betreuers Prof. Dr. Rüdiger Prasse in folgenden Beiträgen vorab veröffentlicht:

Matthies SA, Rüter S, Prasse R, Schaarschmidt F (2015) Factors driving the vascular plant species richness in urban green spaces: Using a multivariable approach. Landscape and Urban Planning 134: 177-187.
doi: 10.1016/j.landurbplan.2014.10.014

Matthies S, Kopel D, Rüter S, Toger M, Prasse R, Malkinson D (2013) Vascular plant species richness patterns in urban environments – Case studies from Hannover, Germany and Haifa, Israel. In Malkinson D, Czamanski D, Benenson I (Eds.), Modeling of Land-Use and Ecological Dynamics. Cities and Nature Springer, Berlin, Heidelberg, pp. 107-118.
doi: 10.1007/978-3-642-40199-2_6

Matthies SA, Rüter S, Schaarschmidt F, Prasse R (2017) Determinants of species richness within and across taxonomic groups in urban green spaces. Urban Ecosystems 20: 897-909.
doi: 10.1007/s11252-017-0642-9

Rüter S, Matthies SA, Zoch L (2017) Applicability of Modified Whittaker plots for habitat assessment in urban forests: Examples from Hannover, Germany. Urban Forestry and Urban Greening 21: 116-128.
doi: 10.1016/j.ufug2016.11.008

Sehnde, den 20.10.2017

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