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RESEARCH PAPER

Moving north under the eye of the public: The dispersal ecology of the Nosferatu spider, documented by citizen scientists

Nadja Pernat [a,b], Sascha Buchholz [a,b], Jan Ole Kriegs [c], Jan Steen [a], Hilke Hollens-Kuhr [a,b,*]

[a] University of Münster, Institute of Landscape Ecology, Heisenbergstr. 2, 48149 Münster, Germany
[b] Centre for Integrative Biodiversity Research and Applied Ecology (CIBRA), Heisenbergstr. 2, 48149 Münster, Germany
[c] LWL-Museum für Naturkunde (LWL State Museum of Natural History), Münster, Sentruper Str. 285, 48161 Münster, Germany

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ABSTRACT

Citizen participation in tracking the spread of newly introduced or invasive species is an effective tool in nature conservation. Recently arrived species that pose threats to humans, animals, or plants—especially those widely covered in the media—are particularly suitable for citizen-led monitoring.

In this study, we selected the Nosferatu spider (*Zoropsis spinimana*), a species spreading from the Mediterranean to northern Europe, to investigate whether its media coverage motivates citizens to report observations. Additionally, we aimed to gather insights into the spider's dispersal ecology through citizen science data. We utilized Google News and Google Videos as indicators of media presence, Google Trends as a proxy for public awareness, and citizen science observation data to assess the spider's distribution and ecology. Our analysis of 3,017 citizen science observations from different sources revealed a north-eastern spread of *Z. spinimana*. We found a temporal correlation between media presence, Google search activity, and the number of citizen-reported observations. Additionally, there was a strong spatial correlation between federal states with the highest media presence and the highest number of citizen reports. Most observations were recorded between August and October, with the majority occurring inside human dwellings. Hence, the current dispersion dynamics and extensive media coverage of *Z. spinimana* appear to be significant factors driving increased public awareness, as evidenced by higher search interest and a greater number of citizen observations.

Introduction

Climate change, characterized by rising temperatures, increased exposure to extreme events, changes in water availability, and shifting weather patterns, significantly impacts ecosystems worldwide (Calvin et al., 2023). Many terrestrial and aquatic animals are highly sensitive to these changes in their environment, including alterations in temperature and precipitation (Fogarty et al., 2017; Kellermann & Van Heerwaarden, 2019; Medina et al., 2020; Srivastava et al., 2020; Zhu et al., 2014). As a result, they exhibit dynamic behaviours and ecological responses, often leading to dispersal towards the poles or higher altitudes (Blois et al., 2013; Engelhardt et al., 2022; Hickling et al., 2006; Montoya & Raffaelli, 2010; Thomas, 2010; Wilson & Fox, 2021). Besides climate warming, several other drivers may influence the northward expansion of a species in Europe. Intensive trade and travel via waterways, motorways or train routes facilitate and accelerate natural expansion and the overcoming of geographical barriers, particularly for less mobile species (Nedvěd et al., 2011). When establishing populations, anthropogenically induced land use changes, such as urbanization, and ecosystem disturbances can present an opportunity for introduced or expanding species (Gil-Tapetado et al., 2024). Expansion might also be driven by rapid evolutionary adaptations, such as broadening ecological niches caused by mutations, existing genetic variation or genetic mixing of former isolated populations (Krehenwinkel & Tautz, 2013).

The consequences of such range shifts are manifold. New species may move into areas that were previously unsuitable for them, leading to modifications in ecosystem structure and changes in biotic interactions, such as predator-prey or plant-pollinator relationships (Gretta et al., 2017). Furthermore, dispersing species may become pests in their new home ranges, affecting food quality within ecosystems, as well as human health and economies (Fogarty et al., 2017; Madin et al., 2012; Roy et al., 2024; Wilson & Fox, 2021). To address these challenges, it is crucial to detect range shifts early and ensure timely implementation of suitable management strategies (Brown et al., 2008; Fogarty et al.,

* Corresponding author.
E-mail address: hilke.hollens-kuhr@uni-muenster.de (H. Hollens-Kuhr).

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2017).

However, acquiring robust and comprehensive data on species' range expansions is often hindered by data limitations. One promising approach to overcome this obstacle is citizen science, for example by engaging citizens in data collection efforts. Citizens have been involved in biodiversity monitoring for many years. However, in the past two decades, citizen engagement has significantly increased as user-friendly mobile applications (apps) and web-based interfaces to document nature observations have emerged and digital photography has become more prevalent and affordable (Bonney et al., 2016; Molls, 2021; Newman et al., 2012; Pernat et al., 2022; Vohland et al., 2021). This digitization not only led to data-driven, citizen science projects with unstructured, opportunistic sampling but also intensified communication between scientists and citizen scientists, facilitating the bidirectional use of media to provide and obtain information about the programs. As a result, millions of observations are being shared on international platforms such as iNaturalist and Observation.org, as well as in species-specific programs, in a short amount of time. Observation metadata, including location, date, and user-contributed annotations, as well as hidden information in multimedia files (Pernat et al., 2024), enriches the dataset. iNaturalist and Observation.org data have significantly contributed to biodiversity research, aiding in understanding single and multi-species distribution (Beninde et al., 2023; Serniak et al., 2023), community ecology (Leong & Trautwein, 2019), pathogen tracking (Saavedra et al., 2023) and the discovery of new species or interactions (Rosa et al., 2022).

Involving citizens in monitoring the dispersion or impact of invasive species has proven successful for respective projects (Encarnação et al., 2021; Palmer et al., 2017), as research objectives can usually be clearly communicated to the media and the public. Depending on the media, however, reports may not be scientifically objective: One strategy to gain attention from the public, for example, is to present the introduced species as a threat to native flora and fauna or to human health (Jarić et al., 2020). Such narratives have the potential to amplify public fear and potentially worsen societal attitudes toward certain groups of organisms, not only for introduced, but also for native or naturally expanding animals. This communication strategy is for example exploited for the oil beetle species *Meloe proscarabaeus* due to its toxicity or the spider *Zoropsis spinimana* for its large body size and its painful bites. *Zoropsis spinimana* (Dufour, 1820) is a thermophilic Mediterranean species, which has increased its range towards the North for >20 years, apparently enabled by climate warming. The spider belongs to the family Zoropsidae and has a distinctive appearance with a robust body and long legs. It is characterized by its dark brown or reddish-brown coloration, which helps it blend seamlessly with its surroundings. One of the notable features of the spider are markings on the cephalothorax evoking the vampire of the 1922 German silent film Nosferatu, which led to the German common name of the spider, Nosferatu spider. *Zoropsis spinimana* was first recorded north of the alps near Basel, Switzerland, (Hänggi, 2003) in 1994 and in 1997 near Innsbruck, Austria (Thaler & Knoflach, 1998). First German records occurred in 2005 and 2006 in a human housing in Freiburg (Hänggi & Bolzern, 2006).

Z. spinimana is a nocturnal predator hunting primarily arthropods. It is one of the few spiders in Europe which can penetrate the human skin resulting in a painful bite with local symptoms as swelling and redness (Gloor et al., 2010). *Z. spinimana* is native to the Mediterranean region, particularly found in countries like Spain, Italy, Greece, and France in various habitats including gardens, forests, and urban areas. For roughly 30 years, this species has been rapidly expanding its range toward northern Europe likely facilitated by global warming, while its initial dispersal is attributed to human-mediated factors, such as the transport of goods (Hänggi & Bolzern, 2006). In middle Europe *Z. spinimana* seems to be synanthropic, it is mainly recorded in houses or close to buildings (Hänggi & Bolzern, 2006; Hänggi & Zürcher, 2013; Nentwig et al., 2013). There are only few records of the species found in forest nest boxes or below field stones in the open countryside of central Europe (Hänggi et al., 2020; Kriegs, 2023). In spring, *Z. spinimana* females build a cocoon in a well-protected hiding place. After approximately 30 days, 20 to 100 young hatch. The young remain close to the mother for a further moulting stage, after which they spread out (Foelix et al., 2015).

Although the species was first observed in Germany almost 20 years ago, it has only been reported frequently in the media for the last two years, probably facilitated by Tik-Tok videos that went viral showing *Z. spinimana* in domestic environments. But did the latest increase in media presence lead to higher public awareness for this non-native spider species, which would in turn help to gain insights into the dispersal ecology of *Z. spinimana* through citizen science?

To answer this overall question, we

i) analyse how the media presence of *Z. spinimana* influences public awareness using conservation culturomics tools to assess the relationship between people and nature by contents of various types of online data, citizen science observations and Google Trends data. These are used as proxies for public awareness and are related to the number of Google News and Google Video items to investigate potential temporal and spatial correlations. The tools of conservation culturomics provide novel opportunities to investigate human-nature interactions on large scales (Correira et al., 2021). Google Trend index has been applied as proxy to measure the public's engagement with a topic (Felgentreff et al., 2023; Soriano-Redondo et al., 2017), whereas other studies worked with the number of Google web or news items to assess the content available on the internet to estimate public attention (Jarić et al., 2019; Moore & Hyman, 2024).
ii) investigated the time periods and geographical distances of *Z. spinimana's* northward spread based on citizen science data from different platforms of semi-structured to unstructured programs.
iii) finally investigate whether citizen science records can be used to extract ecological information about the spider in its new distribution area. Many observation data on citizen science platforms include additional information (secondary data) about the species, which can be seen in images or described in text (Pernat et al., 2024). Unlike primary data, which provide information on the location and date of observation, secondary data may reveal details about species traits and behaviour, biotic interactions, or environmental conditions. Specifically, we examine the phenology and preferred habitats of *Z. spinimana* by utilizing the metadata and filtering existing images in the observation dataset.

