Technische Universität München
TUM School of Life Sciences

Opening the gates, closing the doors

Deciding for which animals we design wildlife-inclusive cities

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Preface

Almost three and a half years have passed since I left the Netherlands for Germany to start my PhD here. And what an interestingly wild ride it was. Looking back at these years, I can state that I'm quite content with how they turned out.

In all honesty, coming to Bavaria was a bit of a leap of faith. I had worked with plants in cities before, but animals in cities were something that I only passingly dealt with. I came here with the knowledge that I would be investigating what made it possible for animals to be present in cities, but never would I have expected that so much of it would be happening in the social domain. It feels great to have to admit that even after those years of working in the field, it still looks like there's an endless number of things to still discover.

I find that nature in cities is full of surprises. It's both more resilient, and more at risk of being destroyed than I expected. It tries to establish itself in some form or another, often successfully, in almost every nook and cranny that it can find. Even if the environment is extremely hostile, some plant or animal will find a way to use it sooner or later – until it's displaced by the heavy hand of society. There is some beauty to change being one of the constants in the urban environment, and seeing the constant destruction, renewal, and adaptation of different forms of nature.

None of this is possible without the people living in cities. Indeed, they play a key element in making this happen. The hundreds or thousands of people that live in a neighbourhood each have a small say in shaping their environment. If not through official means, then through unofficial means. This horde of stakeholders with individual views, ideals, needs, and history, directly and indirectly dictate the current-day and future structure of the city, and their choices will be felt for generations to come, just as the choices of generations past are still felt in cities today.

To say that I underestimated just how little information there was available on both the animals that we can find and attitudes and views towards animals in cities in

Germany is an understatement. It can best be described as an endless dark void with some occasional beams of light illuminating the little bit of scattered knowledge that we have. Even though it can be somewhat dejecting from time to time to realize just how little is known and how helpful it would be if we would know more, it's heartening that in recent years more and more researchers have taken it to themselves to illuminate parts of that dark void of information. I hope that this trend will continue, and we will learn to use this knowledge to the benefit of society. I'll forever be inspired by people such as Menno Schilthuizen that show just how much of an evolutionary pressure cooker cities are, and people like Hal Herzog that did their best to illuminate how people view and appreciate animals.

In the end, we can hope only that the choices that we make will be looked upon in a positive light by those that come after us. This is one of the drivers for me to continue with what I'm doing: to aid in the creation of a world that's a pleasure to live in for us, but also for those that will follow. As most of us are, and will be, living in cities, this is the prime environment to work on that. I hope that this thesis will find its audience with those that have similar aspirations, and that it will help guide them to knowledge and inspiration to fulfil them.

"And yet, the confrontation with the starkness of this process of conversion makes me sad. Is that inconsistent of me? No – of course we must regret what we lose, but that does not mean that what we gain is worthless."

(Menno Schilthuizen, 2018)

Acknowledgements

Firstly, I would like to thank my Doktorvater Prof. Dr. Wolfgang Weisser for enabling me to study urban ecosystems and learn more about the social aspect of nature. Thank you for your guidance and trusting me to be able to independently figure out things for myself and giving me the freedom to do so. I hope you will continue being successful in all the new fields you expand into, and that you manage to keep the (frankly, at the time of writing, enormous) chair running as smoothly as it is now.

I would also like to thank Thomas Hauck and Peter Noack, whose advise and conversations on fields that I at the start of my PhD was quite unfamiliar with pointed me into the right direction to form a comprehensive view and opinion of both the design of cities and the nature of social sciences.

I'd like to express my gratitude to my colleagues at the chair, who have always been a great source of community and support. For that, I'd like to thank you. Thank you for the fun times and for being such welcoming and kind people. Your experience in academia and insights into it have been enlightening, and your passion for your work is inspiring. I'd like to particularly thank Sven for helping me understand German academia and having great talks about its strengths and weaknesses, and Benjamin for his insights coming from his extensive experience of having been a PhD candidate in the same chair and dealing with everything that comes with doing a doctorate at the TU München. Many thanks to Vicky for the interesting conversations and for being a friend.

Thank you, Monika Egerer, for the interesting conversations and the moral support you gave, even when I complain a lot about what we don't know in the field. Additionally, I'd like to thank the people in the UPE group for being so welcoming and building a community of urban ecologists on our faculty.

I would like to express my thanks to the BAYSICS project, without whose funding I would not have been able to work on my doctorate. It has been very interesting to

see all the different topics that people work on in one project and to experience the ins and outs of a new citizen science project.

I'm grateful to everyone that's worked with me on papers. Your input and points of view have been very enlightening to me. I firmly believe that the effort you've put into our manuscripts has made them better than I would have been able to produce on my own.

Many thanks Norbert Schäffer, Thomas Rödl, and Angelika Nelson from the LBV in Bavaria for their cooperation and collaboration and allowing me to work with the data from the 'Igel in Bayern' project.

I'd like to thank my friends in the Netherlands, who've become like a second family to me and always made me feel like home when I came back to visit. I hope to be able to visit you more often once I'm done.

An express shout-out to my friends in Freising and Munich for keeping me sane and being a community that you can rely on. Thank you for making time for me and hanging out. May the CAW always stay a welcoming place for new international students in Freising, and may we play many more sessions of Dungeons & Dragons in the mystical future where allegedly people seem to have more free time.

Heel veel dank aan mijn moeder, Linda Noordwijk. Je hebt altijd in me geloofd, en zonder jouw advies en hulp had ik het heel veel zwaarder gehad dan ik het nu heb gehad. Ik hoop dat ik je trots kan blijven maken, en dat ik je ooit zo veel terug kan geven als je mij hebt gegeven. Ook heel erg bedankt aan mijn broertjes, Silvio en Enzio, die ondanks hun eigen ups en downs daar voor mij waren mij altijd te hulp zijn geschoten. Ik hoop dat jullie ook bereiken wat jullie willen, en dat ik daarbij kan helpen.

And last, but not least, sincere, and heartfelt thanks to my love, Mar. Thank you for sticking with me on this adventure and believing in me. Your love and support have kept my spirits up and helped me keep my eye on the ball through this journey, and

your sharp mind and understanding societies present and societies past are truly astonishing. Words truly cannot sufficiently translate my gratitude to you.

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Summary

It is increasingly recognized that animals are and have always been an integral part of cities, and that they are here to stay. Even though cities are inherently human-dominated environments and there is a culture of maintaining a rather strong distinction between human and animal spaces, many animals have managed to create their own beastly spaces within the human-dominated cities. This presence of animals in urban areas – sometimes in opposition to the cities' human inhabitants' wants and preferences – can cause conflict between cities' human- and non-human inhabitants.

The observation that there are conflicts between humans and animals in cities complicates the increased effort to include and invite wildlife in the design of cities. Research has shown that nature in cities is beneficial to the physical and mental well-being of people. Projects such as *Animal-Aided Design (AAD)* try to (re)design cities or parts of cities with animals in mind throughout the whole construction process from planning to execution, to finally monitoring of the biological system once the construction is done. While this has proven moderately successful in promoting and maintaining certain animals in cities, a paucity of knowledge and available information with regards to both the ecological and social-ecological patterns and processes in cities necessitates working on assumptions that have yet to be proven right or wrong. Often, even rather basic information such as which or how many animals are present in cities, or how people view different animals in cities is not available, necessitating guesstimating and operating on a trial-and-error base.

In light of the foregoing, this thesis aims to assess some of the basic ecological and social-ecological patterns within urban ecosystems. While they are understandably often treated separately, human attitudes strongly influence the ecology of cities, and this in turn influences how the humans that live in cities perceive nature in cities. While ideally the ideas of this thesis would be used in any project that tries to incorporate animals into the urban fabric, the planning cycle of *AAD* (fig. 1) is used

as a backdrop for this thesis, since it includes both the ecological and social considerations within each stage of the planning cycle. It quickly becomes apparent that already in the first step, the **analysis and concept phase**, you reach the limit of what information and knowledge are available in Germany – where the project and thesis author are based – very early on. There was, before the publication of one of the chapters in this thesis, no estimation of how many – or which – animal species were in German cities, or how they compare with the surrounding environment. Granted that this is probably a consequence of the historical lack of massive (standardized) species occurrence databases such as the *Global Biodiversity Information Facility (GBIF)*, the digitalization of *German State databases*, or the advent of grand global Citizen Science initiatives that aim at collecting occurrence data on different species such as *eBird* and *iNaturalist*, it is hard to fault anyone on

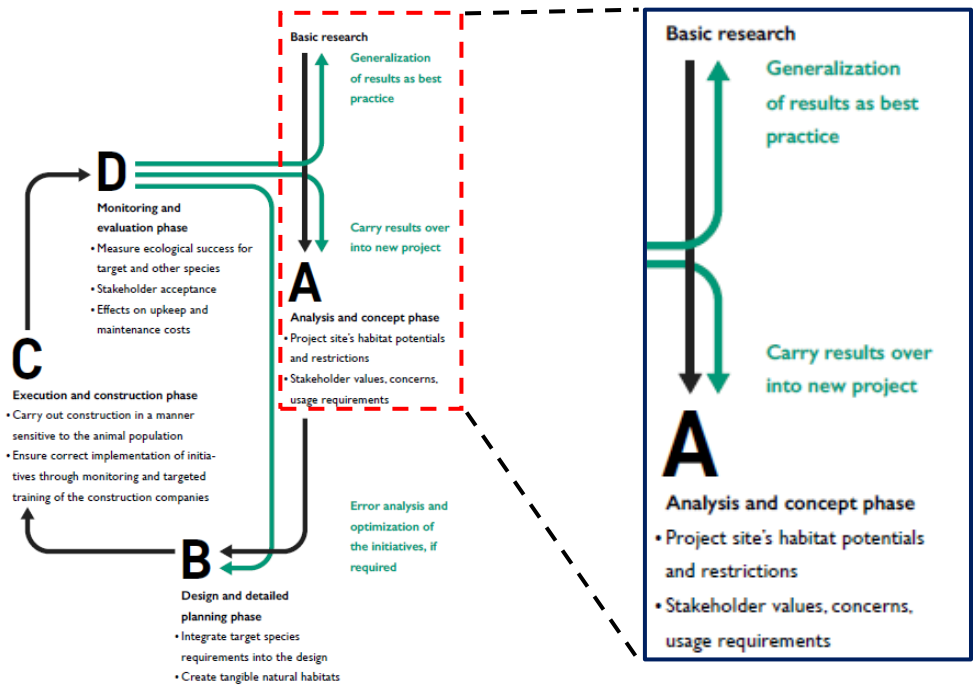

Figure 1. Animal-Aided Design (AAD) planning cycle, with the part of the cycle that this thesis touches on most highlighted. Adapted from: Hauck, T. E., & Weisser, W. W. (2019). Animal-Aided Design in the living environment—Integrating the needs of animal species into the planning and design of urban open spaces. (p. 60).

this, but one would expect that with the age of the current openly available animal occurrence databases, basic investigations such as these would have already been conducted. The situation is very similar on the more social-ecological aspect of the **analysis and concept phase** in AAD, where basic information such as how people perceive different animals in cities or where they want them to be in cities is lacking, or very limited to individual conflict-prone animals or ´animals´ as a nondescript blanket-term. While the existing studies are insightful, this does make comparisons between different animals difficult, if not impossible.

