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PERSPECTIVES AND REVIEWS

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Citizen science and wildlife biology: Synergies and challenges

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Abstract

Citizen science (CS) has evolved over the past decades as a working method involving interested citizens in scientific research, for example by reporting observations, taking measurements or analysing data. In the past, research on animal behaviour has been benefitting from contributions of citizen scientists mainly in the field of ornithology but the full potential of CS in ecological and behavioural sciences is surely still untapped. Here, we present case studies that successfully applied CS to research projects in wildlife biology and discuss potentials and challenges experienced. Our case studies cover a broad range of opportunities: large-scale CS projects with interactive online tools on bird song dialects, engagement of stakeholders as citizen scientists to reduce human–wildlife conflicts, involvement of students of primary and secondary schools in CS projects as well as collaboration with the media leading to successful recruitment of citizen scientists. Each case study provides a short overview of the scientific questions and how they were approached to showcase the potentials and challenges of CS in wildlife biology. Based on the experience of the case studies, we highlight how CS may support research in wildlife biology and emphasise the value of fostering communication in CS to improve recruitment of participants and to facilitate learning and mutual trust among different groups of interest (e.g., researchers, stakeholders, students). We further show how specific training for the participants may be needed to obtain reliable data. We consider CS as a suitable tool to enhance research in wildlife biology through the application of open science procedures (i.e., open access to articles and the data on publicly available repositories) to support transparency and sharing experiences.

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animal observations, conservation, education, participatory research, stakeholder involvement, technical applications

1 | INTRODUCTION

Citizen science (CS) is a research format for scientists and volunteers to collaboratively investigate various topics (Bonn et al., 2016). Recent decades have seen rapid growth of public participation in scientific processes (Kullenberg & Kasperowski, 2016) and the promotion to take up the manifold opportunities for scientists and citizens to work together to mutual benefit (Ceccaroni & Piera, 2017; ECSA 2015). The current rise of CS projects and the high visibility of CS activities in national and international platforms (e.g., Zooniverse, https://www.zooniverse.org) express the professionalisation of CS. Citizen science has gained appreciation in science, society and politics (Kullenberg & Kasperowski, 2016) and dedicated associations in Europe and elsewhere (e.g., ECSA—European Citizen Science Association or ACSA—Australia Citizen Science Association) have been launched to support and foster CS at both national and international levels (Göbel, Newman, Cappadonna, Zhang, & Vohland, 2017).

Research involving people from within and outside academia has a long history in the field of wildlife biology. For example, current ornithology largely benefits from a set of scientific data derived from the "Migration Observer Cards" collected by birding enthusiasts in North America since the late 19th century (Palmer, 1917; Zelt, Courter, Arab, Johnson, & Droege, 2012). The programme is considered among the earliest CS activities (Irwin, 1995). The enthusiasm for the observation of birds is ongoing and large programmes such as the "Breeding Bird Survey" (UK) or the "Christmas Bird Count" (USA) are well established examples of CS. Nowadays, CS goes beyond the collection of observations of arrival and departure dates of bird species. For instance, between 2011 and 2016, almost 170 citizens joined a CS project in the Czech Republic that records singing yellowhammers (*Emberiza citrinella*) using smartphones or digital cameras (see case study 3.1). Within 5 years, the Czech Republic became one of the most thoroughly mapped countries in terms of bird dialects, with almost 4,000 recordings (Diblíková et al., under review).

Such growth of CS is clearly associated with technological development (Nature Publishing Group, 2015), which not only facilitated the communication with all participants but also reduced the costs of equipment needed for the collection of the data and broadened the variety of tasks that can be performed (Blaney, Jones, Philippe, & Pocock, 2016). Public engagement now ranges from generating research questions to the collection and scientific analysis of data and to communicating the research results back to the public (Bela et al., 2016; Shirk et al., 2012). Citizen science has been successfully implemented in various scientific fields, not only in biology, ecology and conservation (e.g., Brooks, 2013; Fore, Paulsen, & O'Laughlin, 2001; Howard, Aschen, & Davis, 2010; Penrose & Call, 1995), but also in biochemistry (Lee et al., 2014), astronomy (Lintott et al., 2008), comparative genetics (Singh et al., 2017) and physics (Barr, Kalderon, & Haas, 2017; Sørensen et al., 2016). This indicates the wide application of a CS approach across disciplines (Follett & Strezov, 2015; Toomey & Domroese, 2013).

In times when CS is debated as a new way of conducting science with and for society (Silvertown, 2009), there is a need for reflections about its potentials and challenges also in biological disciplines, such as behavioural biology and/or ecology and wildlife biology. For the purposes of this manuscript, we will refer to wildlife biology in the text. The symposium "Citizen Science and Behavioural Biology: between challenges and real chances" at the 8th European Conference on Behavioural Biology held in Vienna (Austria) in 2016 brought together scientists applying CS in their research to discuss the advantages and challenges associated with this approach. We present in this study the outcomes of the discussions which focussed mainly on the following three questions:

1. What is the added value of CS in wildlife biology studies?
2. Which are the major challenges that scientists in wildlife biology need to overcome to implement CS in their research?
3. What is the yet untapped potential of CS for wildlife biology studies?