We anticipate that with increasing media presence, citizens will become more aware of the species, prompting searches for this species on Google and leading to more frequent observations and uploads on citizen science platforms. In addition, we expect to be able to trace the spatial spread of *Z. spinimana* since it was first detected in Germany with the help of citizen science data. Visual inspection of image data and analysis of observation data should reflect its synanthropic behaviour in its introduced ranges. Based on our findings, we discuss which characteristics and traits of *Z. spinimana* make it particularly suitable for public involvement in research, and derive recommendations for how citizen science can be used to study the distribution and ecology of other alien arthropod species.

Materials and methods

Occurrence datasets

Occurrence records of *Z. spinimana* were obtained from two sources: the Global Biodiversity Information Facility (GBIF) and the Arachnological Society (Arachnologische Gesellschaft Deutschland, AraGes). *Zoropsis spinimana* records were obtained from GBIF via gbif.org on

March 3rd, 2024 (GBIF, 2024). The dataset was filtered to include only records from Germany and the citizen science platforms iNaturalist and Observation.org.

iNaturalist (2024), established in 2008, and Observation.org (2024), established in 2004, serve as prominent citizen science platforms and global repositories for biodiversity observations. Users can document and upload their observations through respective apps or websites, accompanied by photos or audio vouchers. The platforms implement rigorous quality control measures. Both use automated identification algorithms, but while iNaturalist includes (expert) community consensus, Observation.org deploys targeted expert verification.

Both platforms offer tools to engage the community in collecting specific data, e.g., certain taxonomic groups or types of ecological interactions. On iNaturalist, all users can create projects to collate and group observations, featuring a respective project page and possibilities to communicate with project members. Observation.org offers 'Challenges' and 'Bioblitzes', which can be set up in collaboration with an institution. Challenges are rather long-term, large-scale projects that focus on a specific species group and challenge users to document as many species of that group as possible; Bioblitzes are more often short-term, local events that document the range of species on a smaller scale (Meeus et al., 2023).

Founded in 1960, AraGes aims to advance knowledge about arachnids in Central Europe and supports arachnological research in the region, serving as a vital link between amateur enthusiasts, governmental bodies, and academic researchers. One of AraGes' core objectives is to compile spider distribution data in an online atlas sourced from various channels such as scientific monitoring, citizen reports, and publications. Since 2022, the atlas has also incorporated data from naturgucker.de, a nationwide citizen science program where individuals can report species observations.

From the AraGes atlas (Arachnologische Gesellschaft, 2024), *Z. spinimana* records were extracted from expert monitoring, individual citizen reports to AraGes, and publications on October 13th, 2023. Naturgucker.de observations were excluded due to the program's lack of generalized data quality validation (https://www.naturgucker.info/naturguckerde/datenqualitaet), resulting in three observation categories: expert, validated citizen science, and publications. Expert observations, conducted by arachnologists, offer rigorous scientific monitoring despite potential variations in collection protocols. Although their collection methods may be more systematic compared to other sources, contributing to the spider atlas is not necessarily part of their professional academic duties, thus following rather semi-structured citizen science principles than institutional monitoring. Validated citizen science reports are observations communicated to the AraGes via a web form (https://atlas.arages.de/writemessage) or as registered user of the spider atlas. While these records are opportunistically generated, they undergo stringent validation by AraGes experts, ensuring high data quality. Additionally, the AraGes dataset comprises four *Z. spinimana* locations in scientific publications.

Datasets from AraGes and GBIF were merged, retaining variables such as species count, collection date, georeferences (longitude and latitude), region (federal country), and data source category (expert, validated citizen science or publication from AraGes, and iNaturalist or Observation.org from GBIF). We excluded observations before 2008 from the dataset for this is the year when iNaturalist was launched.

Google Trends dataset

Google Trends is a helpful tool that provides information on how often a specific term, such as 'Nosferatu-Spinne' (spider), was searched for on Google over a certain period. The search activity index of Google Trends (https://trends.Google.de/trends/) measures the fraction of queries that include the term in question in the chosen region or country at a particular time, relative to the total number of queries during that time span. The value of the index ranges from 0 to 100. A value of 100 indicates the time when the term was searched the most, so all other index values are relative to this maximum (Felgentreff et al., 2023; Stephens-Davidowitz & Varian, 2014). We used the term 'Nosferatu-Spinne' as search query in Germany between January 1st, 2005 to December 31st, 2023. For the time span with highest search activity indices (third and fourth quarter of 2022 (July 1st, 2022 and December 31st, 2022)) we also determined the interest by federal states to find out in which federal states the term was searched for most frequently.

Media presence

To analyse the media presence of *Z. spinimana* in Germany the generic search term 'Nosferatu' was googled, as there is no standardized spelling for the Nosferatu spider in the German media (for example, Nosferatuspinne, Nosferatu-Spinne, Nosferatu, Nosferatu Spinne). The number of results in Google News and Google Videos on only German pages were counted for each month during January 1st, 2008 to December 31st, 2023, and taken as a proxy of media presence. The newspaper, magazine or institution that wrote the article or the person or broadcaster that produced the video was listed. Whenever possible, the newspaper, magazine, institution, or broadcaster has been assigned to the federal state in which it was published.

Data analysis

All statistical analyses of the data were conducted in R Studio (R Core Team, 2024). To visually explore the spatial distribution of *Z. spinimana* across occurrence datasets and years, maps were programmed that display the cumulative observations by data source pear year, applying packages *countrycode* (Arel-Bundock et al., 2018), *rnaturalearth* (Massicotte & South, 2023), *rnaturalearthdata* (South, 2017), *sf* (Pebesma, 2018) and *tidyverse* (Wickham et al., 2019). In addition, north-eastern expansion in metres were calculated from the maximum latitude and longitude from the cumulative yearly observations using the *distGeo* function from the *geosphere* package (Hijmans, 2022) and displayed as crosshairs in the distribution maps.

A cross-correlation with the *ccf* function from the *tseries* package (Trapletti & Hornik, 2023) was performed to test whether an increased media presence at a specific point in time leads to a simultaneous or lagged increase in public awareness, as measured by increasing occurrence records or rising Google Trends indices.

To test for correlation between media presence and public awareness across federal states during the peaks of high media presence in the third and fourth quarter of 2022 we summed up the monthly data on Google News articles, Google Videos, Google Trend Search Index and observations. Since data were not normally distributed, Spearman correlation was used.

The ecological data on phenology were directly extracted from the timestamps of all citizen science data and visualized using ggplot2 in the *tidyverse* package. For the investigation of the habitats where *Z. spinimana* was documented, photos uploaded by citizen scientists as evidence of species occurrence on Observation.org and iNaturalist were inspected individually ($n = 1345$). Habitats were categorized as follows: *captured*, if the spider appeared to be trapped in a container; *in or on the house*, if the animal was photographed inside a house or a domestic structure was visible but it was not clear whether it was inside or outside; *garden or backyard*, if the spider was photographed outdoors (garden, balcony, backyard); and *away from house*, if *Z. spinimana* was documented outside the domestic environment. In most cases of garden or backyard and away from house, the location had to be verified with Google maps using the coordinates provided for each observation.

Results

The dataset comprised 3017 records of *Z. spinimana*, of which the AraGes dataset comprised 1232 records (experts: $n = 110$, validated citizen science: $n = 1118$, publications: $n = 4$) and 1785 records belong to the GBIF dataset (iNaturalist: $n = 712$, Observation.org: $n = 1073$) (see Appendix A: Fig. 1). Since 2.5 % of the citizen scientists reported the same specimen several times, a total of 3270 reports of *Z. spinimana* were documented in the five different data sources analysed. Half of the observations were made in the year 2022 (53.1 %, $n = 1613$) with the majority of the data stemming from citizens reporting their observations to the AraGes. The share of all observations was under 1 % for all years between 2000 and 2016 (see Appendix A: Fig. 2).

Impact of media presence on public awareness

The time series of number of Google Videos, number of Google News, Google Trend index and citizen science observations were synchronous, indicating an impact of media on public awareness (Fig. 1; see Appendix A: Table 1). While the values between 2008 and 2022 were zero or close to zero for the four proxies, they all show a strong increase in the third quarter of 2022 and a decrease towards the end. A similar pattern is seen for 2023, with an increase in the third quarter, but the increase is much less pronounced than in 2022.