In this thesis, I addressed the basic questions of 1) how many – and which – animals are present in cities in Germany, 2) How much people like the different urban animals, and 3) where people want the urban animals to be and how that relates to how much they like them. These questions relate to the apparent paucity of information on these topics in Germany, and research towards urban nature as a whole. In short, 1) almost half of all animal species within a 50km radius of a city in Germany are also present in the city in question itself, and the vast majority of animal species are present in at least one city in our study, albeit with some variation between the different taxa; 2) students in Germany have very variable attitudes towards the different animals in cities; and 3) inhabitants of Munich (Bavaria) want the various urban animals to different extents in different parts of the city, and tend to want animals closer to their homes if they like them more. Additionally, because of the non-insignificant (short-term) effect of the COVID-19 pandemic not only on the author of this thesis's work but also on the ecology of cities and attitudes towards animals in cities, 4) a COVID-19 lockdown-related pattern in urban animal observations made by citizen scientists will be discussed towards the end of this thesis booklet.

While these questions can stand by themselves, as a collection they provide the start of a synthesis between the ecological and social-ecological patterns in urban ecosystems. The effects of architecture, city planning, management, and other anthropogenic effectors are increasingly being considered with regards to their

effect on urban biodiversity and urban species assemblages. As nature in cities is often there *by the grace* of its human inhabitants, either through tolerance of their presence or promotion of their presence, insights into where human urban inhabitants want animals to be in cities or not might give us an indication of why animals are where they are in cities, and what human actions promote or obstruct their presence in different parts of the cities. These insights could then again be used to design urban structures that are beneficial to humans and animals alike, fitting within the spatial and social context presented.

Zusammenfassung

Es wird zunehmend anerkannt, dass Tiere ein integraler Bestandteil der Städte sind, waren, und dass sie bleiben werden. Obwohl Städte von Natur aus von Menschen dominierte Umgebungen sind und es eine Kultur der strikten Trennung zwischen menschlichen und tierischen Räumen gibt, ist es vielen Tieren gelungen, ihre eigenen tierischen Räume innerhalb der von Menschen dominierten Städte zu schaffen. Diese Präsenz von Tieren in städtischen Gebieten - manchmal im Widerspruch zu den Wünschen und Vorlieben der menschlichen Bewohner - kann zu Konflikten zwischen den menschlichen und nicht-menschlichen Bewohnern der Städte führen.

Dass es in Städten zu Konflikten zwischen Menschen und Tieren kommt, erschwert die verstärkten Bemühungen, wild lebende Tiere bei der Gestaltung von Städten einzubeziehen und einzuladen. Die Forschung hat gezeigt, dass sich die Natur in Städten positiv auf das körperliche und geistige Wohlbefinden der Menschen auswirkt. Projekte wie Animal-Aided Design (AAD) versuchen, Städte oder Teile von Städten unter Berücksichtigung von Tieren während des gesamten Bauprozesses (neu) zu gestalten, von der Planung über die Ausführung bis hin zur Überwachung des biologischen Systems nach Abschluss der Bauarbeiten. Dies hat sich zwar als einigermaßen erfolgreich erwiesen, wenn es darum geht, bestimmte Tiere in den Städten zu fördern und zu erhalten, doch aufgrund des Mangels an Wissen und verfügbaren Informationen über die ökologischen und sozial-ökologischen Muster und Prozesse in den Städten muss von Annahmen ausgegangen werden, deren Richtigkeit oder Unrichtigkeit erst noch bewiesen werden muss. Oft liegen nicht einmal grundlegende Informationen darüber vor, welche oder wie viele Tiere in den Städten vorkommen oder wie die Menschen die verschiedenen Tiere in den Städten sehen, so dass Schätzungen vorgenommen werden müssen und man auf der Grundlage von Versuch und Irrtum arbeiten muss.

Vor diesem Hintergrund zielt diese Dissertation darauf ab, einige der grundlegenden ökologischen und sozial-ökologischen Muster in städtischen Ökosystemen zu

bewerten. Obwohl sie verständlicherweise oft getrennt behandelt werden, beeinflussen menschliche Einstellungen die Ökologie von Städten stark, und dies wiederum beeinflusst, wie die Menschen, die in Städten leben, die Natur in Städten wahrnehmen. Obwohl die Ideen dieser Dissertation idealerweise in einem Projekt verwendet werden sollten, das versucht, Tiere in das städtische Umfeld zu integrieren, wird der Planungszyklus der AAD (*fig. 1*) als Hintergrund für diese Dissertation verwendet, da er sowohl die ökologischen als auch die sozialen Überlegungen in jeder Phase des Planungszyklus einschließt. Es wird schnell deutlich, dass man bereits im ersten Schritt, der Analyse- und Konzeptionsphase, sehr früh an die Grenzen dessen stößt, was in Deutschland - dem Sitz des Projekts und des Verfassers der Arbeit - an Informationen und Wissen verfügbar ist. So gab es bis zur Veröffentlichung eines der Kapitel dieser Dissertation keine Schätzung, wie viele - oder welche - Tierarten in deutschen Städten vorkommen und wie sie im Vergleich zur Umgebung stehen. Zugegeben, dies ist wahrscheinlich eine Folge des historischen Mangels an massiven (standardisierten) Artenobservationsdatenbanken wie der Global Biodiversity Information Facility (GBIF), der Digitalisierung deutscher staatlicher Datenbanken oder des Aufkommens großer globaler Citizen-Science-Initiativen, die darauf abzielen, Observationsdaten zu verschiedenen Arten zu sammeln, wie eBird und iNaturalist, aber man würde erwarten, dass im Alter der aktuellen, offen zugänglichen Tierobservationsdatenbanken grundlegende Untersuchungen wie diese bereits durchgeführt worden wären. Ähnlich verhält es sich mit dem eher sozial-ökologischen Aspekt der Analyse- und Konzeptionsphase AADs, wo grundlegende Informationen darüber fehlen, wie die Menschen verschiedene Tiere in den Städten wahrnehmen oder wo sie sie in den Städten haben wollen, oder sich sehr stark auf einzelne konfliktträchtige Tiere oder "Tiere" als unbestimmten Oberbegriff beschränken. Die vorhandenen Studien sind zwar aufschlussreich, doch macht dies Vergleiche zwischen verschiedenen Tieren schwierig, wenn nicht gar unmöglich.

In dieser Dissertation habe ich mich mit den grundlegenden Fragen beschäftigt, 1) wie viele - und welche - Tiere es in deutschen Städten gibt, 2) wie sehr die Menschen die verschiedenen Stadttiere mögen, 3) wo die Menschen die Stadttiere haben wollen und wie das mit ihrer Beliebtheit zusammenhängt. Diese Fragen beziehen sich auf den offensichtlichen Mangel an Informationen zu diesen Themen in Deutschland und in der Forschung zur Stadtnatur im Allgemeinen. Zusammenfassend lässt sich sagen, dass 1) fast die Hälfte aller Tierarten im Umkreis von 50 km um eine Stadt in Deutschland auch in der betreffenden Stadt selbst vorkommt und dass die überwiegende Mehrheit der Tierarten in unserer Studie in mindestens einer Stadt vorkommt, wenn auch mit gewissen Unterschieden zwischen den verschiedenen Taxa; 2) Studenten in Deutschland haben sehr unterschiedliche Einstellungen zu den verschiedenen Tieren in den Städten; 3) die Einwohner von München, Bayern, wünschen sich die verschiedenen Stadttiere in unterschiedlichem Ausmaß in verschiedenen Teilen der Stadt und neigen dazu, Tiere näher an ihrem Wohnort zu haben, wenn sie sie mehr mögen. Da die COVID-19-Pandemie nicht nur auf die Arbeit des Verfassers dieser Dissertation, sondern auch auf die Ökologie der Städte und die Einstellung zu Tieren in der Stadt einen nicht zu vernachlässigenden (kurzfristigen) Einfluss hatte, wird gegen Ende dieser Dissertation ein mit der COVID-19-Sperre zusammenhängendes Muster bei der Beobachtung städtischer Tiere durch Bürgerwissenschaftler diskutiert.

Diese Fragen können zwar für sich allein stehen, aber in ihrer Gesamtheit bilden sie den Anfang einer Synthese zwischen den ökologischen und sozial-ökologischen Mustern in städtischen Ökosystemen. Die Auswirkungen von Architektur, Stadtplanung, Management und anderen anthropogenen Einflüssen werden zunehmend im Hinblick auf ihre Auswirkungen auf die städtische Biodiversität und die städtischen Artengemeinschaften untersucht. Da die Natur in den Städten oft durch die Gnade der menschlichen Stadtbewohner vorhanden ist, entweder durch Duldung oder Förderung ihrer Anwesenheit, könnten Erkenntnisse darüber, wo die menschlichen Stadtbewohner Tiere in den Städten haben wollen oder nicht, uns

einen Hinweis darauf geben, warum sich Tiere dort befinden, wo sie sich in den Städten befinden, und welche menschlichen Handlungen ihre Anwesenheit in verschiedenen Teilen der Städte fördern oder behindern. Diese Erkenntnisse könnten dann wiederum genutzt werden, um städtische Strukturen zu entwerfen, die sowohl für Menschen als auch für Tiere vorteilhaft sind und sich in den jeweiligen räumlichen und sozialen Kontext einfügen.

