Integrating scientific literacy as part of a citizen science approach on natural research on seed predation along an urban-rural gradient

Der Fakultät Nachhaltigkeit der Leuphana Universität Lüneburg

zur Erlangung des akademischen Grades Doktor der Naturwissenschaften

-Dr. rer. nat.-

vorgelegte kumulative Dissertationsschrift von

Victoria Leonie Miczajka-Rußmann

geb. am 04.09.1983 in Hardheim

angefertigt am Institut für Ökologie, Fakultät Nachhaltigkeit,

Leuphana Universität Lüneburg

2017

Einbezug eines Citizen Science Projektes in die Erforschung von Samenausbreitung entlang eines Stadt-Land-Gradienten unter Berücksichtigung der Vermittlung eines naturwissenschaftlichen Grundverständnisses

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„Handle so, dass die Maxime deines Willens jederzeit zugleich als Prinzip einer allgemeinen Gesetzgebung gelten könne.“

Kategorischer Imperativ nach Immanuel Kant (1724-1804)

Contents

Summary

In an increasingly urbanized world, consequences for humans, animals, plants are often unknown. Fundamental changes in landscapes due to landscape fragmentation, intensified agriculture or biodiversity loss dramatically impact ecosystems and their functions. Humans increasingly shifted their lifestyle from outdoor activities towards indoors, which are facilitated and depend on mostly digital technologies that are discussed to increase the risk of nature alienation. On the other hand, these readily available digital technologies offer chances to connect with people worldwide. This connectivity offers manifold opportunities to share data and to recruit people looking for new entertaining and interesting experiences as cooperation partners for the scientific community in so-called citizen science approaches. In citizen science, non-scientists are integrated in the data gathering of scientists. Being part of scholarly research, the citizen scientists receive up-to-date information on the research topic, which fosters the learning of the scientific background and thereby ideally supports the general scientific literacy that might be little developed due to a lack of interaction with nature. Especially for children in an urban societal background, there are concerns of alienation from nature due a significant shift away from nature-based activity and recreation, when compared to past generations. However, even though direct contact with nature is nowadays often infrequent, a solid knowledge about nature is essential to understand the consequences of biodiversity loss, the limitation of natural resources and the need for a sustainable development. Theoretically, citizen science cooperation offers a unique opportunity to integrate the public in the scientific gain of knowledge, further explaining the nature of science and fostering an increased awareness for biodiversity conservation and sustainable development.

Inspired by these challenges, I investigated in my dissertation seed predation, an important ecosystem function that has hardly been part of citizen science project. As seed predation has only rarely been investigated along urban-rural gradients and to integrate the question if the background (urban vs. rural) of primary school children affects their environmental knowledge, I selected study sites in and around Lüneburg and Hamburg, in Northern

Germany. In my ecological experiments, I found that slugs are important seed predators that independently of urbanization predated about 30% of all seeds in the anthropogenically used landscapes investigated. Also, I could for the first time integrate primary school children in a citizen science approach into this research and show that even seven year old children can record data as reliable as a scientist. Finally, I investigated the native species knowledge from the children taking part as citizen scientists in my research, considering possible differences due to their urban or rural background. Contrary to my expectation, the urban or rural background had no significant effect on the species knowledge. However, my work provides a good foundation to transfer the approach of introducing a basic foundation of a taxonomical species concept in primary school to foster further understanding on biodiversity and ecosystem functions.

In summary, my dissertation combined different disciplinary approaches showing synergies between the single disciplines to support strategies for a successful sustainable development in the spirit of an education for sustainability. I could highlight the great potential of inter- and transdisciplinary approaches combining natural research with scientific literacy in a citizen science project on a local scale, which may serve as a model for implementing citizen science projects in schools elsewhere. I highly recommend this successful approach for similar cooperation on larger scales to counter challenges of pressing societal problems.

Even though each cooperation will has its own unique challenges, the synergetic advantages will likely outweigh the disadvantages. In this context, there should be more emphasis on the education for sustainable development, not only in schools but other educational institutions like universities, to face the global urbanization with its manifold challenges and opportunities.

Zusammenfassung

Gerade in einer zunehmend urbanisierten Welt sind Menschen, aber auch Tiere und Pflanzen mit zahlreichen Veränderungen konfrontiert, die in ihrer Konsequenz teils noch nicht bekannt oder auch nicht absehbar sind. Urbanisierung geht neben landschaftlichen Veränderungen allgemein auch mit gesellschaftlichen Veränderungen und technologischen Entwicklungen wie einer verstärkten Digitalisierung einher, was sich auf den Alltag aber auch auf die Möglichkeiten des Informationsaustausches auswirkt. Zum einen findet eine Verlagerung der menschlichen Aktivitäten aus der Natur hin in geschlossene Räume mit einer Fokussierung und zugleich Abhängigkeit von Technik statt, was die Frage einer möglichen Naturentfremdung aufwirft, zum anderen bietet dies Möglichkeiten sich mit Menschen weltweit auf Knopfdruck zu vernetzen. Diese Vernetzung unter Einbezug neuer Techniken zum Datentransfer ermöglicht es große Datenmengen teils über tausende Kilometer Entfernung auszutauschen, live an deren Generierung teilzunehmen oder diese zu bewerten. Diese Möglichkeiten globaler Vernetzung werden heutzutage mehr und mehr dafür genutzt, Menschen die auf der Suche nach Unterhaltung sind, sei es als einmaliges Event oder kontinuierliche Beschäftigung, als Kooperationspartner für die Wissenschaft zu rekrutieren. Gleichzeitig bietet sich dadurch die Möglichkeit unsere Zivilbevölkerung in wissenschaftliche Erkenntnisprozesse verstärkt einzubinden, aber auch für deren Arbeits- und Wirkungsweise zu sensibilisieren. Die vereinfachten Zugänge (naturwissenschaftliches) Wissen aus erster Hand zu erhalten sind hierbei nicht zu unterschätzen. Gerade in Zeiten von Biodiversitätsverlust, der Gefährdung von Ökosystemen und großen drängenden gesellschaftlichen Fragen globaler Ungerechtigkeit ist eine Sensibilisierung und Wahrnehmung von nachhaltigen Lösungsansätzen globaler Probleme wichtiger denn je.

Auf dieser Ausgangslage habe ich mich in meiner Dissertation mit dem Erforschen bzw. Verstehen einer Ökosystemfunktion entlang eines anthropogenen geprägten Landschaftsgradienten beschäftigt und hierbei die wissenschaftliche Bildung von Grundschulkindern berücksichtigt, indem ich sie in einem sogenannten Citizen Science Projekt in mein naturwissenschaftliches Forschungsvorhaben einbezogen habe. Bei Citizen Science handelt es sich um eine bewusste Kooperation zwischen Menschen, die in der Wissenschaft arbeiten und solchen, die nicht zwangsläufig einen wissenschaftlichen

Hintergrund haben, sich aber für diese und deren thematische Zugänge interessieren. Als Versuchsflächen dienten mir Schulhöfe in und um Lüneburg und Hamburg herum.

In meiner Dissertation wollte ich gezielt die unterschiedlichen Denk-, Arbeits- und Handlungsweisen verschiedener Disziplinen aber auch Akteure nutzen, um Synergien im Sinne nachhaltiger Entwicklung und damit auch im Sinne einer Bildung für nachhaltige Entwicklung zu leisten. Konkret habe ich hierbei die Ökosystemfunktion des Samenfraßes entlang eines Stadt-Land-Gradientens untersucht und die Bedeutung von Schnecken für den selbigen quantifiziert. Diese Forschung habe ich in einem Citizen Science Ansatz erstmals Grundschulkindern zugänglich gemacht, indem ich diese in die wissenschaftliche Datenerfassung einbezogen habe. Dieser Citizen Science Ansatz war gleichzeitig eine Pilotstudie um zu prüfen, ob Kinder im Alter von sieben bis zehn Jahren wissenschaftliche Daten so zuverlässig erheben können, dass sie mit denen von Wissenschaftlern vergleichbar sind. Dies hat sich als grundsätzlich möglich erwiesen, wobei der Erfolg der Erfassung grundsätzlich durch die Aufgabenkomplexität bestimmt war. Darüber hinaus habe ich sichergestellt, dass die Kinder nicht einfach nur Teil eines wissenschaftlichen Projektes waren, sondern dass ihnen ein tieferes Verstehen sowohl über den fachwissenschaftlichen Hintergrund zum taxonomischen Artbegriff und Ökosystemfunktionen, als auch über die Natur der Naturwissenschaften (Nature of science) zugänglich war. In diesem Zusammenhang habe ich untersucht, ob es zwischen Kindern die in städtischen und ländlichen Gegenden aufwachsen Unterschiede in ihrem Wissen zu einheimischen Arten gibt, um mögliche Anzeichen von städtisch bedingter Naturentfremdung aufzudecken.

Zusammenfassend lässt sich sagen, dass ein inter- und transdisziplinärer Forschungsansatz einige Herausforderungen mit sich bringt, vor allem weil oftmals eine gemeinsame Sprache gefunden werden muss, allerdings überwiegen die synergetischen Vorteile diese Herausforderungen bei weitem, so dass dieser Ansatz als einzig plausibel erscheint, wenn es um die erfolgreiche Umsetzung von Zielen einer nachhaltigen Entwicklung gehen soll. Dieser Ansatz zeigt sich besonders im Gedanken einer Bildung für nachhaltige Entwicklung, die die Bedeutung von Bildung im Zusammenhang mit wissenschaftlichen Zugängen zur Lösung globaler Probleme hervorhebt und im (schulischen) Alltag viel stärker forciert werden sollte.

General introduction

"*The impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems*"

(McKinney 2002)

Sustainability

The concept of sustainability combines scientific research with ethical basic understanding as it includes not only political and technological progress but makes a change in mentality, standards and moral values necessary and possible through new knowledge (Michelsen *et al.* 2011). In this dissertation I follow the definition of the Brundtland-Commission for sustainable development "to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Global developments towards more sustainability include three main transformative infrastructures in global economy - energy systems, urban space and land-use systems (WBGU 2011). In the context of necessary transformations, science and education play a crucial role in promoting active participation from the public to support a highly motivated society concerned about future sustainability (WBGU 2011).

Stoltenberg (2010) distinguishes four dimensions in her model of sustainable development– economy, ecology, sociology and culture. Her principal claim is to face the varying role of humans as the cause, the driver and the potential troubleshooter of environmental and societal changes and further understand the theoretical and empirical responsibility that increase equally with growing knowledge and ignorance the same way (Michelsen *et al.* 2011). Consequently, there is an important change from classical environmental education with threat scenarios towards future-shaping modernization highlighting that a positive development within one dimension also affects other dimensions (de Haan & Harenberg 1999). By announcing the decade 2005-2014 the "UN Decade of Education for Sustainable

Development" the UN (United Nations) emphasized that education for sustainable development is not an option but the priority as education is the key towards a better quality of life (UNESCO 2005). Michelsen *et al.* (2011) highlight the importance of diverse education opportunities at different places within and without school context as ecological awareness, competence and action ability only develop through emotion and systematical knowledge of connection. Consequently, the capacity to act with extensive system knowledge requires an interdisciplinary approach beyond a pure technical orientation and further a transdisciplinary application of knowledge in practice with different stakeholders (Fischer & Michelsen 2000). This process of independent increase and development of knowledge is supported by the idea of learning rather than teaching (Arnold 1999). At the same time learning should be accompanied by interactive sharing of ideas within diverse segments of society (Reed *et al.* 2010). Summarizing, it is important to open scientific research inter- and transdisciplinaryly with neutral explanation of hard facts, offering simultaneously joint search for knowledge and solution for environmental and societal challenges and further sustainable development. In the following I will present the outcome of my dissertation where I focused on the environmental challenge of biodiversity conservation by research on understanding the ecosystem function of seed predation and integrating primary school children into the natural scientific research approach via citizen science. Further, I investigated the state of native species knowledge from the participating children. In this inter- and transdisciplinary approach of my research I combined and addressed three out of 17 sustainable development goals that are intended by the UN to be achieved between 2015 and 2030 (Fig. 1).

Figure 1. Overview of the sustainable development goals of the UN to be achieved until 2030 with a focus on three goals that will be addressed within this dissertation by using an inter- and transdisciplinary research approach (modified after UN 2015).

Ecosystem function

In 2010, the Convention on Biological Diversity (CBD) declared a "Strategic Plan for Biodiversity" (United Nations Decade on Biodiversity, period 2011-2020) with the aim that until 2020 people should be aware and know about the importance of conservation and sustainable use of biodiversity. This focus on biodiversity is important as ongoing multiple changes in landscapes alter biodiversity, species composition, and entire ecosystems, usually with negative consequences for ecosystem functions (Fischer *et al.* 2006; Hector & Bagchi 2007; Scherber *et al.* 2010). Invasive species, landscape fragmentation, intensified agriculture and pesticide use have a high influence on flora and fauna, especially in areas with high human population density (McKinney 2002; DeFries *et al.* 2004; Foley *et al.* 2011). In those fast changing systems it is crucial to have a deeper understanding how ecosystem structure and functioning are influenced or determined by the potential disruption of plant-animal interactions (Tilman *et al.* 2006; Tylianakis *et al.* 2008). The intensification of environmental resource use like freshwater, fertile soil, biogeochemical cycles or climate regulation to satisfy instant human needs (therefore called ecosystem services) often conflicts with biodiversity and nature conservation (DeGroot 1992; DeGroot *et al.* 2002; DeFries *et al.* 2004). It is crucial to gather a quantitative understanding of ecosystems and their services important for human livelihoods to solve this trade-off and ensure sustainability for future generations (Fig. 2). This trade-off also demands better knowledge of how ecosystem functions respond to local short-term and global long-term effects of land use (DeFries *et al.* 2004). Consequently, different landscape-scale perspectives need to be integrated into research on ecosystem function with its influences on trophic interactions (Tscharntke *et al.* 2005).

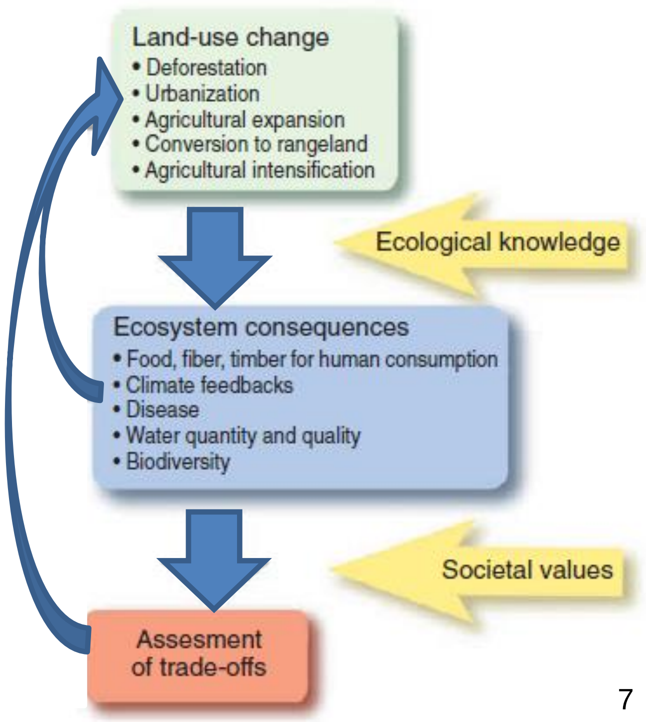

Figure 2. Schematic overview of possible consequences for ecosystems due to land-use change highlighting the need for ecological knowledge and societal values to respond rising trade-offs of natural resources use (modified after DeFries *et al.* 2004).

There are many studies about ecosystem functions on different landscapes scales but results depend on the study system and the local context (Dauber *et al.* 2005; Srivastava & Vellend 2005; Tscharntke *et al.* 2005; Schmidt *et al.* 2008; Farwig *et al.* 2009; Batary *et al.* 2011). One important ecosystem function effecting general landscape structures but the regeneration of disturbed or fragmented landscapes is seed predation (Chambers & MacMahon 1994; Hulme 1998; McConkey *et al.* 2012). In some studies seed predation is actively distinguished into seed predation (straight seed consumption) and secondary seed predation (seed consumption after dispersal) with respective differences for plant recruitment as it can be important for the understanding of seed dynamics and plant communities (Kollmann 2000; Moles *et al.* 2003; Honek *et al.* 2005; Vander Wall *et al.* 2005; Heggenstaller *et al.* 2006; Hämäläinen *et al.* 2017). However, for my dissertation, I will not further focus on secondary seed predation as it turned out that it was not of significance in my studies.

Many studies showed that seed predation is influenced by abiotic and biotic interactions like landscape features across different scales, habitat structures, plant species diversity or different animal-plant interactions (Hulme 1998; Kollmann 2000; Steffan-Dewenter *et al.* 2001; Vander Wall *et al.* 2005; Scherber *et al.* 2010; Pufal & Klein 2013). Important seed predators such as primates, rodents, carabids, millipedes, ants, slugs or birds are well investigated especially within natural habitats like tropical forests and in temperate regions i.e. in forests, grasslands or agricultural land (Horvitz & Corff 1993; Schupp 1993; Engel 2000; Wenny 2000; Theimer 2001; Honek *et al.* 2003; Couvreur *et al.* 2004; Roth & Vander Wall 2005; Vander Wall *et al.* 2005; Breitbach *et al.* 2010; Koprdová *et al.* 2010; Magrach *et al.* 2011; Türke *et al.* 2012; Türke *et al.* 2013a; Boch *et al.* 2015).

Furthermore, there have been studies investigating the influence of seed predation within fragmented landscapes, but studies mainly focus either on urban or rural areas investigating seed predation instead of investigating it along an urban-rural gradient (Loman 2007; Booman & Laterra 2009; Kappes *et al.* 2009; Magrach *et al.* 2011; Gardiner *et al.* 2014; Bode *et al.* 2015; Pufal & Klein 2015). Furthermore particularly a quantification of these processes and their function in anthropogenic landscapes is poorly understood. Of additional interest is the impact of different seed predators (i.e. earthworms, slugs, arthropods and small rodents) on plant community compositions in anthropogenic landscapes, as they represent several species exploiting the same class of environmental resources(Griffith *et al.* 2013; Jonason *et al.* 2013; Dudenhöffer *et al.* 2016; Korell *et al.* 2016). A special focus within this research is on gastropods as they represent a diverse taxonomical class with dominant feeding behavior (Buschmann *et al.* 2005; Türke & Weisser 2013b; Le Gall & Tooker 2017).