We base the present contribution on the current discourse of CS and share our experiences from applying CS in different case studies addressing questions in wildlife biology and report lessons learned for future research.

2 | CHARACTERISTICS OF CITIZEN SCIENCE

Citizen science can be seen as a generator of research (Silvertown, 2009) and knowledge in a participatory way (Shirk et al., 2012). Recently, Wiggins & Crowston (2011) analysed 30 CS projects and suggested a classification of CS based on the primary project goals (action, conservation, investigation, virtual and education) and the importance of the context to participation.

Action-based activities are initiated by volunteers to encourage local involvements (bottom-up). Such activities require substantial volunteer commitment aiming at contributing to research at the interface between sustainability and science.

Conservation-based activities address questions about the management of the environment, fostering stewardship by the citizens and raising awareness via educational projects. Several monitoring activities can be referred to this type of CS, relying on long-term funding and highly dedicated participants (e.g., our case study 3.2 on cheetahs (*Acinonyx jubatus*) in Namibia).

Investigation-based activities assess scientific inquiries through volunteers. Investigation and conservation CS projects provide researchers with large quantities of data contributing to long-term monitoring and natural resource management goals (e.g., our case studies on yellowhammer dialects and red fox *Vulpes vulpes* behaviour).

Virtual-based activities follow a similar goal as investigation-based activities, with the difference that the production and validation of scientific knowledge is mainly mediated by online participation (e.g., Chimp&See: https://www.chimpandsee.org; Higgs Hunter: www.higgshunters.org; Phylo: www.phylo.cs.mcgill.ca; Snapshot Serengeti: https://www.snapshotserengeti.org; Quantum Moves: www.scienceathome.org/games/quantum-moves). Virtual CS might bear a large potential for investigating wildlife with camera trap images from remote locations (Arandjelovic et al., 2016).

Education-based activities aim especially at increasing scientific literacy and raising awareness about the environment (Bela et al., 2016; Bonney et al., 2009) rather than on data collection. Such activities come at relatively high costs and therefore substantial funding is needed to ensure partnerships and long-term effects (e.g., our case study 3.3 on the involvement of students in research).

The classification of CS can be of high value when conceptualising a CS programme and may help to understand motivations to engage in CS as well. Such motivation can arise from personal interest (Rotman et al., 2014) or may be derived from the interest of the community to contribute to a specific local issue such as for instance water pollution (Kragh, 2016). Some CS projects dealing with human–wildlife conflicts show that the active participation of stakeholders can mitigate conflict situations and improve the economic situation of these participants. A good example is the cheetah research project on farmland in Namibia presented in case study 3.2. This project developed methods to reduce the livestock losses by cheetahs, resulting in farmers ceasing to kill the animals and supporting conservation research. Similarly, Lichtenfeld, Trout, and Kisimir (2015) have shown that the community (Massai, Tanzania) can get involved in scientifically assessing the efficacy of conservation efforts.

Furthermore, inquiry-based learning and exchange of know-how are strong motivational drivers for the participation in CS projects, as demonstrated by several programmes in schools (see case study 3.3). Understanding the motivation of the participants can enhance recruitment, ensure long-term engagement and ultimately lead to the success of the project (see case study 3.4). Projects related to biodiversity and conservation seem to attract most citizen scientists, as they feel they are helping the environment (Geoghegan, Dyke, Pateman, West, & Everett, 2016). Professional scientists may be motivated to establish CS projects because they get access to habitats that are otherwise inaccessible (see case studies 3.2 and 3.3) and are able to collect more data in less time (see case study 3.1; see also Evans et al., 2005; Worthington et al., 2012). Citizen science may also be applied to derive the wisdom of crowds, for which several citizen scientists are expected to provide the same answer, before it is regarded as "correct," as for instance in the CS project "Serengeti Lion Project". At the project's website "Snapshot Serengeti", volunteers can help identifying animals captured by camera traps. Each photograph is shown to several volunteers, and their assessments of the animal identification are correct with an accuracy of 98.6%, according to an aggregation algorithm (Hines, Swanson, Kosmala, & Lintott, 2015).

Several CS contributions focus on observations of birds (e.g., Cooper, Hochachka, & Dhondt, 2007; Snäll, Kindvall, Nilsson, & Pärt, 2011). For example, volunteers can supervise nest cameras provided by researchers to track the fledging success (e.g., Cooper, 2013; Cooper, Bailey, & Leech, 2015; Cooper, Voss, & Zivkovic, 2009). Such observations are probably easier to perform and more reliable than those including the identification of specific behaviours such as patterns of vigilance or agonistic encounters. However, a recent study relied on citizen scientists to record interactions between birds of different species to determine hierarchies or social networks in groups (Miller et al., 2017). The number of such projects is increasing, which mirrors a growing interest of behavioural scientists in CS and citizens in participating in behavioural research (Hecht & Cooper, 2014; Stewart et al., 2015; Williams, Porter, Hart, & Goodenough, 2012).