Introduction

An introduction to cities

Nature in cities will be hard to comprehend without an understanding of the nature of cities, and urbanization in general. The Merriam-Webster Dictionary defines urbanization as 'the quality or state of being *urbanized* or the process of becoming urbanized', in which 'to urbanize' is 'to cause to take on *urban* characteristics', and 'urban' is 'of, relating to, characteristic of, or constituting a city'. Meanwhile, the Cambridge Dictionary defines urbanization as either 'the process by which more and more people leave the countryside to live in cities' or 'the process of becoming more like a city'. Urbanization is thus defined as many different but related things, with cities being the key element in those definitions. Cities, however, are also defined in a multitude of ways. What constitutes a city has been a long-term subject of debate, with the conclusion often equating to 'depends on who you're asking' (Davoudi, 2008; Fawcett, 1932; Krupat & Guild, 1980; Weeks, 2010, 2010). Definitions of cities and urban areas can range from the simple "… an area occupied by a continuous series of dwellings, factories, and other buildings, harbour and docks, urban parks and playing fields, etc, which are not separated from each other by rural land…" (Fawcett, 1932) – but how many dwellings? – and EUROSTAT's multiple-condition definition that defines cities as local administrative units (LAU's) where at least half of the population lives within a contiguous urban centre with a population density of at least 1500 inhabitants per km^2 with at least 50`000 inhabitants (Koceva et al., 2016), or whether they had acquired official legal city status at some point in the past. These definitions differ in scale, restrictiveness, and even type of condition; they are just a few of the many definitions of cities available. It does not help that there can be quite some heterogeneity in structure and culture between cities, or different historical conditions for an area to be considered a city. They often tend to boil down to some relative level of scale (*relatively* large), population number

(*relatively* large), population density (*relatively* dense), building structure (*relatively* dense and high), ground sealing (*relatively* high levels of impervious surface), and social structures (such as type of employment), but there is no universal one-size-fits-all definition. In other words: places built by people, with many buildings and many people doing many different things that are *not agriculture*. As Weeks (2010) observantly notes, urban and rural are nowadays rather ends of a (might I add, multidimensional) continuum than dichotomous states, described by – among others – variables such as population size, land area, population density, and social and economic concentration.

Nature in cities

At a first glance, cities do not conjure an image of an ecosystem that contains much non-human life. And depending on what city you are in, or where in a city you are, you might be right. There are cities that contain large swathes where the only shade of green you'll see on a walk is an acrylic parasol above a stone terrace. However, cities can be quite heterogeneous in structure, and nature often finds a way to establish itself in unexpected spaces. Examples of this are dandelions, spring draba, and ferns that grow out of bricks on the sides of buildings or canals, or bats and sparrows that use buildings to nest in while using surrounding waterbodies or green areas to forage for food. City pigeons and seagulls might even fight you over food if they see the chance for a quick meal. In contrast to these more rocky built-up areas, there is both very visible and elusive nature in the form of shrubs, trees, and animals in many of the gardens, parks, and abandoned lots in cities (Cornelis & Hermy, 2004; Hansen et al., 2020; MacGregor-Fors et al., 2016; Mayorga et al., 2020; Nielsen et al., 2014; Niemelä, 1999; Paker et al., 2014; Rega et al., 2015; Vergnes et al., 2012).

Figure 2. Even in the most hostile of environments, nature finds a way to thrive and survive. Spring draba (Draba verna) growing out of the moss-covered cracks of a wall of bricks in Leiden, the Netherlands.

Animals in cities

The construction of cities changes many aspects of the environment, which causes the urban environment to favour certain, often more generalist, traits over others and leads to a difference in species composition between rural and urban environments (Aronson et al., 2016). Even though cities are primarily human-dominated environments, animals have always been able to find their space in them. Often despite the wishes of the human inhabitants to strictly separate human and wildlife spaces, a convention established in Europe around the 18th century (Deliège, 2019), wild animals will find their place to live in environments designed to keep them out (Philo & Wilbert, 2000). With the predicted expansion of urban areas (Chen et al., 2020), it has become increasingly relevant to understand nature in cities.

Most animal species that are present in cities are a subsection of the animal species present in the surrounding region (Aronson et al., 2014; Sweet, Apfelbeck, et al., 2022), and despite selection for similar traits in city species, there are only a few global species (Aronson et al., 2014). Studies suggest that bird and arthropod species richness and phylogenetic diversity are reduced in urban areas, and that the communities shift towards species with certain traits (Aronson et al., 2014; Ibáñez-Álamo et al., 2017; Knop, 2016; Morelli et al., 2016; Piano et al., 2020). However, while birds have been particularly well-studied, only a few of the many arthropod taxa tend to be considered (Fenoglio et al., 2020), and other taxonomic groups tend to be understudied. However, for those groups on which studies have been conducted, a similar pattern tends to appear: urban areas support fewer species, and the species that it does support have similar traits (Duchamp & Swihart, 2008; Jung & Threlfall, 2018).

However, the patterns look less negative when one considers Europe, where urban areas have a rather long history. Studies show that in Europe, large proportions of bird species found in the surroundings may also occur in cities (Ferenc et al., 2014; Guetté et al., 2017), that the species richness of terrestrial animals isn't consistently

lower in urban areas (Saari et al., 2016), and that effects of urban areas on biodiversity depend on the structure of a city (Beninde et al., 2015; Ives et al., 2016). Cities are shown to be able to harbour a high species diversity, and are commonly richer in species than the increasingly intensified rural areas around them (Turrini & Knop, 2015).

Human relationships with wildlife in cities

Attitudes towards wildlife in cities

Even though Kellert's earlier work on the attitudes of urban inhabitants towards wildlife was already published in the 80's (Kellert, 1984), studies on the attitudes of urban inhabitants have been scarce and far apart. Most studies regarding the attitudes of people towards wildlife consider big charismatic wildlife such as wolves and bears outside of urban areas. However, in recent years there has been an increased interest towards people's attitudes towards urban animals and the factors affecting those attitudes (e.g. Ambarli, 2016; Baharuddin et al., 2013; Bjerke et al., 2003; Bjerke & Østdahl, 2004; Hosaka et al., 2017; Rupprecht, 2017). Many of these studies concern the attitudes towards potential conflict species that have the potential to be damaging to humans, their belongings, or domesticated animals (Ambarli, 2016; Booth & Ryan, 2019; Manzolillo et al., 2019). A smaller number of studies concern themselves with attitudes towards multiple species, making it possible to compare attitudes towards different animals and sometimes discern where those differences come from (Bjerke & Østdahl, 2004; Muslim et al., 2018; Rupprecht, 2017). Considering that animals are not all viewed and liked equally, and the high density and number of potential stakeholders in urban environments, it is important to consider attitudes towards animals that are already abundant in cities *and* animals that could expand their range into cities, in order to avoid the harshest human-wildlife conflicts in cities and align inhabitant and conservation values.

Where in cities do people want animals to be?

Not only studies related to how well certain animals are liked in cities, but also those related to *where* people want them to be in cities, and how strong the effect of their attitudes towards them are in determining right and wrong places for animals in cities, are rare and spatiotemporally distant. The usage of different methods, and the differences in culture, history, and generational context at each location at any given time makes generalizing rather hard, and specificity is often lacking in favour of using 'animals' as a generalized group. Nonetheless, there is a small body of literature discussing what are considered right or wrong places for animals in cities (Hosaka et al., 2017; Muslim et al., 2018; Rupprecht, 2017), and these studies provide useful insights into the acceptability of animals in cities, which could be used to inform focus points and where more work is needed to convey the importance of urban biodiversity. In general, more studies that investigate location-based attitudes towards specific animals in cities across different places and cultures are needed to be able to provide planners and designers of wildlife-inclusive cities with appropriate guidelines.

Benefits of nature in cities for human inhabitants

Physical and mental well-being

Studies have shown that the urban nature might be beneficial for the physical and mental well-being of human inhabitants (e.g. Farooq, 2022; Fuller et al., 2007; Hansmann et al., 2007; Hartig et al., 2014; Keniger et al., 2013; Reyes-Riveros et al., 2021; Rojas-Rueda et al., 2019; Sandifer et al., 2015; Tzoulas et al., 2007), as well as providing social benefits (Hartig et al., 2014; Kaźmierczak, 2013; Reyes-Riveros et al., 2021). Fuller et al. (2007), for example, demonstrated that in Sheffield (UK) there was a measurable positive association between species richness in urban greenspaces and the well-being of greenspace visitors. More specifically, psychological benefits such as restoration from mental fatigue were strongest in

relationship to firstly plant- and secondly bird-richness, but there was also a positive association with green space area and the number of different habitats in a green space. However, Dallimer et al. (2012) warn that it might not be the plant and animal richness itself that positively relates to well-being, but *perceived* richness, causing a mismatch between the benefits of actual biodiversity and perceived biodiversity. This was especially jarring in their study, since it was also conducted in Sheffield and they observed that people were rather bad at identifying even the most widespread species recorded in ecological surveys. Southon et al. (2018), contrarily, reported that for meadows in Bedford and Luton (UK) they did not find a positive association between health and well-being metrics and perceived species richness. They did, however, find a positive association between perceived species richness and satisfaction of their sites and nature connectedness, as well as a positive association between nature dose (in this study: how often people used the green space) and people's psychological well-being. This is to show that while there seem to be be benefits to human well-being from urban nature, the mechanisms behind the benefits are heterogeneous and unclear because of the correlational nature of most studies (Keniger et al., 2013), and much research still needs to be done to uncover the mechanisms behind perceived benefits of urban nature to a city's inhabitants.

Urban resilience and microclimate

Nature doesn't only bring benefits to people's wellbeing but can also improve urban resilience and the microclimate in cities in numerous ways. For example, greenspaces mitigate the urban heat island effect by regulating the local temperature and providing shade (Gómez-Baggethun et al., 2013; Hardin & Jensen, 2007; Oliveira et al., 2011; Rahman et al., 2017), avoid flooding (Costa et al., 2021; Xiao et al., 2017; Xiao & McPherson, 2011), and vegetation itself can reduce the noise from human activities (Akay & Önder, 2022; Xu et al., 2022) and removes pollutants

from the air (Escobedo & Nowak, 2009). An extensive review of the topic is available in Gómez-Baggethun et al., 2013.

Incorporating nature into the structure of cities

There are numerous projects and initiatives that aspire to increase the amount of nature in cities, to make cities more socially and environmentally resilient, and to provide many other benefits that nature can provide for their environments. Examples of these are URExSRN in the Americas, URBAN GreenUP in the European Union, and the NK Tegelwippen in The Netherlands. Projects such as Animal-Aided Design (AAD: Hauck & Weisser, 2019) and ECOLOPES (Perini et al., 2021) additionally aspire to increase and diversify the presence of animals in cities. To do so, all the necessities for their sustained presence and success need to be available. This a-priori often requires the presence of (sometimes specific) trees, shrubs, lightly managed green, other animals, and occasionally open water or sand (*Animal-Aided Design in the Living Environment - Integrating the Needs of Animal Species into the Planning and Design of Urban Open Spaces.*, 2019). What exactly is required depends on which animals are being promoted (Apfelbeck et al., 2019, 2020; *Animal-Aided Design in the Living Environment - Integrating the Needs of Animal Species into the Planning and Design of Urban Open Spaces.*, 2019). A common misconception is that this all takes up a lot of horizontal space, but many animals are perfectly capable of using vertical space, if designed well. Façades and walls, as well as flat roofs, tend to be essentially unused space that with the right design can be turned into low-maintenance green spaces, without taking away much of the horizontal space that humans tend to want.