Consequently, in the first part of my dissertation I focused on the investigation of seed predation along an urban-rural gradient with different cafeterias, also addressing the effect of anthropogenic landscape changes at different spatial scales on seed predation by different functional groups (Chapter I). The different cafeterias allowed seed access to everyone and only to specific functional groups ranging from slugs and earthworms to arthropods and rodents (Fig. 3, 5.A). A main focus laid on the impact of slugs on seed predation as they are known to be important generalist herbivores influencing crop yields or general plant species compositions (e.g. Le Gall & Tooker 2017).

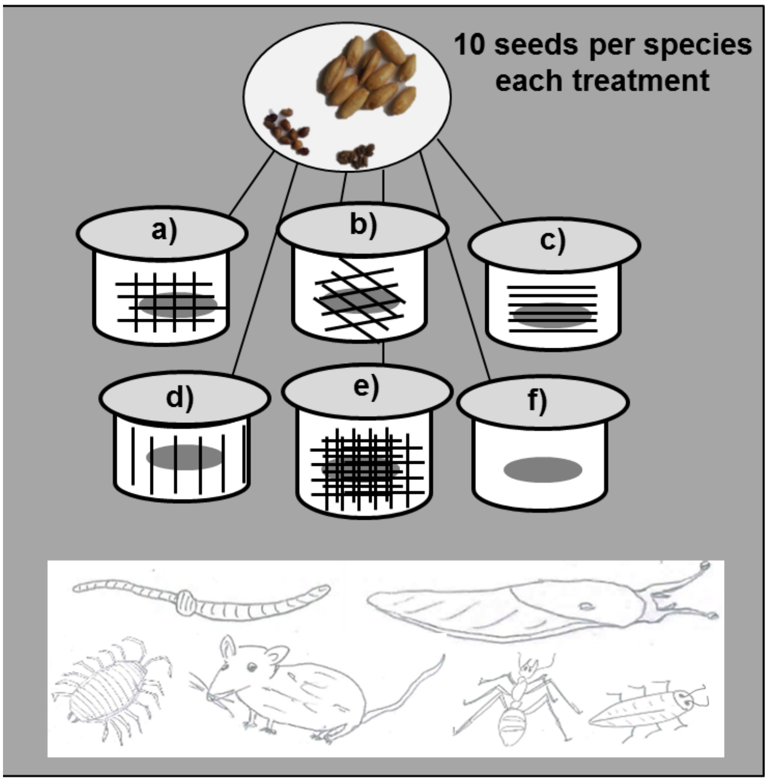

Figure 3. Schematic overview of the cafeterias for one control and five different exclosure treatments with possible seed predators on scale 1x1 m with a choice of 10 seeds from three different plant species each. Each treatment contained different combinations of mesh wire cages, plastic rain roofs, sand-filled petri dishes, bamboo golf tees, insect glue and slug repellent fencing.

Citizen science

Citizen science is a kind of cooperation between scientists and non-professionals working together on an equal footing within authentic scientific research that range from short and small-scale personal research experiences to large-scale and long-standing projects (Dickinson *et al.* 2012). This kind of research cooperation with the public is disciplinary independent but often used i.e. in biology to collect large amounts of data (which would not be possible by scientists only) about animal behavior, distribution or reproduction (Bonney *et* *al.* 2009), conservation efforts from specific species protection programs (Low *et al.* 2009) or monitoring biodiversity (Donnelly *et al.* 2014).

Learning about a new species via smartphone application (software program for phone operating system, ADS 2010) or being part of the quest for an interstellar dust grain is easier than ever before (Hand 2010; Dickinson *et al.* 2012). Anyone can take part independent from social or professional background, no matter if someone is interested in nature right on the door-step or in more global projects. In recent years, the digital opportunities have increased tremendously using the internet for data exchange (Lowman *et al.* 2009; Dickinson *et al.* 2012). In Germany, the use of citizen science has grown considerably when the German consortium “Bürger schaffen Wissen” was founded by different science research centers and the BMBF (Federal Ministry of Education and Research) and started its website in 2014 (www.buergerschaffenwissen.de). Furthermore, the European Citizen Science Community (ECSA, www.ecsa.citizen-science.net) was founded in 2013, the Swiss Citizen Science Network in 2015 (www.schweiz-forscht.ch) and the Austrian Citizen Science Network in 2017 (www.citizen-science.at) and two large international conferences covering all issues relevant to citizen science have recently been established in Europe and North America (Europe: International ECSA Conference, first held in 2016; North America: Citizen Science Association Conference, first held in 2012). This growing interest in research-cooperation between scientists and the public is likewise reflected the increasing share of publications including citizen science content (Fig. 4). This reflects the huge potential of citizen science combining authentic scientific research with effective social response to current environmental challenges (Jordan *et al.* 2009).

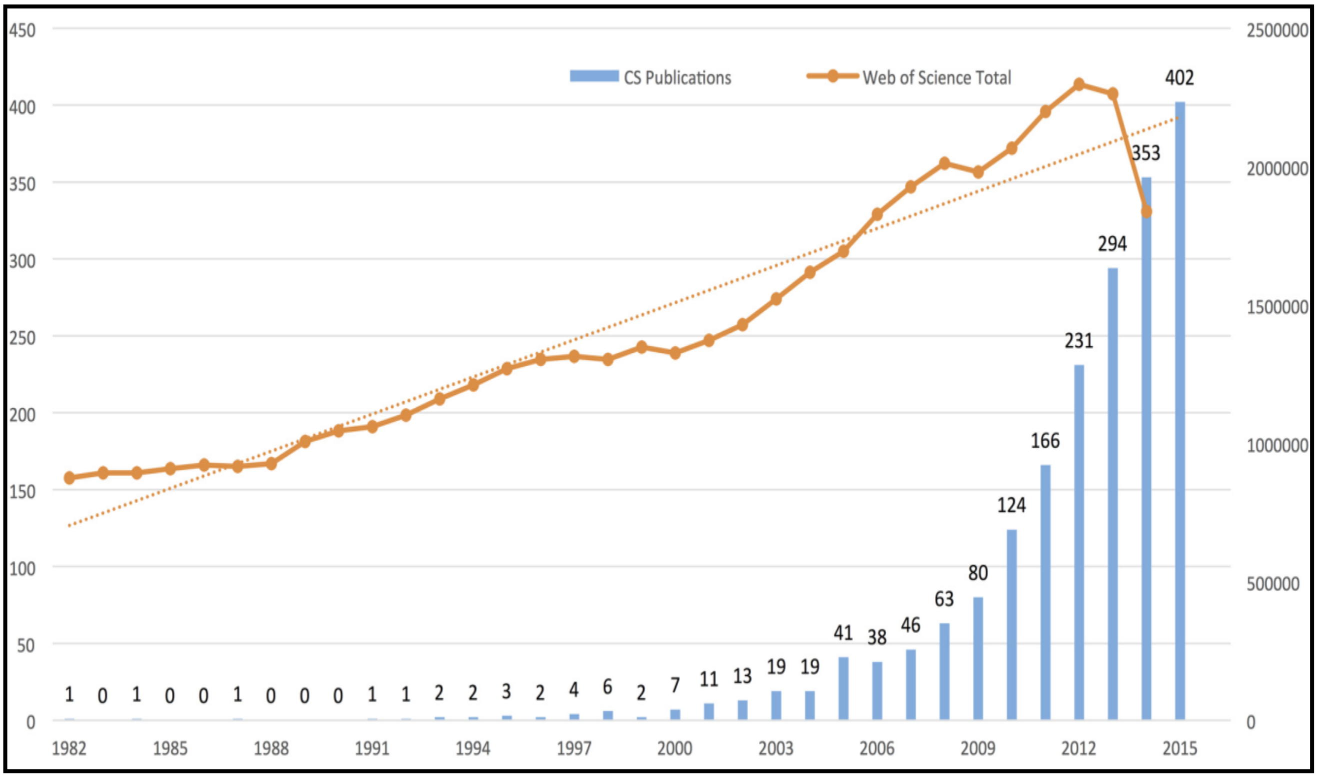

Figure 4. Overview of the development of study publications in total in the Web of Science (orange) compared to those with citizen science content (blue) within the past 33 years (modified after Kullenberg & Kasperowski, 2016).

Ideally, common to all these projects is the exchange of data on an equal footing, as on the one hand scientists receive large amounts of data, which they could not collect on their own. On the other hand participating citizen scientists receive profound background information on the research topic, importantly with low learning barriers for possible inquiries and increased awareness to often unfamiliar topics (Wiggins & Crowston 2011). However, despite many benefits of citizen science there are discussions about data quality as this approach might be particularly susceptible to errors and biases (Fore *et al.* 2001; Genet & Sargent 2003; Lovell *et al.* 2009; Dickinson *et al.* 2010; Kremen *et al.* 2011).

So far, to the best of my knowledge, there were no studies on complex research topics like ecosystem functions nor were there any projects specifically integrating children into citizen science projects with complex context. However, the integration of children is a welcome opportunity of citizen science as the education possibilities are of profound development and improvement of environmental and scientific knowledge. In the second part of my dissertation I integrated primary school children into my research to assess their reliability as citizen scientists, comparing the quality of their performance within different tasks with my own data recording (Fig. 5.B). Furthermore, it was intuitive to integrate the children into my research as I used “their” schoolyards and daily surrounding as field sites (Chapter II).

Environmental education and scientific literacy

Parallel to the “United Nations Decade on Biodiversity” (CBD 2010) the UN declared the Decade from 2005 to 2014 to the “UN Decade of Education for Sustainable Development” (UNESCO 2005). The UN explained the decision with the necessity to face crucial global challenges in a global education initiative that establishes and opens educational programs to everyone. This education initiative should enable people worldwide to acquire knowledge and values to learn behaviors and lifestyles that are required for a sustainable future and positive societal transformation (German Commission for UNESCO 2011). A small piece of the puzzle in education is an initiative to improve the awareness and knowledge of scientific literacy within society (Jordan *et al.* 2009). The term of scientific literacy is discussed over a long period of time including many different aspects of science, particularly the way science is communicated with and within the public (Laugksch 2000; NAS 2016). For example, Shen (1975) distinguished the practical know-how to solve problems, the public awareness and capability of an own scientifically grounded opinion, and the cultural scientific motivated society aspect, in the context of scientific literacy. Furthermore, the National Science Education Standards of the US (NRC 1996) defined scientific literacy as the “knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity”. Moreover, Bauer *et al.* (2000) introduced the idea of measuring an understanding about the nature of science in quantifying the public knowledge about facts, methodologies and different scientific institutions. However, already Roger (1948) warned that the simple contact with science cannot shape a scientific literate person with the ability to think critically as such competence needs years of practice and in particular a development of awareness of the underlying philosophy (Matson & Parsons 2002; National Research Council 2012). In the following I refer to the definition of Durant (2009) that scientific literacy is the understanding of what science is, how it works and not just knowing as much detailed knowledge as possible. The common saying “no understanding without knowledge and no knowledge without understanding” reflects the tight connection that knowledge and understanding normally increase interdependently. Consequently, in class I gave lectures to the participating children about scientific literacy in addition to an evaluation of their knowledge about native plant and animal species as important parameters of ecosystem functions. The children should not only learn facts about ecosystem functions and plant-animal interactions, but that trial and error are important parts of scientific practice as long as analyzing the possible causes. Together with the children I discussed different ideas, beliefs and suggestions about science and their main research interests (dinosaurs, universe and animal-human relationship) implementing issues what research includes in general, what kind of questions should be asked and which equipment would be helpful in which discipline (Fig. 5.C).

In the third part of my dissertation I focused on a comparable assessment of children's knowledge about nature and the species occurring in habitats they interact with regularly. Several studies highlight the importance of early years education on this topic (Balmford *et al.* 2002; Lindemann-Matthies 2006; Jordan *et al.* 2009; Allen 2015). I therefore transferred the approach of an investigation of an ecosystem function to the quantification of the native species knowledge of children growing up along an anthropogenic landscape gradient. So far, knowledge on this topic is fragmentary and empirical data are difficult to compare as the methods used are highly diverse (Laaksoharju & Rappe 2010; Gifford & Nilsson 2014; Lückmann & Menzel 2013). In my study I present an approach of introducing a simple definition of the species concept to primary school children as important foundation for their basic understanding of biology and their role and place in nature as in the age of seven to ten years this orientation is essential (Keogh 1995; Allen 2015). Furthermore I present a simple but highly comparable method to assess different environmental knowledge as a foundation for education approaches like on biodiversity conservation.

Figure 5. A) Experimental set-up of different cafeteria exposures for different seed predators (A.1) with a slug consuming colored seeds (A.2). B) Integrating primary school children into authentic scientific research on ecosystem functions like seed predation and dispersal in their daily surrounding (B.1 set-up of treatments; B.2 assistance filling in the field protocol). C) Children conducting the practical part of the scientific literacy component within the project of integrating primary school children into research on ecosystem functions on their schoolyards (C.1and C.2).

Summary of included studies

The first part of my dissertation focuses on the influence of slugs on seed predation in a highly anthropogenically structured landscape (**Chapter I**). The second part centers on the integration of children from primary schools within this area in a citizen science approach on research on seed predation (**Chapter II**). Additionally, the third part concentrates on possible influences and differences on the native species knowledge from children growing up in highly human-designed landscapes (**Chapter III**). This dissertation is inter- and transdisciplinary oriented to address the different aspects (Chapter I-III) synergistically pursuing the goal of more awareness towards sustainability in society. I chose this strategy with different disciplinary approaches as they influence each other in the context of responsibility for a sustainable behavior of each human being as we highly influence ecosystems and therewith biodiversity conservation.

Summarizing, this dissertation addresses three main questions:

(1) What is the influence of slugs on seed predation along an urban-rural gradient in the temperate region of Northern Germany?

(2) Do primary school children gather reliable data on the ecosystem function of seed predation within a citizen science project?

(3) Are there differences in the native species knowledge from the primary school children from urban to rural areas?

In the first part (Chapter I) I addressed question **(1)**. Consequences for ecosystem functions such as pollination or seed dispersal due to landscape changes are often complex and not fully understood. Recently, post-dispersal seed predation by smaller animals like ground-dwelling granivores was concentrated in temperate regions. Especially for slugs contrasting influences on plant species compositions due to seed predation were investigated but their foraging behavior along an urban-rural gradient is largely unknown. I investigated the role of slugs as seed predators along such a gradient aiming to identify scale-dependent anthropogenic drivers that might affect slugs and their function as seed predators. Using a combination of seed cafeteria experiments offering differently-sized seeds and pitfall traps, I measured seed predation rates and a proxy for slug abundance on schoolyards and field margins in areas with different land use. My results indicated that slugs are important seed predators for small-seeded species regardless of anthropogenic land use. Furthermore, slug abundance was the most important predictor for seed predation rates, whereas landscape variables might be still too unspecific in their influence compared to other variables such as pest and natural enemy interactions. Interestingly, the abundance of slugs is not necessarily affected by the wider landscape context spatially assessed on a larger radius of sealed to unsealed surface. However, slug abundance was positively related to the availability of smaller-scaled microhabitats or woody vegetation structures. Likely, this positive relationship reflects consequences of small-scale effects on the foraging behavior of slugs resulting in increased seed predation rates. In conclusion, I show that slug abundance has a significant influence on overall seed predation in anthropogenic landscapes mainly due to the influence of microhabitats on the foraging behavior of slugs. Consequently, in addition to their abundance, their foraging behavior should be taken into account when managing seed predation by slugs and furthermore the availability of possible natural enemies controlling the slugs itself.

The second part of my dissertation (Chapter II) focuses on question **(2)**, as it is common standard that the scientific community benefits from valuable contributions by citizen scientists that are integrated into scientific research curricula. So far, most of the projects have focused on the participation of adults on often ecological topics. These topics deal with questions about individual species in their habitats, different life-cycles and life-histories of animals or plants, explicit ecosystems or phenology, but ecosystem functions that support ecosystem health are rarely addressed. Moreover, the integration of children into research is often not considered, as the data gained might be particularly susceptible to errors. I took this as initial motivation when deciding on an approach integrating primary school children in a citizen science project on research on seed predation as ecosystem function assuming that they can be reliable citizen scientists. To enhance to comparability of the results, the participating children used the same experimental set-up as I used it in the study presented in chapter I.

The children installed and controlled the treatments by themselves with minimal additional support. To allow a comparison of collected data qualitatively and quantitatively I gathered data for the same treatments in addition to the children on the respective sites. The results showed that children recorded data on seed predation similarly to myself, but under- or overestimated associated vegetation data. Consequently and opposed to the widespread opinion, I conclude that primary school children can be reliable citizen scientists in authentic research projects, but their participation should be task-dependent according to their skill level. For all citizen science approaches, I would generally recommend specific training for more sophisticated tasks accompanied by the support of general scientific literacy.

In the third part of my dissertation I focused on the basics in scientific literacy and environmental education answering research question **(3)** (Chapter III). Therewith, I followed the idea that the integration of primary school children as citizen scientists into research should provide them with appropriate content of the science background of the project. Recently, it is assumed that people's status of scientific literacy including knowledge about nature is limited compared to past generations. This assumption is based on an increasing urbanization and consequently more limited exposure to nature. Moreover heavily modified urban areas are not only characterized by a decrease of natural and semi-natural habitats, but the type of habitat is often configured to support human comfort. The everyday life experience about nature awareness and knowledge about the native flora and fauna of the residents might be influenced by these contrasting habitats with obvious differences in land use. Children in particular, might suffer from a lack of outdoor play opportunities with the risk of an alienation from nature. Thus, I investigated if the natural surroundings in which children grow up affect their knowledge on native species, to test if children growing up along an urban-rural gradient might differ in their alienation from nature. I used a simple evaluation of native species in form of a species alphabet and found that the species knowledge did not differ between children from urban and rural areas. However using this outcome to address a possible alienation from nature is difficult as there are several studies focusing on the similar topic, but with very different methods that are hard to compare in their results. Consequently, an overall statement of the percentage of correct answers to quantify children's species knowledge as good enough or poor is not possible, as there are no comparable numbers. Consequently, I highly recommend performing further studies with the approach of the species alphabet or related tools to gain deeper understanding on the species knowledge of children to further discuss possible consequences as alienation from nature. Additionally, I would recommend the introduction of a clear species definition in early education to find the right placement for itself in nature and further develop a right concept for subsequent scientific literacy.