The cross-correlation analysis confirms the found pattern (see Appendix A: Fig. 3). The time series of the number of citizen science observations and the number of Google Videos show the strongest significant correlation with a time lag of zero (lab = 0, ACF = 0.804, $p < 0.05$). A significant, positive correlation was also found between number of observations and Google News with a time lag of -1, meaning, that the number of news increased around one month earlier than occurrence records (lab -1, ACF = 0.845, $p < 0.05$). The time series of Google Trend index and number of videos or number of news, respectively, demonstrate the highest correlation values without any time shift (Number of videos: lab = 0, ACF = 0.941, $p < 0.05$; number of news: lab = 0, ACF = 0.929, $p < 0.05$).

The spatial analysis of media presence and public awareness during the peak period in the third and fourth quarter of 2022 shows that the highest levels of media presence and public awareness were observed in southwestern and central-western Germany. In contrast, less media presence and public awareness was found in the northern and eastern regions (Fig. 2). Most news items could be assigned to the regional press of Baden-Württemberg and North Rhine-Westphalia (Fig. 2A), while the majority of the videos were published by broadcasters in the federal state of North Rhine-Westphalia (Fig. 2B). The highest search activity was recorded in Baden-Württemberg, Rhineland-Palatinate, and North Rhine-Westphalia (Fig. 2C), and the majority of occurrence records were found in Baden-Württemberg and North Rhine-Westphalia (Fig. 2D).

No significant spatial correlation could be found between media presence and Google Trend Search Index as a measure of public awareness (News ~ Google Trend Index: Spearman, $r = 0.45$, $p = 0.07$; Videos ~ Google Trend Index: Spearman, $r = 0.46$, $p = 0.07$). However, there was a spatial significant correlation between media presence and the number of occurrence records among federal states (News ~ Occurrence: Spearman, $r = 0.92$, $p < 0.01$, Videos ~ Occurrence: Spearman, $r = 0.79$, $r < 0.01$).

Spatio-temporal spread of Z. spinimana across Germany

Most records were made in the federal states of Baden-Württemberg (42.2%, $n = 1270$), North Rhine-Westphalia (20.6%, $n = 620$) and Hesse (17.7%, $n = 532$). Accordingly, the maps show a corresponding clustering in the south-western part of Germany, but also a clear north-easterly movement of the citizen scientists' observations from 2008 to 2023 (Fig. 3 or a more detailed version in Appendix A: Fig. 4). The greatest distance between the record locations is 197 km to the east between 2013 and 2014. From 2019 onwards the eastern and northern expansion limits change annually.

Phenology and ecology

The analysis of the timestamps reveals a clear peak of citizen science observations in September ($n = 736$) and August ($n = 682$), followed by October ($n = 440$) (Fig 4A). Broken down by data source, these monthly peaks are caused by the unstructured citizen science programs iNaturalist, Observation.org and the citizens submissions to the AraGes, while the expert records are more evenly distributed over the months (Fig. 4B).

The analysis of the citizen science images showed that it was difficult to derive information about the location of the spider from the close-up images (Fig. 5). Where it was possible or could be verified with the

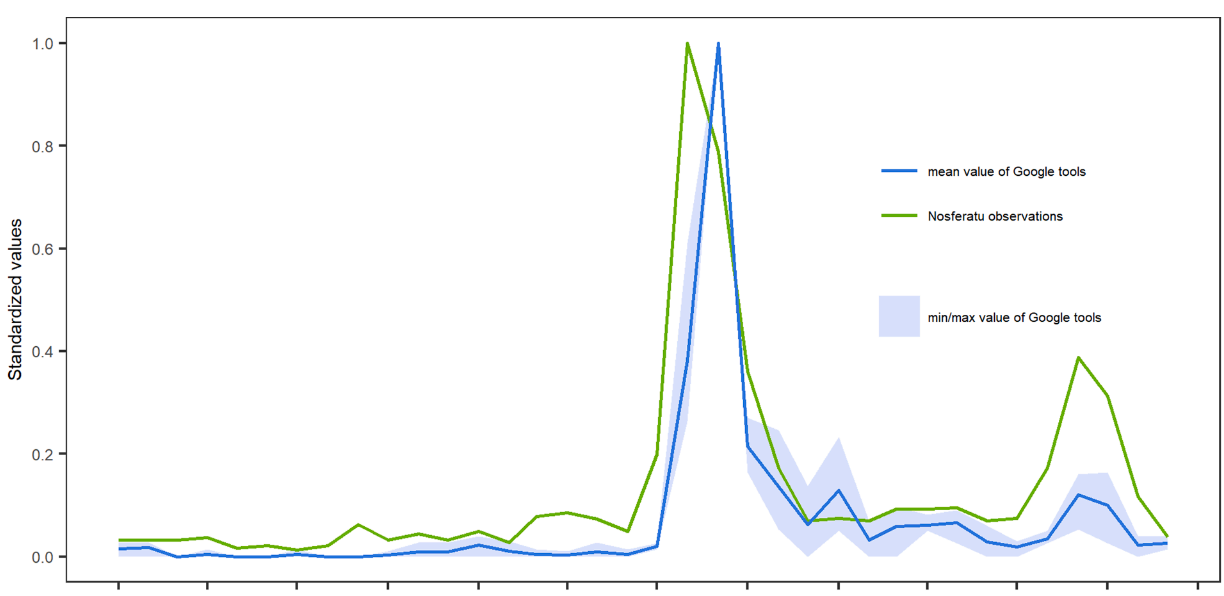

Fig. 1. Time series of number of citizen science observations, Google Trend Search Index, number of Google News and number of Google Video items between 2021 and 2024. For better comparison, all data is standardized (scaled between 0 and 1) and then visualized using the mean values of Nosferatu observations (green line) and all three standardized Google tools values taken together (blue line). Variability within the Google tools is visualized by the ribbon, showing minimum and maximum values of each date.

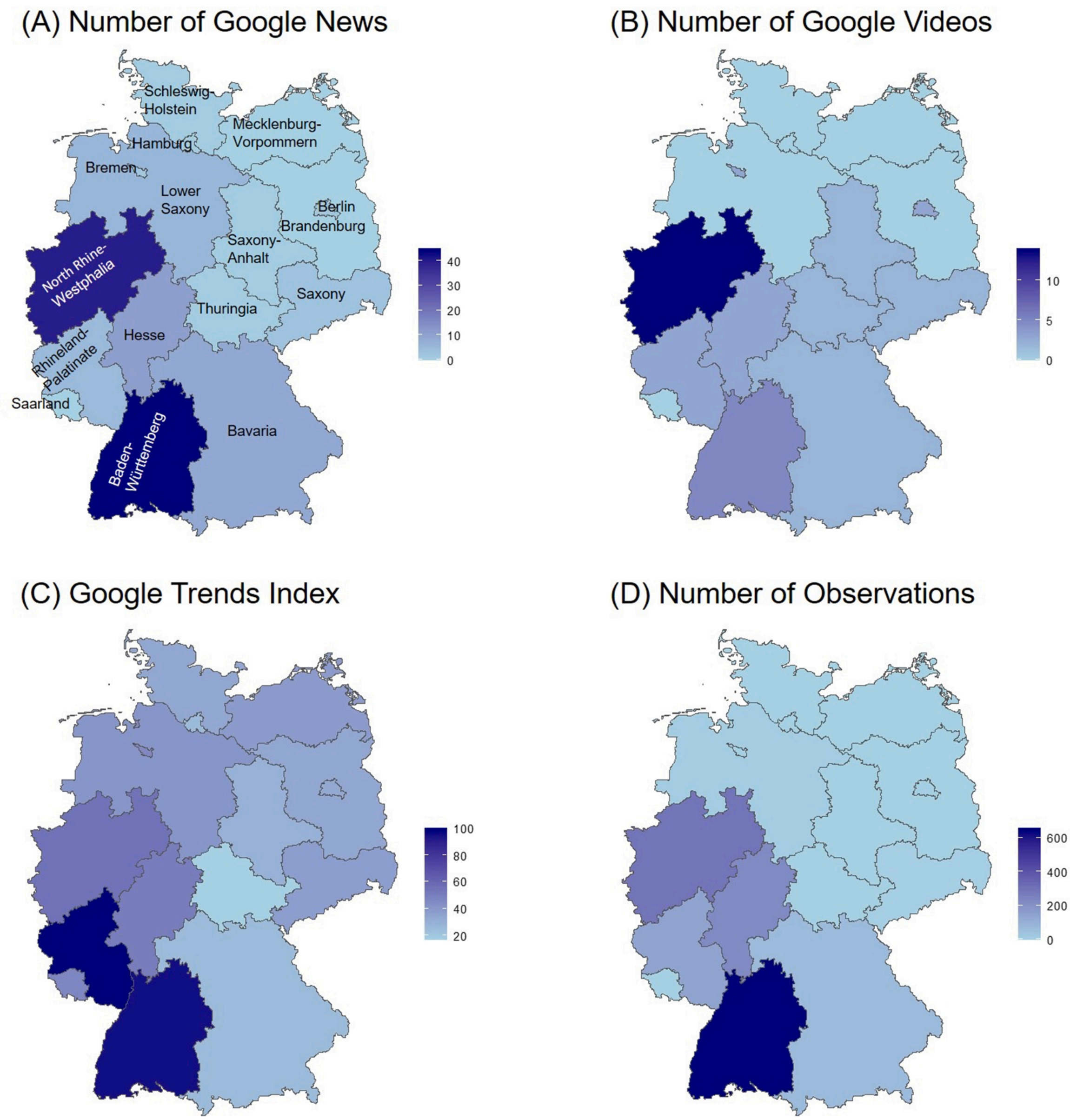

Fig. 2. Number of Google News (A), number of Google Videos (B), Google Trend Search Index (C) and number of citizen science observations (D) for each German federal state in the third and fourth quarter of 2022 (July 1st to December 31st, 2022).

geocoordinates, there was a clear tendency for the spiders to be reported mainly inside human dwellings (in or on the house: 68.5%, $n = 922$), especially during the winter season. Observations outside the house mainly happened in spring - but with a few exceptions always in the immediate vicinity (garden or backyard: 10.6%, $n = 143$). *Z. spinimana* was very rarely sighted away from people's homes (away from house: 0.2%, $n = 3$) (see Appendix A: Table 2).