This thesis' direct context and contribution to the discipline

Ideally, the findings and methods of this thesis would be used and considered by any project that aspires to increase the amount of nature in cities. The current thesis uses the AAD framework as the background for its reasoning, since AAD incorporates both the ecological and social aspects, while being strongly grounded in the design of cities and incorporates the existing structures of the cities it is applied in into its design and philosophy. The clearly stated steps and necessities, both in knowledge that must be accessible to architects and city planners as well as in necessities for the animals to be considered, that are defined in its framework also allow for critical appraisal of – sometimes glaring – gaps in existing knowledge and methodologies that will need to be addressed in order to improve the odds of success for initiatives of its kind, and avoid preventable complications in the process of greening our cities.

The basic AAD planning cycle is as follows (*Animal-Aided Design in the Living Environment - Integrating the Needs of Animal Species into the Planning and Design of Urban Open Spaces.*, 2019):

A. *Analysis and concept phase.* The habitat potential and ecological restrictions of the project site are investigated with the knowledge of (urban) ecological research. Human stakeholder values, concerns, and usage requirements are addressed, in order to not plan something that is disliked by said stakeholders.
B. *Design and detailed planning phase.* The habitat requirements for selected target species are integrated into the design. This boils down to creating tangible and functional natural habitats for these target species, respecting their ecological requirements.
C. *Execution and construction phase.* Construction of the project is carried out in a way that is not detrimental to the (existing) animal population. Care has to be taken that the measures in the design are correctly implemented –

through monitoring and targeted training of the involved construction companies.

D. *Monitoring and evaluation phase.* After construction is done, a long-time monitoring scheme should be implemented for the project site to investigate the ecological success of the measures, the stakeholder acceptance of the measures and animals over time, and the effects of the measures on upkeep and maintenance costs over time.

The knowledge gained from the ecological, social, and economical success of the project can then be used to expand the body of literature on the topic through research, and it can be used to improve plans for future projects to promote animals in cities in a sustainable manner.

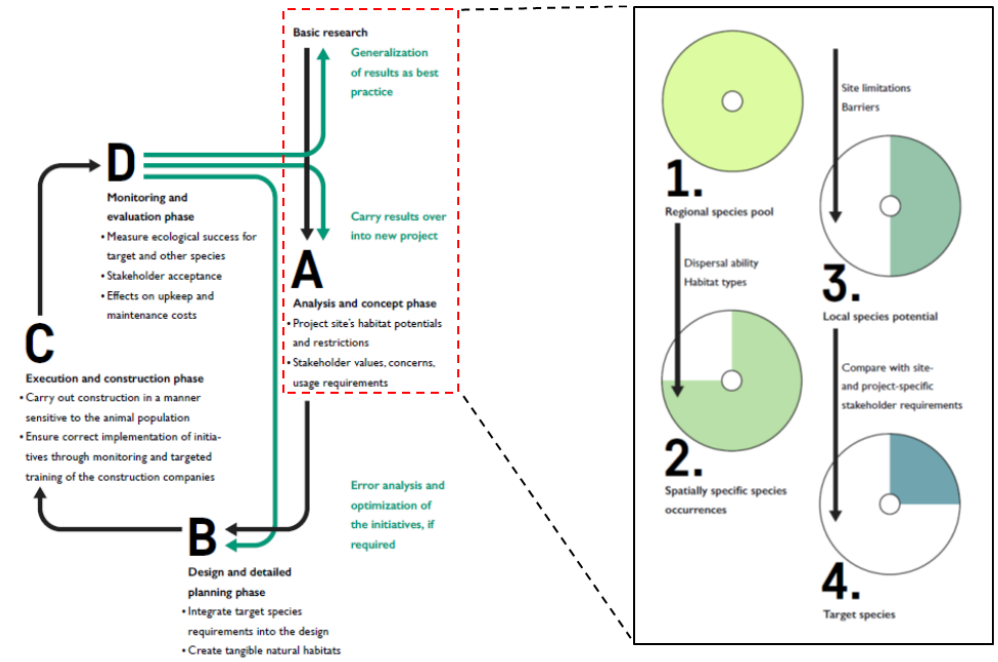

Figure 3. The planning cycle of Animal-Aided Design (left) with special focus on the selection mechanism for target species at project sites (right). Adapted from Hauck & Weisser, 2019, fig. 1 & 2.

The work in this thesis mostly relates to adding basic research to the body of literature in the field so that the designers can make better informed choices in the design process. Specifically, it relates to the selection of target animals at the start of the planning cycle. The first study of this thesis aims to produce expectations for how many animals from the regional species pool can be expected to be present in the city, to give an indication of the richness of the city compared to the surrounding region. This relates mostly to circles 1 and 2, and somewhat to circle 3 in *fig. 3*. The second and third studies of this thesis aim to produce reasonable expectations of how people in German cities might value different animals in cities. The second study relates positive or negative attitudes to urban animals to how familiar German students are with them, and the third study relates where in their city and how far away from their homes the inhabitants of Munich want the animals to be to positive or negative attitudes towards them. Summarized, the first study indicates the unfiltered potential for animals in the city, and the second and third studies indicate the – not regarding specific locations' habitat and other limitations – potential target species after stakeholder preferences have been considered, so to speak.

The final study of this thesis touches on a more fundamental issue regarding knowledge generation necessary for any framework that incorporates animal observation data to function by considering how a severe social disruption, in this case that experienced during the first lockdown of the COVID-19 pandemic, influences citizen science observation data. Many biodiversity investigations use (publicly available) citizen science data because of the sheer quantity of data and the limits of what a single or a group of researchers can observe in comparison to the wider populace. While there are known challenges with the usage of citizen science data in research, often related to error and bias (Bird et al., 2014; Johnston et al., 2022), in general, citizen science data has been invaluable for ecological research (e.g. Border et al., 2017; Gordo et al., 2021; Greenwood, 2007; Smith et al., 2021; Sweet, Rödl, et al., 2022). The first study of this thesis is one such investigation that uses public citizen science data in addition to government-managed data. It is

imperative to know how these kinds of social disruptions affect citizen science animal observation collection efforts, and how we might deal with potentially abnormal observation patterns that emerge as a result, in order to safeguard the quality of basic research. For this goal, we used five years of hedgehog observation data from the LBV in Bavaria. Additionally, and importantly, differences in hedgehog observation pattern changes on different levels of urbanization were investigated, as the restrictions imposed to combat the pandemic altered people's mobility patterns, which could in turn affect observation patterns on different urbanization densities (Basile et al., 2021; Crimmins et al., 2021; Kishimoto & Kobori, 2021; Manenti et al., 2020; Rose et al., 2020; Sánchez-Clavijo et al., 2021).

As a whole, this thesis aims to facilitate the design of wildlife-inclusive urbanism by providing much-needed knowledge and methods that are vital, yet lacking, in the young and developing field of urban ecology.

Methods

The studies that make up the chapters of this thesis each use different methods, so to summarize them in one unified methods section here would not be possible. Thus, each study's methods will be summarized shortly in writing and later in *table 1* at the end of this chapter.

The first study of this thesis is an investigation of the animal species-richness of German cities in comparison with the 50km radius around their centre, based on both publicly available data and data of the different German state governments. The second study is based on a survey investigation on the relationship between how familiar German students are with 91 different urban animals in Germany and how much they like them. The third study follows up on that with a survey that is designed to investigate place- and scale-based attitudes towards 32 animals in Munich, Germany. Finally, the fourth study assesses the effect of the COVID-19 pandemic on citizen science data with use of hedgehog observations done by citizen scientists of the LBV from 2016 to 2020.

Study areas

The investigations in this thesis are all conducted in Germany. The studies are conducted on various different spatial scales and regions of differing sizes. Reasons for this stem from the nature of the questions asked, limitations of data availability, and practical feasibility of the investigation on certain scales. The first study considers Germany on a national level; the second study considers students across a few cities in Germany; the third study considers the inhabitants of the city of Munich alone, as a consequence of the nature of the question, practical usage of the knowledge, and feasibility of the investigation; The last study focuses on patterns within Bavaria.

In the following section is a short description of the areas relevant to this dissertation, followed by the methods of the individual studies.

Germany

The country of Germany is situated in the middle of Europe and is part of the European Union (*figure 4*). It is the fourth biggest country in the EU with a size of 357'376 km^2 and has the largest population with over 83 million inhabitants (Eurostat, 2022). In 2021, more than 77% of the German population lived in urban areas (United Nations, Department of Economic and Social Affairs, Population Division, 2019). Germany is a federal parliamentary republic comprised of 16 states, three of which are city-states. The 16 states each have their own constitution and are largely autonomous.

Bavaria

Bavaria is the biggest state in Germany and contains the geographical centre of Europe. More than 13 million people live on the approximately 70'550 km^2 land of this state. Bavaria has a southern and south-eastern border with Austria, of which a big part are the Alps.

Munich

Munich is the capital city of the Free State of Bavaria, Germany. Within its 310.7 km^2 urban area, it houses more than 1.5 million inhabitants (Statistisches Amt der Landeshauptstadt München, 2021).

Figure 4. Map of Germany's location in Europe and in the world. Germany is indicated in the dotted area, bordering countries are indicated in grey. Within Germany, the 16 German states are indicated.

Study 1: Data from public and governmental databases show that a large proportion of the regional animal species pool occur in cities in Germany

Data collection and processing

As part of a previous study, 23 cities in Germany (*figure 5*) including at least one from each of the states of Germany were selected. Fifteen of these were chosen because they contained a site of another research project on promoting animals in cities (Weisser & Hauck, 2017), followed by eight more with more than 100 000 inhabitants. The political boundaries of these cities were collected, and a 50km buffer around each one was drawn.

Observation data of 11 taxa was requested from GBIF and the individual German states. These taxa were *Amphibia, Aves, Mammalia, Reptilia* (vertebrates), *Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera* (insects), and *Araneae* (arachnids). Data from 1980 until 2018 was used because animal observation records in Germany strongly increased around that period of time. The data that was within the 50km radii around the city centres was then kept.

The data was not uniform and needed to be processed before analysis. Records that were erroneously georeferenced to the country, that were close to biodiversity institutions with dead and live animals (such as museums and zoos), that were not in Germany, or had any other spatial anomaly were removed with the 'CoordinatecCleaner' (Zizka et al., 2019) R-package. Following that, any record that was not a field observation was removed, and metadata was used to remove any additional record that was related to biodiversity institutions. Furthermore, observations where the species was unknown or hybrid were removed from the data, and subspecies were simplified to their binomial name. Synonym names of vertebrate species were changed to their currently accepted scientific names.