General discussion

Sustainability

To the best of my knowledge, my dissertation is one of first studies investigating the integration of scientific literacy as part of an inter- and transdisciplinary citizen science approach on natural research on ecosystem function. Hence, one important finding of my dissertation is the high productivity of exchange of insights and findings combining different disciplinary approaches to engage sustainable development. The aim of sustainable development with justice and equality can only be achieved due to synergies between different disciplines. These efforts for a higher joint aim are connected with difficulties and challenges as it requires empathy and priority for the community. Species conservation, among many other pressing issues societies are facing, depends not only on an educated human population (McKinney 2002), but the sustainable development itself. Especially the management of urban areas will be crucial for this development as at the one hand urbanization causes the biggest problems, but on the other hand it has the highest potential to solve it (Brelsford *et al.* 2017).

I chose the strategy with different disciplinary approaches as they influence each other in the context of responsibility for a sustainable behavior of each human as we highly influence ecosystems and therewith biodiversity conservation (Ellis & Ramankutty 2008). Especially in a highly urbanized society with unknown consequences for humans and the complex animal-plant interactions, I highly recommend more combined research approaches as I applied in my dissertation. Only with flexible combinations between disciplines like education and natural sciences we can “greatly improve species conservation in all ecosystems” (McKinney 2002) towards more sustainability, but a better quality of life in general (UNESCO 2005). This requirement echoes the UN decade on education for sustainable development reflecting the demand of a collective sustainability that is supported by as many people as possible.

Ecosystem function

Humanity depends on ecosystem functions and services (DeFries *et al.* 2004; Yang *et al.* 2013). In this context the influence of different abiotic and biotic habitat properties on seed predation is important which in turn affects plant species compositions (Hulme 1998; Forget *et al.* 2005; Scherber *et al.* 2010). In temperate regions, the influence of slugs as significant herbivorous pests on yield success and seed predation rates seem to be one of the most important besides to other small rodents and ground-dwelling invertebrates (Schupp 1993; Honek *et al.* 2003; Forget *et al.* 2005; Koprdová *et al.* 2010; Magrach *et al.* 2011; Türke & Weisser 2013b; Boch *et al.* 2015; Korell *et al.* 2016; Le Gall & Tooker 2017). Especially in agricultural systems they can have tremendous influence as the use of a molluscicide removing slugs and snails increased plant sizes about 37% (Rees & Brown 1992). Furthermore, slugs may also attack rare plants (Maze 2009) or even cause the extermination of specific seedlings when slug abundance is very high (Honek *et al.* 2017).

My results confirm that slugs are dominant seed predators compared to small rodents and ground-dwelling invertebrates, with a total seed predation of around 30% for slugs. The predation rate was influenced by microhabitat structures influencing the foraging behavior of the slugs. However, there was no significant dependency of slugs from a specific landscape structure along an urban-rural gradient, which might be explained by the fact that slugs are generalists in their habitat requirements. There have been studies showing varying habitat preferences of slugs (i.e. grasslands or forests) (Buschmann *et al.* 2005; Türke *et al.* 2012), but these preferences might be lapsed due to fast changing landscape structures and the high adaptability of slugs (Knop & Reusser 2012). Focusing on natural slug enemies or potential influences on slug’s foraging behavior might be a key to counter and to control the high adaptability of slug pest. Le Gall & Tooker (2017) reviewed that farmers would appreciate new pest control approaches as the commercially available solutions are often ineffective and expensive. Likewise, Fusser *et al.* (2016) highlight the potential of field margin vegetation to support natural enemies instead of pests, but on the other side criticize the lack of studies focusing on natural enemies (e. g. carabid beetles (Symondson *et al.* 2002)) and pests simultaneously. In general there is still the need for more research on slugs and snails as their ecology is poorly described (Le Gall & Tooker 2017).

In summary, these findings confirm other studies emphasizing the difficulty of finding general patterns on ecosystems functions across different landscape scales (Dauber *et al.* 2005; Tscharntke *et al.* 2005; Schmidt *et al.* 2008; Batáry *et al.* 2011) or on animal-plant interactions in particular (Steffan-Dewenter *et al.* 2001; Forget *et al.* 2005; Pufal & Klein 2013). However, it also highlights the importance of a better understanding of ecosystems functions and services as the effect on landscapes might be crucial for future management strategies (Tscharntke *et al.* 2005). In this context an emphasis lays on the solution of the trade-off between societal essentials and possible consequences on ecosystems towards a sustainable use of natural resources (DeFries *et al.* 2004).

Citizen science

Insights in biotic interactions within landscapes such as the quantification of seed predation rates by slugs and the potential of natural enemies to control pest slugs are of importance for society. Therefore, I designed a citizen science project showing that primary school children can be reliable citizen scientists if tasks are appropriate for their development. This seems to be intuitive, but should be considered as an important result, emphasizing the same restrictions for adults taking part in a citizen science project. When discussing potential bias and error in the data recorded by citizen scientists this is an important finding as there are some studies (Fore *et al.* 2001; Genet & Sargent 2003; Lovell *et al.* 2009; Dickinson *et al.* 2010; Kremen *et al.* 2011) questioning the data quality of citizen science approaches in general.

Based on the experience of my dissertation, I became convinced that the method of citizen science is perfectly useful for combining varying topics and disciplines for participants with any backgrounds (Dickinson *et al.* 2012; Jordan *et al.* 2015). The manifold opportunities of subject combinations offer a high potential of exchange between the scientists and the participating citizen scientists on an equal footing. An equal footing supports a transparent position of the scientific community that receives (experimental) data and in return provides profound background information on the research topics and the fundamental nature of science.

Citizen science is not a recent development. For example, the cooperation of data exchange between scientists and hobby ornithologists is documented from around 1900 ("Annual Christmas Bird Count" by the National Audubon Society). Nevertheless, with the advent of information science and the wide availability of easy to use devises and applications, citizen science received major attention. However, particularly in the context of education, citizen science is a current buzzword facing the risk to lack a minimum standard of scientific literacy. Today, there are hardly any principles of an education aim that should at least be achieved, although one would expect the compliance of an ethical standard in every citizen science project with the win-win situation for all parties as a golden rule. So far Bonn *et al.* (2016) highlighted the potential of using citizen science as an helpful tool combining education and natural science, but there is little recommendation on the “know how”. Therefore, I would recommend more research on the general understanding of the nature of science from the participants to evaluate the use of citizen science in comparison to classical environmental education or similar cooperation approaches (e.g. sparkling science in Austria). Here, we should ask broad questions like ‘how scientific literate should we or our children are? How much does the public need to know about nature? Which research can only be done by scientists?’

Scientific literacy

The request for a scientifically literate society, assessing and facing the global challenges of urbanization with its consequences on biodiversity and species conservation, needs to be tackled interdisciplinary by the education and the natural sciences. However, to start a successful initiative on the public awareness for their responsibility on conservation and sustainable use of biodiversity, we should know the foundation of their knowledge on the different subjects.

In my study investigating the native species knowledge from children growing up in urban and rural areas I did not find knowledge differences along the urban-rural gradient, potentially because the differences in nature exposure of children in general have changed compared to past generations. Possible decrease in varying outdoor activities might be mainly due to the increased fear of parents of traffic or crime harming their children (Louv 2011). These social and cultural motivated influences on the knowledge from children highlight the need for extensive tools to distinguish e.g. knowledge about nature or about the nature of science between generations, cultures or other target groups (Gifford & Nilsson 2014). Again not knowing the initial learning situation from a target group increases the risk of early science misconceptions or missed learning content just confronting them with complex technical background (Allen 2015). In addition, this highlights again the importance of a broader science understanding as a scientifically literate person needs the ability to think critically about science itself and not just know as much detail as possible about it (Matson & Parsons 2002).

My research approach with the initial discussion of the interactive definition of the term ”species” confirms the assumption from Allen (2015), that early year educators have an important responsibility in supporting learning efforts on an early effective science education.

For an effective educational campaign better knowledge of nature does not automatically result in a positive behavior or perception towards it, but the combination of knowledge acquisition with practical nature experiences should result in higher nature and conservation awareness (Storksdieck *et al.* 2005; Jannah *et al.* 2013). Additionally, we should seek for the small piece of the puzzle in education and improve the awareness and knowledge of scientific literacy in society (Jordan *et al.* 2009). Facing the global urbanization with the potential risk of ”nature deficit disorder” (Louv 2011), education needs to acquire knowledge and values on behaviors and lifestyles for a sustainable future combining environmental education, scientific literacy and authentic nature contact both in urban and rural areas.

The quest for inter- and transdisciplinary research approaches on ecosystem function and scientific literacy compounds some challenges as it requires an understanding and knowledge from different disciplines. Furthermore joint communication and empathy is a key to enter into a dialogue with the public. This dialogue is the foundation for common quest for sustainability as sensitivities and peculiarities are usually not helpful. While science needs to be more transparent and approachable, the public needs also to be better informed and more aware of global challenges like biodiversity loss or human dependence on ecosystems (Yang *et al.* 2013). The exchange of information first hand seems to be a good opportunity to support public’s knowledge and awareness on biological conceptions and, in case of a citizen science project, of the nature of science as well. The potential of citizen science to provide basic knowledge for the general public is huge as everybody can take part in manifold project combinations (Dickinson *et al.* 2012). However, it also exist the case that the public is informed, but still requests advice from the “real” scientists. In fact, scientists should improve their communication with the public by giving clearer advices or call to action instead of “only considering and weighing” problems. Furthermore, the publics need to take more responsibility for their behavior and their own actions.

As stressed above, I strongly recommend elaborating on dialogue strategies between and among disciplines, both, within the scientific community and between science and the general public. Dialogue and increased basic knowledge about nature and the nature of science is the key instead of former scaremongering, highlighting solution paths instead of problems and horror scenarios.

Summarizing, more focus should be on the integration of citizen science in combination with an understanding of the nature of science into education accompanied by natural sciences. Especially in the education of children, the approach of citizen science has high potential to make current scientific knowledge accessible in school. Further, the nature of science can be explained not only abstract but in kind on authentic research first hand with a variety of different projects, topics or methodological approaches. There are many different disciplines offering such cooperation between science and non-science integrating children and the general public in advances in scientific knowledge. This integration promotes a scientifically literate society that should be informed, interested and concerned about biodiversity and general sustainable development worldwide in combination with a (more) transparent scientific community (Figure 6).

There is only one world to live in.

"*Only after the last tree has been cut down / Only after the last river has been poisoned / Only after the last fish has been caught / Then will you find that money cannot be eaten.*"

"Native American saying" or Obomsawin (1972)

Figure 6. A few impressions of the inter- and transdisciplinary approach on Integrating scientific literacy as part of a citizen science approach on natural research on seed predation along an urban-rural gradient.

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Article overview

Overview of articles included in this cumulative Ph.D. thesis

(In accordance with the guideline for cumulative dissertations in Sustainability Science [January 2012], in the following termed “the guideline”)

Title of the PhD thesis: Integrating scientific literacy as part of a citizen science approach on natural research on seed predation along an urban-rural gradient

Papers included

1. Miczajka, V.L., Klein, A.-M., Pufal, G. (2015) Elementary school children contribute to environmental research as citizen scientists. Published in PLoSONE 10(11): e0143229. doi:10.1371/journal. pone.0143229

2. Miczajka, V.L., Klein, A.-M., Pufal, G. (2017) The ABC of native species – a helpful tool to assess species knowledge and address nature awareness. Submitted to: Journal of Biological Education.

3. Miczajka, V.L., Klein, A.-M., Pufal, G. (2017) Increased slug abundance leads to higher seed predation along an urban-rural gradient. Will be submitted to Basic and applied ecology.

Table 1. Authors' contributions to the articles and articles publication status (according to §16 of the guideline).

Article #	Short title	Specific contributions of all authors	Author status	Weighting factor	Publication status	Conference contributions
I	Elementary School Children Contribute to Environmental Research as Citizen Scientists	VLM, GP: research design, data collection and analysis; VLM: literature review; VLM, AMK, GP: writing of the paper	Co-author with predominant contribution	1.0	2015 Published in PLoSONE 10(11), IF 4.41	GfÖ 2013
II	The ABC of native species – a helpful tool to assess species knowledge and address nature awareness	VLM: research design; literature review VLM, GP: data collection and analysis VLM, AMK, GP: writing of the paper	Co-author with predominant contribution	1.0	2017 Under review: Journal of Biological Education, IF 0.95	ESA 2014
III	Increased slug abundance leads to higher seed predation along an urban-rural gradient	VLM, GP: research design, literature review, data collection and analysis VLM, AMK, GP: writing of the paper	Co-author with predominant contribution	1.0	2017 Will be submitted to: Basic and Applied Ecology, IF 2.29	
			Sum:	3.0		

Publication status

IF = ISI Web of Science - Impact Factor respectively in the year of publication

Explanations

Specific contributions of all authors:

VLM = Victoria Leonie Miczajka

AMK = Alexandra-Maria Klein

GP = Gesine Pufal

Author status (According to §12b of the guideline):

- Single author (Allein-Autorenschaft): Own contribution amounts to 100%.
- Co-author with predominant contribution (Überwiegender Anteil): Own contribution is greater than the individual share of all other co-authors and is at least 35%.
- Co-author with equal contribution (Gleicher Anteil): (1) own contribution is as high as the share of other co-authors, (2) no other co-author has a contribution higher than the own contribution, and (3) the own contribution is at least 25%.
- Co-author with important contribution (Wichtiger Anteil): own contribution is at least 25%, but is insufficient to qualify as single authorship, predominant or equal contribution.
- Co-author with small contribution (Geringer Anteil): own contribution is less than 20%.

Weighting factor (According to §14 of the guideline):

- Single author (Allein-Autorenschaft) 1.0
- Co-author with predominant contribution (Überwiegender Anteil) 1.0
- Co-author with equal contribution (Gleicher Anteil) 1.0
- Co-author with important contribution (Wichtiger Anteil) 0.5
- Co-author with small contribution (Geringer Anteil) 0

Conference contributions

GfÖ Annual Meeting of the Ecological Society of Germany, Austria and Switzerland, 09.-13.09.2013, Potsdam, Germany, www.gfoe.org. Talk.

ESA Annual Meeting of the Ecological Society of America, 10.-15.08.2014, Sacramento, California, USA, www.esa.org/am/. Talk.

2. Symposium Sustainability in sciences (SISI), Federal Ministry of Education and Research, 08.05.2014, Humboldt Carré, Berlin, www.fona.de/en/index.php. Invited poster.

GEWISS: Citizen Science Think Tank Workshop, Bürger schaffen Wissen, Citizen Science Plattform, 08.07.2014, Kalkscheune, Berlin, Germany, www.buergerschaffenwissen.de. Invited participation and workshop discussion.

Summer school "'Empirische Forschung zur Bildung für nachhaltige Entwicklung - Themen, Methoden und Trends", finanziert BMBF, 21.-29.07.2014, University Vechta, https://www.uni-vechta.de/erziehungswissenschaften/hochschuldidaktik/prof-dr-rieckmann-marco/forschung/. Poster.
→Miczajka et al. (2016) Neue Wege in der Kommunikation zwischen Bildungs- und Naturwissenschaft – ein inter- und transdisziplinäres Forschungsprojekt. In: Barth, Matthias/Rieckmann, Marco (Hrsg.) Empirische Forschung zur Bildung für nachhaltige Entwicklung: Themen, Methoden und Trends.

GEWISS Bürger schaffen Wissen, Citizen Science Plattform: Citizen Science in Germany – Strategy for sustainability and innovation, 16.03.2016, Festsaal der Berliner Stadtmission, Berlin, Germany. Project communication through storytelling.

Chapter I

Increased slug abundance leads to higher seed predation along an urban-rural gradient

Victoria L. Miczajka, Alexandra-Maria Klein, Gesine Pufal

Will be submitted to: Basic and Applied Ecology

Abstract

Anthropogenic landscape changes affect not only habitats within landscapes, but also community composition and species abundances. Subsequent consequences for ecosystem functions (i.e. seed predation or dispersal) in anthropogenic landscapes are often not fully understood. In recent years, research on post-dispersal seed predation by smaller animals in temperate regions received more attention as seed predator diversity, abundance or activity are affected at the landscape scale by surrounding environments.

Concentrating on facultative generalist seed predator, this study aimed to assess the role of slugs for seed predation along an urban-rural gradient and identify scale-dependent anthropogenic drivers that might affect either slugs or their function as seed predators.

We used a combination of seed cafeterias and pitfall traps in schoolyards and field margins in areas with different land use to gauge a proxy for slug abundance and seed predation rates.

Our results show that slugs are important seed predators for small seeded plant species regardless of anthropogenic land use. Slug abundance was the most important predictor for seed predation rates, whereas landscape variables like woody vegetation or microhabitat variables had little influence. Interestingly, the abundance of slugs is not necessarily affected by the landscape context such as increased urbanization but small-scale increases in woody vegetation or microhabitat promoted slug abundance.

In conclusion, the abundance of slugs has a positive influence on overall seed predation in anthropogenic landscapes, caused by microhabitat effects on the foraging behavior of slugs, which might be an important subject for the management of slugs mediating seed loss in farmed or garden habitats.