Discussion

This study investigated the spread of *Z. spinimana* across Germany using citizen science observations and examined whether these observations are spatially and temporally correlated with public awareness, as measured by conservation culturomics tools. We found that the 3017 observations from different citizen science data sources clearly indicated a north-eastern direction of the annual spread of *Z. spinimana*. Additionally, there was a temporal correlation between media presence (Google Videos and Google News) with Google searches (Google Trend Index) and with the number of citizen science observations. Furthermore, a strong positive spatial correlation was demonstrated between the federal states with the highest media presence and the highest number of citizen science records.

Surveillance of invasive alien species with citizen science has become an accepted and useful tool for research and environmental management (Pocock et al., 2024; Price-Jones et al., 2022). Unstructured citizen science projects that focus on collecting data can be valuable for detecting invaders early on and tracking their spread. These mechanisms also work for alien species, whose invasion potential has not yet been elucidated. For example, in Germany, the first records of the non-native Asian bush mosquito (*Aedes japonicus*) and the Asian tiger mosquito (*Aedes albopictus*) were predominantly documented by citizen scientists in multiple federal states. Their subsequent spread from the southwest to the northeast could also be traced on the basis of numerous specimens of these mosquitoes collected by citizen scientists (Pernat et al., 2021). This pattern of expansion from southwestern to north-eastern Germany, which we also demonstrated for *Z. spinimana*, is somewhat typical for introduced or naturally spreading arthropod species that expand their ranges northward from the Mediterranean in response to climate

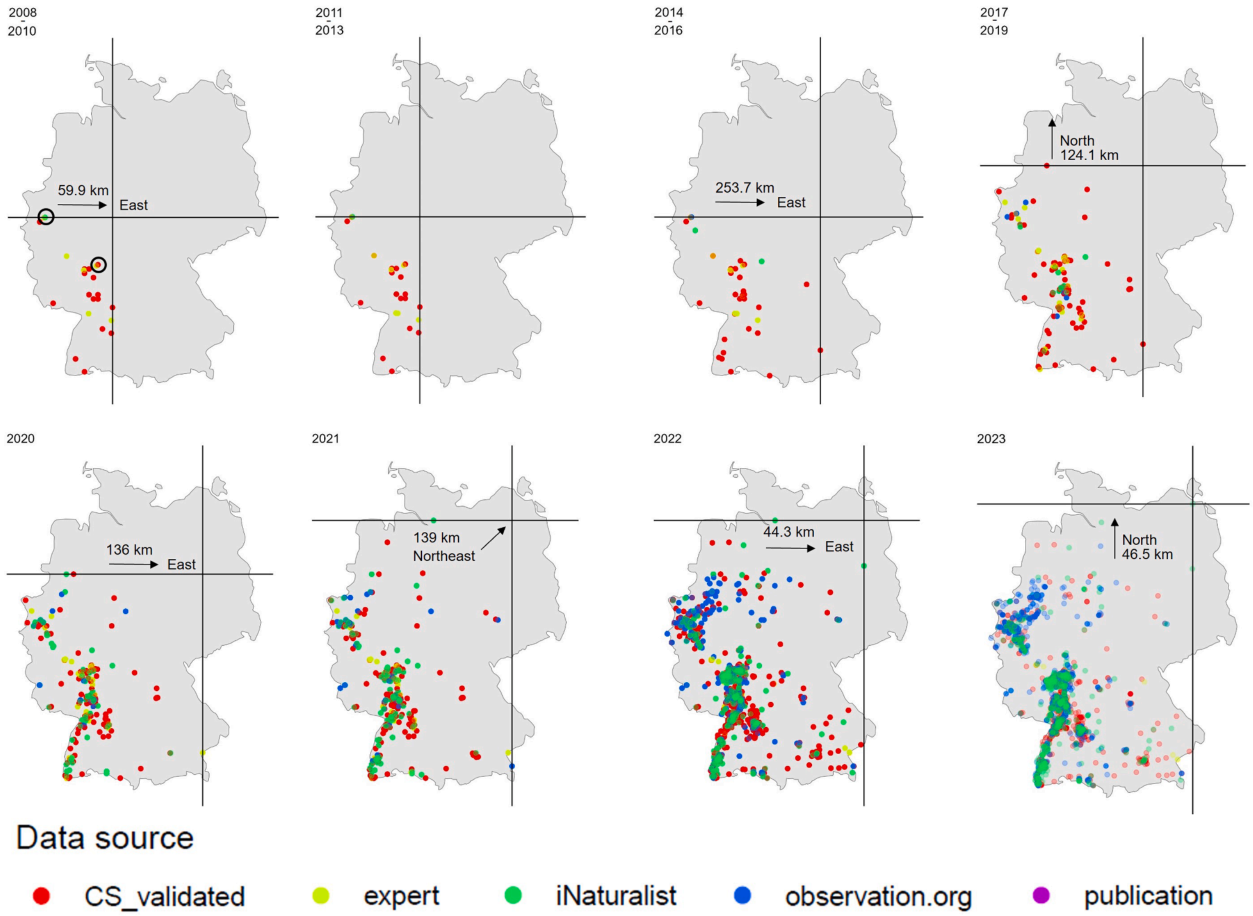

Fig. 3. Spread of *Z. spinimana* across Germany over the years 2008 to 2023 by data source, displaying a clear north-eastern direction of expansion. The crosshairs present the annual maximum longitude and latitude for accumulated points. Changes in the eastern and northern maxima are displayed with arrows and corresponding distances in km. The observations circled in black on the 2008–2010 map show the original easternmost and northernmost observations in the first year of our data analysis (2008).

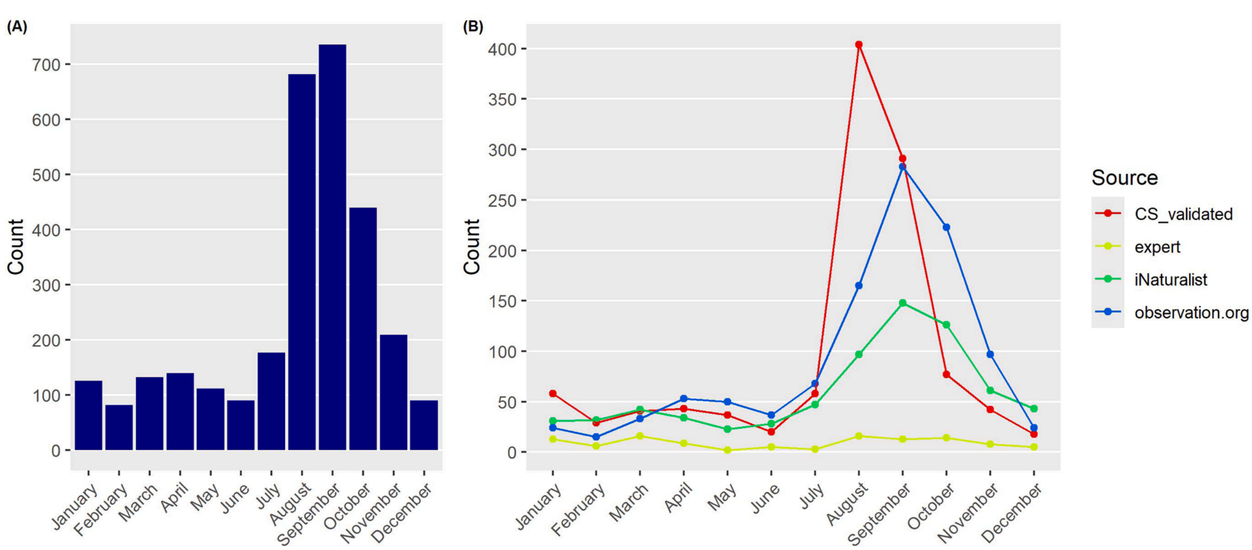

Fig. 4. Total monthly observation counts (A) and observation counts by source (B).

warming. The Breisgau region in the federal state of Baden-Württemberg is one of the warmest regions in Germany, with an average temperature that supports the introduction and establishment of thermophile, non-native arthropods (Statista: https://de.statista.com/statistik/daten/studie/1070875/umfrage/waermste-orte-in-deutschland-nach-durchschnittstemperatur/). Furthermore, the dispersal of less mobile invaders from France or Italy (through Switzerland) via the natural barrier of the Alps is facilitated by heavy traffic on the cross-border

Fig. 5. Example for citizen science images of *Z. spinimana* captured, in the house, in or on the house, and garden or backyard (clockwise).
Photo credits: © Matthias Feuersenger, https://observation.org/observation/235320263, CC-BY-NC—ND © Hippodamia, https://observation.org/observation/255072975, CC-BY-NC—ND © Kai Winter, https://observation.org/observation/253013566, CC-BY-NC—ND © DMF, https://observation.org/observation/267500611, CC-BY-NC—ND

highways and on the River Rhine. Indeed, there is evidence that arthropods "hitchhike" passively via ship or car (Eritja et al., 2017; Meurisse et al., 2019; Vestbo et al., 2018; Vlk et al., 2012). *Zoropsis spinimana* probably spreads by shipping on waterways or other human-mediated transport (Hänggi & Zürcher, 2013; Nedvěd et al., 2011; Wirth & Schulemann-Maier, 2024). The typical temporal-spatial development of observation clusters along the Rhine, its tributaries and adjacent highway routes – from the city of Freiburg via the Rhine-Neckar and Frankfurt metropolitan regions to the Ruhrgebiet area – supports this thesis.