Where available, the red list of Germany was used to decide whether species would be kept in the analysis, and for species that were not in the red list a cut-off of 50 observations was made to decide whether it would be kept or not.

After data processing, 5.568.438 datapoints in the GBIF dataset and 2.623.835 datapoints in the federal state dataset were used for further analysis.

Data analysis and statistics

The lists of species observed inside the cities and in the surrounding areas were compared to each other. We calculated 1) the number of species occurring only in the surrounding areas, 2) the number of species occurring both in the surrounding areas and in the city and 3) the number of species only found within the city. This analysis was performed for every taxon, city, and dataset separately. We investigated whether there was a significant difference between the mean species richness of cities and their surroundings using paired t-test. We also compared the combined species pools of the cities and the surrounding areas with each other for each taxon. This was done for both data sources (GBIF and the German states) separately. These analyses were done twice: 1) with all available cities, and 2) using the cities*taxon combinations with a Chao sample coverage of more than 0.85, estimated using the iNEXT (Chao & Jost, 2012; Hsieh et al., 2016) R-package. Finally, using Generalized Additive Models (GAM) (Wood, 2021) we analysed the relationship between the percentage of species of the whole 50-km buffer that were present in the cities and the percentage of observations that were made within the cities.

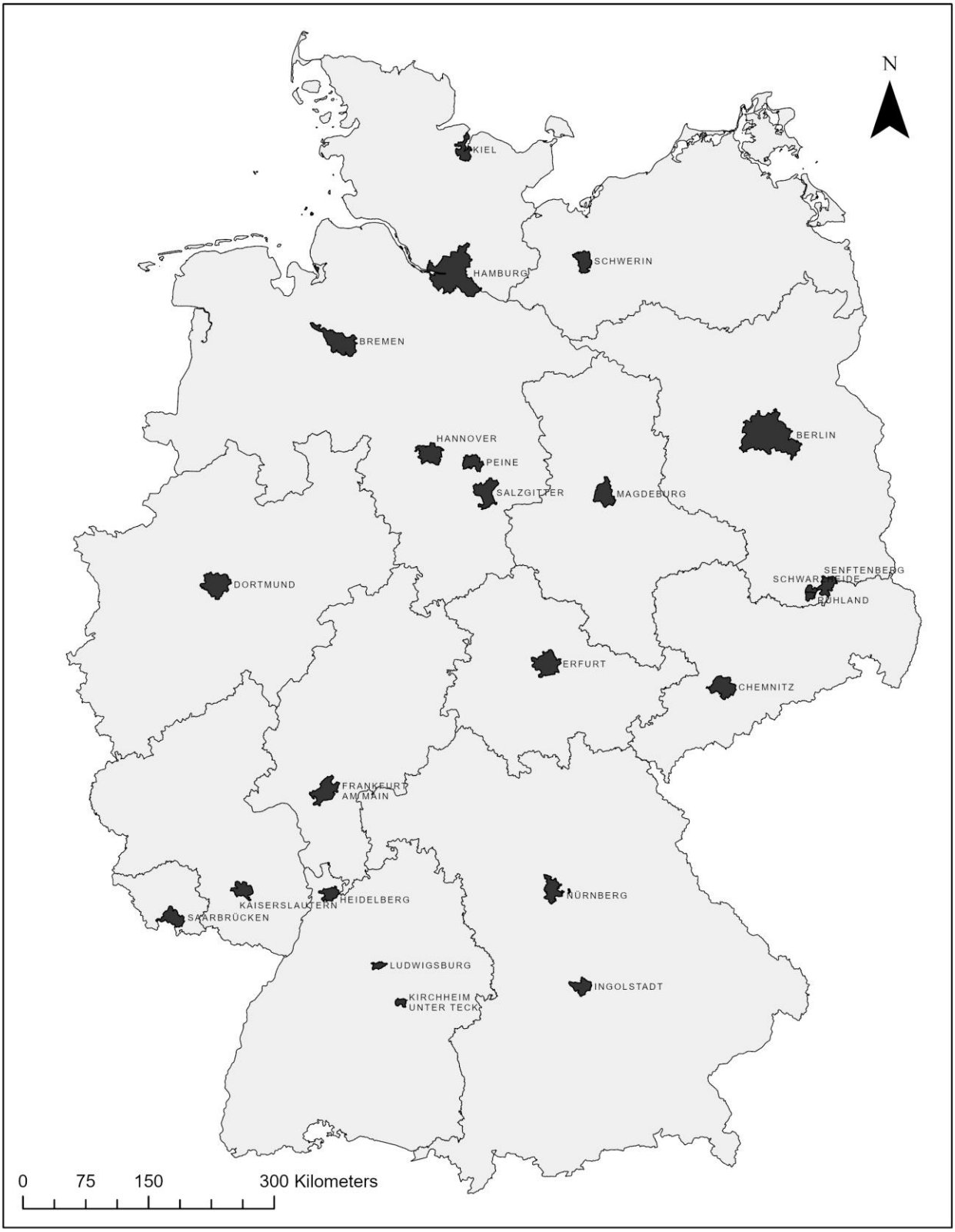

Figure 5. Map of Germany with the cities where the species pool of the surrounding region was compared with the species pool of the city itself. Cities are indicated in black and are labelled with their respective names.

Study 2: The relationship between knowing and liking for 91 urban animal species among students

Data collection

An online questionnaire was made with SoScisurvey (Leiner, 2019), and then distributed to students at the Technical University of Munich, the University of Jena, and the University of Kassel. Students were informed beforehand about the goals of the survey and could voluntarily join at any time that was convenient for them by following a link or QR code to the questionnaire. Students were also encouraged to share the questionnaire with others. If at any time during the filling in of the questionnaire they did not want to continue, they were free to drop out and revoke their participation, at which point their answers would not be considered in the analyses. Our procedure assured full anonymity, and it is not possible to trace answers back to people. The questionnaire could be answered in German and in English. The survey was administered from 22.10.2019 until 12.02.2020.

We asked six basic demographic questions, of which two were facultative, followed by questions about each of the 91 animals: how familiar students were with them (3-point Likert scale) and how much they liked them (5-point Likert scale). The 91 animals were chosen among mammals, birds, reptiles, amphibians, arthropods, and other invertebrates in order to cover a wide range. We deliberately chose some animals that many people may not know but that are sometimes closely related to human settlements. Taxa that were difficult to distinguish for non-experts due to similarity or small size were grouped at the higher commonly recognized taxonomic level, such as genus (e.g., redstarts and dormice) and in some cases higher taxonomic levels (e.g., spiders). Common names for the animals were used in lieu of their scientific names.

Data analysis and statistics

In order to test whether participants' mean familiarity with the animals and attitudes towards them differed significantly from neutral, two-sided Bonferroni-corrected T-tests were used. The same analysis was applied to higher taxa, on which additionally pairwise comparisons were performed.

Correlation analyses were used to investigate the relationship between familiarity with the animals and their attitudes towards them. Additionally, the relationship between the variability of attitudes towards the animals and familiarity with them was tested.

Study 3: There's a place for every animal, but not on my lawn: a survey on attitudes towards urban animals and where people want them to live

Data collection

We designed a survey to investigate how the attitudes of Munich's inhabitants towards 32 animals related to where they placed them in their city. A subset of the co-authors (not including the author of the current dissertation) then distributed 10.000 flyers to houses and residential buildings around 40 squares in Munich. The chosen squares were spread over different parts of the city that had variable levels of greenness and building density, as to gain a representative overview of the living conditions in the city. The administration period of the survey was between 14.06.2021 and 11.07.2021 and it was conducted in German. Only people who were 18 years or older and accepted the consent form to join the survey could participate, and 305 people across 38 squares did (*figure 6*).

Questions relating to the attitudes of the participants towards each animal were answered on a five-point Likert scale (1 = do not like at all; 5 = like very much). Participants then indicated where they wanted each animal to be: *at their home*, *on their balcony*, *in their garden*, *in their neighbourhood*, *in city parks*, *somewhere else in the city*, *outside of the city*, or *nowhere at all*, with these locations not being mutually exclusive choices.

Data analysis and statistics

The locations that the participants could choose were classified into three relational scale levels: *the homezone* (ordinal value 0)*, the neighbourhood scale* (ordinal value 1)*, and the city-wide scale* (ordinal value 2) (*figure 7*). 'Nowhere' was excluded from the analyses relating to the relational scale because it didn't indicate a location that participants wanted the animals to be on, but rather an absence of that.

Figure 6. ***Main map****: map of Munich with the number of people around each square that participated in the survey regarding where inhabitants of Munich would like certain animals to be in the city in relationship to how much they like the animals. The size of each circle indicates the number of participants from the respective square. The names of the squares are indicated next to their respective circles.* ***Upper right map****: Location of Munich in Germany.* ***Lower right map****: Location of Germany in the world.*

Figure 7. Relational scale groupings of the locations in this study. Green shaded areas indicate (urban) green spaces. Black shaded areas indicate traditionally human dominated locations. Home, garden, and balcony were set in the homezone; the neighbourhood and city park were set on that the neighbourhood scale; the whole city and the outside of the city were set on the city-wide scale. From: Sweet et al. manuscript in progress.

Linear mixed-effect models and generalized linear mixed-effect models were used for statistical analysis, with the anonymized participant ID numbers number as random effect to account for the fact that each participant answered the questions about each individual animal. The analyses were as follows:

1) differences between animals in the number of locations chosen,
2) probabilities that the animals were placed at each location,
3) differences in scale levels where participants placed the animals,
4) differences in attitudes towards the animals,
5) whether the scale level that participants placed animals on was related to their attitudes towards hem,
6) whether the number of locations participants placed the animals on was related to their attitudes towards them.

Potential associations between animals and locations were investigated using a PCA based on the results of analysis 2.

Study 4: COVID-19 lockdown measures impacted citizen science hedgehog observation numbers in Bavaria, Germany

Data collection

Hedgehog observation data was requested from the LBV (Landesbund für Vogelschütz e.V.) in Bavaria. This data was collected as part of their 'Igel in Bayern' (hedgehogs in Bavaria) project, where citizen scientists record hedgehog observations, which started in 2015 and is still active. Duplicate observations were resolved after obtainment in order to clean the dataset, and only data collected between 2016 and 2020 were used for analysis. After cleaning and selection of years, 83.008 observations remained over the five years (*figure 8*).

