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PERSPECTIVES AND NOTES

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Citizen science as a bottom-up approach to address human–wildlife conflicts: From theories and methods to practical implications

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Abstract

Although biodiversity conservation is a prioritized topic globally, agreements and regulations at multiple levels often fail to meet the desired effects due to insufficient knowledge transmission about and tolerance toward environmental protection measures among the public. To find effective measures to solve human–wildlife conflicts (HWCs) and promote a sustainable coexistence, it is essential to gain the public's understanding of the importance of preserving biodiversity. To spur progress in solution-oriented conservation science, we examine how citizen science (CS) can complement research in the HWC field and coexistence/mitigation strategies. We find that CS (1) is an effective tool for gathering wildlife data and (2) empowers citizens to participate in or drive (in a bottom-up manner) wildlife research and management. Each HWC has a unique social, economic, and geographical context, which makes it challenging to find appropriate mitigation measures. We developed a Global and Local Geographic (GLG) model that provides practical guidelines for implementing CS in HWC research. We argue that the inclusion of youth is fundamental to achieving coexistence between people and wildlife; thus integrating CS into formal education or including an educational component in CS projects can support the sustainable conservation of wildlife species and foster environmentally aware future generations.

KEYWORDS

coexistence, human–wildlife interaction, participatory research, public environmental awareness, stakeholder engagement, wildlife monitoring

1 | INTRODUCTION

The rapid and continuous loss of biodiversity has widely been recognized as a major sustainability challenge for people and wildlife globally (Foley et al., 2005). In response, international agreements, new policies, regulations and laws have been translated into a variety of conservation initiatives that aim, for

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example, to monitor biodiversity loss and wildlife development (Johnson et al., 2017; Pereira & Cooper, 2006). However, the "top-down" nature of many conservation measures could lead to conflicts between differently opinioned groups in society (Lute, Navarrete, Nelson, & Gore, 2016), making implementation challenging. To avoid these human–human conflicts, it is essential to gain the understanding and cooperation of local residents. Citizen science (CS) has the potential to address this gap by involving citizens in knowledge generation such as monitoring and encourage them to actively participate in developing management strategies related to wildlife species.

"Human–wildlife conflict occurs when the needs and behavior of wildlife impact negatively on the goals of humans or when the goals of humans negatively impact the needs of wildlife. These conflicts may result when wildlife damage crops, injure or kill domestic animals, threaten or kill people" (Madden, 2004). As the term HWC became recognized and widely used in the field of wildlife conservation, studies have questioned the use of this term for positioning wildlife as conscious human antagonists (Peterson, Birckhead, Leong, Peterson, & Peterson, 2010) and seemingly giving the wrong impression that the conflict is limited between these two actors (humans and wildlife) while in reality, a large part of the conflict is between humans who have opposing opinions about a specific wildlife species (Carter & Linnell, 2016; Hill, Webber, & Priston, 2017; Redpath, Bhatia, & Young, 2015). In fact, many studies addressing HWCs have focused on the human–human conflict between differently affected stakeholders caused by the negative interaction between humans and wildlife (Browne-Nuñez & Jonker, 2008; Dickman, 2010; Thirgood, Woodroffe, & Rabinowitz, 2005). Dillon, Stevenson, Wals, and Editors (2016) described HWC as a "wicked problem"—a problem that is difficult to understand and is constantly shifting, as a wide range of stakeholders with opposite perspectives are involved—which highlights its multi-layered structure and complexity.

Due to its interdisciplinary characteristics, its participatory nature and the rapid development of digitalization, CS can be used to address both direct conflicts between humans and wild animals and the resulting human–human conflicts. Accordingly, this study will apply the broad definition of HWC, as shown in Figure 1. This definition includes conflict between directly affected citizen groups and the species in question (green arrow) and two types of human–human conflicts: first, that between citizens with different values (e.g., nature protection vs. agriculture) (red arrows) and, second, that between policy makers and citizens (hierarchical conflicts) (orange arrow). It is essential to address both: (a) negative human–wildlife interactions and (b) resulting sociological conflicts between differently affected groups (human–human conflict) to develop sufficient measures to mitigate HWCs (Nyhus, 2016).