3 | CASE STUDIES

Here, we present four case studies that apply CS in the field of wildlife biology to show the added value of CS and to identify challenges experienced when implementing CS projects. Each case study provides a short overview of the species or species group of interest and the scientific and/or societal questions addressed. Specific structures of the projects are emphasised and research findings are presented briefly. The case studies are defined according to the classification proposed by Wiggins & Crowston (2011) as mentioned above.

The first case study (by LD & PP; investigation-based activities) highlights how web-based tools enable large-scale public engagement in research projects. The second case study (by JM & BW; conservation-based activities) demonstrates how stakeholders engage as citizen scientists in a conservation project to reduce human–wildlife conflicts. The third case study (by SW & DF; education-based activities) reports three different projects involving citizens and students to (i) gain information about wildlife in gardens and (ii) contribute to the long-term monitoring of two avian species of birds. The fourth case study (by SK; investigation-based activities) shows that the collaboration between an academic institution and key media players can lead to successful recruitment of citizen scientists. Aims and achievements of the case studies are summarised in Table 1. All case studies refer to research projects in the field of wildlife biology.

3.1 | Mapping yellowhammer dialects in the Czech Republic

The case study "Dialects of Czech Yellowhammers" started in 2011, when the yellowhammer was elected as the bird of the year in the Czech Republic. With this election, the Czech Ornithological Society aimed to raise awareness of the population decline of birds living in open landscapes. Associated with each annual announcement, activities are organised by the society for citizens to learn more about the species and to engage in its conservation. The yellowhammer is very easy to recognise both by sight and by listening to its song, and it has been known for more than 100 years that yellowhammers have distinct birdsong dialects (Oppel, 1869; Röse, 1869). However, until then, yellowhammer dialects in the Czech Republic were still largely unexplored.

Therefore, the aim of the project was to map the distribution of different yellowhammer dialects in the Czech Republic and to locate the presumed delimitation between two main dialect groups (Procházka et al., 2013; Table 1). During the first year, the CS project provided already enough data to identify the border between these two dialect groups (Petrusková et al., 2015). However, questions about the geographical distribution of the individual dialects remained unanswered and the public interest persisted. Consequently, the project was extended into a long-term project. A new website was launched to provide citizens opportunities to upload their recordings and visualise them. Each sound recording appeared as a map point marked with a question mark, which was changed into the symbol representing the dialect, once the recording was analysed by researchers of the Charles University in Prague. The visualisation gave volunteers real-time feedback on the progress of the CS research. While the recordings were not accessible for volunteers, they had reading access to other data associated with them (e.g., date of the recording, surrounding habitat, etc.). Since the project originally started as a part of the campaign of the Czech Ornithological Society, in the first year, most volunteers were recruited among members of this society. However, radio broadcasts and newspapers were also spreading information about the project. Radio broadcasts were an especially important partner to recruit a large number of citizen scientists in the subsequent years, even those without any particular interest in nature or ornithology. Two main challenges had to be dealt with (i) the quality of the sound recordings and (ii) the uneven spatial distribution of the sampling effort.

Citizens were encouraged to use common devices for sound recordings, such as cell phones or smartphones, digital sound recorders or digital cameras. However, not all of the devices covered the bandwidth of yellowhammer song. Therefore, to allow dialect recognition, a sufficient basic quality of the recordings had to be ensured. For this purpose, a "testing soundtrack" (containing monotonal sounds ranging from 1 to 10 kHz) was created, by which citizens could verify their devices. The database of suitable devices was regularly updated by researchers according to the reports of the participants. To encourage volunteers to record in unexplored localities, researchers developed an online game inspired by geocaching (an outdoor recreational activity in which participants use GPS devices to hide and seek containers, called "geocaches"). This led to doubling the spatial coverage within twelve months. The bulk of the work associated with the project, data analysis, public relations and web development was mainly performed by two PhD students, who worked part-time. The main costs were associated with the development and maintenance of the website. In 5 years, 166 volunteers and seven scientists collected more than 4,000 recordings covering approximately 90% of the Czech Republic's territory (Diblíková et al., under review). The success of the project "Dialects of Czech Yellowhammers" inspired the initiation of CS projects on yellowhammer dialects in other countries. In 2013, an international project, "Yellowhammer Dialects", was launched to compare the dialect distribution of yellowhammers in their native and exotic range (Great Britain and New Zealand, respectively) 140 years after complete isolation (Pipek et al., 2018). Later on, other countries such as Poland, Switzerland (Ambühl, van Boheemen, Pipek, Procházka, & Ehrengruber, 2017) and Latvia joined in recording yellowhammer dialects; the first two being hosted on the project website. Other countries are welcome to use the same website for their own CS projects on yellowhammer dialects. Researchers have also been collecting individual recordings posted on "xeno-canto" and other servers containing bird songs. These efforts eventually led to an unprecedented coverage of the species range and will allow a deeper understanding of the processes behind dialect formation and maintenance. The mutual benefits in this project are improved knowledge of the general public on birdsongs and the current status of birds living in agricultural landscapes, a meaningful application of modern technologies encouraging people to go outside and experience nature, and finally an unprecedented data set on birdsong variation that would not have been possible to collect without CS (Table 1).