In order to be able to investigate any effect of the COVID-19 lockdown on the share of more-and-less urban observations, the 20m * 20m resolution 2015 impervious surface density map was downloaded from the European Union's Copernicus Land Monitoring Service (Langanke, 2016), and the mean imperviousness density of a 200m radius circle around each hedgehog observation was calculated.

Data analysis and statistics

Generalized additive models were used 1) to compare the number of hedgehog observations each week in 2020 with those of the four preceding years and 2) to compare the observations made *per person* each week in 2020 with those of the four preceding years. To see whether the share of observations in different urbanization levels during the first COVID-19 lockdown were aberrant compared to the same time-period in preceding years, the observations were divided into increments of 20% impervious surface density and linear models were built between 2016-2019 and extrapolated into 2020 to create an expected proportion of observations in each urbanization level. The expected range of proportions in each urbanization class was then compared to the realized proportions in 2020.

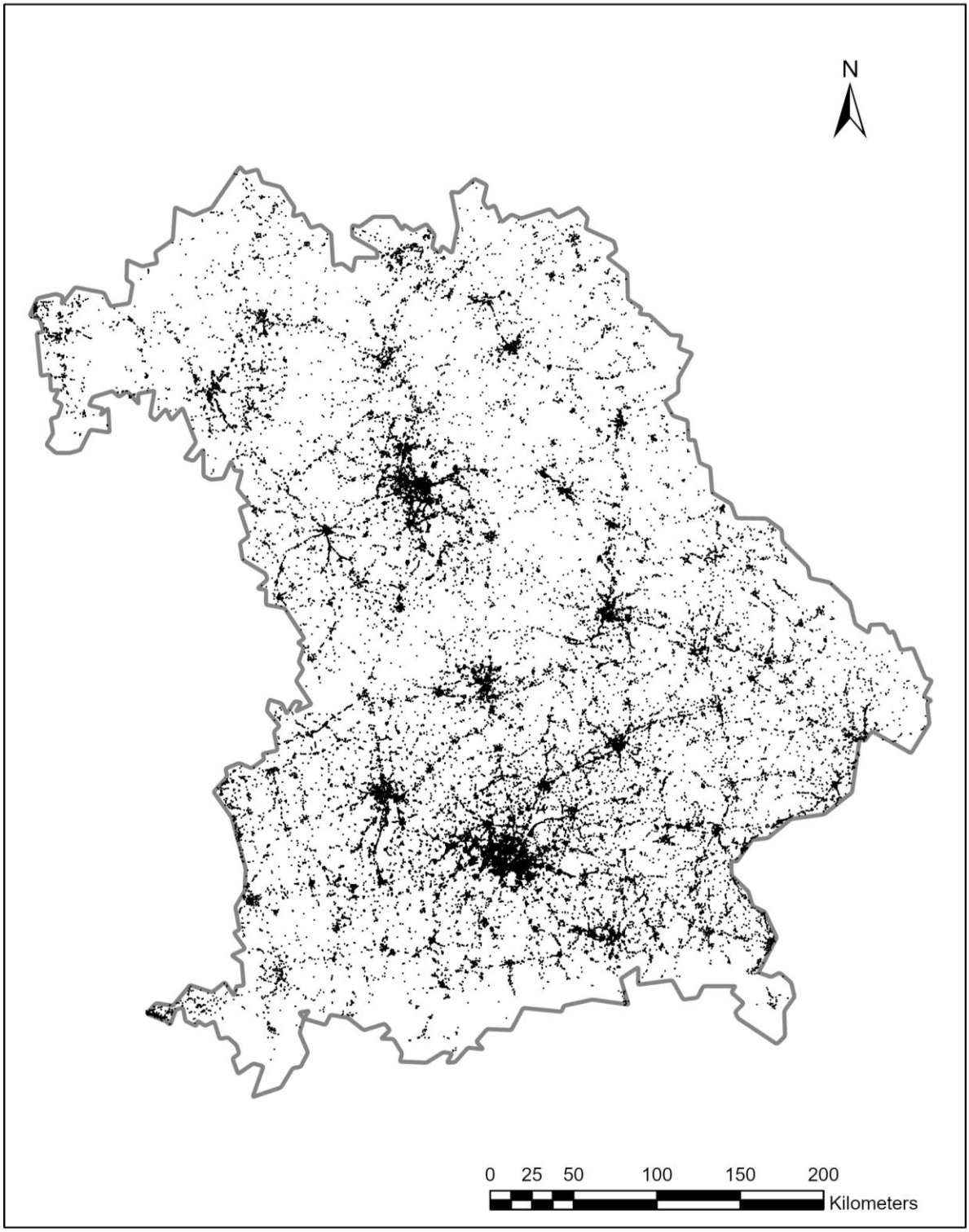

Figure 8. Pointcloud of all hedgehog observations made with the LBV's "Igel in Bayern" (Hedgehogs in Bavaria) project between 2016 and 2020. Every black point indicates an individual hedgehog observation.

Table 1. Tabular summary of the methods of the different studies of this dissertation. More detailed

Study Title	Authors	Journal	Region	Scale
Data from public and governmental databases show that a large proportion of the regional animal species pool occur in cities in Germany.	Fabio S.T. Sweet; Beate Apfelbeck; Maximilian Hanusch; Cynthia Garland Monteagudo; Wolfgang W. Weisser	Oxford University Press - Journal of Urban Ecology	Germany	National
The relationship between knowing and liking for 91 urban animal species among students	Fabio S.T. Sweet; Peter Noack; Thomas E. Hauck; Wolfgang W. Weisser	SocArxiv: PREPRINT - Journal TBD	Germany: Munich, Jena, and Kassel	Multiple cities
There's a place for every animal, but *not in my back yard: a survey on attitudes towards urban animals and where people want them to live*	Fabio S.T. Sweet; Anne Mimet; Md Noor Ullah Shumon; Leonie P. Schirra; Julia Schäffler; Sophia C. Haubitz; Peter Noack; Thomas E. Hauck; Wolfgang W. Weisser	TBD	Munich	City
COVID-19 lockdown measures impacted citizen science hedgehog observation numbers in Bavaria, Germany	Fabio S.T. Sweet; Thomas Rödl; Wolfgang W. Weisser	Wiley - Ecology and Evolution	Bavaria	State

methods sections are included in the different studies' dedicated sections.

Study type	Data collection method	Data processing	Data analysis methods	Timeframe
Spatial big data analysis	Request data from German states officials Download publicly available data from GBIF	Data cleaning using RStudio and QGIS.	Paired T-Tests. Sample coverage estimation with iNEXT R-Package (Hsieh et al. 2016)	1980-2018
Survey	Survey using online questionnaire via SoSciSurvey - data directly importable to Rstudio Visit lectures to explain survey to students and invite them to join survey and invite others - voluntarily and anonymous	Data wrangling - turning wide data into long data format Calculate summary statistics in RStudio	Bonferroni-corrected T-Tests Correlation analyses with Pearson's correlation coefficient	22.10.2019 - 12.02.2020
Survey	Survey using online questionnaire via SoSciSurvey - data directly importable to Rstudio Put printed invitation to survey in Mailboxes around squares in Munich and promote on BAYSICS portal	Data wrangling - turning wide data into long data format Calculate summary statistics in RStudio	Linear mixed-effect models Principal Component Analysis Generalized linear mixed-effect models	14.06.2021-11.07.2021
Spatial big data analysis	Request hedgehog observation data from LBV in Bavaria Download 20 m x 20 m resolution 2015 impervious surface densiy map of the European Union's Copernicus Land Monitoring Service	Data cleaning using ArcGIS Pro and Excel Calculate impervious surface density around every observation point	Generalized Additive Models Linear Regression to create prediction intervals	2016-2020

Studies: Overview and Results

This thesis contains four studies consisting of – at the time of writing – two published research articles, one manuscript in review, and one manuscript ready for submission. In the following, a summary of and a statement of all the authors contributions in each study will be presented. The complete manuscripts are attached in *Appendices A-D*

1. Data from public and governmental databases show that a large proportion of the regional animal species pool occur in cities in Germany

Fabio S.T. Sweet, Beate Apfelbeck, Maximilian Hanusch, Cynthia Garland Monteagudo, Wolfgang W. Weisser

Published in *Journal of Urban Ecology* 8(1), 2022

DOI: 10.1093/jue/juac002

Summary

One of the issues regarding welcoming more animals into the city is that, at least in Germany, there is a lack of information on what animals *are* present in cities. This is partially because of a lack of observation data within the city, and partially due to the relative novelty of research on urban biodiversity. Knowledge of urban biodiversity and potential urban species is vital for the planning and design of spaces for animals in cities, as all of their life-cycle necessities need to be met for them to form a stable presence.

Because a basic inventory of the species richness in German cities was not available, we investigated for 11 animal taxa, of which were four vertebrate groups (*Amphibia, Aves, Mammalia, Reptilia*), six were insect groups (*Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera*), and one arachnid group (*Araneae*), whether they were present in and around 23 German cities, including at least one city from each of the 16 German states. For this, we requested species observation data from two data sources: the Global Biodiversity Information Facility (GBIF) and the German states. Animal occurrence records in a 50km radius around the centre of each city were compared to the respective city were extracted, and after data processing, 5.568.438 datapoints in the GBIF dataset and 2.623.835 datapoints in the German state dataset were used for further analysis.

For each database and taxon we analysed all cities where the number of occurrences of a taxon was ≥50, and additionally did a separate analysis where Chao's sample

coverage was >0.85. Of 253 possible city*taxon combinations, in the GBIF dataset 141 fulfilled the criterion of ≥50 observations, and 120 of these additionally fulfilled the criterion of >0.85 sample coverage; in the German states dataset there were only 62 combinations that fulfilled the criterion of ≥50 observations, and of these 58 additionally fulfilled the criterion of >0.85 sample coverage.

Firstly, the animal occurrence records within each city were compared to those in their respective surrounding region, for each taxon individually, and for all taxa together. Across all taxa, without the sample coverage cut-off of >0.85, on average 38.9±7.1% (GBIF) and 34.5±12% (German states) of the species in the regional species pool was found in the city; with the sample coverage cut-off these numbers increased to 44.9±7.2% (GBIF) and 40.8±9.6% (German states). The percentage of species from the regional species pool represented in their respective cities was not equal between regions and could range from more than 20% to almost 70%.

Then, all cities were pooled together and the cumulative species pool of all the cities together was compared to that of surrounding regions. Without the sample coverage cut-off of >0.85, the percentage of species in the surrounding regions' species pool that was found in at least one of the cities was 83.2% in the GBIF dataset, and 75.3% in the German states' dataset; with the sample coverage cut-off these numbers were 84.1% and 74.2% respectively.