Keywords: Ecosystem function, Arthropods, Granivory, Cafeteria-experiment, Gastropods

Introduction

Fundamental changes in landscapes due to landscape fragmentation, urbanization, intensified agriculture, biodiversity loss or invasive species dramatically impact ecosystems and their functions (Boivin et al., 2016; DeFries, Foley, & Asner, 2004; Foley et al., 2011; Hautier et al., 2015; McKinney, 2002; Mitchell et al., 2015; Scherber et al., 2010). These different influences that humans either intentionally or unintentionally exert on ecosystems, consequences for ecosystem functions are hard to predict in anthropogenically influenced landscapes (DeFries et al., 2004). Ecosystem functions that are specifically affected by human interventions are interactions between animals or between plants and animals like seed predation or seed dispersal. These interactions may change drastically due to changes in species composition caused by human impacts such as intensive land use including agricultural intensification and urbanization, which form novel anthropogenic ecosystems (Mitchell et al., 2015; Tylianakis, Didham, Bascompte, & Wardle, 2008). In intensively used anthropogenic ecosystems, functions such as pollination, seed predation or dispersal are often affected negatively, for example through the loss of interacting species, loss or alteration of the resources or changes in activity and behavior (Farwig et al., 2009; Garibaldi et al., 2011; McKinney, 2006; Tscharntke, Steffan-Dewenter, Kruess, & Thies, 2002).
Post-dispersal seed predation by smaller animals like arthropods and molluscs influenced by different habitat structures has recently received attention (Boch, Fischer, Knop, & Allan, 2015; Fusser, Pfister, Entling, & Schirmel, 2016; Alois Honek, Martinkova, Saska, & Koprdova, 2009; Jonason, Smith, Bengtsson, & Birkhofer, 2013; Mauchline, Watson, Brown, & Froud-Williams, 2005; O'Rourke, Heggenstaller, Liebman, & Rice, 2006; Rodrigo, Retana, & Pico, 2004; Türke et al., 2013). The surrounding environment and its composition and structural complexity can influence seed predator diversity, their abundance, activity and behavior (Kappes et al., 2009; Kappes & Schilthuizen, 2014; Wenny, 2000). Rates and intensity of seed predation of a single plant species can change depending on the interacting seed predators (i.e. ground beetles, isopods or mollusks) that may show different feeding behaviors (Blattmann, Boch, Türke, & Knop, 2013b; Alois Honek et al., 2009; Pufal & Klein, 2013, 2015). These smaller seed predators influence seed predation mainly on the habitat scale in their immediate surroundings due to a lower mobility compared to larger seed predating animals, such as rodents, that might also influence seed predation at larger scales (i.e. landscape scale) (Lange et al., 2014; Pufal & Klein, 2015; Sattler, Duelli, Obrist, Arlettaz, & Moretti, 2010).

Several studies have addressed seed predation by different functional groups (i.e. rodents, ground beetles, birds or ants) either in rural or urban areas (Bode & Gilbert, 2016; Booman, Laterra, Comparatore, & Murillo, 2009; Gardiner, Prajzner, Burkman, Albro, & Grewal, 2014). Pufal and Klein (2015) addressed seed predation by different functional groups in contrasting anthropogenic landscapes and highlighted the shift between functional groups and their importance for seed predation from rural to urban areas. However, we still know very little about changes in the role of different generalist seed predators and the landscape effects on different habitat scales that inform these changes along a gradient of human land use. To elucidate the potential shift in seed predation rates along an urban-rural gradient, we conducted a cafeteria seed predation experiment targeting different functional groups, such as slugs, earthworms, arthropods and rodents. This would allow us to address the effect of anthropogenic landscape changes at different spatial scales on seed predation by different functional groups. However, for most non-slug seed cafeterias, slugs were able to circumvent slug-repelling measurements, which compromised treatments for all other functional groups. Other studies also reported partly massive damage of cafeteria-style experiments by slugs (whether they used slug repellent or not) (Pufal & Klein, 2015; Russell, Lambrinos, Records, & Ellen, 2017) and this inspired us rather than assessing different functional groups of seed predators, to focus on seed predation by slugs along an urban-rural gradient.

Slugs are omnivorous and facultative granivores, with different gastropod species showing no seed preference but rather differences in the amount of consumed seeds (Blattmann et al., 2013b). Seed predation by slugs has been investigated for several plant species in different habitats (Farwig et al., 2009; Alois Honek et al., 2009; Türke et al., 2012, 2013), however, the overall role of slugs for post-dispersal seed predation along an urban-rural gradient remains largely unknown. We therefore investigated whether seed predation by slugs changed along an urban-rural gradient and which scale-dependent anthropogenic changes might affect seed predation by slugs. Specifically, we tested whether seed predation by slugs is rather influenced by the abundance of slugs (which might be affected directly by human actions), by the larger landscape context (which might have an effect on slug abundance) or by habitat structures at the microhabitat scale, which might affect the slugs' foraging behavior. Furthermore, we were interested in the overall role that slugs play in seed predation of smaller seeds compared to other ground-dwelling granivores to quantify their influence on the local seed fate.

Consequently, we investigated seed predation in two cafeteria experiments, where one allowed free access to all ground-dwelling seed predators and the other allowed only access by slugs, combined with pitfall traps to assess slug abundance. We assume that seed predation by slugs will be strongly affected by slug abundance, but this will be moderated by the vegetation structure. A dense vegetation structure to prevent moisture loss and provide sufficient forage at the habitat scale will be more important for slugs than for example the amount of available usable habitat (i.e. non-sealed area) at a larger scale. Due to the loss of suitable habitat with increasing urbanization, we expect seed predation by slugs to decrease due to lower slug abundance in less suitable habitats.

Methods

Study area and sites

The study was conducted along an urban-rural gradient from the city of Lüneburg (53°N, 10°E) to its surrounding area in Lower Saxony, Northern Germany from the end of May until the end of August 2013. We chose 16 field sites, which included eleven schoolyards from elementary schools in the city area and surrounding rural villages and five rural field sites on field margins of rapeseed fields outside of settled areas. The structural composition of the schoolyards varied in details but mainly comprised surfaces that were paved, mulched, had bare soil, grassy areas or maintained lawn. All schoolyards had solitary trees, shrubs, hedges and playground equipment. The rural field site areas comprised mainly grass, bare soil and shrubs, hedges, solitary trees and forest edges.

Spatial scales of the urban-rural gradient

We realized an urban-rural gradient at the landscape scale (280 x 280 m) and at the habitat scale (40 x 40 m) with the centre for the measurements between the two replicates at each site. At these scales, we used the ratio of sealed to unsealed surfaces in m^2 to define the urban-rural gradient (UI) with a low UI representing low amount of sealed surface and hence more natural and semi-natural areas whereas a high UI (high amount of sealed surface) is a proxy for more urbanized area. Sealed surfaces were e.g. roads, buildings and parking lots, unsealed surfaces were hedgerows, trees, shrubs, crop fields or grasslands. Their amount in the study areas at the different spatial scales was estimated from aerial photographs in Google Maps (www.google.de/maps, 2015) at the highest resolution.

At the habitat scale (40x40m), we recorded the percentages of sealed surfaces (roads, buildings and paved surfaces), woody vegetation (hedgerows, forest fragments, single trees, hedges and shrubs), cropland (arable fields or vegetable patches) and grassland (grassland or lawns) and also quantified the habitat heterogeneity of these habitat types by calculating their Shannon-diversity index (Ramezani, 2012). The habitat heterogeneity was assessed from aerial photographs in Google Maps (www.google.de/maps, 2015) and additionally confirmed visually at each site. We assessed vegetation height and cover, plant species richness and the percentage of bare soil in squares of one by one metre around each set-up, because the immediate microhabitat structures can be important for slugs' movement and activity (Kappes et al., 2009). For more details in a similar spatial set-up, see Pufal and Klein (2015).

Cafeteria experiment

The seed removal experiment was conducted on flat grassy areas and comprised six treatments on each site. Each set of six treatments (one replicate) was set up in an area of one by one meter. We set up two replicates per site, each for two nights, approximately ten meters away from each other and surveyed these between three and four times over the course of four months. In 45% of the surveys, at least one replicate was destroyed by presumably wildlife, people or the weather. In those cases, we only used the results from the remaining replicate.

Each treatment only allowed access for a specific group of ground-dwelling seed-removing animals, using different combinations of mesh wire cages, plastic rain roofs, sand-filled petri dishes, bamboo golf tees, insect glue and slug repellent fencing (for comparable set-up see Miczajka, Klein, & Pufal, 2015). We used three different seed species (*Avena sativa* L. (Poaceae), *Daucus carota* L. (Apiaceae) and *Trifolium pratense* L. (Fabaceae)) with ten seeds from each species in each treatment. All seeds were airbrushed with water-soluble fluorescent colours, with each colour corresponding to a specific treatment (Lemke et al. 2009).

After two nights of exposure, we controlled the set-ups, counting remaining seeds within treatments and searching approximately ten minutes around each replicate to locate potentially dispersed seeds, using UV-flashlights (ELECSA 1122; Elecsa, Germany). When seeds were damaged by animals or completely destroyed, they were classified as consumed. Seeds were classified as dispersed when they were found intact outside the respective treatment. If seeds were not recovered, we assumed seed predation and missing seeds were therefore also classified as consumed. In all future analysis, we used consumed seeds (sum of damaged and missing seeds) as response variable. At the surveys it was evident that slugs were able to breach the slug-repellent fencing and compromised all other treatments. We therefore only analysed data from the treatment that allowed access for all ground-dwelling animals (seeds on sand with rain cover) (from here on referred to as free treatment) and the treatment that allowed access only to slugs (seeds in sand-filled petri dishes, surrounded by mesh wire cage, rain cover and insect glue) (from here on referred to as slug treatment).

Pitfall traps

At each of the ten study sites, we set up four pitfall traps twice from June to August 2013. The 500 ml plastic cups were placed into the ground, covered with a metal grid (10x10mm) to avoid non-target catches and also covered with a plastic rain roof. The cups were filled with approximately 250ml salt water to avoid attracting specific taxa because we wanted a representative catch of the granivorous ground-dwelling fauna (Teichmann, 1994). The four pitfall traps were placed one to two metres apart in a row along our experimental set-up. Pitfall traps were collected every two and a half weeks and the number of slug individuals per trap was counted. Species identification was not possible due to the poor condition of the samples. In some study sites, a number of pitfall traps were destroyed by wildlife. We hence did not use the sum of individuals from pitfall traps as proxy for abundance but the mean number of individuals per trap and site.

Statistical analyses

For statistical analyses we used the statistical program R version 3.2.3, (R Core Team, 2015). We used generalized linear mixed effect models (GLMM) (package lme4, Bates et al. 2015) with subsequent least square mean comparisons (package lsmeans, Lenth 2017) to compare seed predation rates of the three different seed species with each other and between the free and the slug treatment. We used a binomial error distribution for the ratio of consumed to available seeds as response variable, treatment and seed species (including their interaction term) as fixed effect and date of exposure nested in site as random effect. Model fit was tested with the DHARMa package (Hartig 2017) and to correct for apparent overdispersion, an observation level random effect was added (Harrison 2014).

To test for spatial environmental effects on the abundance of slugs, we used landscape and microhabitat variables in a set of two generalized linear mixed effect models (landscape scale model and microhabitat model) with the abundance of slugs as response variable with a poisson error distribution. In the landscape scale model, we decided a priori to only use the percentage of woody vegetation as the habitat component as this has been shown to be a favourable habitat for slugs (Fusser et al., 2016). The landscape scale model hence contains landscape gradient, habitat heterogeneity and woody vegetation as fixed effects. We further used an information theoretic approach by comparing a set of candidate models based on the prior analyses (Grueber et al. 2011).

We chose the more conservative threshold of $r > 0.5$ for an indicator of collinearity (Booth et al. 1994, Dormann et al. 2013) and therefore removed the habitat scale gradient from the landscape models, because it was strongly correlated with the landscape gradient and habitat heterogeneity. For the microhabitat model, no correlation coefficient was larger than 0.5 and we retained all variables in the model (vegetation height, vegetation cover, percentage of bare soil, plant species richness).

In all models, landscape and microhabitat variables were centred to decrease variability. We assumed that seed predation by slugs along an urban-rural gradient can be influenced by human land use either through changes in the abundance of slugs or through landscape and microhabitat effects that mediate slug abundance and/or behavior. Here, we only used data from the time frames when pitfall traps and cafeteria experiments were set up at the same times. This excludes data from the first (end of May and early June) and the last round of cafeteria experiments (late August). All three candidate models were generalized mixed effect models with a binomial error distribution, the ratio of consumed to available seeds in the slug treatment as response variable and date of exposure nested in sites, seed species and an observation level random term as random effects. We decided to use seed species as random rather than fixed effect, because we were not interested in the effect of seed species on seed predation but still aimed to account for the variability in the data due to the different seed species. Candidate model 1 (slug abundance model) included mean slug abundance as fixed effect. Candidate model 2 (landscape scale model) included the landscape gradient, habitat heterogeneity and percentage of woody vegetation as fixed effects. Candidate model 3 (microhabitat model) included vegetation height, vegetation cover, percentage of bare soil and plant species richness as fixed effects.

To test the importance of slugs for total seed predation by ground-dwelling granivores, we assessed the effect of slug abundance on seed predation rates in the free treatment in a GLMM. Again, we only used data from those times when pitfall traps and cafeteria experiments were set up simultaneously. We used a binomial error distribution with the ratio of consumed to available seeds in the free treatment as response variable, landscape scale, habitat heterogeneity and woody vegetation as fixed effects and date of exposure nested in sites, seed species and an observation level (to cope with overdispersion (Harrison 2014)) as random effects.

Results

Seed predation by slugs

From a total of 5700 (100%) seeds exposed in the field, 1278 (22.4%) seeds were consumed and 130 (2.3%) were dispersed. The interaction between seed species and treatment was not significant but treatment and seed species as single variables had significant effects on seed predation rates (Table 1). All three seed species were more often consumed in the free treatment compared to the slug treatment (Table 1). Overall, *A. sativa* seeds were most preferred not only by slugs but also by all potential ground-dwelling seed predators and were significantly more often consumed than the other two species (Fig. 1, Appendix A Table 1). More than 60% of all provided *A. sativa* seeds were consumed in the free treatment and they were also consumed almost three times as often as the other two seed species. Similar results were achieved in the slug treatment. Here, 20% of all *A. sativa* seeds were consumed, which was also more than four times as many consumed seeds as from the other two species (Appendix A Table 1). Within each treatment, predation by *T. pratense* and *D. carota* was similar (Fig. 1, Table 1).

Seed dispersal rates (i.e. number of recovered seeds) were negligible in the slug treatment and varied between 1.89 % (*A. sativa*) and 6.95 % (*D. carota*) in the free treatment (Appendix A Table 1). Due to these low seed dispersal numbers, all following analyses were only carried out for seed predation data.

Table 1. Least square mean contrasts between seed species within the treatment and between treatments (free and slug) for each seed species.

Contrasts	Free treatment			Slug treatment		
	Estimate±SE	z-ratio	p-value	Estimate±SE	z-ratio	p-value
A. sativa - D. carota	4.752±0.451	10.529	<0.0001	3.573±0.593	6.027	<0.0001
A. sativa - T. pratense	4.448±0.439	10.122	<0.0001	3.026±0.553	5.471	<0.0001
D. carota - T. pratense	-0.303±0.406	-0.748	0.7350	-0.547±0.639	-0.856	0.6683

Species	Contrast free - slug treatment		
	Estimate ±SE	z-ratio	p-value
A. sativa	5.249±0.491	10.694	<0.0001
D. carota	4.070±0.587	6.935	<0.0001
T. pratense	3.826±0.543	7.048	<0.0001

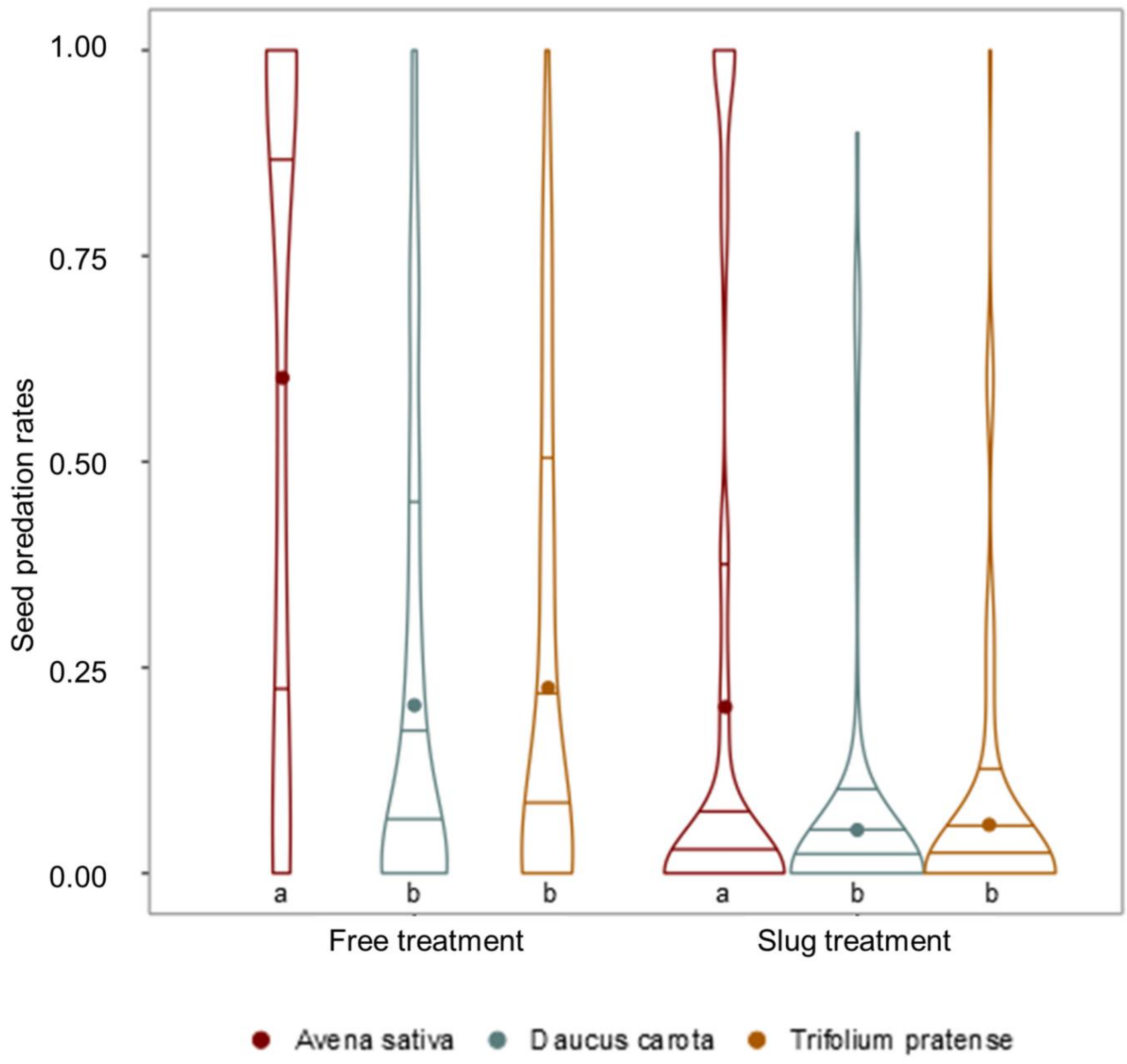

Fig. 1. Violin plots of seed predation rates of three seed species in two experimental treatments. Different lower case letters below the plots indicate significant differences between the species within the same treatment. Circles represent the mean, lines the quartiles (25%, 50%, 75%).