After being first described in Alan Irwin's book "Citizen Science: A Study of People, Expertise, and

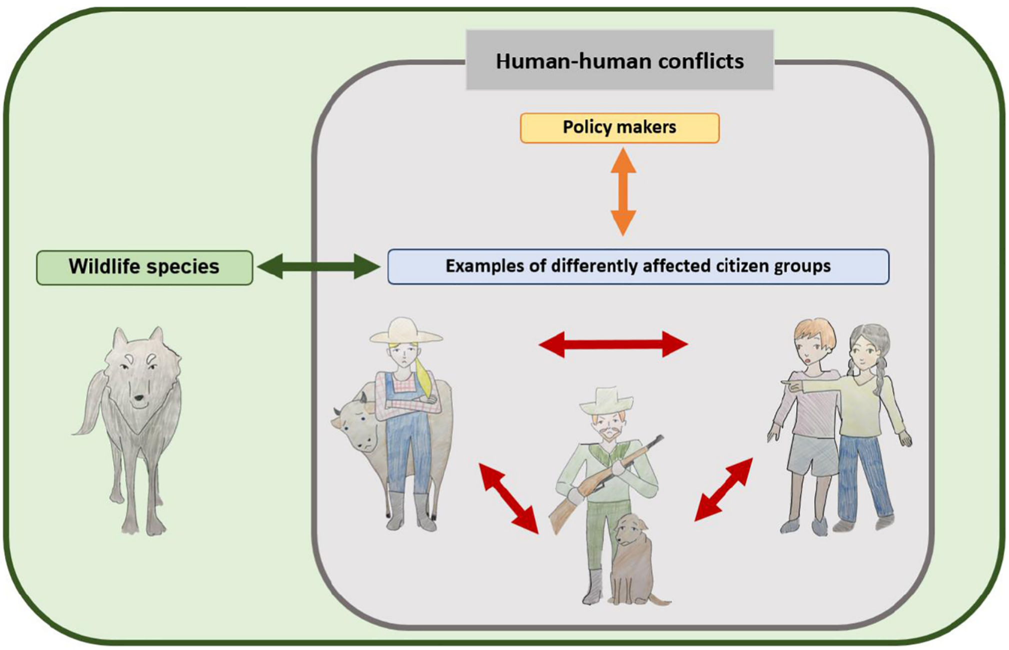

FIGURE 1 The perspective of human–wildlife conflict (to our understanding, a large part of human–wildlife conflicts are actually human–human conflicts)

Sustainable Development" in 1995 (Bonney, Phillips, Ballard, & Enck, 2016), CS has evolved rapidly and globally, with the dual purpose of benefiting scientific research and public participation in science (Bonney et al., 2009). During the last couple of decades, there have been varying definitions of CS (MacPhail & Colla, 2020), which has led to suggestions pointing out the necessity to find a globally acknowledged definition for the term (Heigl, Kieslinger, Paul, Uhlik, & Dörler, 2019). In this paper, we will apply the definition in the green paper of the European Commission, which defines CS as "general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort, or surrounding knowledge or with their tools and resources" (Shaping Europe's Digital Future, 2014).

This paper reviews different models of HWCs to understand the complexity of this problem. Additionally, it examines the many characteristics of CS and discusses how these two fields can be integrated to find solutions which enable a better coexistence of humans and wildlife.

2 | MODELS OF HUMAN–WILDLIFE CONFLICTS

This section reviews theories and models of HWCs, as theoretic understanding is essential in choosing effective CS methods for mitigation (Frank, Glikman, & Marchini, 2019). Table 1 provides an overview of key publications on theories of HWCs. The selection is based on a key word search in the Scopus database with terms related to "human wildlife conflict," "theories," and "models."