Even though the numbers might slightly vary between datasets, our results show that the vast majority of species also occur in cities, but also that they don't occur in all cities. Species richness was not equal amongst the cities, and there were also differences visible amongst taxa in how much of the regional biodiversity was represented in the cities. Since there was no earlier inventory of the recorded animal species richness in German cities, this study provides an expectation of potential species richness of German cities compared to their surroundings. It establishes that many animals actually do call German cities home, and that it would be worthwhile

to investigate which factors benefit urban biodiversity to better plan and design for wildlife-inclusive cities.

Author's contributions

F.S.T.S. participated in the conceptualization of the study together with **B.A. and W.W.W.. B.A., W.W.W., and M.H.** requested the governmental dataset. **M.H.** and **C.G.M.** standardized the governmental dataset and designed the basis for the cleaning of the dataset. **F.S.T.S.** requested the GBIF data**. C.G.M. and M.H.** assisted in processing the dataset and offered critical advice in the dataset's initial exploration. **F.S.T.S.** prepared the datasets for analysis: this includes data cleaning and selection. **F.S.T.S** performed formal analysis, wrote the original draft, and produced all figures. **All authors** reviewed and edited subsequent versions of the manuscript.

2. The relationship between knowing and liking for 91 urban animal species among students

Fabio S.T. Sweet, Peter Noack, Thomas E. Hauck, Wolfgang W. Weisser

Under review in *Animals*

Preprint available on *SocArXiv* (2020)

Preprint DOI: 10.31235/osf.io/gv6yx

Summary

Even though there is growing consensus that nature should be promoted in cities, there is little information on what kind of nature the human inhabitants of these cities prefer. One hypothesis is that people like nature that they are more familiar with better. Currently, studies on attitudes towards urban nature, and urban animals especially, are scarce and spatially- and temporally far apart. In order to lead projects that aspire to promote biodiversity in a city to a successful conclusion, it is not only necessary to know what the potential promotable species are, but also mind the acceptance of the people that will then live in and around them.

Using questionnaires, we studied the familiarity and attitudes of 475 students towards 91 urban animals in Germany and investigated whether familiarity towards the animals affected their attitudes towards them. The students were on average quite familiar with most animals in the survey but didn't like all of them equally. Most birds, mammals, reptiles, and amphibians were well liked, but attitudes towards arthropods and gastropods varied wildly per animal.

For more than two-thirds of the animals, the attitudes of people that were more familiar with them were higher than the attitudes of people that were not so familiar with them. For two of animals, people that were more familiar with them liked them less, and for the rest of the animals there was no significant correlation between how familiar people were with them and how much they liked them. When the average familiarity and attitude scores of the animals were tested for a correlation, the

analysis indicated that the more familiar animals were not per sé the better liked ones, but that attitudes towards the animals were more extreme if people were more familiar with them.

These results indicate that people like individual animals more if they are more familiar with them, but that attitudes to animals are not only dependent on how familiar they are with them. It rather modulates the general attitude towards individual animals primarily for the better, but also sometimes for the worse, in combination with other factors that influence their attitudes towards them. Knowing which animals are liked or disliked can help to anticipate which animals might be acceptable for people in urban environments and which could be considered a nuisance, and could help indicate for which extra care should be taken in the planning and design of wildlife-inclusive urban environments.

Author's contributions

P.N., T.E.H., and W.W.W. conducted a pilot to the study. **F.S.T.S.** participated in the conceptualization of the study and methodology together with **P.N., T.E.H., and W.W.W.**. **W.W.W. and F.S.T.S.** distributed the questionnaires at the TUM, **P.N. and F.S.T.S.** distributed the questionnaires at the FSU, and **T.E.H.** distributed the questionnaires at Uni Kassel. **F.S.T.S.** performed formal analysis with guidance of **P.N.**. **All authors** participated in the writing of original draft. **F.S.T.S.** produced all figures. **All authors** reviewed and edited subsequent versions of the manuscript.

3. There's a place for every animal, but not in my back yard: a survey on attitudes towards urban animals and where people want them to live in Munich

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Summary

Not only is it important to know which animals people like in cities, it's also important to know where they want them to be. While there have been few studies that investigated people's attitudes towards animals, there have been even fewer that investigated where people want them to be in cities, and only a handful of studies that considered whether attitudes might affect where in cities people want the animals to be. The few studies that considered where people wanted the animals to be are spatially very far spread apart and show that such things are dependent on where you ask the question. Additionally, only one of these considered the question for animals individually instead of 'animals' as a fluffy term.

We conducted an online survey on inhabitants of Munich to investigate their attitudes towards 32 urban animals and where they want them to be. Attitudes towards animals were rated on a five-point Likert scale. Participants indicated for each animal whether they wanted them to be *at their home*, *on their balcony*, *in their garden*, *in their neighbourhood*, *in the city park*, *somewhere in the city*, *outside of the city*, or *nowhere*. These locations, with the exception of *nowhere*, were then clustered into relational scales. The first three were placed in *the homezone,* the following two on the *neighbourhood scale*, and the last two on the *city-wide scale*.

Our results indicated that animals were not equally wanted on the different locations, and that there was variation between and within taxa on where people placed the animals. There were, however, also some general patterns across

animals: 1) people primarily did not place animals in *the homezone*, but placed them more readily in the *neighbourhood scale* and the *city-wide scale*; 2) Within all of the relational scales, participants also placed the animals more readily in the traditionally greener spaces than traditionally built-up areas; 3) people that liked an animal more placed it closer to their home, and the on average better liked animals were also on average placed closer to home – this was true for all animals considered but with variation in effect strength; and 4) people that liked an animal more additionally placed it on more locations, and the on average better liked animals are also the animals that tend to be placed on more locations – this was also true for all animals considered but with variation in effect strengths.

This study shows that people place animals closer to home if they like them more, but also that they mostly do not place them close to their homes. This has elements of NIMBY-ism, especially since they are a lot more willing to have the animals somewhere in their neighbourhood, as long as it's not directly at their homes. The knowledge gained from this study can be used by planners and architects as an indication of the willingness of people to have certain animals close to their homes when designing for more wildlife-inclusive cities. Follow-up studies should try to establish how demographics, exposure, and habits influence the willingness of people to have these animals in different places in the city. Additionally, if replicated in more different places across the globe with animals of similar functional groups, the generalizability of these patterns can be investigated to see whether the patterns found in Munich are generally applicable to the design of cities for animals and humans around the globe.

Author's contributions

F.S.T.S., M.N.U.S., L.P.S., J.S., S.C.H., and W.W.W. drafted the original concept. **F.S.T.S., M.N.U.S., L.P.S., J.S., S.C.H., P.N., and W.W.W.** designed the original methodology. **M.N.U.S., L.P.S., J.S., and S.C.H.** distributed the flyers to the

questionnaires around Munich. **M.N.U.S., L.P.S., J.S., and S.C.H.** performed preliminary analysis. **F.S.T.S.** performed formal analysis with guidance of **P.N. and W.W.W.**. **F.S.T.S.** wrote the original draft and produced all statistical figures. **T.E.H.** produced *figure 1* of the manuscript. **All authors** contributed to the subsequent versions of the manuscript.

4. COVID-19 lockdown measures impacted citizen science hedgehog observation numbers in Bavaria, Germany

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Summary

Opportunistic species observations, including most done by citizen scientists, are spatially and temporally based on when and where there are people. While these types of observations are the most numerous, social- and environmental context can affect their distribution.

The first COVID-19 lockdown in Germany in 2020 was an event that caused a significant disturbance in the daily lives of the country's inhabitants. Social distancing measures disrupted social life, and many amenities were unavailable. This provided us with the prime opportunity to conduct an investigation on the effects of social disruption on animal observations done by citizen scientists.

We investigated whether 2020 was an aberrant year with regards to hedgehog observations compared to the preceding four years, with hedgehog observations collected by citizen scientists in the '*Igel in Bayern*' ('*Hedgehogs in Bavaria*') project from the Landsbund für Vogelschutz (LBV). Similar to studies in other countries on the effect of COVID-19 on animal observations, we also investigated whether the share of observations done in more urbanized environments changed during the lockdown period.

There was an increase in the number of hedgehog observations during the COVID-19 lockdown, which could be attributed to an increase in the number of people doing hedgehog observations rather than an increase in the number of observations done by each observer. After the lockdown period, the number of observations and observers quickly returned to regular levels. Interestingly, while studies in other

countries reported an increase in the share of urban animal observations during the lockdown, we found no change in the share of observations done in more urbanized areas compared to less urbanized areas. This is possibly the result of differences in COVID-19 measures between Bavaria and the regions where other studies have been carried out, in particular the lack of measures limiting traveling for outdoor activities in Bavaria.

This study indicates that societal context can considerably influence the patterns found in opportunistically sampled species observations. The presence and absence of other potential activities significantly affects the reporting and spatial distribution of animal observations to citizen science portals, and it is advised to consider the circumstances under which citizen science data is collected and be mindful of the societal context.

Author's contributions

F.S.T.S and W.W.W. drafted the original concept of the manuscript and methodology. **F.S.T.S.** processed and cleaned the dataset. **F.S.T.S.** performed formal analysis with support of **W.W.W.**. **F.S.T.S.** wrote the original draft and produced all figures. **T.R.** supplied the hedgehog data from the LBV and offered critical advice in the dataset's initial exploration and cleaning. **All authors** reviewed and edited subsequent versions of the manuscript.

Discussion

A mix of biological, architectural, sociological, and anthropological knowledge is necessary in order to successfully build wildlife-inclusive cities. Generally, this boils down to knowledge of which animals are and can be present in cities and why that is the case, what the people living there would think of these animals being in their cities and why, and whether they would accept that, and finally, how to design and build infrastructure and urban structures in such a way that ecological and social requirements don't clash. This dissertation aims to expand the toolset and knowledge base that is necessary for architects and city planners to realize wildlife-inclusive urbanism.

Main findings

The first study in this dissertation shows that cities in Germany are already quite biodiverse. On average, they contain almost half of all the animal species in the surrounding area, and almost all of the animal species were present in at least one of the cities that the study considered. The study also indicates that most cities in Germany are undersampled with regards to animals, especially compared to the surrounding regions, and that when urban sampling effort is higher the share of animals that is shared between the city and the region also increases.

The second study in this dissertation shows that that students in Germany were quite familiar with many of the animals present in cities but didn't like them equally. Especially attitudes towards arthropods varied significantly. There was no relationship between the overall familiarity of a species and attitudes towards them, but for most animals, when considered individually, the students that were more familiar with them also liked them more.

The third study in this dissertation shows that the inhabitants of Munich rather placed animals somewhere away from their home environment than directly around

their homes. Additionally, the participants placed animals on more locations and closer to their homes if they liked them more, and those that were on average liked the most were also placed closest to home and on most locations in the city.