We correlated overall search interest, as represented by Google Trend Index, with the number of Google News and Google Video items and with the number of citizen science observations of *Z. spinimana*. The strong positive correlation between the Google Trends Index and Google News and Google Videos suggests that people watching the videos or reading the news about *Z. spinimana* are prompted to google specifically for the species. Since there is no lag between the respective time series peaks, it can be assumed that consumption of a clip or article immediately activates people to acquire more knowledge, i.e. to google about the species on the Internet. In contrast, the number of citizen science records peaks about a month after the high point of Google News and Google Videos. As people do not find or search for a spider immediately after the media report, a delay between the peak in media reports and occurrence records can occur. This may represent an adaptive response known as short-term fluctuation change (Potter, 2011). Therefore, our results are consistent with those of other studies that show a clear positive correlation between the timing of communication campaigns and participation in citizen science projects, i.e. the frequency of participation increases after press releases or social media posts (Pernat et al., 2022; Schumann et al., 2024; Van Vliet et al., 2014; Würschum et al., 2019).

However, in contrast to citizen science projects that purposefully communicate their objectives to recruit or retain participants, there was no Nosferatu-specific project or challenge on iNaturalist or Observation.org as well as no call-to-action by the AraGes in the analysed period. Therefore, media coverage of *Z. spinimana* is assumed to have been one driving factor for the increase of public awareness measured in higher search interest and higher number of observations. People who encounter spiders may remember a media report about *Z. spinimana* and wish to know if it is indeed this species, especially if they notice resemblances from media-related images. This actionism could be catalyzed, by the fear and disgust that many people have of spiders (Gerdes et al., 2009), that may have been reinforced by reports of the size and toxicity of *Z. spinimana* (Dekramanjian et al., 2023; Phillips et al., 2021). Furthermore, raised attention towards spiders through media may lead to a more frequent documentation of this arthropod group on citizen science platforms in general, which in turn increases the probability of detection of *Z. spinimana*. For example, the similarity between a specific native mosquito and the non-native Asian tiger mosquito was assumed to increase the frequency of the indigenous look-alike's submissions in the mosquito atlas, among which the tiger mosquito was then detected (Pernat et al., 2021). Lastly, amateur arachnologists and people interested in spiders may have actively searched for *Z. spinimana* or started to report it due to media coverage, especially in the case of AraGes members. However, the notable advancement in the capabilities of identification apps, coupled with their intuitive user interface, has led to a significant increase in the number of records of *Z. spinimana* contributed by Observation.org or iNaturalist, accounting for over 50 % of these contributions over the past few years. We also believe, that it might be much more convenient even for experts to use apps than, for example, to enter data directly into the AraGes spider atlas.

Besides the high media presence, a second factor that presumably increased both the spider's citizen science records and expert's observations is its current distribution dynamics. Although *Z. spinimana* has not been labelled invasive, the framework of Blackburn et al. (2011) can also be applied to this introduced species, which would be allocated being in the stage of spread and sequential establishment of populations. As the 'invasion' lag has been overcome and populations are now rapidly growing and expanding, there is higher detection probability and frequency of encounters with *Z. spinimana*, leading to spatial clustering of citizen science records and corresponding (local) media coverage along the dispersal path of *Z. spinimana*. This pattern is reinforced by the spider's human-mediated dispersal and its likely transition to fully synanthropic behaviour. In other words, the larger the human population density, the more people discover the spider and report their observations to unstructured citizen science projects (Geldmann et al., 2016; Geurts et al., 2023). While in its Mediterranean habitat, *Z. spinimana* is found in and around houses, but also in forests and rocky areas (Nedvěd et al., 2011). Colder temperatures, especially in winter, may have driven *Z. spinimana* to a more synanthropic lifestyle in Germany (Nentwig et al., 2013). This suggestion is corroborated by our visual inspection of images and the phenology of species recordings by citizen scientists.

August, September and October are the months with the most citizen science records. Interestingly, this late summer to fall maximum is also found in the expert observations, but similarly high numbers were also reported by this group for January and March. Citizen science data often show a seasonal bias, which is due to the recording behaviour of people, e.g., influenced by weekends or nice weather (Di Cecco et al., 2021; Rosário et al., 2024). In addition, the activity times and detectability of the respective organisms plays a key role and are the driving factors for the phenological pattern in this case. In spring, *Z. spinimana* builds a cocoon in a hidden brood chamber and does not leave it, making it unlikely to find individuals of this species by accident. When the young hatch, they remain close to the mother during moulting stage and disperse in late summer (Foelix et al., 2015; Nentwig et al., 2024). During this time, the species can be easily (accidentally) spotted by citizen scientists, for example on light-colored, plain walls or floors. Indeed, our image analysis confirmed, that the spider is mainly photographed in or on the house especially in late summer, early fall. In contrast, the expert findings of *Z. spinimana* are more equally distributed over the months and – according to our visual inspection of the given coordinates – also included more natural habitats. It is likely that experts systematically search for spiders outside and document everything they find as compared to accidental findings in the house.

In conclusion, our hypotheses regarding the usability of citizen science data to track the dispersal of *Z. spinimana* and infer ecological insights were confirmed. In addition, as expected, we found positive correlations between media presence, public awareness and number of citizen science observations. However, with *Z. spinimana* we have selected a spider that cannot be considered representative of the successful use of citizen science data to investigate alien Araneae species. Only a small proportion of spider species lives quite obviously in the house, such as the domestic house spider (*Tegenaria domestica*), the zebra spider (*Salticus scenicus*) and long-bodied cellar spiders (*Pholcus* spec.), or in the garden, like the European garden spider (*Araneus diadematus*) and the walnut orb-weaver spider (*Nuctenea umbratica*) (Nentwig et al., 2024). We assume that people tend to observe and report species in their immediate environment, so there should be a taxonomic bias towards synanthropic species on citizen science platforms. Another factor contributing to the taxonomic bias is the charisma of a species. Charisma refers not only to the attractiveness of the organism due to positive traits, such as the beauty of a flower, the colourfulness of a butterfly, or the cuteness of a squirrel, but also to traits such as strength and deadliness, such as in sharks and snakes (Jarić et al., 2020). Charismatic species are not only more often the subject of academic research, but also overrepresented in citizen science data and favourably featured by the media (Caldwell et al., 2024; Callaghan et al., 2020; Jarić et al., 2024; Kidd et al., 2018; Troudet et al., 2017). Because *Z. spinimana* frightens or fascinates many people, regardless of whether it is truly dangerous or not, the citizen science data situation on *Z. spinimana* was ideal for answering our research questions. A similar example of a charismatic arthropod is the conspicuous domestic centipede *Scutigera coleoptrata*, which is also spreading northward and is capable of biting (Kriegs & Meyer, 2024). With this data foundation, not only migration routes and corresponding drivers can be elucidated in future studies. Also, given the significant interest, the public could collect physical specimens – in case of non-threatened species – for studies on the phylogeography and genetic changes associated with range shifts, similar to respective citizen science projects with native species (Cunningham-Eurich et al., 2023).

What can be done when species of research interest are not charismatic, synanthropic or otherwise attractive to record for the people and to be featured in the media? As societal preferences are strongly correlated with taxonomic bias in species recording, the recording of less charismatic species by citizen scientists should be promoted (Troudet et al., 2017). This has been successfully done by citizen science platforms such as Observation.org by running Bioblitz competitions that encourage the recording of all possible species. In addition, the rapid progress in implemented species recognition algorithms of biodiversity monitoring apps allows a wider range of people discover and record less-known taxa, which also presents a learning opportunity. While using apps such as ObsIdentify, citizen scientists can be motivated by rewarding digital badges based on the taxonomy of the observed species or to participate in (local) challenges to record specific species. For example, in 2023, the LWL State Museum of Natural History, Münster in co-operation with Observation.org announced the challenge "Geh aufs Ganze für die Wanze" (Go all out for the bug) to fill data gaps in Heteroptera recordings, which resulted in >115,000 observations of 497 species (more than half of the Heteroptera species documented for Germany). These types of initiatives allow near real-time monitoring of the distribution of species such as the European praying mantis *Mantis religiosa* (Beckerbauer et al., 2024) or the Jersey tiger *Euplagia quadripunctaria* (Poorthuis et al., 2024), even without a dedicated media coverage, which can only be managed with additional resources.