Landscape effects on slug abundance

Slug abundance across sites was highly variable, with a mean of 2.8 (±8.72 SD) slugs per pitfall trap. When comparing the landscape and the microhabitat model, the landscape model had a lower AICc (282.3) than the microhabitat model (283.7) but the ΔAICc was only 1.4, making a ranking of the better fitting model indecisive. In both the landscape and microhabitat models, none of the explanatory variables had a significant effect on slug abundance (Fig. 2, Table 2).

Table 2. Effects of landscape and microhabitat variables on slug abundance. Given are estimates ± standard error, z-value, p-value as well as the AICc and standardized weight for each model.

Fixed effects	Estimate ± SE	Z-value	P-value	AICc	weight
Landscape model				282.3	0.663
Intercept	-1.859±0.635	-2.926	0.003		
Landscape gradient	-0.638±1.292	-0.494	0.622		
Habitat heterogeneity	-3.199±2.960	-1.081	0.280		
Woody vegetation	0.014±0.039	0.359	0.719		
Microhabitat model				283.7	0.337
Intercept	-2.033±0.664	-3.063	0.002		
Vegetation cover	0.008±0.024	0.354	0.723		
Vegetation height	-0.010±0.023	-0.441	0.659		
Bare soil	0.025±0.020	1.201	0.228		
Plant species richness	-0.188±0.239	-0.784	0.433		

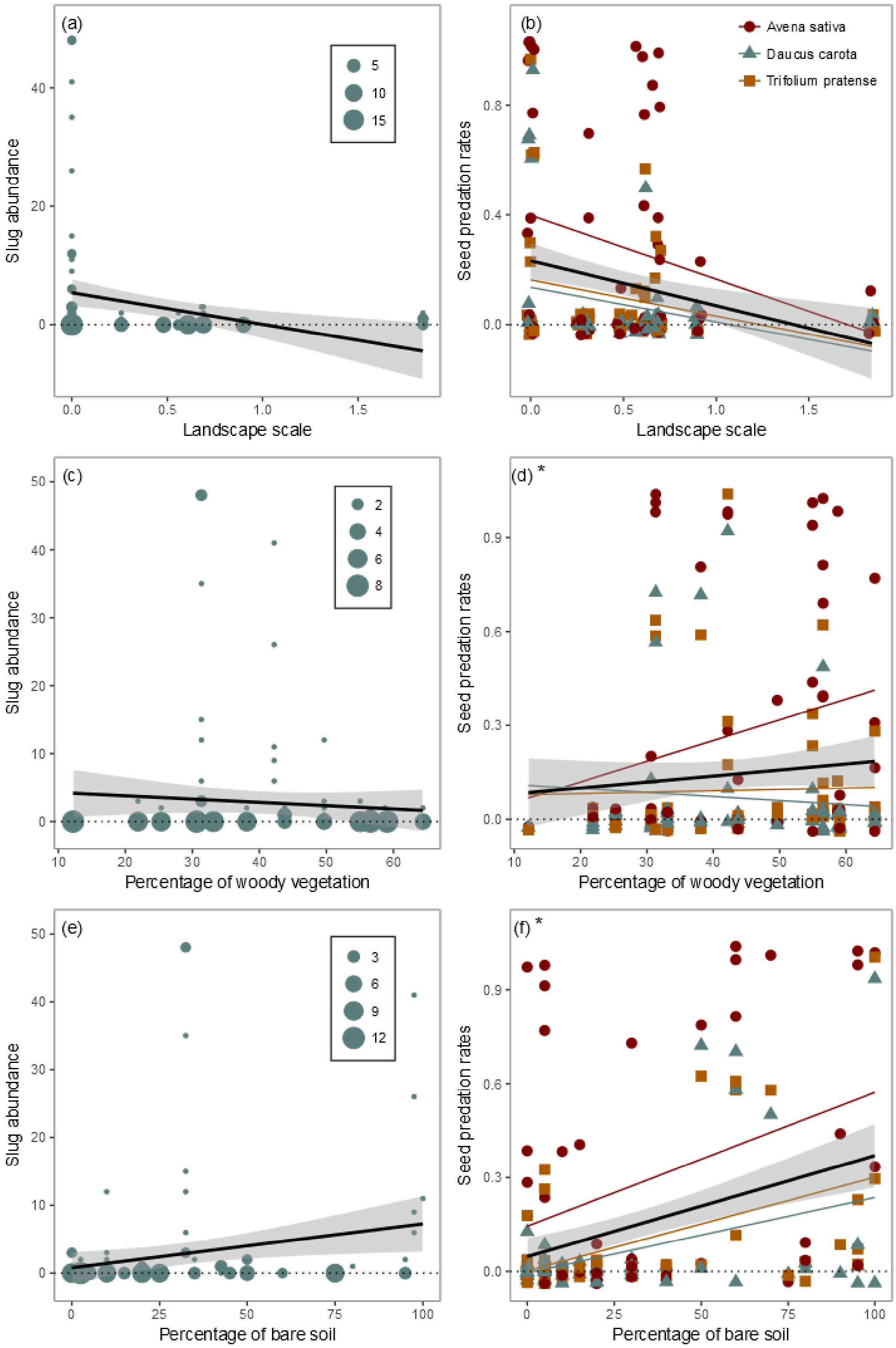

Fig. 2. Landscape (sealed/unsealed) and microhabitat variable effects on slug abundance and slug seed predation rates. Bubble plots in panel a, c and e show effects on slug abundance with the size of bubbles representing the number of pitfall traps for the respective slug abundance. Panels b, d and f show effects on seed predation rates in the slug treatment. Significant effects are highlighted with an asterisk behind the panel numeration (* $p < 0.05$). In these panels, the black line represents the mean across the three seed species with a 95% confidence interval (grey area) and points are jittered.

Effects on seed predation by slugs

When comparing all three candidate models, there were only low differences in the ΔAICc, with the model containing slug abundance as the explanatory variable ranked the highest (AICc=324.97), followed by the microhabitat model (AICc=325.7) and the landscape model (AICc=327.7). Slug abundance had a strong positive effect on seed predation and in the landscape and microhabitat models, woody vegetation, percentage of bare soil and plant species richness, respectively, affected seed predation rates by slugs positively (Fig. 2, Table 3).

Table 3. Coefficients of the candidate models for landscape, microhabitat and slug abundance. Given are estimates ± adjusted standard error, z-value and p-value (significant variables are highlighted in bold).

Fixed effects	Estimate ± adj. SE	Z-value	P-value
Landscape gradient			
280x280 m	-3.048±2.581	-1.181	0.238
Habitat heterogeneity	-5.602±5.535	-1.012	0.312
Woody vegetation	**0.168± 0.075**	**2.248**	**0.025***
Microhabitat			
Vegetation cover	-0.022±0.036	-0.628	0.530
Vegetation height	-0.005±0.017	-0.323	0.746
Bare soil	**0.061± 0.027**	**2.293**	**0.022***
Plant species richness	**0.517± 0.226**	**2.284**	**0.022***
Slug abundance			
Slug abundance	**0.424±0.144**	**2.948**	**0.003****

Role of slugs as generalist seed predators

Assuming that seed predation by slugs in the free treatment is comparable to seed predation in slug treatment, the proportion of seeds consumed by slugs in the free treatment is 30% (compare Appendix A Table 1). When testing the effect of slug abundance on seed predation rates in the free treatment, slug abundance had a positive effect on seed predation (Estimate±SE = 0.171±0.075, z-value = 2.294; p-value = 0.022). With increasing slug abundance, the seed predation rate in the free treatment also increased (Fig. 3).

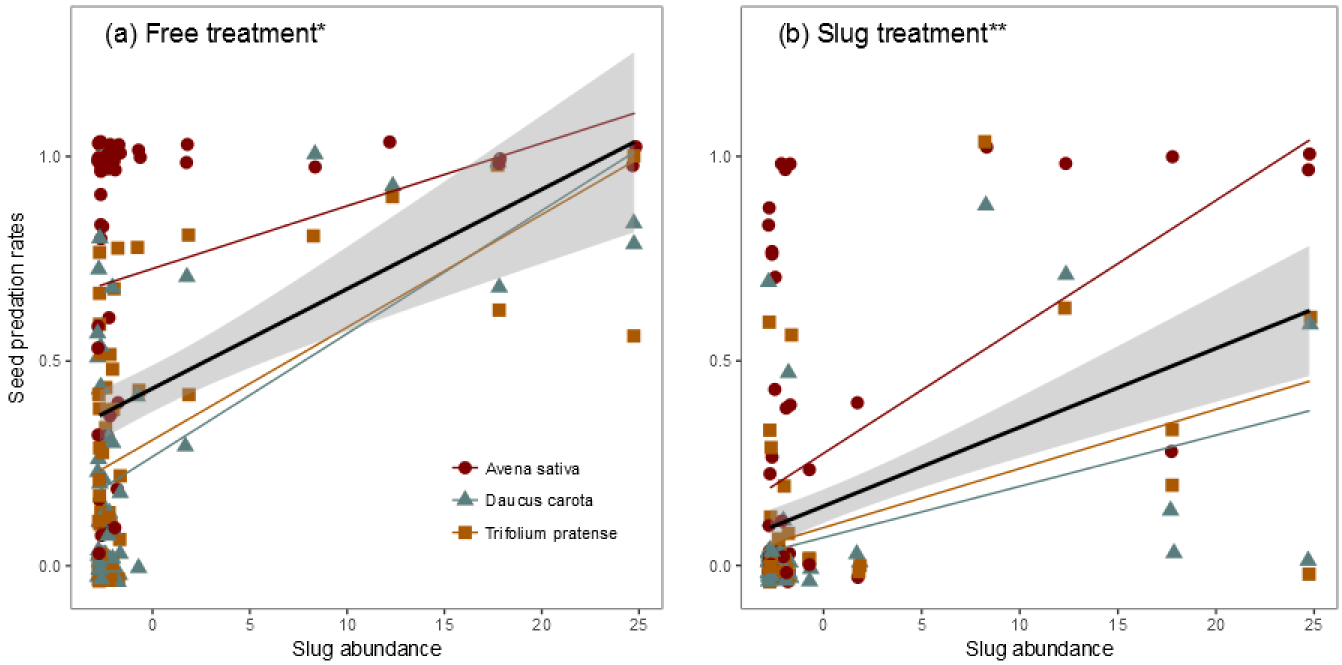

Fig. 3. Effects of slug abundance on seed predation rates in the free (a) and slug (b) treatment. The black line represents the mean seed predation across the three species with 95% confidence intervals (grey area). Note that slug abundance is centered and points are jittered.

Discussion

We could show that slug abundance promoted seed loss. This might be due to other variables than surface effects, as we found no significant landscape scale effect on slug abundance nor seed predation along the urban-rural gradient with similar predation patterns for the free and the slug treatment (with generally more predation of the large seed species (*A. sativa*), especially in the free treatment).

It is a well-known fact, that slugs are generalist herbivores with serious consequences on species diversity within vegetation (Buschmann, Keller, Porret, Dietz, & Edwards, 2005; Eggenschwiler et al., 2013; Fusser et al., 2016; Maron & Crone, 2006; Willis et al., 2006). The consequences of seed predation by slugs can be very different with positive or negative consequences for the vegetation community dependent on the foraging behavior and the slug species (Buschmann et al., 2005). For example, slugs can have a positive effect on plant species diversity reducing seeds of the most common plant species supporting more seldom plants (Buschmann et al., 2005). Contrary, in case of an invasive slug eating seeds that normally escape common seed predators may result in extermination of the seedlings at places with high slug abundances (Honek, Martinkova, Koprdova, & Saska, 2017). However, further negative effects such as cosmetic damage or the devaluation of crop are not only caused by invasive slugs but are often resulting in an increased slug pellet application (Willis et al., 2006). Knowing an approximate for the influence of slug abundances in correspondence of slugs' foraging behavior on seed predation can be important in the context of natural habitats controlling biological pest as a contribution of potential ecosystem services.

We assume that the influence of slug abundance is an important prediction variable on seed predation, especially in woody vegetation or microhabitats with high percentages of bare soil or high numbers of plant species richness, showing increased seed predation rates. These results fit very well with the outcomes of other studies highlighting i.e. woody vegetation or species-rich field margins as important slug habitats (Eggenschwiler, Speiser, Bosshard, & Jacot, 2013; Fusser et al., 2016; Türke et al., 2012).

Again, as we found no significant effect of the landscape scale on seed predation or slug abundance other variables like bare soil or plant species richness as microhabitat variables are more important. We assume that higher rates of bare soil protect slugs from drying out or soil cultivation management and additionally that higher plant species richness offers varying attractiveness as food or habitat for slugs. An increased activity of slugs due to improved field margins was also showed by Eggenschwiler et al. (2013), highlighting an improved protections of slugs from desiccation. Also microclimatic conditions like ambient temperature or soil moisture, the variable cultivation of (garden) plots (divers or monoculture, grass or vegetables, organic or with pesticides like slug pellets) or the availability of natural enemies may have a significant influence on slug activity and abundances (Fusser et al., 2016; Smith et al., 2006; South 1992; Tscharntke et al., 2016; Willis et al., 2006).

Summarizing we can say that the abundance of slugs has a significant influence on overall seed predation of 30% in anthropogenic landscapes. One third of the overall seed predation by slugs might be acceptable as long as the habitat shows a moderate heterogeneity. However again, if the slug abundance is high and natural enemies are missing it may result in extermination of the seedlings, in cosmetic damage of crop or in crop loss in private gardens with often low plant abundances. Further we suppose that not the sheer number of slugs, but the influence of microhabitat and landscape managements consequently affect the foraging behavior of slugs, which could be an important subject in the management of modulate seed predation by slugs. This assumption is supported by our candidate models showing hardly differences in the AIC-values with consequences for seed predation rates instead of slug abundances. We agree with Le Gall and Tooker (2017) that if we cannot control the abundance of slugs, we might find strategies to affect their foraging behavior.

We agree with other studies (i.e. DeFries et al. 2004) that human influences on varying ecosystem functions with possible consequences for biotic interactions are difficult to detected and further management predictions sometimes imprecise. Biological pest control within natural habitats will always be dependent of crop type, pest or predator or landscape structure and management (Tscharntke et al., 2016). We could show that slugs are important seed predators in anthropogenic landscapes with significant consequences for overall seed predation rates. This biotic interaction may further be influenced by more complex subjects like other specific animal-plant interactions, animal species abundances or distributions (Blattmann, Boch, Türke, & Knop, 2013a; Buschmann et al., 2005; Kappes & Schilthuizen, 2014; Smith et al., 2006). Further knowledge of variables, biotic and abiotic interactions affecting slug or other animal abundances might make it easier to extrapolate consequences for ecosystems and therewith ecosystem functions and services.

Conclusion

Generally in many systems natural habitats have the potential to increase biological pest control, however they can also fail to do so in case of benefiting pest better than natural enemies (Tscharntke et al., 2016). In case of pest slugs that are responsible for significant economic damage and yield loss, the pest control can be very difficult, particularly in not tilled fields (Le Gall & Tooker, 2017). There exist only a few controlling opportunities mainly on pesticide foundation with inconsistent control and increased risk for the environment (Castle et al., 2017; Le Gall & Tooker, 2017). We support the more sustainable postulation from Le Gall and Tooker (2017) for more ecological based pest management on the foraging behavior of slugs or natural enemy control as it is cheaper and safer for the environment as especially drinking water is seriously affected by molluscicides (Castle et al., 2017).

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CRAN package repository:
https://cran.r-project.org/web/packages/available_packages_by_name.html (last access 19-08-2017)

Package lsmeans (Least-Squares Mean) (2017) Russell Lenth, russell-lenth@uiowa.edu

Package DHARMa (Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models) (2017) Florian Hartig, florian.hartig@biologie.uni-regensburg.de

Package lme4 (Linear Mixed-Effects Models using 'Eigen' and S4) (2017) Ben Bolker et al., bbolker+lme4@gmail.com

Package MuMIn (Multi-Model Inference) (2015) Kamil Bartón, kamil.barton@go2.pl

Appendix

A

Table 1. Number (and percentages) of the total of consumed or dispersed seeds for three seed species (*A. sativa, D. carota and T. pratense*) in two treatments.

	Provided seeds in each treatment	Free treatment		Slug treatment	
		Consumed	Dispersed	Consumed	Dispersed
Seed species					
Avena sativa	950	572 (60.21%)	18 (1.89%)	192 (20.21%)	0 (0.00%)
Daucus carota	950	194 (20.42%)	66 (6.95%)	50 (5.26%)	3 (0.32%)
Trifolium pratense	950	214 (22.53%)	37 (3.89%)	56 (5.89%)	6 (0.63%)

Chapter II

Elementary school children contribute to environmental research as citizen scientists

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RESEARCH ARTICLE

Elementary School Children Contribute to Environmental Research as Citizen Scientists

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Abstract

Research benefits increasingly from valuable contributions by citizen scientists. Mostly, participating adults investigate specific species, ecosystems or phenology to address conservation issues, but ecosystem functions supporting ecosystem health are rarely addressed and other demographic groups rarely involved. As part of a project investigating seed predation and dispersal as ecosystem functions along an urban-rural gradient, we tested whether elementary school children can contribute to the project as citizen scientists. Specifically, we compared data estimating vegetation cover, measuring vegetation height and counting seeds from a seed removal experiment, that were collected by children and scientists in schoolyards. Children counted seeds similarly to scientists but under- or overestimated vegetation cover and measured different heights. We conclude that children can be involved as citizen scientists in research projects according to their skill level. However, more sophisticated tasks require specific training to become familiarized with scientific experiments and the development of needed skills and methods.