Finally, the fourth study in this dissertation shows that societal disruption can severely affect patterns found in opportunistic citizen science observation data, and that it is advisable to at least know the timing big societal disruptions when conducting analysis with this type of data, exemplified by the first COVID-19 lockdown in Germany.

Animal species richness in cities

As the first study in this dissertation shows, cities in Germany are already quite biodiverse. Our results with regards to birds – generally the best-studied animal taxon – are in line with what previous studies have found in Central- and Northern-European cities, namely that a large proportion of birds of the regional species pool can occur within city borders (Ferenc et al., 2014). Other taxa are not historically as well-studied in cities as birds, but the few studies that do exist show similar findings: mammalian species richness was found to be equally high in two eastern-US cities as in their surroundings, settlements play an important role in bat diversity in Southern Germany (Mehr et al., 2011), and different urban insect groups in eastern Germany were found not to be equally species rich, i.e. Hymenopteran species richness was found to be high while Lepidopteran species richness was relatively low compared to rural areas (Theodorou et al., 2020). Generally, however, for most taxa considered in the first study, urban areas were relatively species rich. This is heartening knowledge for those that aspire to promote animal biodiversity in cities, since it indicates that there is quite some potential to do so with the right planning and management.

Problems and biases in animal observation data in cities

Be this as it may, one needs to be aware of the limitations and biases that come with animal observation data in cities, and what that means for the interpretation of the results. In the following, I will discuss the main biases and issues that were relevant during the analyses of the first and last study of this dissertation, and what that then means for the interpretation of urban animal species observation data.

Differences between data sources

In the first study, we found that here was a significant difference between the databases that we used in the share of observations in the city compared to the surrounding region, and the sheer number of observations for any taxon. GBIF tended to have more data available for most cities, and was especially more useful for invertebrate groups than the data from the German states. Individual German states each have their own methods and reasons for collecting data, and sampling effort for the different taxa was highly heterogeneous between the various states. Vertebrate groups tended to be very well sampled in the German states where data was available, but generally the amount of observation data for non-lepidopteran invertebrate groups was very low, and little – sometimes none – could be used. While vertebrate observations were also overrepresented in the GBIF data, there was more usable data for the invertebrate groups compared to the German state data. This resulted in the situation that comparisons of Diptera, Hemiptera, Hymenoptera and Araneae possible in the GBIF dataset, while sensible comparisons could not be done with regards to these taxa in the German states dataset.

The data was also not equally readily accessible between data sources. GBIF is an online repository of observation data from many different sources, and this data is readily available and can be downloaded and used freely as long as you cite the data. The German states each have individual stances when it comes to sharing their species observation data, and these range from giving the data for usage relatively

freely to not sharing the data at al – if they have collected and digitized any observation data to start with. This resulted in us having – a priori, before any selection with regards to usable data for analysis was done – data from all 23 cities and their surroundings we selected in the GBIF dataset and only being able to acquire data from 18 German states. Additionally, the GBIF data is already standardized within their data structure and taxonomy, while each German state uses different data structures and data types in addition to not always using the same taxonomic names across states. With this taken in consideration the GBIF data would already be preferable due to ease of use and access alone.

Spatial bias

In extent to the differences between the data sources, there is another source of bias in Germany: the spatial bias that depends on the data source and how the data is collected. Opportunistic data collected through citizen-science initiatives tends to have an spatial biases to more easily human-accessible areas (Di Cecco et al., 2021; Dickinson et al., 2010; Piccolo et al., 2020), while the governmental data focused more on natural and semi-natural areas outside of cities. Hence, in datasets like those from GBIF and the hedgehog data of the LBV, urban areas – the places where people live and do things are highly- or even over-represented in comparison with governmental data, where urban areas are underrepresented. Being aware of this bias helps clarify what questions can and cannot be answered with the data available.

Taxonomic bias

A common source of bias in opportunistically sampled (especially citizen-science) animal observation data is taxonomic bias. Especially rare (Dickinson et al., 2010) and more charismatic (Troudet et al., 2017) animals are more commonly sampled. The

most obvious indication if this is that birds are severely over- and arthropods are severely underrepresented (Troudet et al., 2017). Even within the generally highly-sampled group birds themselves, Callaghan et al. (2021) found that in unstructured citizen science data bigger species were more readily observed than smaller ones and that those in bigger flocks were more readily observed than individuals, although they found that bias towards rare and common species depended on the platform used as a result of the audience, i.e. recreational observers (such as in iNaturalist) leaned more towards common species while more avid birdwatchers (such as from eBird) leaned towards rarer species.

There are many other factors that can add to the taxonomic bias. Species detectability, for example, can be mediated or exacerbated by the recording process, since making records of small birds can be more difficult if a photograph is needed than when acoustic identification or context-clue based records are possible, and in such a case bigger birds can be easier to record (Callaghan et al., 2021). Difficulty of identification is another of these factors, as species that are easier to identify are more readily recorded than those that are hard to identify (Boakes et al., 2016). Finally, animal observation programs can have taxon-specific focuses, which directly exacerbates some taxa having more observations than others. Observers' expertise, effort, and preferences are key factors in shaping the biases that belay animal observation data.

Unstructured observation data is still valuable

Despite its common biases and limits, unstructured and semi-structured observation data is still a very important source of biodiversity data in general, and for animals in particular. While relative abundances of animals are very hard to deduct from it, the data does importantly show that an animal has been spotted in a certain area, or in a certain environment. In the case of urban animals, it is often the most abundant

form of observation data available and can sometimes even give an indication of what people perceive as noteworthy, or what they (want to) interact with.

Attitudes towards urban animals in Germany

The studies included in this dissertation indicate that attitudes towards animals in German cities are not uniform, and are dependent on the animal in question and the context the animal is placed in. While people were found to be aware of the animals in their cities, they did not appreciate them equally, and that appreciation ranged from a high liking for some animals to severe dislike for others, which could lead to them noy wanting the animal to be anywhere – even outside of the city itself (e.g., cockroaches). There has not been a lot of research to attitudes towards urban nature in Germany, but the pace has been picking up in recent years. In the following section some noteworthy recent research will be highlighted.

In the Urban Productive Ecosystems group at the TU Munich, research is being done on the perceptions of urban community gardeners on nature in their systems and what that means for ecosystem functioning (e.g. Egerer & Philpott, 2022; Schmack & Egerer, 2022). They show for example that management types of the community gardens significantly affect animal communities in them and that attitudes towards bees in community gardens tend to be very positive, while wasps are not only generally disliked, but even the gardeners do not always see the value and ecosystem services that they bring.

At the TU Berlin, researchers like Tanja Straka and Simon Mösch investigate how different contexts and values affect people's attitudes towards urban nature (e.g., Lippert et al., 2022; Straka, Bach, et al., 2022; Straka, Mischo, et al., 2022) and more specifically urban mammals (e.g., Mösch, 2022) respectively, and show that different types of urban nature are not equally valued, and people have many reasons different for valuing or disliking it.

Finally, as part of AAD, Hauck & Weisser (2019) investigated housing companies' perceptions of wildlife in the residential environment. They indicate housing companies have clear preferences for specific types of urban animals around their buildings, and that this can be related to social desirability as well as management and maintenance costs, but also that problems with wildlife were rare and minor with regards to planning, construction, and maintenance.

While the body of literature on attitudes towards nature, and urban animals more specifically, is rather limited in Germany, it's growing and bit by bit providing more insights into the way it's perceived in cities and what that means for nature conservation in cities. The research in the current dissertation adds to this body of literature, and the work done by the different urban social-ecologists in Germany stands to complement and broaden our knowledge of the field.

What does this mean for wildlife-inclusive urbanism?

In order to successfully gain and maintain more wild animals in cities, we need to know what's ecologically possible and socially acceptable to effectively design for both humans and animals. The results and methods from the studies in this dissertation can be used to guide and aid in making design choices on habitat for animals and where to place them.

Taking the example of Animal-Aided design, this knowledge would initially be relevant at the start of the planning cycle, in the 'analysis and concept phase'. The results from the first study give an initial indication for how species-rich you can expect a city to be for different taxa, and for cities that are not in the study, the methods can be used to estimate how species-rich the city currently is and which species are and could be present. This can be paired with a survey on what relevant stakeholders think of potential animals that could be relevant for target-animal selection. Later on, the methods from the survey in this dissertation that was conducted in Munich would become relevant again, since they stakeholder

acceptance could be gauged and compared to expected values in how well they accept the animals. Additional, more qualitative studies geared to specific aspects of attitudes could then be conducted to discern the reason for these values, and the findings and before- and after- comparisons can then be used to inform future planning. Ideally, this order of processes would be used in any wildlife-inclusive city framework, since without the (implicit) acceptance of the human inhabitants of cities, wildlife-inclusive urbanism will fail to reach its potential. Without knowledge of the nature in cities, planning will be based on naught but air. Since urban nature can bring a manifold of benefits for cities' inhabitants, from psychological wellbeing to urban resilience and climate mitigation, there is reason to want to know what urban nature can be built and what inhabitants prefer and dislike. When combined with the expertise of architects and urban planners, this could be used to increase the amount of urban greenery more easily, to the benefit of humans and animals alike.

Conclusions

The studies in this dissertation sought to facilitate incorporating animals in cities. The first and last study sought to provide basic ecological knowledge necessary to plan for animals and have an expectation of what would be possible, while the social ecological studies provide an expectation of what people in cities in Germany might think of the animals in them and where they want them to be, as well as provide the methods replicate the studies in different cities and animals.

We found that German cities have a high potential for animal species richness, and that many cities are surprisingly species-rich, despite severe undersampling of cities within animal observation data. Furthermore, we also found that social disruption can severely impact opportunistic animal observation data, but that this data is nonetheless valuable for ecological research – as long as you are aware of its limitations. We found that people tend to like urban animals more if they are more familiar with them, but that the better-known animals are not per se the better liked ones; attitudes toward better known animals are just more extreme. Finally, we found that the people that like a certain animal more also want it to be closer to their home and on more places in their city, and that this is true for all animals we considered in our studies. The on average better liked ones are generally also wanted closer to homes and on many places than the less liked ones.

Together, these studies add to the methods and knowledge needed to decide which animals to preferably promote and build for in cities. We have an indication of which animals are possible, which ones are liked, and where they are and are not wanted. I used Animal-Aided Design as a background and example of how this might be included into a framework, but ideally any project that seeks to explicitly include animals into their vision of the fabric of cities take these findings into account and build upon the scientific work that is being conducted to assist their work, for the benefits of humans and animals alike.

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