Data availabilty

Data will be made available by time of publication on the University of Münster repository server.

CRediT authorship contribution statement

Nadja Pernat: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Conceptualization. **Sascha Buchholz:** Writing – review & editing, Conceptualization. **Jan Ole Kriegs:** Writing – review & editing, Conceptualization. **Jan Steen:** Writing – review & editing, Formal analysis. **Hilke Hollens-Kuhr:** Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Conceptualization.

Declaration of competing interest

All aouthors have no actual or potential conflict of interest or competing interest including any financial, personal or other relationships with other people or organizations that could inappropriately influence or be perceived to influence our work.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.baae.2025.02.002.

References

Arel-Bundock, V., Enevoldsen, N., & Yetman, C. (2018). Countrycode: An R package to convert country names and country codes. *Journal of Open Source Software, 3*(28), 848. https://doi.org/10.21105/joss.00848

Arachnologische Gesellschaft (2024): Atlas of the European Arachnids, accessed at https://atlas.arages.de accessed on November 23, 2023.

Beckerbauer, S., Poorthuis, L., Franzen, A., & Kriegs, J. O. (2024). Die Ausbreitung der Europäischen Gottesanbeterin Mantis religiosa (Linnaeus 1758) in NRW, Deutschland und Europa: Citizen Science-Projekte machen die Mechanismen der Ausbreitung einer wärmeliebenden Art sichtbar. *Abhandlungen aus dem Westfälischen Museum für Naturkunde, 106*, 185–196.

Beninde, J., Delaney, T. W., Gonzalez, G., & Shaffer, H. B. (2023). Harnessing iNaturalist to quantify hotspots of urban biodiversity: The Los Angeles case study. *Frontiers in Ecology and Evolution, 11*, Article 983371. https://doi.org/10.3389/fevo.2023.983371

Blackburn, T. M., Pyšek, P., Bacher, S., Carlton, J. T., Duncan, R. P., Jarošík, V., Wilson, J. R. U., & Richardson, D. M. (2011). A proposed unified framework for biological invasions. *Trends in ecology & evolution, 26*(7), 333–339. https://doi.org/10.1016/j.tree.2011.03.023

Blois, J. L., Zarnetske, P. L., Fitzpatrick, M. C., & Finnegan, S. (2013). Climate change and the past, present, and future of biotic interactions. *Science, 341*(6145), 499–504. https://doi.org/10.1126/science.1237184

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science, 25*(1), 2–16. https://doi.org/10.1177/0963662515607406

Brown, P. M. J., Roy, H. E., Rothery, P., et al. (2008). *Harmonia axyridis* in Great Britain: Analysis of the spread and distribution of a non-native coccinellid. *BioControl, 53*, 55–67. https://doi.org/10.1007/s10526-007-9124-y

Caldwell, I. R., Hobbs, J.-P. A., Bowen, B. W., Cowman, P. F., DiBattista, J. D., Whitney, J. L., Ahti, P. A., Belderok, R., Canfield, S., Coleman, R. R., Iacchei, M., Johnston, E. C., Knapp, I., Nalley, E. M., Staeudle, T. M., & Láruson, Á. J. (2024). Global trends and biases in biodiversity conservation research. *Cell Reports Sustainability, 1*(5), Article 100082. https://doi.org/10.1016/j.crsus.2024.100082

Callaghan, C. T., Poore, A. G. B., Mesaglio, T., Moles, A. T., Nakagawa, S., Roberts, C., Rowley, J. J. L., VergÉs, A., Wilshire, J. H., & Cornwell, W. K. (2020). Three frontiers for the future of biodiversity research using citizen science data. *BioScience*, biaa133. https://doi.org/10.1093/biosci/biaa131

Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P. W., Trisos, C., Romero, J., Aldunce, P., Barrett, K., Blanco, G., Cheung, W. W. L., Connors, S., Denton, F., Diongue-Niang, A., Dodman, D., Garschagen, M., Geden, O., Hayward, B., Jones, C., , … Péan, C., & Core Writing Team. (2023). IPCC, 2023: Climate change 2023: Synthesis report. In H. Lee, & J. Romero (Eds.), *Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647 (First). Intergovernmental Panel on Climate Change (IPCC).

Correia, R. A., Ladle, R., Jarić, I., Malhado, A. C., Mittermeier, J. C., Roll, U., Soriano-Redondo, A., Verissimo, D., Fink, C., Hausmann, A., Guedes-Santos, J., Vardi, R., & Di Minin, E. (2021). Digital data sources and methods for conservation culturomics. *Conservation Biology, 35*(2), 398–411. https://doi.org/10.1111/cobi.13706

Cunningham-Eurich, I., Kontou, D., Yordanova, M., Maeda-Obregon, A., Favreau, E., Wang, J., et al. (2023). Using citizen science data to assess the population genetic structure of the common yellowjacket wasp, *Vespula vulgaris*. *Insect Molecular Biology, 32*(6), 634–647. https://doi.org/10.1111/imb.12862

Dekramanjian, B., Bartumeus, F., Kampen, H., Palmer, J. R. B., Werner, D., & Pernat, N. (2023). Demographic and motivational differences between participants in analog and digital citizen science projects for monitoring mosquitoes. *Scientific Reports, 13*(1), 12384. https://doi.org/10.1038/s41598-023-38656-y

Di Cecco, G. J., Barve, V., Belitz, M. W., Stucky, B. J., Guralnick, R. P., & Hurlbert, A. H. (2021). Observing the observers: How participants contribute data to iNaturalist and implications for biodiversity science. *BioScience, 71*(11), 1179–1188. https://doi.org/10.1093/biosci/biab093

Encarnação, J., Teodósio, M. A., & Morais, P. (2021). Citizen Science and Biological Invasions: A Review. *Frontiers in Environmental Science, 8*, Article 602980. https://doi.org/10.3389/fenvs.2020.602980

Engelhardt, E. K., Biber, M. F., Dolek, M., Fartmann, T., Hochkirch, A., Leidinger, J., Löffler, F., Pinkert, S., Poniatowski, D., Voith, J., Winterholler, M., Zeuss, D., Bowler, D. E., & Hof, C. (2022). Consistent signals of a warming climate in occupancy changes of three insect taxa over 40 years in central Europe. *Global Change Biology, 28*(13), 3998–4012. https://doi.org/10.1111/gcb.16200

Eritja, R., Palmer, J. R. B., Roiz, D., Sanpera-Calbet, I., & Bartumeus, F. (2017). Direct Evidence of Adult Aedes albopictus Dispersal by Car. *Scientific Reports, 7*(1), 14399. https://doi.org/10.1038/s41598-017-12652-5

Felgentreff, E. S., Buchholz, S., & Straka, T. M. (2023). From science to society to practice? Public reactions to the insect crisis in Germany. *People and Nature, 5*(2), 660–667. https://doi.org/10.1002/pan3.10434

Foelix, R., Erb, B., & Eggs, B. (2015). Morphologische Besonderheiten der Kräuseljagdspinne *Zoropsis spinimana*. *Arachne, 20*(3), 4–15.

Fogarty, H. E., Burrows, M. T., Pecl, G. T., Robinson, L. M., & Poloczanska, E. S. (2017). Are fish outside their usual ranges early indicators of climate-driven range shifts? *Global Change Biology, 23*(5), 2047–2057. https://doi.org/10.1111/gcb.13635

Geldmann, J., Heilmann-Clausen, J., Holm, T. E., Levinsky, I., Markussen, B., Olsen, K., Rahbek, C., & Tøttrup, A. P. (2016). What determines spatial bias in citizen science? Exploring four recording schemes with different proficiency requirements. *Diversity and Distributions, 22*(11), 1139–1149. https://doi.org/10.1111/ddi.12477

GBIF (2024): Occurrence Download, https://doi.org/10.15468/dl.af792h (retrieved on March 4, 2024 from GBIF.org).