Introduction

Worldwide, ecosystems change rapidly due to human actions and it is therefore vital to understand underlying ecological processes and functions to halt biodiversity loss [1]. Consequently conservation efforts need to be enhanced [2]. Conveying knowledge of biodiversity and ecosystem functions to the public requires new forms of communication between different structures of society [3,4]. To make the importance of conserving the environment and its species and functions more tangible for society, the knowledge transfer should focus on visible ecosystem functions like herbivory, pollination, seed predation and dispersal [5–7]. Citizen science programs that integrate non-professional volunteers into authentic scientific research and conservation efforts, offer therefore an opportunity to promote public engagement and advance research in ecology and conservation by connecting science and education [8]. Furthermore, citizen science projects range from large scales to local research experiences [9] where participants gather valuable data on temporal and geographical variation in monarch butterfly eggs and larvae [10], monitor endangered, threatened and rare plant species in the greater Chicago,

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Illinois, region [11] or practice sustainable coffee production that comes with sustainable livelihoods [12]. These collections vary in extent, effort, and quality and include different data types like count [13], phenological [14], and species abundance data [15] or estimations on vegetation surveys [16]. Depending on the data type, the collection requires specific skills, time and prior ecological knowledge of the participants. Hence, different studies discuss diverse methods to evaluate the quality and comparability of data collected by citizen scientists with those by scientists [10,15,17,18].

So far, most citizen science projects in conservation ecology concentrate on a specific species (i.e. the endangered Grevy's zebra (*Equus grevyi*) [19]), a particular region (i.e. the Oak Creek Wildlife Area [20]) or a unique ecosystem (i.e. the Florida Lakewatch [21]). Consequently, participants learn about the target species or a particular interaction between an animal and its habitat [22,23], but more complex interactions or ecosystem functions are rarely approached by citizen scientists.

To assess the land use impact on ecosystem functions in anthropogenic landscapes, we conducted a transdisciplinary research project by combining research on seed predation and dispersal as ecosystem functions with environmental education and the integration of elementary school children as citizen scientists. Studies show that being engaged in ecological experiments together with scientists can increase the children's knowledge about science in general and ecology specifically [24–26]. In the experimental part of our project, children and scientists investigated seed predation and dispersal by ground-dwelling animals in a cafeteria experiment, because there is little knowledge about these functions along an urban-rural gradient [27]. We chose these functions because they are easy to comprehend, their impact is instantly visible and similar approaches might be transferable to projects on herbivory or pollination. The children had the opportunity to further develop the understanding of their daily surrounding environment, strengthen their systematic thinking early in the process of scientific literacy learning, and be part of authentic scientific research [28–30].

The aim of this case study was to test whether elementary school children were able to conduct an ecological experiment and collect data qualitatively similar to scientists. Specifically, we compared estimated vegetation cover, measured vegetation height and count data for seed removal. We hypothesized that children would achieve similar results to scientists for measured and count data but might over- or underestimate vegetation cover due to their inexperience.

Methods

Study area and sites

The study took place along an urban-rural gradient in ten schoolyards in the cities of Hamburg (53°N, 9°E), Lüneburg (53°N, 10°E) and the surrounding area in Lower Saxony, Northern Germany. The structural composition of the schoolyards varied in details but mainly comprised surfaces that were paved, mulched, had bare soil, grassy areas or maintained lawn. All schoolyards had solitary trees, shrubs and hedges and playground equipment (Fig 1A). The seed removal experiment was generally set up on grassy areas and comprised six treatments.

Educational program

A total of 302 elementary school children (eight to ten years old) from 14 classes in ten schools participated in 12 lessons provided by scientists in each class (S1 Appendix). Each class was taught by one scientist, whereas the teacher only had a supervising role. The scientific and educational content of the project contributed to the official curriculum for grades two to four in Lower Saxony and Hamburg, hence the study was conducted as part of the educational

Fig 1. Illustration of the data collection on schoolyards. (A) Experimental set-up at a typical school yard, (B) schematic overview of the experiment with the different tasks children had to carry out, (C) children counting seeds in the treatment and (D) seed counting with UV-flashlights and umbrella.

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curriculum from the children in school [31,32]. The aims of those core curricula for the children are to formulate questions and test hypotheses. They should also be able to observe and explain natural phenomena, combine the learned knowledge and be able to understand them with the help of observations, questions, descriptions, analyses, measurements and experiments. We supported these by focusing on the concepts of habitats, native and non-native species and plant-animal interactions (specifically seed predation and dispersal) as well as the development of hypotheses and how to answer them. These topics were taught with different interactive exercises, games, discussions and learning materials. During the lessons, children kept a project journal with given exercises and options to document their project participation.

Four lessons were dedicated to the citizen science experiment. Here, we explained the relevance of the children's participation for our research, children practiced the required tasks (how to fill out the field protocol, setting up the experiment, which variables to count, estimate and measure and how to describe the vegetation) and we discussed the observed data.

Necessary permits to conduct research at the schoolyards and to involve children in the study were obtained from the education authorities in Lower Saxony (Niedersächsische Landesschulbehörde) and Hamburg (Freie und Hansestadt Hamburg, Behörde für Schule und Berufsbildung) in conjunction with the included educational program in schools. Further necessary informed consent from the next of kin, guardians and caretakers on behalf of the children enrolled in the study was given in written form and stored in schools to protect participants' confidentiality. We did not collect any identifying information about the children. Children taking part in the project only collected empirical data on seed removal so permission from an ethics committee was not required.

Experimental set-up

Experiments (six treatments total) were set up from April to June 2013 at all sites (see S2 Appendix for specific dates). Each treatment provided access for a specific group of seed removers with different combinations of mesh wire cages, petri dishes filled with sand, plastic rain roofs, bamboo golf trees, insect glue ("Aurum Insektenleim", Neudorff, Germany) and slug fences ("Snail Stop",Ringpoint). These combinations allowed access for either slugs, arthropods, earthworms, small rodents, all ground-dwelling seed-removing animals and no animals (control) (comparable set-up see [33]).

Scientists colored seeds with six different water-soluble fluorescent colors (Wicked Colors; CREATEX, USA, airbrush gun 39199 Revell, Germany) [34], with each color corresponding to a specific treatment. Scientists provided ten seeds of oat (*Avena sativa* L.) and ten of red clover (*Trifolium pratense* L.) for each treatment. These seeds were referred to as "big" (*A. sativa*) and "small" (*T. pratense*), respectively, or their common name, because this was easier to comprehend for the children. We will from now on use *A. sativa* and *T. pratense*.

A group of two to four children set up one treatment out of six during class in each schoolyard. In seven of the participating classes, treatments were set up simultaneously by all groups (from now on referred to as "simultaneous group") and one after another in the remaining seven classes (from now on referred to as "sequential group"), depending on the discipline and power of concentration in each class. Consequently, the supervision of the simultaneous group was less intensive than in the sequential group.

Data collection and comparison

Children used pre-designed field protocols to record: their group members, treatment with its color of seeds, number of exposed seeds, weather conditions, dates of set-up and end of experiment, type of cover (i.e. sand, moss or grass), vegetation cover, vegetation height and number of recovered seeds at the end of the experiment. Vegetation data (cover and height) were assessed in squares of one by one meter by each group at the location of their treatment (Fig 1B), but summarized by the scientists to one data set per class (mean value out of the group data), because some groups filled out their sheet only partly or even lost it (S2 Appendix).

Children recorded cover estimates in words (i.e. "lots of cover", "without plants", S2 Appendix) and measured vegetation height with a ruler in centimeter. Scientists estimated vegetation cover in percentages and measured vegetation height at the same times and locations but recorded these data separately. To compare the estimates of vegetation cover from scientists with those of children, vegetation cover was transcribed post-hoc into categories of 25% steps, resulting in five categories (values in between were rounded to the next closest category). Firstly, all phrases used by children to describe vegetation cover were transcribed into the five categories. Hence, "all covered/no free surface with grass, moss, clover" was for example interpreted as 100% of cover or "without plants with sand and soil" was 0% of cover (for the whole transcription see S2 Appendix). Because the sample size of vegetation data was too small for meaningful statistical analyses, we only used the raw data, mean and standard deviation to describe differences in the data between children and scientists (S2 Appendix).

After two nights of exposure, children counted the remaining intact seeds in their treatment and recorded the numbers in their field protocol (Fig 1C). When seeds were missing, they searched for approximately ten minutes to locate potentially dispersed seeds using UV-flashlights (ELECSA 1122; Elecsa, Germany) and black umbrellas to minimize the influence of sunlight (Fig 1D). The missing not detectable seeds were assumed to be predated. Seeds were also classified as predated when they were visibly damaged. Scientists counted seeds in all treatments in the morning of the same day before the children.

For this study, we only analyzed the count data of seeds remaining in the treatments (as a proxy for seed removal) and we did not distinguish between the different treatments when comparing data from children and scientists. We compared seed count data between scientists, simultaneous group and sequential group separately for *A. sativa* and *T. pratense* seeds. Therefore, we performed two-sided Wilcoxon signed-rank tests for independent groups and non-parametric data for small sample sizes using the software program R [35]. The similarity of data was calculated as the percentage of data points collected by the children that were similar to those of scientists, assuming that the scientists' data points were all accurate (100%).

Results

The vegetation cover recorded by children and scientists ranged from 0% to 100%. Only in five classes out of 14, children and scientists provided similar cover estimates (Table 1, S2 Appendix). Even though mean values of cover estimates are rather similar (Table 1), the direct comparison shows that children either under- or overestimated vegetation cover (Fig 2A, S2 Appendix).

Scientists measured vegetation heights between 0–40 cm whereas children measured 5–800 cm (S2 Appendix), corresponding to one matching measurement in one field site out of 14 (Table 1, S2 Appendix).

From the total number of provided seeds (1680), scientists recorded 88.7% remaining in the treatments and children recorded 83.9% seeds. Children in the simultaneous group and scientists counted comparable numbers of remaining *A. sativa* seeds ($W = 1021$, $p = 0.090$, similarity = 78.57%) and *T. pratense* seeds ($W = 1057$, $p = 0.056$, similarity = 59.52%) (Fig 2B, Table 1, S3 Appendix). Remaining *A. sativa* seeds were also counted similarly by scientists and children in sequential groups ($W = 886$, $p = 0.516$, similarity = 83.33%), but in the sequential group children counted significantly fewer *T. pratense* seeds ($W = 1020$, $p = 0.042$, similarity = 52.38%) compared to scientists (Fig 2B, Table 1).

Discussion

There was only little concordance in the estimation and measurement of vegetation cover and height data between children and scientists. However, seed count data from children and scientists was mostly similar and differed only considerably when children counted *T. pratense* seeds in sequential group.

Prior to our project, the children had no comparable experience or training in conducting scientific experiments. Our results demonstrate that collecting estimates—even using simple phrases—or measuring height is difficult for them. We assumed that describing vegetation cover in words would be sufficient to achieve comparable estimates. However, fractions and percentages are only taught in grade six in secondary school [36] and it appeared that practising a task that the children have no experience in, was not sufficient. The dramatic differences

Table 1. Comparison of vegetation cover, height and seed count data collected by children and scientists.

Data	Grouping	Mean±SD		Similarity
		Children	Scientists	
Vegetation data				
Cover estimation (%)	class	38.6± 37.7	46.4±40.3	05/14
Height measurement (cm)	class	92.3±225.5	18.9±13.5	01/14
Seed count data				
A. sativa seeds	Simultaneous group	9.0±2.6	9.4±3.1	78.57%
	Sequential group	9.3±1.9	8.9±2.7	83.33%
T. pratense seeds	Simultaneous group	7.7±2.2	8.8±2.2	59.52%
	Sequential group	8.2±3.1	9.1±1.8	52.38%

Note: Grouping indicates how data was collected by the children (as class, in sequential or simultaneous groups). For vegetation cover and measurement N = 14, for seed count data N = 336 (42 for each group). Similarity is given as matches between children and scientists/field sites for vegetation data and percentages of matching data between children and scientists for seed counts.

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in the measured vegetation height might be due to misinterpretation of the tasks the children were given. Instead of measuring the vegetation height at the location of the experimental set-up, some children also included surrounding shrubs or trees.

Counting is an innate skill for children aged eight to ten because they learn it early in their development [37]. Counting remaining seeds in the treatments therefore resulted mostly in similar data between children and scientists. Children only encountered difficulties in counting *T. pratense* seeds (one to two millimeters in diameter), because this task required attention and care and small seeds were missed more often. Even though the difference between sequential and simultaneous groups compared to scientists was small (52.38% vs. 59.52% similarity), this difference was still statistically significant. This is contrary to the assumption that group work is often more effective than whole-class teaching [38]. However, we assume that the differences might be due to an overexcitement from children in sequential groups under the direct supervision of a real scientist and therefore mistakes might have occurred more frequently [39]. Sequential groups were also mostly formed in classes where children were more lively or inattentive. It is therefore difficult to disentangle whether the differences are an inherent effect of the sequential group approach or due to attitudes of the specific children.

We feel confident that our results indicate that it is to some extent possible to integrate elementary school children as citizen scientists in projects that investigate ecosystem functions, if these projects require skills that the children are already familiar with. Citizen science projects that involve skills, which are beyond the children's educational level, would require intensive preparation and training.

We assume that the children gained a deeper insight into ecological background on native habitats and plant-animal interactions. This did not only support the learning content within the curriculum for grade two to four [31,32], but was also an opportunity to apply and integrate active science learning into their otherwise mostly traditional school routine [40,41]. Our project also gave them the opportunity to take part in actual scientific research and communicate with scientists firsthand about their work, which was shown to be more effective than education by teacher-centered teaching in other studies [24–26,42].

When working not only with children but participants from the public in general, it is important to find the right extent of participation to avoid the risk of losing motivation, which can result in possible errors. This might happen due to overextension and mental over- or

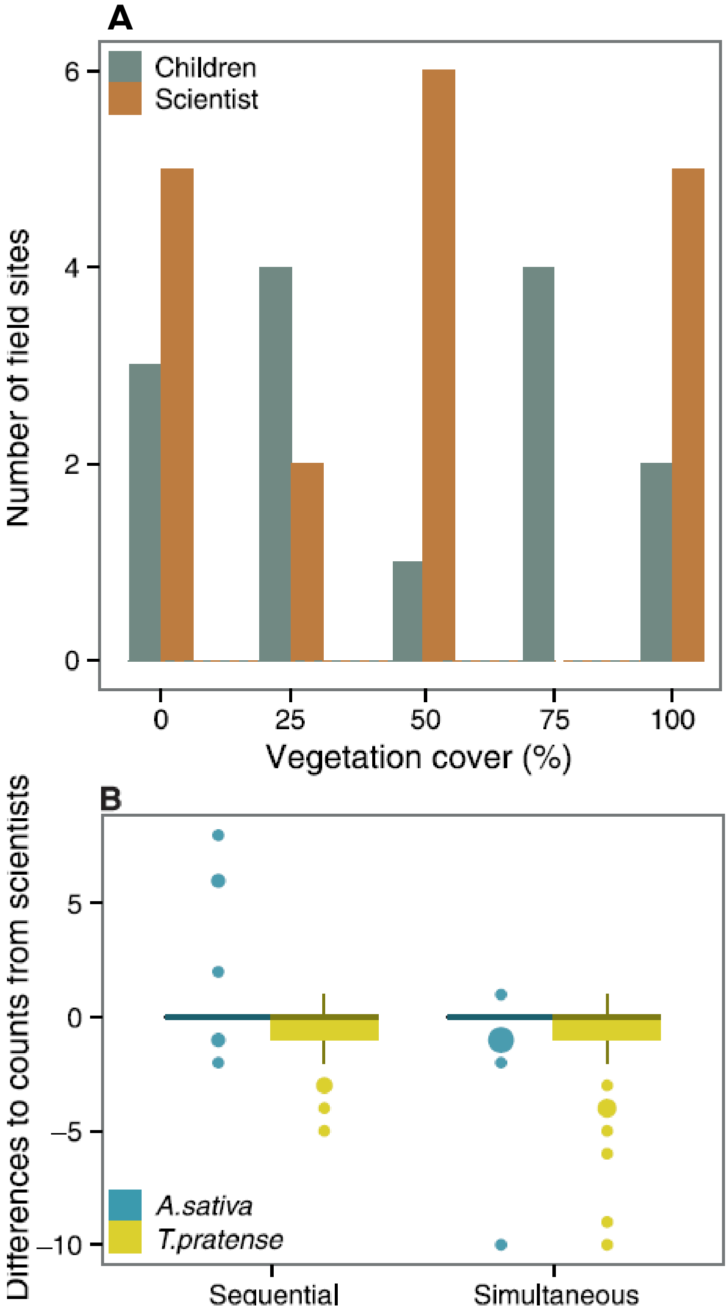

Fig 2. Comparison between estimated vegetation cover and seed count data between children and scientists. Bar plots in (A) show the number of field sites at which the different cover categories (in %) were recorded. Box plots in (B) show the differences of the children's counts (in sequential and simultaneous groups) compared to seed counts by scientists. The size of the outliers reflects the number of data points.

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underload because participants need time to repeat and practice new methods [43] to gain familiarity with scientific thinking.

It is often criticized that data recorded by citizen scientists is not reliable [15,18], but other approaches show that data recorded by citizen scientists can be qualitatively similar to data collected by researchers [10,23,44–46]. The seed count data from our study were mostly similar between children and scientists, but measuring and estimation data were not, which demonstrates that the reliability of data is task-dependent [17,20]. We therefore emphasize how important it is for citizen science projects to consider the skills and prior knowledge of participants when specific data will be collected. Consequently, it is instrumental to combine experimental approaches with the appropriate educational content to accompany a project, which can benefit scientists and participants alike. We postulate that citizen science projects for children can be designed to a) collect valuable data for ecological research by employing skills that are appropriate for their educational level and to b) support their environmental education in school by addressing topics and methods that are relevant at their specific stage of education. Our study can serve as a blueprint for the development of more transdisciplinary studies to promote public engagement and advance research in conservation programs by connecting science and education early on—by aspiring to make nature conservation more tangible for society and therefore in general more effective, one could not start early enough in childhood to promote nature awareness.