The studies focusing on the human side analyzed two levels—the individual level and the social level—indicating that these two aspects play an important role in the decision-making process. The studies (Hudenko, 2012; Kansky et al., 2016) focusing on the

TABLE 1 Publications that applied different theories in the field of human–wildlife conflict

Subject	Name of theory/model	Focus	Reference
Humans	Micro–macro level model	Combining cognitive hierarchy theory of human behavior and materialist theory of culture to explore the social and cultural aspects of HWC in a global context	Manfredo and Dayer (2004)
	Theories on judgment and decision-making	Reviewing cognitive theories, theories of emotion and affect, and theories that integrate both cognitive and emotion approaches to human decision-making in the context of HWC	Hudenko (2012)
	Social identity theory (SIT)	Applying SIT to understand how stakeholder groups interact, why they conflict and how collaboration can be achieved to solve HWC	Lute, Bump, and Gore (2014), Lute and Gore (2014)
	Wildlife tolerance model (WTM)	Explaining a person's tolerance toward a wildlife species by combining two models: the outer model, which focuses on the perceived costs and benefits based on the extent to which a person experiences a species, and the inner model, which focuses on 11 variables that impact tolerance through costs and benefits	Kansky, Kidd, and Knight (2016)
	Moral foundations theory (MFT)	Explaining disagreement between different stakeholders over HWC policies by applying the MFT, which explains morals as intuitions rooted in at least five foundations (authority, care, fairness, in-group loyalty, and disgust)	Lute et al. (2016)
Wild animals	Behavioral theory	Mitigating HWC by understanding the mechanism by which animals process information and make decisions	Blackwell et al. (2016)
Both	Integrated social and ecological theory	Addressing HWCs by applying social and ecological theory to identify the multiple nested levels of influence in human and animal behavior	Lischka et al. (2018)

individual level examined the impact of personal experience and character variables on the decision-making process of wildlife management, while the studies addressing the social level (Lute et al., 2014, 2016; Manfredo & Dayer, 2004) additionally looked at the interaction within and between interest groups. Blackwell et al. (2016) examined how animals process information and make decisions, while Lischka et al. (2018) proposed a conceptual model that addresses both human and animal behavior, by integrating social and ecological theory.

Understanding theories of human behavior and decision-making in HWCs are important when designing a CS project engaging participants with diverse interests and motivations, while theories on animal behavior can be implemented in the technical development of CS projects by improving monitoring methods.

3 | ISSUES IN CITIZEN SCIENCE

3.1 | Interdisciplinary

CS links various fields, such as science, education, communication, and society (Wals, Brody, Dillon, & Stevenson, 2014), due to its interdisciplinary characteristics (Figure 2). CS has broadened the possibilities for research in the field of science. While budgets, research duration and human resources limit institutional research today and probably in the future, CS can provide solutions for cost-efficient, long-term and large-scale projects based on the voluntary participation of citizens (Bonney et al., 2014; Commodore, Wilson, Muhammad, Svendsen, & Pearce, 2017; Follett & Strezov, 2015). CS has also an educational effect, as participants gain confidence in science and are able to improve their knowledge of the research field (Haywood & Besley, 2014; Roche & Davis, 2017; Shirk et al., 2012). In the field of communication, CS has increased the interaction between citizens and scientists, which is beneficial for both: citizens gain a better understanding of scientific processes by having the rare opportunity to directly communicate with scientists, whereas scientists receive immediate feedback on their scientific contributions and their effect on the wider public (Bonney et al., 2016; Freitag, 2016; Van Vliet, Bron, & Mulder, 2014). The impact of CS can also reach society: changes in the environmental awareness of citizens and changes in their attitudes toward science have the potential to influence management strategies and policies (Bonney et al., 2009; Kullenberg & Kasperowski, 2016; McKinley et al., 2017).

This interdisciplinary characteristic of CS enables a holistic approach to complex problems and challenges such as HWCs.

3.2 | Data reliability

As participants' level of engagement greatly depends on how and by whom the project was initiated, this section will discuss the two main contexts in which a CS