Gerdes, A. B. M., Uhl, G., & Alpers, G. W. (2009). Spiders are special: Fear and disgust evoked by pictures of arthropods. *Evolution and Human Behavior, 30*(1), 66–73. https://doi.org/10.1016/j.evolhumbehav.2008.08.005

Geurts, E. M., Reynolds, J. D., & Starzomski, B. M. (2023). Turning observations into biodiversity data: Broadscale spatial biases in community science. *Ecosphere, 14*(6), e4582. https://doi.org/10.1002/ecs2.4582

Gil-Tapetado, D., Ferrari, A., Ronchetti, F., et al. (2024). Distribution widening of a ground-nesting social bee across Europe favored by climate change and urban setting. *Apidologie, 55*, 35. https://doi.org/10.1007/s13592-024-01077-5

Gloor, D., Blick, T., Nentwig, W., Kropf, C., & Hänggi, A. (2010). *Spiders of europe*. University of Bern. https://doi.org/10.24436/1

Gretta, T. Pecl, et al. (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science, 355*, eaai9214. https://doi.org/10.1126/science.aai92

Hänggi, A. (2003). Nachträge zum „Katalog der schweizerischen Spinnen“. 3. Neunachweise von 1999 bis 2002 und Nachweise synanthroper Spinnen. *Arachnologische Mitteilungen, 26*, 36–54. https://doi.org/10.5431/aramit2604

Hänggi, A., & Bolzern, A. (2006). *Zoropsis spinimana* (Araneae: Zoropsidae) neu für Deutschland. *Arachnologische Mitteilungen, 32*, 8–10. https://doi.org/10.5431/aramit3202

Hänggi, A., & Zürcher, I. (2013). *Zoropsis spinimana* – eine mediterrane Spinne ist in Basel (NW-Schweiz) heimisch geworden. *Mitteilungen der Naturforschenden Gesellschaft beider Basel, 14*, 125–134.

Hänggi, A., Inches, S., & Brunner, S. (2020). *Zoropsis spinimana* – eine gebietsfremde Spinnenart aus dem Mittelmeerraumbesiedelt auch Vogelnistkästen. *Ornithologischer Beobachter, 117*, 262–266.

Hickling, R., Roy, D. B., Hill, J. K., Fox, R., & Thomas, C. D. (2006). The distributions of a wide range of taxonomic groups are expanding polewards. *Global Change Biology, 12*, 450–455. https://doi.org/10.1111/j.1365-2486.2006.01116.x

Hijmans, R. (2022). *geosphere: Spherical Trigonometry* (Version R package version 1.5-18,) [Software]. https://CRAN.R-project.org/package=geosphere.

iNaturalist (2024). Available from https://www.inaturalist.org.

Jarić, I., Correia, R. A., Roberts, D. L., Gessner, J., Meinard, Y., & Courchamp, F. (2019). On the overlap between scientific and societal taxonomic attentions—Insights for conservation. *Science of The Total Environment, 648*, 772–778. https://doi.org/10.1016/j.scitotenv.2018.08.198

Jarić, I., Courchamp, F., Correia, R. A., Crowley, S. L., Essl, F., Fischer, A., González-Moreno, P., Kalinkat, G., Lambin, X., Lenzner, B., Meinard, Y., Mill, A., Musseau, C., Novoa, A., Pergl, J., Pyšek, P., Pyšková, K., Robertson, P., Von Schmalensee, M., … Jeschke, J. M. (2020). The role of species charisma in biological invasions. *Frontiers in Ecology and the Environment, 18*(6), 345–353. https://doi.org/10.1002/fee.2195

Jarić, I., Normande, I. C., Arbieu, U., Courchamp, F., Crowley, S. L., Jeschke, J. M., Roll, U., Sherren, K., Thomas-Walters, L., Veríssimo, D., & Ladle, R. J. (2024). Flagship individuals in biodiversity conservation. *Frontiers in Ecology and the Environment, 22*(1), e2599. https://doi.org/10.1002/fee.2599

Kellermann, V., & Van Heerwaarden, B. (2019). Terrestrial insects and climate change: Adaptive responses in key traits. *Physiological Entomology, 44*(2), 99–115. https://doi.org/10.1111/phen.12282

Kidd, L. R., Gregg, E. A., Bekessy, S. A., Robinson, J. A., & Garrard, G. E. (2018). Tweeting for their lives: Visibility of threatened species on twitter. *Journal for Nature Conservation, 46*, 106–109. https://doi.org/10.1016/j.jnc.2018.10.001

Krehenwinkel, H., & Tautz, D. (2013). Northern range expansion of European populations of the wasp spider *Argiope bruennichi* is associated with global warming–correlated genetic admixture and population-specific temperature adaptations. *Molecular Ecology, 22*, 2232–2248. https://doi.org/10.1111/mec.12223

Kriegs, J. O. (2023). Freilandfund einer Nosferatuspinne *Zoropsis spinimana* (DUFOUR, 1820) in Münster. *Natur und Heimat, 83*, 148–150.

Kriegs, J. O., & Meyer, M. (2024). Spinnenläufer *Scutigera coleoptrata* (Linnaeus, 1758) in Nordrhein-Westfalen und im Rest der Welt: Live-Karten der klimabedingten regionalen Ausbreitung auf Observation.org und eine Einordnung in das weltweite Auftreten der Art. *Abhandlungen aus dem Westfälischem Museum für Naturkunde, 106*, 163–170.

Leong, M., & Trautwein, M. (2019). A citizen science approach to evaluating US cities for biotic homogenization. *PeerJ, 7*, e6879. https://doi.org/10.7717/peerj.6879

Madin, E. M. P., Ban, N. C., Doubleday, Z. A., Holmes, T. H., Pecl, G. T., & Smith, F. (2012). Socio-economic and management implications of range-shifting species in marine systems. *Global Environmental Change, 22*(1), 137–146. https://doi.org/10.1016/j.gloenvcha.2011.10.008

Massicotte, P., & South, A. (2023). *rnaturalearth: World map data from natural earth* (Version R package version 0.3.4) [Software]. https://CRAN.R-project.org.

Medina, R. G., Lira-Noriega, A., Aráoz, E., & Ponssa, M. L. (2020). Potential effects of climate change on a Neotropical frog genus: Changes in the spatial diversity patterns of Leptodactylus (Anura, Leptodactylidae) and implications for their conservation. *Climatic Change, 161*(4), 535–553. https://doi.org/10.1007/s10584-020-02677-7

Meeus, S., Silva-Rocha, I., Adriaens, T., Brown, P. M. J., Chartosia, N., Claramunt-López, B., Martinou, A. F., Pocock, M. J. O., Preda, C., Roy, H. E., Tricarico, E., & Groom, Q. J. (2023). More than a bit of fun: The multiple outcomes of a Bioblitz. *BioScience, 73*(3), 168–181. https://doi.org/10.1093/biosci/biac100

Meurisse, N., Rassati, D., Hurley, B. P., Brockerhoff, E. G., & Haack, R. A. (2019). Common pathways by which non-native forest insects move internationally and domestically. *Journal of Pest Science, 92*(1), 13–27. https://doi.org/10.1007/s10340-018-0990-0

Molls, C. (2021). The Obs-Services and their potentials for biodiversity data assessments with a test of the current reliability of photo-identification of Coleoptera in the field. *Tijdschrift voor Entomologie, 164*(1–3), 143–153. https://doi.org/10.1163/22119434-bja10018

Montoya, J. M., & Raffaelli, D. (2010). Climate change, biotic interactions and ecosystem services. *Philosophical Transactions of the Royal Society B: Biological Sciences, 365* (1549), 2013–2018. https://doi.org/10.1098/rstb.2010.0114

Moore, M. J., & Hyman, A. A. (2024). What can conservation culturomics tell us about factors driving public interest in aquatic endangered species. *Biological Conservation, 289*, Article 110397. https://doi.org/10.1016/j.biocon.2023.110397

Nedvěd, O., Pekár, S., Bezděčka, P., Líznarová, E., Řezáč, M., Schmitt, M., & Sentenská, L. (2011). Ecology of Arachnida alien to Europe. *BioControl, 56*(4), 539–550. https://doi.org/10.1007/s10526-011-9385-3

Nentwig, W., Blick, T., Bosmans, R., Gloor, D., Hänggi, A., & Kropf, C. (2024). *Spiders of Europe*. Online at https://www.araneae.nmbe.ch.

Nentwig, W., Gnädinger, M., Fuchs, J., & Ceschi, A. (2013). A two year study of verified spider bites in Switzerland and a review of the European spider bite literature. *Toxicon, 73*, 104–110. https://doi.org/10.1016/j.toxicon.2013.07.010

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., & Crowston, K. (2012). The future of citizen science: Emerging technologies and shifting paradigms. *Frontiers in Ecology and the Environment, 10*(6), 298–304. https://doi.org/10.1890/110294

Observation.org (2024). Observation International and local partners. Available at https://observation.org.