3.2 | Farmer–carnivore conflict on commercial farmland in Namibia

This case study is a long-term CS project on free-ranging cheetahs on commercial farmland in Namibia (Table 1). The project was initiated in 2002 by a former Namibian NGO (Okatumba Wildlife Research) and the Leibniz Institute for Zoo and Wildlife Research (IZW), Berlin, Germany, in collaboration with a farmer community in central Namibia. The local farmers (stakeholders) engaged in the development of the design of the project and in data collection. For projects addressing human–wildlife conflicts, it is important to develop trustful relationships with the stakeholders affected by the conflicts, for instance by acknowledging the conflict from their point of view. The economic revenue of Namibian farmers strongly depends on livestock, but cheetahs and leopards (*Panthera pardus*) occasionally

TABLE 1 Summary of the case studies, presenting the geographical scale and/or number of citizen scientists, aims of the projects, added value of the citizen scientist contributions and major challenges encountered during the project

Project and website	Geographical scale and/or number of citizen scientists	Aims	Added value	Major challenges
Dialects of Czech Yellowhammers http://strnadi.cz	78,866 km^2, 166 volunteers	Map the distribution of yellowhammer song dialect in the Czech Republic and identify presumed delimitation between two dialect groups	Raising awareness of population decline of birds of countryside Improvement of public knowledge on birdsongs Motivation of people to get outside Unprecedented data set on birdsong variation	Suboptimal quality of song recording Uneven sampling effort
Cheetah Research Project https://fb.com/IZWCheetahResearchProject	45,000 km^2, approximately 800 farmer families in central Namibia	Determine the spatial land use and diet composition of the threatened cheetahs on private farmland in Namibia	Mitigation of farmer—cheetah conflict, that is, reducing numbers of killed livestock animals Change in farmer perception towards cheetahs, that is, reduction in trapping and killing cheetahs Provided basis for the Leopard Research Project, initiated by farmers Improvement of communication skills of scientists	Farmers need to trust the researchers and be patient because solving the conflict using sound scientific data requires several years of research.
Nature in your backyard http://naturvorderhaustuer.boku.ac.at/	428 students and 22 teachers in Vienna and Lower Austria	Analyse the effects of garden management and surrounding land use on hedgehogs, birds, butterflies and wild bees in gardens Identify motivating factors for engagement in biodiversity conservation and CS	Raising awareness for biodiversity in gardens and related garden management Investigate motivation of students to participate in CS Data set collection on hedgehogs, birds, butterflies and wild bees and garden management	Data validation and training of school students to guarantee reliable data Adapting research to the school curriculum Time and financial resources for intensive cooperation with schools Lack of long-term funding
The year of the greylag geese https://www.sparklingscience.at/en/projects/show.html?--typo3_neos_nodetypes-page[id]=376	Approximately 150 students and 10 teachers	Involve local schools in the long-term monitoring of an individually marked flock of greylag geese	Demonstrate the large potential of students in observing animal behaviour Change in the local attitude towards research Improvement of communication skills of scientists	Low appreciation of such form of collaboration among scientists Lack of long-term funding
Social alliances and flying area in northern bald ibis social behaviour https://www.sparklingscience.at/en/projects/show.html?--typo3_neos_nodetypes-page[id]=951	Approximately 250 pupils and 20 teachers	Investigate the relationship between social behaviour and physiology in the critically endangered northern bald ibis Assess the effect of the collaboration on the performance of pupil' learning Build a regional network for long-term cooperation between research and education institutions	Relevant contributions for the scientific community on (i) the complex interplay between stress, social behaviour and parasite burden and (ii) movement ecology of adult and sub-adult individuals Establishment of a network with local, national and international stakeholders for CS projects (museums, zoos, schools, universities) Improvement of communication skills of scientists	Limited financial resources Lack of professional training for scientists in communication and mediation skills

(Continues)

TABLE 1 (Continued)

Project and website	Geographical scale and/or number of citizen scientists	Aims	Added value	Major challenges
Foxes in the City http://berlin.stadtwildtiere.de/info/berlin/mitmachen	Approximately 1,000 contributors and 50 citizen scientists conducting tasks	Increase awareness and acceptance of urban wildlife and collecting data on human presence and fox distribution Link this anthropogenic impact to fox behaviour	Communicating information on urban wildlife, for example, on the prohibition of feeding wild animals Reducing the fear of people from fox transmitted diseases by informing about the absence of rabies in Germany Disease transmission control: supporting pet vaccination against canine distemper virus	Lack of funding especially for better web tools/apps Supervision and training of citizen scientists and the required manpower to do so Fitting schedules of the scientific project and media project

TABLE 2 Examples of useful generic software applications (apps) available online for CS projects, including their advantages and limitations