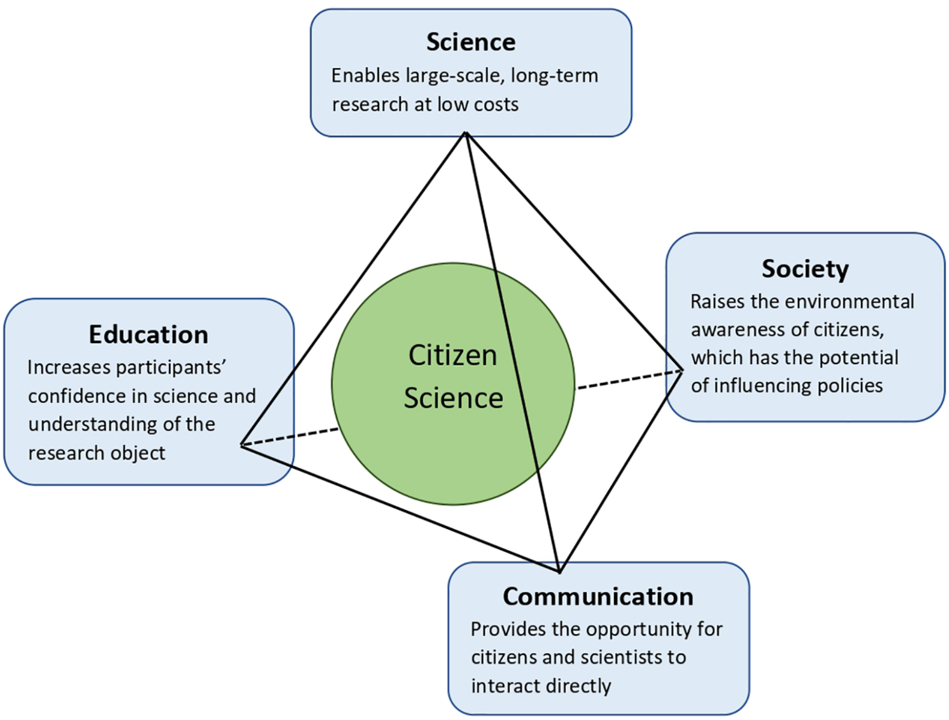

FIGURE 2 Citizen science is an interdisciplinary field that links various fields (based on Ostermann-Miyashita et al., 2019)

project might evolve. The first is citizen-driven projects (bottom-up), which aim to solve a problem in the community that is often left unaddressed by policymakers (Pettibone, Vohland, & Ziegler, 2017), and the second is scientist-driven projects that are organized by scientists who seek public engagement to solve a concrete scientific question. An example of citizen-driven projects is the CS project "Safecast," which was founded as a response to the lack of government data on radiation levels after the Fukushima Nuclear Power Plant disaster in 2011 and engaged citizens in gathering radiation data with a self-developed Geiger counter (Brown, Franken, Bonner, Dolezal, & Moross, 2016). The level of citizens' engagement varies greatly among scientist-driven projects: while there are projects where citizens are involved only in data collection, others task citizens with the analysis and evaluation of the gathered data. Some even integrate citizens actively in the design and planning of the projects (Follett & Strezov, 2015).

Concerns about the validity of the data gathered by nonprofessionals (citizens) for use in scientific research have been repeatedly pointed out. In response, various efforts have been made to remove errors and uncertainties in data collection both statistically and methodically (Bird et al., 2014; Isaac, Van Strien, August, De Zeeuw, & Roy, 2014; Kelling et al., 2019). The results indicate that providing adequate training, using project designs that prevent judgment errors, using artificial intelligence and reducing error factors through impact assessment are effective measures (Bonney et al., 2009).

Neglected issues in a local community, such as health, economic or environmental concerns, are the main drivers of bottom-up CS projects, which is also the case for HWC. In contrast, scientist-led programs approach research questions that cannot be answered without the involvement of the public, for example, making use of local and indigenous knowledge or sheer manpower. For both extreme cases and for the cases in between these extremes, there are now numerous best-practice examples of project organization and data analysis.

Digitalization has been a key factor for the rapid development of CS in recent years. The widespread use of computers and smartphones has made it possible for citizens to participate in projects regardless of their location or available time. The processing of large amounts of data has become possible, many projects utilizing specific applications have emerged, and CS is expected to expand further through digitalization (Kullenberg & Kasperowski, 2016). As described in the "Wildlife monitoring" section below, digitalization has also been a key driver for CS projects in the field of HWCs through technologies that are connectable to and displayable through several mediums, such as smartphones, computers and image-based identification (Willi et al., 2019). Social media is also increasingly important, as social media platforms function not only as connection tools but also as information sources and output platforms for some projects to redistribute collected data to the public.