Palmer, J. R. B., Oltra, A., Collantes, F., Delgado, J. A., Lucientes, J., Delacour, S., Bengoa, M., Eritja, R., & Bartumeus, F. (2017). Citizen science provides a reliable and scalable tool to track disease-carrying mosquitoes. *Nature Communications, 8*(1), 916. https://doi.org/10.1038/s41467-017-00914-9

Pebesma, E. (2018). Simple features for R: Standardized support for spatial vector data. *The R Journal, 10*(1), 439. https://doi.org/10.32614/RJ-2018-009

Pernat, N., Kampen, H., Jeschke, J. M., & Werner, D. (2021). Citizen science versus professional data collection: Comparison of approaches to mosquito monitoring in Germany. *Journal of Applied Ecology, 58*(2), 214–223. https://doi.org/10.1111/1365-2664.13767

Pernat, N., Zscheischler, J., Kampen, H., Ostermann-Miyashita, E.-F., Jeschke, J. M., & Werner, D. (2022). How media presence triggers participation in citizen science—The case of the mosquito monitoring project 'Mückenatlas'. *PLOS ONE, 17* (2), Article e0262850. https://doi.org/10.1371/journal.pone.0262850

Pernat, N., Canavan, S., Golivets, M., Hillaert, J., Itescu, Y., Jarić, I., Mann, J. M. R., Pipek, P., Preda, C., Richardson, D. M., Reiseira, H., Vaz, A. S., & Groom, Q. (2024). Overcoming biodiversity blindness: Secondary data in primary citizen science observations. *Ecological Solutions and Evidence, 5*(1), e12295. https://doi.org/10.1002/2688-8319.12295

Phillips, T. B., Bailey, R. L., Martin, V., Faulkner-Grant, H., & Bonter, D. N. (2021). The role of citizen science in management of invasive avian species: What people think, know, and do. *Journal of Environmental Management, 280*, Article 111709. https://doi.org/10.1016/j.jenvman.2020.111709

Pocock, M. J. O., Adriaens, T., Bertolino, S., Eschen, R., Essl, F., Hulme, P. E., Jeschke, J. M., Roy, H. E., Teixeira, H., & De Groot, M. (2024). Citizen science is a vital partnership for invasive alien species management and research. *iScience, 27*(1), Article 108623. https://doi.org/10.1016/j.isci.2023.108623

Poorthuis, L., Beckerbauer, S., Dahl, A., & Kriegs, J. O. (2024). Die Spanische Flagge (Euplagia quadripunctaria (Poda, 1761): Verlauf der Ausbreitung einer wärmeliebenden Art in Deutschland mit besonderem Fokus auf Nordrhein-Westfalen. *Abhandlungen aus dem Westfälischen Museum für Naturkunde, 106*, 197–205.

Potter, W. J. (2011). Conceptualizing Mass Media Effect. *Journal of Communication, 61* (5), 896–915. https://doi.org/10.1111/j.1460-2466.2011.01586.x

Price-Jones, V., Brown, P. M. J., Adriaens, T., Tricarico, E., Farrow, R. A., Cardoso, A. C., Gervasini, E., Groom, Q., Reyserhove, L., Schade, S., Tsinaraki, C., & Marchante, E. (2022). Eyes on the aliens: Citizen science contributes to research, policy and management of biological invasions in Europe. *NeoBiota, 78*, 1–24. https://doi.org/10.3897/neobiota.78.81476

R Core Team. (2024). *R: A language and environment for statistical computing.* [Software]. https://www.R-project.org/.

Rosa, R. M., Cavallari, D. C., & Salvador, R. B. (2022). iNaturalist as a tool in the study of tropical molluscs. *PLOS ONE, 17*(5), Article e0268048. https://doi.org/10.1371/journal.pone.0268048

Rosário, Inês. T., Tiago, Patrícia., Chozas, S., & Capinha, C. (2024). *Drivers of temporal bias in biodiversity recording by citizen scientists*. https://doi.org/10.1101/2024.07.22.604598

Roy, H. E., Pauchard, A., Stoett, P., Renard Truong, T., Bacher, S., Galil, B. S., Hulme, P. E., Ikeda, T., Sankaran, K., McGeoch, M. A., Meyerson, L. A., Nuñez, M. A., Ordonez, A., Rahlao, S. J., Schwindt, E., Seebens, H., Sheppard, A. W., & Vandvik, V. (2024). *IPBES Invasive Alien Species Assessment: Summary for Policymakers (Version 3)*. https://doi.org/10.5281/ZENODO.7430692 [object Object].

Saavedra, I., Rabadán-González, J., Aragonés, D., & Figuerola, J. (2023). Can citizen science contribute to avian influenza surveillance? *Pathogens, 12*(9), 1183. https://doi.org/10.3390/pathogens12091183

Schumann, A., Greving, H., Bruckermann, T., Kimmerle, J., Harms, U., & Brandt, M. (2024). We want you! Recruitment strategies for the success of a citizen science project on urban wildlife ecology. *Frontiers in Environmental Science, 12*, Article 1258813. https://doi.org/10.3389/fenvs.2024.1258813

Serniak, L. T., Chan, S. S., & Lajtha, K. (2023). Predicting habitat suitability for Amynthas spp. in the United States: A retrospective analysis using citizen science data from iNaturalist. *Biological Invasions, 25*(3), 817–825. https://doi.org/10.1007/s10530-022-02947-8

Soriano-Redondo, A., Bearhop, S., Lock, L., Votier, S. C., & Hilton, G. M. (2017). Internet-based monitoring of public perception of conservation. *Biological Conservation, 206*, 304–309. https://doi.org/10.1016/j.biocon.2016.11.031

South, A. (2017). *rnaturalearthdata: World vector map data from natural earth used in „rnaturalearth"* (Version R package version 0.1.0,) [Software]. https://CRAN.R-project.org/package=rnaturalearthdata.

Srivastava, D. S., Céréghino, R., Trzcinski, M. K., MacDonald, A. A. M., Marino, N. A. C., Mercado, D. A., Leroy, C., Corbara, B., Romero, G. Q., Farjalla, V. F., Barberis, I. M., Dézerald, O., Hammill, E., Atwood, T. B., Piccoli, G. C. O., Ospina-Bautista, F., Carrias, J., Leal, J. S., Montero, G., … Campos, A. B. A. (2020). Ecological response to altered rainfall differs across the Neotropics. *Ecology, 101*(4), e02984. https://doi.org/10.1002/ecy.2984

Stephens-Davidowitz, S., & Varian, H. (2014). *A hands-on guide to Google data*. https://www.aeaweb.org/conference/2016/retrieve.php?pdfid=14330&tk=S7QBBHGE.

Thaler, K., & Knoflach, B. (1998). *Zoropsis spinimana*(Dufour), eine für Österreich neue Adventivart. *–. Berichte des naturwissenschaftlich-medizinischen Verein Innsbruck, 85*, 173–185.

Thomas, C. D. (2010). Climate, climate change and range boundaries. *Diversity and Distributions, 16*(3), 488–495. https://doi.org/10.1111/j.1472-4642.2010.00642.x

Trapletti, A., & Hornik, K. (2023). *Tseries: Time series analysis and computational finance* (Version R package version 0.10-55,) [Software]. https://CRAN.R-project.org/package=tseries.

Troudet, J., Grandcolas, P., Blin, A., Vignes-Lebbe, R., & Legendre, F. (2017). Taxonomic bias in biodiversity data and societal preferences. *Scientific Reports, 7*(1), 9132. https://doi.org/10.1038/s41598-017-09084-6

Van Vliet, A. J. H., Bron, W. A., & Mulder, S. (2014). The how and why of societal publications for citizen science projects and scientists. *International Journal of Biometeorology, 58*(4), 565–577. https://doi.org/10.1007/s00484-014-0821-9

Vestbo, S., Toft, S., Swanson, H. A., Olesen, J. M., & Funch, P. (2018). Transportation Infrastructures and Arthropod Dispersal: Are Harvestmen (Opiliones) Hitchhiking to Northern Europe? *Journal of Ethnobiology, 38*(1), 55–70. https://doi.org/10.2993/0278-0771-38.1.055

Vlk, R., Balvín, O., Krištín, A., Marhoul, P., & Hrúz, V. (2012). Distribution of the Southern Oak Bush-cricket *Meconema meridionale* (Orthoptera, Tettigoniidae) in the Czech Republic and Slovakia. *Folia Oecologica, 39*(2), 155–165.

Vohland, K., Land-Zandstra, A., Ceccaroni, L., Lemmens, R., Perelló, J., Ponti, M., Samson, R., & Wagenknecht, K.(Hrsg.). (2021). *The science of citizen science*. Springer International Publishing. https://doi.org/10.1007/978-3-030-58278-4

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller, E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V., … Yutani, H. (2019). Welcome to the Tidyverse. *Journal of Open Source Software, 4*(43), 1686. https://doi.org/10.21105/joss.01686

Wilson, R. J., & Fox, R. (2021). Insect responses to global change offer signposts for biodiversity and conservation. *Ecological Entomology, 46*(4), 699–717. https://doi.org/10.1111/een.12970

Wirth, A., & Schulemann-Maier, G. (2024). Updated distribution of *Zoropsis spinimana* (Dufour, 1820; Araneae: Zoropsidae) in Germany and novel insights into its ecology based on a citizen science survey. *Frontiers in Arachnid Science, 3*, Article 1383339. https://doi.org/10.3389/frchs.2024.1383339

Würschum, T., Leiser, W. L., Jähne, F., Bachteler, K., Miersch, M., & Hahn, V. (2019). The soybean experiment '1000 Gardens': A case study of citizen science for research, education, and beyond. *Theoretical and Applied Genetics, 132*(3), 617–626. https://doi.org/10.1007/s00122-018-3134-2

Zhu, H., Wang, D., Wang, L., Fang, J., Sun, W., & Ren, B. (2014). Effects of altered precipitation on insect community composition and structure in a meadow steppe. *Ecological Entomology, 39*(4), 453–461. https://doi.org/10.1111/een.12120