Supporting Information

S1 Appendix. Information on the participating classes (anonymized) and age of children (NA = not available).
(DOCX)

S2 Appendix. Vegetation data from children and scientists, N = 14 (NA = not available; _a or _b = two classes from the same school took part in the experiment).
(DOCX)

S3 Appendix. Raw data from the seed experiment from children and scientists, N = 336 (42 for each group), (NA = not available; _a or _b = two classes from the same school took part in the experiment, N original seeds = 10).
(DOCX)

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Author Contributions

Conceived and designed the experiments: VLM AMK GP. Performed the experiments: VLM GP. Analyzed the data: VLM GP. Contributed reagents/materials/analysis tools: VLM AMK GP. Wrote the paper: VLM AMK GP.

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S1 Appendix. Information on the participating classes (anonymized) and age of children (NA = not available).

School	Number of classes	Number of children	Average age of children
A	2	31	7.8
C	1	20	9.0
D	2	48	9.1
F	1	30	8.7
G	1	19	8.9
H	2	44	9.1
J	1	24	9.0
K	2	40	9.6
M	1	23	NA
N	1	23	9.1
Total	14	302	8.9

S2 Appendix. Vegetation data from children and scientists, N = 14 (NA = not available; _a or _b = two classes from the same school took part in the experiment).

School	Date (2013)	Vegetation cover in %		Vegetation height in cm	
		Children*	Scientists	Children	Scientists
A_a	May	NA	25	9	40
A_b	May	NA	25	15	40
C	April	75	100	5	25
D_a	April	25	0	800	0
D_b	April	0	0	NA	0
F	April	25	0	100	0
G	June	0	0	100	15
H_a	June	25	50	12	30
H_b	June	25	100	15	30
J	April	100	100	20	10
K_a	June	0	50	6	20
K_b	May	50	50	5	20
M	April	NA	50	NA	15
N	May	100	100	20	20

* qualitative transcription from children’s vegetation cover description (values in between were rounded to the next closest category):
100% ≙ “all covered/no free surface with grass, moss, clover”,
75% ≙“lots of cover/little free surface with plants and sand”,
50% ≙ “half free, half covered”,
25% ≙ “lots of free surface with plants, soil, stones, leaves“,
0% ≙ “without plants, with sand and soil”.

S3 Appendix. Raw data from the seed experiment from children and scientists,N= 336 (42 for each group), (NA = not available; _a or _b = two classes from the same school took part in the experiment,N original seeds = 10).

School	Plant species	Treatment	Group arrangement	Remaining seeds	
				Scientists	Children
A_a	*Trifolium pratense*	All	sequential	10	10
		Slugs		10	10
		Mice		10	10
		Arthropods		10	7
		Earthworm		10	8
		Control		6	3
	Avena sativa	All		10	10
		Slugs		10	10
		Mice		10	10
		Arthropods		10	10
		Earthworm		10	9
		Control		10	10
A_b	*Trifolium pratense*	All	sequential	7	7
		Slugs		10	10
		Mice		10	10
		Arthropods		8	8
		Earthworm		10	10
		Control		10	10
	Avena sativa	All		10	10
		Slugs		10	10
		Mice		10	10
		Arthropods		10	10
		Earthworm		10	10
		Control		10	10
C	*Trifolium pratense*	All	sequential	10	8
		Slugs		10	10
		Mice		10	10
		Arthropods		9	8
		Earthworm		10	9
		Control		9	8
	Avena sativa	All		10	10
		Slugs		10	10
		Mice		10	10
		Arthropods		10	10
		Earthworm		10	10
		Control		10	10
D_a	*Trifolium pratense*	All	simultaneous	7	2
		Slugs		10	9
		Mice		8	8
		Arthropods		10	4
		Earthworm		6	6
		Control		9	0
	Avena sativa	All		9	10
		Slugs		10	9
		Mice		10	10
		Arthropods		10	9
		Earthworm		10	10
		Control		10	0

School	Plant species	Treatment	Group arrangement	Remaining seeds Scientists	Remaining seeds Children
D_b	*Trifolium pratense*	All	simultaneous	9	9
		Slugs		10	10
		Mice		10	9
		Arthropods		10	10
		Earthworm		8	6
		Control		10	10
	Avena sativa	All		10	10
		Slugs		10	10
		Mice		10	10
		Arthropods		10	10
		Earthworm		10	9
		Control		10	10
F	*Trifolium pratense*	All	simultaneous	8	9
		Slugs		10	10
		Mice		10	10
		Arthropods		10	9
		Earthworm		10	9
		Control		10	10
	Avena sativa	All		10	10
		Slugs		10	10
		Mice		10	10
		Arthropods		10	10
		Earthworm		10	10
		Control		10	10
G	*Trifolium pratense*	All	simultaneous	8	8
		Slugs		10	0
		Mice		9	9
		Arthropods		9	9
		Earthworm		8	5
		Control		0	0
	Avena sativa	All		0	0
		Slugs		10	10
		Mice		0	0
		Arthropods		10	10
		Earthworm		10	9
		Control		10	10
H_a	*Trifolium pratense*	All	sequential	5	0
		Slugs		NA	NA
		Mice		10	10
		Arthropods		NA	1
		Earthworm		10	10
		Control		9	10
	Avena sativa	All		0	6
		Slugs		NA	NA
		Mice		10	10
		Arthropods		2	4
		Earthworm		0	8
		Control		10	10

School	Plant species	Treatment	Group arrangement	Remaining seeds Scientists	Remaining seeds Children
H_b	*Trifolium pratense*	All	simultaneous	6	5
		Slugs		10	10
		Mice		4	NA
		Arthropods		10	10
		Earthworm		9	5
		Control		10	10
	Avena sativa	All		9	9
		Slugs		10	10
		Mice		10	8
		Arthropods		10	10
		Earthworm		8	8
		Control		10	10
J	*Trifolium pratense*	All	sequential	9	8
		Slugs		9	9
		Mice		10	10
		Arthropods		10	6
		Earthworm		10	9
		Control		10	9
	Avena sativa	All		2	8
		Slugs		10	10
		Mice		10	10
		Arthropods		10	10
		Earthworm		10	10
		Control		10	9
K_a	*Trifolium pratense*	All	simultaneous	10	10
		Slugs		10	9
		Mice		10	8
		Arthropods		10	10
		Earthworm		10	10
		Control		10	10
	Avena sativa	All		10	10
		Slugs		10	10
		Mice		10	10
		Arthropods		10	10
		Earthworm		10	9
		Control		10	10
K_b	*Trifolium pratense*	All	sequential	6	5
		Slugs		9	8
		Mice		1	1
		Arthropods		10	10
		Earthworm		7	6
		Control		9	9
	Avena sativa	All		10	8
		Slugs		10	10
		Mice		0	0
		Arthropods		10	10
		Earthworm		10	10
		Control		10	10

School	Plant species	Treatment	Group arrangement	Remaining seeds	
				Scientists	Children
M	*Trifolium pratense*	All	sequential	10	10
		Slugs		10	9
		Mice		10	9
		Arthropods		10	10
		Earthworm		9	9
		Control		10	10
	Avena sativa	All		10	10
		Slugs		10	10
		Mice		10	10
		Arthropods		10	10
		Earthworm		10	10
		Control		10	10
N	*Trifolium pratense*	All	simultaneous	10	6
		Slugs		9	9
		Mice		10	10
		Arthropods		10	10
		Earthworm		3	3
		Control		10	10
	Avena sativa	All		8	8
		Slugs		10	9
		Mice		10	10
		Arthropods		10	10
		Earthworm		10	10
		Control		10	10

Chapter III

The ABC of native species – a helpful tool to assess species knowledge and address nature awareness

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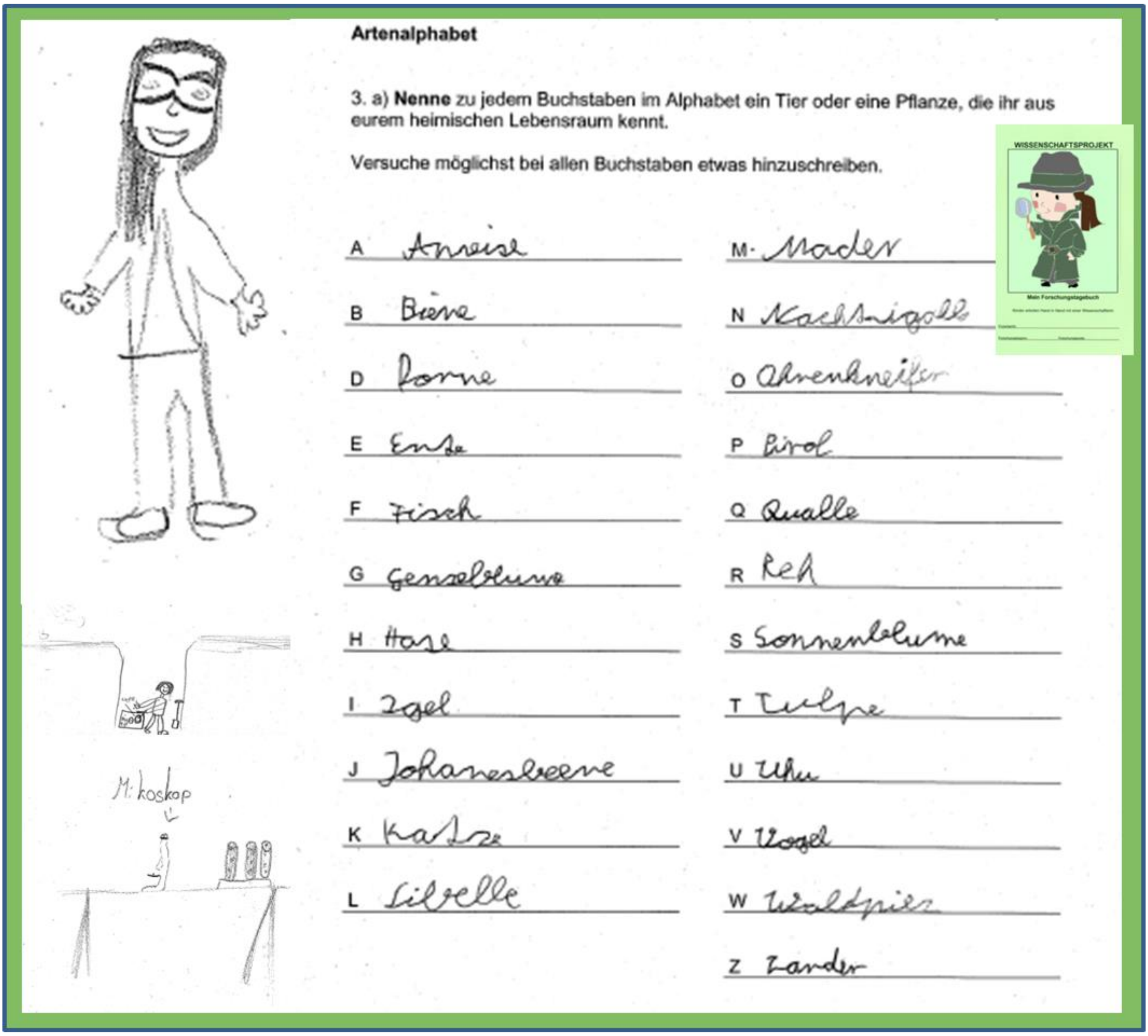

Abstract

Most people live in urbanized areas removed from natural landscapes and we are increasingly concerned about alienation from nature, where especially children are rarely exposed to nature (nature deficit disorder). To assess whether children growing up along an urban-rural gradient are alienated from nature, we investigated how their natural surroundings affected their species knowledge. We used a species alphabet where children named at least one native species per letter of the alphabet. Prior to exercise, we introduced the species concept and explored terms like biodiversity or species loss.

Species knowledge did not differ between children from urban and rural areas. However, urban children named more species, which we attribute to a higher desire to express their knowledge, compared to rural children, for whom native species seem to be more common.

With 62% of right answers, alienation from nature is hard to conclude. There is no consensus on how alienation from nature is defined and previous studies used diverse methods, which makes comparisons difficult. With the species alphabet, we provide an easy-to-apply and highly comparable method, which allows us to gain overview of children's knowledge, build upon in further class content enabling us to make more conclusive comparisons between future studies.

Keywords: scientific literacy, species concept, primary school children, biodiversity, urban-rural gradient

Introduction

Globally, more people are disconnected from nature by living in heavily modified urban areas, where native species decrease and more non-native species occur due to global trade, favorable microclimates and climate change with an increased risk of native biodiversity loss (McKinney 2002; Miller 2005; Hulme 2009). Further urban areas are not only characterized by a decrease of natural and semi-natural habitats but the type of habitat is also vastly different from surrounding areas as it is often arranged for human comfort (Karsten 2005). Consequently, it is evident that especially children nowadays are not as much in contact with nature anymore as in past generations (Anggarendra and Brereton 2016; Louv 2005, 2011; Jordan et al. 2009; Miller 2005; Laaksoharju and Rappe 2010). Especially for urban societies, alienation from nature was hypothesized, which was summarized by Bilton (2014). Louv (2005, 2011) was the first to proclaim a phenomenon called 'nature deficit disorder' describing a situation where a significant shift away from nature-based recreation was observed for children. This was further addressed by Pergams and Zaradic (2008), who observed American and Japanese children within the last 20 years. Arnold (2012) further found a drop in outdoor activities for 50% of American children aged 9-12, with a higher risk for physical and psychological disadvantages (Kuo and Faber Taylor 2004; Pretty et al. 2005; Wells and Evans 2003). Leather and Quicke (2009) and Bilton (2014) point out that many school children have a lack of natural history knowledge due to their teachers' lack of knowledge of wider diversity of life, as taxonomists at universities are disappearing.

Even though alienation from nature was attributed more to people living in urbanized areas (McKinney 2002), the proclaimed 'nature deficit disorder' seems to apply to children living in urban as well as rural areas. This assumption is supported as a decrease in varying outdoor activities or exposure to nature is mainly due to the parents' fear of traffic or crime harming their children, pollution or a lack of green spaces and not necessarily undesirable exposure to nature (Valentine and McKendrick 1997; Taylor, Wiley, and Kuo 1998; Karsten 2005; Gifford and Nilsson 2014; Louv 2005, 2011; Veitch et al. 2013). Only a few studies focus on free-play activities from rural children or nature knowledge compared to urban children but we assume that they have more available access to their neighborhood and unattended nature experiences (Laaksoharju and Rappe 2010; Salmon et al. 2013; Gifford and Nilsson 2014; Lindemann-Matthies 2006). However, verified evidence that children in urban areas are more alienated from nature is fragmentary and studies are difficult to compare (Bogner and Wiseman 1997; Laaksoharju and Rappe 2010; Lückmann and Menzel 2013; Gifford and Nilsson 2014; Lindemann-Matthies 2006).

However Allen (2015) highlighted the fundamental role of early year educators having an essential influence on the conceptual creation of basic scientific understanding and literacy. Allen (2015) constitutes his assumption with the results of a structured interview method study on three- to five-year-old children about their ideas on common taxonomic labels for animal, fish, amphibian, reptile, bird, mammal and insect showing typical learning trajectories as they develop their prototypes within that age. Another study found out, that with the beginning of adolescence, species knowledge of children increases but thereafter the rate of acquiring new species knowledge starts to decrease again (Lindemann-Matthies 2006).

Catchphrases such as species diversity, biodiversity loss, species conservation or Red list (IUCN (International Union for Conservation of Nature and Natural Resources) Red list) are on everyone's lips or in the news, but the term 'species' is, if at all, often very loosely defined or the species concept per se remains diffuse. Reviewing that development, Bilton (2014) proclaims that 'an understanding of where we fit into the natural world, together with natural history study which goes alongside taxonomy and systematics, can serve to increase our connection with wild organisms and places, something which is increasingly difficult in urbanised societies'. Further, a basic understanding of taxonomy lays the foundation for an understanding of ecology. Consequently, we should consider children's understanding of taxonomy when assessing their species knowledge, because once-learned misconceptions are hard to be corrected (Allen 2015). In our study, we will focus on the introduction of a simple definition of the species concept as an important foundation for the understanding of biological systematics and therefore scientific literacy (Keogh 1995).

The term species could be simply defined as reproductive individuals of a community that is isolated from other such communities (Mallet 1995). However, this definition is rarely used in primary schools in Germany (e.g. federal state of Berlin or Hessen have no official use of the term species with taxonomical meaning at all within the curriculum (SenBJS 2004, HKM 1995)), even though terms like (species) biodiversity ('Artenvielfalt') (SBI 2004,2009), species classification ('Artenkenntnis') (MK NDS 2006), animal species ('Tierarten') (TMBJS 2015) or vegetable varieties ('Gemüsesorten') (StMBW 2014) are part of the curriculum. The basic understanding of the concept of species as foundation of systematic thinking is not explicitly part of the primary school curriculum and the term species will only be explained systematically if a teacher is aware of the meaning and its importance for further systematical thinking.

Consequently, we see a deficit in these uncertainties about teaching the species concept, when education on scientific literacy in schools is responsible for raising the awareness of children for understanding and practicing scientific basics. Moreover, there is a risk of the children becoming scientifically indifferent and frustrated (Blown and Bryce 2016, Aikenhead

2011). We also agree with Lakoff and Johnson (1980) that realistic concepts of scientific literacy within environmental education have the necessity to not only inform about nature but to deliver essential basics to allow ‘an understanding that is possible through the negotiation of meaning’.

To address the potential alienation from nature in primary school children, we aimed to assess their knowledge of the different native animal and plant species. The evidence for alienation from nature based on previous studies is still inconclusive, which is certainly also due to the use of very different assessment methods, a missing sound definition and lack of sufficient empirical data. We therefore used an approach, in which we introduced a child-oriented definition of the species concept alongside a novel tool we called species alphabet, which children filled out as part of an inter- and transdisciplinary science project that combined ecosystem functioning research, environmental education and scientific literacy. This practice seemed to be appropriate as children’s naming ability can be seen as indicator for their knowledge of plants and animals (Lückmann and Menzel 2013). With the species alphabet we aim to collect empirical data that would allow us to find a conclusive response to our research question and would also be highly comparable when used in other research projects.

We quantitatively assessed the native species knowledge between primary school children along an urban-rural gradient including children with comparable social and cultural background, but different daily natural surroundings. We hypothesized that urban children know fewer native species than children from rural areas due to a lower exposure to natural habitats and their exposure to more non-native species that increasingly occur in urban areas (McKinney 2002). Consequently we assume that children in urban areas could have difficulties in distinguishing non-native from native species and name therefore more non-natives. With the species alphabet we plan to establish a new tool to easily assess native species knowledge to integrate it in different class activities and use it further to foster environmental education and scientific literacy with regard to authentic nature contact.