The following section explains how CS can be (1) a tool to gather wildlife data and (2) a process to engage citizens in the research on and management of wildlife.

3.3 | Problem solution

Table 2 shows a global selection of highly cited studies which were found by a search with key words related to "citizen science" and "wildlife monitoring" in the Scopus database. While four of the projects targeted all wild animal species in a limited area or specific environment, such as driving roads (Paul et al., 2014), nature parks (Kays et al., 2017; Swanson et al., 2016) and protected areas (Liebenberg et al., 2017), the remaining eight studies considered specific target species. This difference was related to the context of each study. The studies that targeted all wildlife species were mainly focused on collecting large amounts of data or assessing the reliability of citizen-gathered data, while studies focusing on a specific species were often initiated as a response to endangerment or a conflict with that species. This in turn determined the target group, as exposure to some specific species, such as wild boar (*Sus scrofa*), is limited to certain professions, such as farmers (Jordt et al., 2016). Although CS approaches in wildlife studies are practiced globally, many of the most frequently cited case studies are from North America, while few reports originate from Asia and South America (Brown et al., 2016; Schmeller et al., 2017). This reflects that CS is increasingly applied in Western countries but has not yet spread widely to other parts of the world (Ostermann-Miyashita et al., 2019). Except for the study by Liebenberg et al. (2016), which started in the 1980s, all of the examined studies were initiated after 2000, which underlines the novelty of this research field.

Two studies engaged citizens in collecting activities: the monarch butterfly (*Danaus plexippus*) research in North America trained citizens to collect parasite samples (Bartel et al., 2011), and the wolf research in Finland asked citizens to collect wolf feces on an opportunistic basis (Ronnenberg et al., 2017). The research by Liebenberg et al. (2016) supplied nonliterate trackers with a specific smartphone user interface based on icons, which enabled them to document complex geo-ecological information. The study by Paul et al. (2014) in Canada applied a web-based mapping tool for citizens to report

TABLE 2 Summary of wildlife monitoring studies that applied citizen science approaches

Animal species	Region	Time span	Target group	Context	Methods	Reference
Black swan, eastern grey kangaroo	Australia	2007–2009	All citizens	Determining how readily citizens contribute to volunteer monitoring	Report sightings by e-mail or phone calls	Mulder, Guay, Wilson, and Coulson (2010)
Mule deer and elk	United States	2003–2004	Students grades 1–8	Testing the reliability and utility of students in counting ungulates	Students count the number of ungulates along rural school bus routes	Galloway et al. (2011)
Monarch butterflies	North America	2006–2009	Trained citizens	Determining how migration affects infectious diseases of butterflies	Collect parasite samples and report monitoring results	Bartel, Oberhauser, de Roode, and Altizer (2011)
Wintering birds	North America	2007–2008	All citizens	Determining the effect of urbanization and weather on wintering birds	Report sightings using online mapping tools	Zuckerberg et al. (2011)
Wild animals	Canada	2006–2007	All citizens	Testing the accuracy of citizens' wildlife observation compared to that of professional researchers	Report driving data using a web-based mapping tool	Paul, Quinn, Huijser, Graham, and Broberg (2014)
Wild boar	Denmark	2008–2013	Farmers, all citizens	Testing multi-source CS data to determine the cause of wild boar population growth in Denmark	Interviews, questionnaires and the use of a mobile GPS application	Jordt et al. (2016)
Wild animals	Africa	Since 1980s	Trackers	Gathering wild-life information in African countries to protect animals from poachers and prevent wild animal transmitted diseases	Non-literate trackers document data by smartphone icon user Interface	Liebenberg et al. (2016)
Wild animals	Africa	2010–2013	All citizens	Analyzing the trade-off between the effort of citizens and data reliability in the image verification of wild animals	Sort images by species and number and characterize behaviors	Swanson, Kosmala, Lintott, and Packer (2016)
Elk	United States	2016	Local cattle farmers	Testing a citizen-science-based risk model for bovine brucellosis transmission from elk to cattle	Farmers report sightings of elks near their cattle herds	Kauffman et al. (2016)
Wild animals	United States	2012–2014	Trained citizens	Determining how human recreational activities (e.g., hiking, hunting) affect the wildlife of protected areas	Citizens were trained to deploy camera traps	Kays et al. (2017)
Wolves	Finland	2013–2016	Hunters, nature enthusiasts	Genetic monitoring of returning wolves in Finland	Participants collected wolf feces on an opportunistic basis	Granroth-Wilding et al. (2017)
Wolves	Germany	2012–2015	Hunters, all citizens	Searching for ways for wolves and humans to coexist in an area with high wolf density	Wildlife survey by hunters and an official wolf monitoring project	Ronnenberg, Habbe, Gräber, Strauß, and Siebert (2017)