Name and website	App usage	Advantages	Limitations
Epicollect Five http://five.epicollect.net/ (previous versions applied, e.g., by Aanensen, Huntley, Feil, Al-Own, & Spratt, 2009)	Can be designed to manifold purposes	User-friendly, no programming skills needed, enables recording of sounds and videos	Data is stored at an EpiCollect server, however can be extracted though API (POST and GET requests) In private projects (=with limited access), users have to register their email address at Google
Cybertracker https://www.cybertracker.org/ (Liebenberg et al., 2017)	Powerful for field studies in remote localities	Powerful data synchronisation, sending data virtually anywhere, flexibility in the overall design of the app	Installation on desktop requires programming skills at the beginning
Prime8 app www.prim8software.com/ (McDonald & Johnson, 2014)	Collection of behavioural data	Possibility of collecting many behavioural parameters	Collection of complex behavioural observations not always feasible

feed on it, thereby generating conflicts with the farmers. As a consequence, large numbers of cheetahs and leopards have been killed by farmers in the past (Marker, Dickman, Mills, & Macdonald, 2003). Three research stations of the project were established on farmland to become part of the community. During farmer meetings, the most important research questions were identified and a research design was developed. It was decided to establish a project on spatial land use and diet composition of the Namibian cheetahs. For this, cheetahs needed to be captured, and their scats needed to be collected at their marking trees. Farmers were highly committed to pass on their knowledge on how to capture cheetahs with box traps at marking trees (cheetahs cannot be lured by meat, because they only feed on prey killed by themselves). Further, farmers were also highly motivated to capture cheetahs on their own farmland to increase the number of studied animals. Once an individual was captured, the researchers saw this when visiting the traps or were informed by an electronic device or by the farmers. The animal was then immobilised, fitted with a GPS collar, and blood sampled. GPS data downloaded by aerial tracking provided information on spatial land use, whereas blood samples were used for isotope analyses to determine whether cheetahs are specialised on a particular prey species, for example cattle. Scats were used to identify the most recent prey consumed. Farmers provided reference hair of various prey species of cheetahs to compare them with undigested hair found in scats (Wachter, Jauernig, & Breitenmoser, 2006; Wachter et al., 2012). They also supplied blood samples of game species harvested for their private meat consumption. To determine the consumed prey species, the isotope signature of these samples was compared with that of cheetah blood samples (Voigt, Melzheimer, Thalwitzer, & Wachter, 2013; Voigt et al., 2014). The results provided evidence that cheetahs are opportunistic hunters that regularly kill livestock species, but that none of the sampled animals was selectively preying on livestock species. Farmers conducted three transect counts per year to assess wildlife densities on their properties and many farmers set up private camera traps at water holes to monitor wildlife diversity. The transect counts were used by the project to determine prey availability for cheetahs, and the camera trap pictures served to identify carnivore species on the land of the farmers.

The project results enabled farmers to substantially reduce their losses by adapting their livestock management to the spatial movements of cheetahs. This resulted in farmers ceasing to kill cheetahs. The number of cheetahs at the beginning of the study was unknown, thus also any potential change/increase in the study population. However, the practical relevance of the research motivated farmers to continue their support. A few years ago, following a documented increase in leopards in the study area, a group of farmers wrote and submitted a research proposal to a local funding agency with the IZW as a scientific partner. The project was granted and the funds allowed the researchers to start a leopard research project in 2012. This new project strongly profited from the existing dialogue and collaboration with the farmers (Menges & Melzheimer, 2015). The farmers again actively supported the researchers in this study by providing meat for the traps (leopard can be lured by meat because they also feed from carcasses) and by regularly controlling them. In the course of the project, much effort was contributed towards comprehensive communication strategies, including regular presentations at farmer meetings, on social media, in newspapers, radio broadcasts and as part of TV documentations. The maintenance of the communication required approximately 20 working hours per week. Involving farmers as citizen scientists creates a win-win situation and leads to a long-term research partnership. In this case, conservation research resulted in minimising livestock farmer–carnivore conflicts, which was only possible with the commitment of the farmers. Such an approach is also likely to provide conflict mitigations for other human–wildlife conflicts. The key aspect is a trustful and long-lasting relationship with the stakeholders. The access to scientific information on private farmland is another benefit that would not have been possible without engaging the farmers in the research (Table 1).

3.3 | Students as reliable observers and multipliers in wildlife biology research in Austria