Material and Methods

This study involved 13 classes from nine schools with a total of 247 elementary school children aged eight to 10 in the surrounding area and city of Lüneburg and the city of Hamburg in Northern Germany. The species alphabet was part of a larger research project on seed predation and dispersal along an urban – rural gradient. To express the gradient, we calculated a simple urbanization index (UI) for each school by dividing the amount of sealed (i.e. streets, buildings, factory areas) by the amount of unsealed (i.e. forests, grasslands, crop fields, parks) surface in the school's respective catchment area. A low UI therefore represents low amount of sealed surface and hence more rural areas and a high UI (high amount of sealed surface) is a proxy for more urbanized areas.

The educational content of the project contributed to the official curriculum for grades two to four in Lower Saxony and Hamburg (MK NDS 2006, BSB 2011) as we focused in class on animal-plant interactions and basic ecosystem functions with the additional early introduction of the species concept. In interaction with the children, we developed simplified general definitions of the terms species, habitat, native and non-native species (Appendix 1) and in other parts of the project also focused on other content about environment, conservation and ecology.

In the species alphabet, children had to name at least one native plant or animal species for each letter of the alphabet (resulting in a minimum of 23, multiple answers were also accepted). The alphabet did not include the letters 'C', 'X' and 'Y' since we could not find any common plant or animal name in German that started with one of these letters. The alphabet itself was filled in during class by each child within approximately 20 minutes.

Transcribing the answers as correct or false was challenging because many children used common names as they are usual in daily routine. For example, hedgehog ('Igel') would technically represent the family of Erinaceidae with a number of different genera and species. However, because there is only one species of hedgehog in Germany (*Erinaceus europaeus*, proper common name 'Braunbrustigel'), we judged the answer hedgehog as correct, i.e. a native species. We therefore developed a set of case-by-case classifications to categorize all answers. The categories included all answers (total number of answers), native species or genus (right answers), non-native species or genus (non-native answers), native or non-native families and higher-order taxa or no species (false answers). We included genus as correct because most common names used for species in German actually refer to the genus (see also Lückmann and Menzel 2013).

To analyze effects of the urban-rural gradient and the children's gender on the answers, we used generalized linear mixed effect models with UI and gender as fixed effects and school as random effect. Response variables were total, right, non-native and false answers. Total answers had a Poisson error distribution and all other response variables required binomial error distribution because they were used as proportion of total answers. For statistical analysis we used the software program R (2015) with the packages 'lme4' (Bates et al. 2015).

Results

We realized an urban – rural gradient with schools in highly urbanized areas with 70% of sealed catchment area (UI = 2.33) and rural area with 5% of sealed catchment area (UI = 0.05) (Table 1). Based on questions and interactions, we assume that children had no considerable knowledge of the correct meaning of the term species before the project.

The number of total answers increased significantly with increasing urbanization (Figure 1(a)), whereas we found no significant effect of the UI on right, non-native or false answers (Table 2, Figure 1(b), Figure 1(c), Figure 1(d)). In the species alphabet, children provided on average 24.98 ± 6.95 (SD) total answers (more than one species per letter of the alphabet). Of these, 61.99% ± 12.35 were right answers (native species or genus) and 38.01% ± 12.35 false answers (higher order taxa of non-native or native or no species) including 5.52% ± 7.10 of non-native species (non-native species or genus) (Table 1). In the school with the best performance (UI = 2.33), 73.73 % ± 7.25 of the answers were right and 26.27% ± 7.25 were wrong, whereas children from the school with the lowest performance (UI = 0.19) had 56.53% ± 11.97 right and 43.47% ± 11.97 wrong answers. Girls named generally more species and gave more correct answers than boys (Table 2, Figure 1(a), Figure 1(b) and Figure 1(c), Figure 1(d)).

Discussion

Contrary to our assumption that children in urban areas would know fewer species than in rural areas, we found no differences in the knowledge of native and non-native species along the urban-rural gradient. Consequently we expect that the differences in nature exposure between children in urban and rural areas is highly overestimated, as it is well documented that non-native species occur more in urban than rural areas and clear differentiation is often complex as many people accept those species as 'belonging there' (Bremner and Park 2007; McKinney 2002). In accordance with other studies, we therefore suggest to focus more on differences in lifestyle including different dimensions of heterogeneity in societal background instead of urban-rural differences when assessing knowledge about nature as all of the children probably face the same outdoor (play) limitations (Gifford and Nilsson 2014; Bogner and Wiseman 1997; Veitch et al. 2013). We observed and experienced in our project, that especially in urbanized areas, children are provided with numerous environmental education programs and activities, whereas schools in more rural areas are often neglected when it comes to extra-curricular offers. Rural schools complained an undersupply of extra-curricular activities and asked for cooperation whereas urban schools communicated an oversupply of project participation. We therefore assume that potential differences of environmental behavior, attitudes and native species knowledge between urban and rural children appear more blurred as they actually are. Consequently our study supports the approach that early year educators have an important responsibility in supporting efforts to learn about species and nature regardless of where the children grow up (Allen 2015; Louv 2005, 2011).

We could show that species knowledge is similar along the urban-rural gradient but whether the average of 25 species names with 62% of correct and 38% false answers represents alienation from nature across an urban-rural gradient or good species knowledge from all children remains inconclusive. Our results are difficult to compare with those from other studies as each used different methodological approaches (Balmford et al. 2002; Lückmann and Menzel 2013; Laaksoharju and Rappe 2010; Yli-Panula and Matikainen 2014; Patrick et al. 2013). Nevertheless the concern that children nowadays are more alienated from nature is persistent as it is evident that especially children are not as much in contact with nature anymore as in past generations (Anggarendra and Brereton 2016; Louv 2005, 2011; Jordan et al. 2009; Miller 2005; Laaksoharju and Rappe 2010). But how many species should we expect children to know, what would be a good result? And how close to nature should children grow up?

Here, we demonstrate that the species alphabet is not only easy to use and to analyse but also provides the possibility to collect large amounts of empirical data in a relatively short time. We would therefore recommend using the species alphabet as a highly comparable approach to quantitatively discuss results from knowledge acquisitions and for comparisons between different parameters like gender, nationality or age across studies.

Our results also showed that girls named not only more species but also provided general more correct answers than boys. This confirms findings of other studies due to general differences in the awareness of plants and animals and a general acquired need of school performance from girls (Houtte 2004; Laaksoharju and Rappe 2010; Lückmann and Menzel 2013).

Interestingly, we found that urban children named more species in total than children in more rural areas. Our in-class observations indicate that children from more urbanized areas might verbalize their natural knowledge as additional knowledge and experience, which could be explained as need for commitment instead of more advanced species knowledge (Bogner and Wiseman 1997). In contrast, children from rural areas might not make the additional effort to name as many plants and animals as they can and view their native species knowledge not as something unusual but potentially as part of their daily routine.

Overall, we assume that the prior interactive definition of the terms species and habitat was helpful in filling in the species alphabet because children received a basic understanding of relations within and between species. We are confident that children acquired the foundations to connect the term species to biodiversity, species classification or animal and plant species as the needed basis for scientific literacy and conservation action (Allen 2015). Based on our experiences, we would recommend expanding the curriculum and teaching the species concept earlier with more emphasis on the definition. Topics such as reproduction or rearing of offspring is already content of some curricula in Germany (SBI 2004/2009, SenBJS 2004, BSB 2011, MFB Saarland 2010, BM M-V 2004) and a clear understanding of the species concept would advance the teaching of those topics. This would especially be the case in i.e. the federal state of Berlin with reproduction as part of the curriculum but no official use of the term species with taxonomical meaning (SenBJS 2004).

However pure better knowledge of nature and the environment does not automatically result in a positive behavior or perception towards the environment (Jannah et al. 2013). For an effective educational campaign it is highly recommended to combine knowledge acquisition and practical nature experiences to result in successful nature and conservation awareness (Storksdieck, Ellenbogen, and Heimlich 2005). To face the global urbanization with its consequences on society and especially the potential risk of 'nature deficit disorder' by children, it is important to detect further societal influences and accordingly the opportunities to counteract – with a combined offer of environmental education, scientific literacy and authentic nature contact both in urban and rural areas.

Conclusion

This study was carried out within the context of an inter- and transdisciplinary science project using the synergies between ecosystem functioning, environmental education and scientific literacy research.

The easy use of the species alphabet offers the opportunity to combine it with other educational approaches, i.e. memorable name clues (Stagg and Donkin 2016), synoptical keys (Ohkawa 2000), digital imaging keys (Kirchoff et al. 2011), supporting digital video clips (Pfeiffer, Scheiter, and Gemballa 2012) or knowledge base through open-ended learning (Goulder and Scott 2009).

Even though we found no differences in native species knowledge from children in urban or rural areas, the amount of their correctly named species allow only inclusive speculation for overall alienation from nature due to a missing common definition of this phenomenon. We therefore encourage further discussion on whether urbanization effecting children negatively in their attitude towards nature but more specifically, how we find a consensus to define this phenomenon to make observations comparable. We therefore encourage future studies to repeat this easy and highly comparable approach with other societal groups of different age, social background or profession, between school systems or different countries.

Educational implications to use the species alphabet in class

- simple to apply to gain insights into children's knowledge and perception of native and non-native species with minimal preparation as guideline for further class planning
- could be used in subsequent exercises with easy modification for other school subjects:
    - learn about different habitats and its denizen
    - compare native and exotic habitats
    - detect specific animals or plants in daily surrounding
    - species varieties and diversity in general
    - children could write an essay about comparative plant-growing observation
    - one could discuss specific species' popularity compared to others that are frightening
    - address research needs for scientifically literate knowledge
    - not at least address topics like species diversity or conservation

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http://www.bildungsserver.de/Bildungsplaene-Lehrplaene-der-Bundeslaender-fuer-allgemeinbildende-Schulen-400.html

BM M-V: Ministerium für Bildung, Wissenschaft und Kultur des Landes Mecklenburg-Vorpommern (Hrsg.) (2004): Rahmenlehrplan Grundschule - Sachunterricht. ((http://www.bildung-mv.de/export/sites/bildungsserver/downloads/rp-sachunterricht-gs.pdf (Letzter Zugriff: 31.05.2016)).

BSB: Freie Hansestadt Hamburg Behörde für Schule und Berufsbildung (Hrsg.) (2011): Bildungsplan Grundschule – Sachunterricht. (http://www.hamburg.de/contentblob/2481914/25c3a10b03cc2be4003d7b6f9c436787/data/sachunterricht-gs.pdf (Letzter Zugriff: 31.05.2016)).

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TMBJS: Thüringer Ministerium für Bildung, Jugend und Sport (Hrsg.) (2015): Lehrplan Heimat- und Sachkunde. Grundschule. (http://www.schulportal-thueringen.de/web/guest/media/detail?tspi=1264 (Letzter Zugriff: 31.05.2016)).

Table 1 School characteristics and the mean ± SD answers in the species alphabet for each school. Schools are ordered by increasing urbanization index (from rural to urban) and anonymized.

School	Urbanization index	Catchment area (km^2)	Number of children	Total answers Mean (± SD)	Right answers (%) Mean (±SD)	'non-native' answers (%) Mean (±SD)	False answers (%) Mean (±SD)
A	0.05	41.04	15	21.73 (±3.26)	69.90 (±7.57)	0.61 (±2.35)	30.10 (±7.57)
B	0.19	15.68	37	22.81 (±4.29)	56.53 (±11.97)	7.30 (±7.95)	43.47 (±11.97)
C	0.22	22.82	22	21.95 (±5.58)	64.95 (±8.83)	6.30 (±6.65)	35.05 (±8.83)
D	0.31	8.13	10	20.50 (±8.67)	64.88 (±14.89)	4.20 (±10.39)	35.12 (±14.89)
E	0.73	23.74	22	25.86 (±9.15)	64.47 (±7.66)	2.84 (±2.46)	35.53 (±7.66)
F	1.00	6.55	39	26.18 (±7.62)	59.11 (±15.32)	8.58 (±9.26)	40.89 (±15.32)
G	1.49	13.34	18	35.78 (±6.87)	69.16 (±7.68)	4.51 (±2.04)	30.84 (±7.68)
H	1.59	8.03	66	24.06 (±4.30)	57.53 (±11.34)	5.31 (±7.26)	42.47 (±11.34)
I	2.33	2.25	18	27.17 (±6.46)	73.73 (±7.25)	4.18 (±3.18)	26.27 (±7.25)
all	(mean) 0.88	15.73	27.44	24.98 (±6.95)	61.99 (±12.35)	5.52 (±7.10)	38.01 (±12.35)

Table 2 Estimates ± Standard Error and Z-value resulting from generalized mixed effect models on the effects of answers in the species alphabet. The left-hand column shows the intercept and explanatory variables

	Number of total answers		Percentage of right answers		Percentage of non-native answers		Percentage of false answers	
	Est. ± SE	Z - value	Est. ± SE	Z - value	Est. ± SE	Z - value	Est. ± SE	Z - value
Intercept	3.147 ± 0.067	46.86***	0.610 ± 0.130	4.69***	-3.219 ± 0.335	-9.61***	2.788 ± 0.104	26.92***
Gender (male)	-0.111± 0.026	-4.32***	-0.143 ± 0.053	-2.67**	0.192 ± 0.271	0.71	-0.028 ± 0.030	-0.93
UI	0.135 ± 0.057	2.38*	0.090 ± 0.110	0.82	0.026 ± 0.208	0.12	0.075 ± 0.089	0.85

Significant p-values are gives as: p< 0.05 ‘*’, p< 0.01 ‘**’, p< 0.001 ’***’

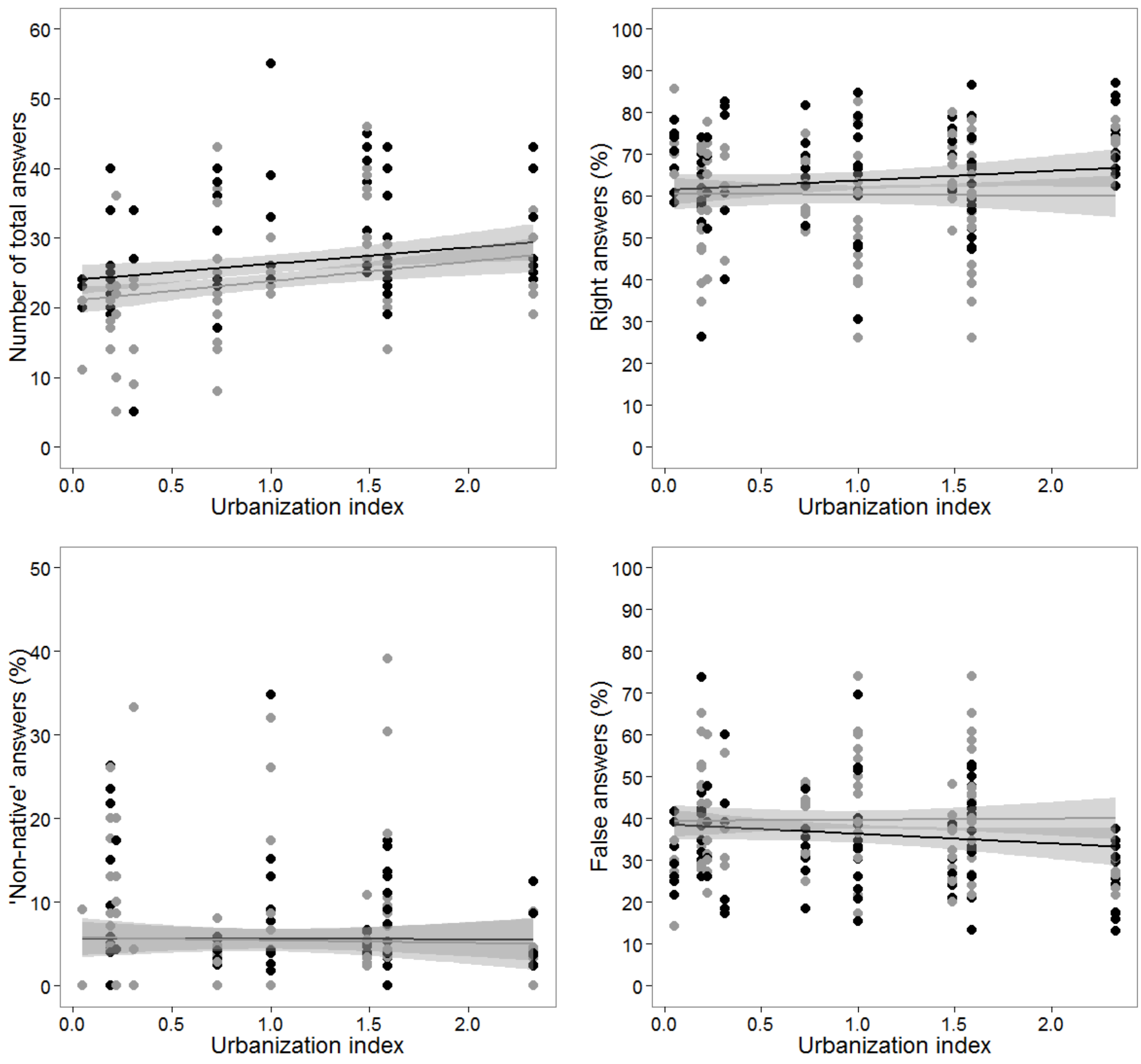

Figure 1. Answers in the species alphabet from children (black for girls and grey for boys) in schools along an urbanization gradient (low index equals more rural areas) with 95% confidence intervals (shaded grey). Panels show a) the number of total answers b) the percentage of right answers c) the percentage of non-native answers and d) the percentage of false answers

Appendix 1

Definitions of the terms that children determined together with the scientists in the environmental education lessons

Term	Determined definition
Species	Animals or plants with the same traits form a group – only members of the group are able to have children that can then have children themselves. This group is called species.
Habitat	Specific place where a specific plant or animal ‘lives, sleeps, eats, and reproduces itself’
Native*	Animals and plants that are known to live here since the resettlement after the last ice age or for many generations. They can survive and reproduce over seasons without humans’ help.
Non-native*	Animals and plants that normally do not live here and need humans’ help with food, housing or overwintering.

*we carried out an exercise about native and non-native species; we did not include a specification of invasive species