The three following CS projects were designed by researchers from two universities in Vienna, Austria (BOKU, i.e., University of Natural Resources and Life Sciences, and University of Vienna). The research questions addressed (i) biodiversity in backyards, that is, the effects of land use on the occurrence of hedgehogs (*Erinaceus europaeus* and *E.roumanicus*), the abundance of 23 bird and 16 butterfly taxa and foraging trip durations of wild bees, (ii) the relationship between social behaviour and physiology in greylag geese (*Anser anser*) and (iii) in northern bald ibises (*Geronticus eremita*; Table 1). The studies were carried out in cooperation with approximately 750 students between 5 and 19 years of age, administered by approximately 45 teachers from kindergartens, primary to academic secondary schools, partly under the supervision of colleges for higher vocational education and biology education researchers. The first study (biodiversity in backyards) aimed at recording biodiversity and animal behaviour in gardens with students and assessed factors that motivate students to participate in biodiversity conservation. The second study (greylag geese) compared the quality of data provided by the students with those obtained by researchers to determine whether students can be involved in the collection of long-term behavioural data. The third study (northern bald ibises) assessed educational goals and tested to what extent the engagement in the project improved the ornithological knowledge of the students. For all three studies, training material and workshops were developed by the researchers and provided to students and teachers prior to the actual field research. Hands-on activities such as setting up hedgehog footprint tracking tunnels (Yarnell et al., 2014) and identification trainings for birds and butterflies as well as methods on how to observe animals and to follow standardised protocols were taught to students and teachers before the start of their participation.

Students conducted 337 interviews on garden management and set up 109 footprint tracking tunnels in gardens in the CS project "Nature in your backyard". The position of the gardens in semi-urban areas, the provision of food for hedgehogs and the presence of meadows in gardens was shown to significantly increase hedgehog occurrence. The number of bird species recorded in 116 investigated gardens was mainly influenced by the sampling effort, structural diversity and flower coverage of the garden. The most common reported behaviour of birds was sitting or flying in the garden, followed by singing or calling and searching for food. Online pre- and post-project surveys showed that the most exciting tasks for students were activities that required special equipment while online data entry was the least popular duty. The variety of taxonomic groups was attractive for both students and teachers but the researchers realised with cross-checking and identification quiz games that students were not always able to identify bird and butterfly species with certainty. Nevertheless, students favoured butterfly and bird observations. Teachers preferred to track hedgehogs, as this was a straightforward task yielding high data quality with hedgehog footprints being easily recognisable. Children from primary schools were very motivated and collected most of the data. High school students provided good data input but their inflexible school curricula often constrained their participation.

The study on greylag geese showed that reliable data can be obtained by well-trained students, as no significant differences were found between the performance of such students and professional biologists in analysing videos of goose behaviour (Frigerio, Kotrschal, Millesi, & Hemetsberger, 2012). These findings demonstrate the potential of involving students in animal behaviour research which considers well defined behavioural parameters (e.g., feeding, resting, walking, vigilance, aggression).

In a different study on northern bald ibises, students were investigating public opinion and knowledge on this species by interviewing 320 people. Preliminary results showed that most people are aware of the critically endangered status of this species and are able to identify them. Furthermore, the study demonstrated that the specific knowledge acquired in the project was retained by the students over the summer holidays, suggesting CS to be suitable also for informal education (i.e., education occurring outside a structured curriculum; Hirschenhauser, Frigerio, & Neuböck-Hubinger, 2016). Students were also involved in behavioural observations, but their time-slots (late morning) did not fit well into the activity patterns of the birds, so the collected data were neither comparable nor useful for the researchers.

The greatest benefits of the engagement of students in the three studies lay in the interactions between educational and natural scientists and the local population, that is the heterogeneous network which was initiated by the schools, providing a large-scale long-term network for conducting CS, which also results in contributions to conference and manuscripts (e.g., Kelemen-Finan et al., under review; Puehringer-Sturmayr et al., 2018; Scheuch et al., 2018). Further, private gardens became accessible for scientists by involving the owners (and their children) as citizen scientists. Students of all age groups can be successfully involved in CS projects if the activities are exciting for them, and the tasks are well defined, can be validated and do not require extensive training by the teachers. In all three studies, staff and resource requirements were relatively high, with at least one scientist per project working 20 hr/week to support teachers. Challenges for the projects included tight schedules and fixed curricula of the schools as well as some logistic constraints (e.g., travelling distance from the schools to the observation sites).

3.4 | The value of broadcast in recruiting volunteers for a study on urban ecology in Germany

Successful CS depends to a large extent on the successful recruitment of participants. This case study on urban red foxes demonstrates how such a successful recruitment can be accomplished. The study has been conducted since 2015 by the Leibniz Institute for Zoo and Wildlife Research in Berlin, Germany, in cooperation with the public broadcasting corporation Rundfunk Berlin-Brandenburg (rbb; Table 1).

One of the manifold consequences of continuously increasing anthropogenic pressure on the environment is the expansion of urban areas, which are composed of highly fragmented and disturbed habitats. While many species suffer from this impact, some can cope well and reach high densities in these novel habitats (e.g., coyotes, *Canis latrans*: Atkinson & Shackleton, 1991; raccoons, *Procyon lotor*: Prange, Gehrt, & Wiggers, 2003). This leads to more frequent encounters between humans and wildlife and thus to an increased demand for studying urban wildlife. The red fox, which has successfully colonised cities all over the world, served as a model species to investigate the mechanisms on how animals can adjust their behaviour to persist in urban environments.

In this study, the researchers captured red foxes in traps and fitted them with GPS collars. Every four minutes these collars record the location and the tri-axial acceleration of the tags attached to the collars, from which behavioural patterns such as trotting, walking, grooming or resting can be derived (McClune et al., 2014; Wang et al., 2015). However, to understand the factors that influence the spatiotemporal habitat use of the red foxes, it is necessary to combine GPS and behavioural data with information on land use and human activity within the home ranges of the animals. While public databases on land use categories exist (e.g., the "FIS BROKER" for Berlin), data on human activities in these areas are inaccessible to scientists. Therefore, the researchers looked for the support of citizens to record human activity in their neighbourhood. Data input of citizens enables the researchers to link the spatial use and movement patterns of red foxes, such as speed and turning angles, with the human presence to show the impact of anthropogenic pressure on behavioural adjustments in urban red foxes.

To recruit citizen scientists, researchers initiated a collaboration with the main regional public broadcasting company, the rbb. In 2015, the rbb started a media campaign on red foxes in Berlin named "Foxes in the city" to promote the project. The topic was covered from many angles in numerous TV and radio shows on several channels in Berlin and Brandenburg. The audience was asked to send in pictures, videos and narratives of their red fox encounters to be published on a dedicated website. The response exceeded the expectations: more than 1,000 people submitted their contributions and nearly 500,000 people followed a TV documentation on "city foxes," with a mixture of scientific information and entertainment. The resulting publicity was then used to kick-start the actual CS module, which requires a high level of citizen participation. Volunteers were provided with an interactive map of Berlin, offering different tasks of data collection, such as mapping dens where foxes are breeding or determining human activity in parks or streets. Once they have chosen a task, they were equipped with all necessary materials and information to start the data collection on their own. Citizen science data are planned to be incorporated into the data set on human presence and disturbance level, for a manuscript on adjustment of urban red foxes to anthropogenic pressure (e.g., landscape of fear).

Linking complex behavioural patterns such as reactions to disturbance, foraging behaviour or flight behaviour with actual human disturbance levels requires a significant amount of data about human activity in the environment of the foxes. Last year experience shows that although citizens are willing to collect relevant information that can be used in research projects, it is rather challenging to gather a substantial amount of data for robust analyses. It may require great effort, time and manpower to spark the interest of people and to advertise a project at the beginning. However, it is even more challenging to keep them motivated over a long period of time. This case study demonstrates that the collaboration with a media operator can be a key factor for the recruitment and motivation of citizen scientists.

4 | TOOLS FOR CS PROJECTS

Several recent studies have shown the power of smartphone applications (apps) in biological research (Adriaens, 2015; August et al., 2015; Jepson & Ladle, 2015). Once introduced into the project, apps raise public engagement, sometimes even by order of magnitude, as the "Leaf-Watch" app for the "Conker Tree Science Project" (Pocock & Evans, 2014) in which citizens were recording damage caused by leaf-mining moths on horse-chestnut in the UK.

Even if the researchers do not have time, skills or funds for developing an app for their specific project, they may profit from generic smartphone apps that allow to map geolocation data with user data input. Some good examples of such apps are summarised in Table 2.

However, the success in employing apps in CS projects may be affected by the age and experience of the participants. For instance, older participants may not be familiar with using a smartphone, while children may not yet own such a device.

Sometimes volunteers do not engage in collecting the data, but assist in analysing them. This is the case in "The Serengeti Lion Project" (Snapshot Serengeti) as well as in "Chimp&See", in which volunteers analyse wildlife photos or videos captured by camera traps via an online system. Both are examples of projects hosted by the Zooniverse web platform (www.zooniverse.org) which is particularly suitable for image analysis. For other tasks, for example sound or video analysis, there is a more flexible web platform, the "Crowdcrafting" (www.crowdcrafting.org) which also provides the web-developers with an application programming interface (API) to enable an easy integration into existing websites.

Modern technologies allow easy building and maintenance of networks with other scientists who share common interests. Social networks are found to be a key to success in CS, forming a community of actors that share professional information (Richter et al., under review). Such networks, being a specific internet platform (e.g., SciStarter) or general social media platforms (e.g., Facebook or Twitter), are used to assist in the recruitment of participants and in disseminating relevant information. The target group of the online platforms is mainly citizens who are interested in participating in a project, but also researchers, scholars, scientific institutions and press representatives may benefit from such platforms and their services (e.g., by a list of CS projects, definitions, news and events). At the international level, several CS associations such as ECSA support and foster the growth of a cross-disciplinary and international CS community.

Among the citizens, stakeholders have a particular personal or financial interest in the topic or in the species of the research project. Sometimes, they may have different goals than the project itself, which might be the case for conservation projects with an involved human–wildlife conflict (Trinogga, Fritsch, Hofer, & Krone, 2013). In such situations, it might be useful to involve the stakeholders in the data collection and to explain the analytical methods and results to provide a trustful working environment. Ideally, once the stakeholders have joined the project as citizen scientists, they get a new perspective on the conflict, becoming more responsive to, for instance, non-lethal solutions and identifying themselves with the project goals.

5 | CONCLUSIONS AND OUTLOOK: POTENTIALS FOR CS IN WILDLIFE BIOLOGY

Based on the experience of our case studies, we consider CS as a powerful tool for research in wildlife biology. Thanks to modern technologies, data can be collected on unprecedented scales even with limited funds. Also, citizens can be involved at various stages of the scientific process and perform different tasks, some even from their homes. Active involvement in CS projects brings not only entertainment and meaningful use of spare-time to citizens, but also increases their scientific literacy (Bela et al., 2016).

Especially with regard to capacity building, several programmes and initiatives were established in Europe to identify challenges and potentials for CS (Richter et al., in press). The programmes identified considerable challenges for CS projects such as the lack of (long-term) funding, the inadequacy of training for scientists and citizens and the scarcity of mechanisms to appreciate the engagement of both (Bonn et al., 2016; Socientize, 2015). In particular, data quality and standards, and the reliability of the data are important aspects as they influence the legitimacy of the entire project in science, society and politics (Bird et al., 2014; Peters, Zhan, Schwartz, Godoy, & Ballard, 2017; Wiggins, Newman, Stevenson, & Crowston, 2011).

When multiple persons are involved in collecting data, inter-observer reliability should be considered. For images or video clips recorded by volunteers, reliability could be calculated by verifying the scoring of the volunteers or, alternatively by exclusively accepting data points which have been scored identically by two or more persons. In education projects, trained teachers could be involved in assuring data quality.

In general, it is advisable to add a training and evaluation-phase for preliminary data before starting an actual data collection (Bonney et al., 2014). Especially in field studies, it would be of advantage to introduce high-quality scientific training for mediators between citizen scientists and researchers or for citizen scientists directly. Well-trained citizen scientists might increase the reliability of the collected data, as *ad hoc* training may consistently reduce the effort for *post hoc* data validation. By dedicating parts of the project costs to the training for mediators and/or citizen scientists, researchers can improve the efficiency of the management of the project. The importance of training the citizens was elucidated by our case study on education CS which demonstrated that high data quality may indeed be obtained by citizens. When the task is simple, specific training is not needed. In the case of study on yellowhammer dialects, volunteers were recording songs and their input was later checked by scientists who analysed the songs (Diblíková et al., under review).

The motivation for long-term engagement may increase with targeted communication, which also strengthens the understanding between groups with different interests. This evidence applies also to CS projects in the field of wildlife biology. In fact, all our case studies suggest that good communication skills are crucial in achieving the goals of the project. Fostering communication in CS and science may motivate more people to join the project and build mutual trust among different participants (e.g., researchers, stakeholders, students).

Publishing the results is a further relevant issue for CS projects, even if the outcome differs from the expectations of the volunteers and researchers. Unsuccessful dissemination may result in volunteers losing their motivation to further participate in a CS project or developing a negative attitude towards science (Rotman et al., 2012). The policies of scientific journals are central to the research communication process and may considerably help to improve the public trust in science, for instance by supporting publication of null results (Nosek et al., 2015).

Overall, CS provides benefits for scientists by increasing the geographical or temporal coverage of research projects, while the participants enhance their knowledge and awareness towards wildlife biology, the environment and science. Additionally, involving the stakeholders as citizen scientists may substantially mitigate human–wildlife conflicts. Nevertheless, new CS projects need adequate financial and time resources for recruiting (and often training) citizens and communicating with them, unless they use existing networks or crowdcrafting. The training required for detecting nuanced behaviours of animals in a standardised way is challenging and may require long time. Therefore, CS is especially powerful when the tasks required from citizens can be quickly learned, as for instance in virtual-based activities.

Concluding, the engagement of citizens in scientific processes has the potential to combine the collection of publishable data with outreach, education and raising awareness, that is providing direct benefits to society without compromising scientific output. Therefore, it may promote long-term changes in the society, by helping to close the knowledge gap between the researchers at the universities and the people outside of academia.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHOR CONTRIBUTIONS

All authors confirm the following statements:

- We adhere to the “Guidelines for the use of animals in research” as published in Animal Behaviour (1991, 41, 183–186) and the laws of the country where the research was conducted.
- The manuscript contains only material that is either original and has not been published or submitted elsewhere or stems from publications identified by a reference.
- All authors have seen the final manuscript and take responsibility for its contents.

DF and SK promoted and organised the symposium bringing the people together for the first time. DF and AR promoted and conceived the manuscript. PP and LD wrote the case study “Mapping yellowhammer dialects in the Czech Republic”. JM and BW wrote the case study “Farmer-carnivore conflict on commercial farmland in Namibia”. SW and DF wrote the case study “Students as reliable observers and multipliers in wildlife biology research in Austria”. SK wrote the case study “The role of a broadcast in recruiting volunteers for a study on urban ecology in Germany”. DF, LD and PP wrote the introduction. AR, DF and PP wrote “Characteristics of citizen science”. AR, BW and PP wrote “Tools for citizen science project”. AR, PP and DF wrote “Conclusions and outlook: potentials for CS in wildlife biology”. DF reviewed every draft of the manuscript. All co-authors always contributed and commented on each draft of the manuscript including the outline at the beginning.

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