their driving data, and the study by Kays et al. (2017) in the eastern United States trained citizens to deploy camera traps in a research suitable pattern. The Serengeti National Park study (Swanson et al., 2016) did not involve citizens in data collection but globally recruited citizens online to identify snapshot images that were taken by camera traps in the park. This is an example of digitalization empowering citizens whose environments do not allow direct interaction with wildlife.

A progressing change in digitalization was observed in the monitoring and reporting of sightings, which was the most common CS method applied in the studies listed above (Table 2). The Australian black swan (*Sygnus atratus*) and eastern grey kangaroo (*Marcopus giganteus*) study (Mulder et al., 2010) relied on analog methods such as phone calls or e-mails, while citizens participating in the wintering bird monitoring study in North America (Zuckerberg et al., 2011) and the wild animal monitoring study in Alabama, Canada (Paul et al., 2014) reported their data using online mapping tools. While this digitalization trend is making the transfer of data faster, easier and more precise through global positioning systems (GPS), the value of analog methods should be reconsidered, as digital tools could be a challenge for some target groups, for example, senior citizens. As the paragraphs above show, each HWC has unique ecological geographic and societal backgrounds, which makes it crucial to develop tailor-made methods to tap the full potential of CS.

3.4 | Building social capital

The other important characteristic of CS is that it empowers citizens by providing the opportunity to actively participate in scientific research that addresses acute environmental issues (Ravetz, 2004). One of the prominent problems in HWCs is that of policy makers at the regional, national and international scales deciding upon species protection measures without considering the local situation or problems the respective and affected population is facing. An example is the study by Pohja-Mykrä (2017), which found that the local community's power (or pressure), which is generated from local identities and ways of life, hinder conservation measures of large carnivores to meet their desired effect, resulting in illegal shooting and the drastic decrease in the Finnish wolf population in 2014. For conservation regimes to be able to function properly, it is essential to increase the understanding of local citizens and to identify solutions on a cooperative basis. CS projects which involve citizens not only in the data collection process but also in the development and evaluation of HWC measures can initiate a process of mutual understanding of the diverse perspectives of differently affected stakeholders (Ceaușu, Graves, Killion, Svenning, & Carter, 2018; Morzillo, De Beurs, & Martin-Mikle, 2014; Reed, 2008). Participation in such CS projects will equip citizens with scientific knowledge to address local problems, be part of the decision-making process and even empower them to take action (Turrini, Dörler, Richter, Heigl, & Bonn, 2018). However, great care has to be taken in designing a participatory CS projects, so that no stakeholder group feels uninformed or disadvantaged, as this could lead to intensified (human–human) conflicts.

One advantage of CS, however, is that citizen involvement is not limited to local residents (stakeholders); rather, it potentially allows anyone who is interested to participate anytime from anywhere. This "anytime and anywhere" characteristic is enabled by digitalization and the rapid growth of online projects such as *Zooniverse* and *Picture Pile*, which allow citizens globally to take part in scientific research equipped only with their computers and smartphones (Kullenberg & Kasperowski, 2016; Ostermann-Miyashita et al., 2019). The Serengeti National Park study (Swanson et al., 2016), as an example case for HWC, recruited citizens online to sort snapshots of wild animals taken in the park. In this way, CS can be an opportunity for interested citizens with limited possibilities to connect to nature (especially in urban areas), to actively take part in research addressing HWCs and to contribute to a better coexistence of human and wildlife (Soulsbury & White, 2016; Swanson et al., 2016).

3.5 | Fitting the problem to the solution

In this section, we focus on the applicability of CS methods by understanding the unique background of each HWC and the sustainability of these methods through the involvement of future generations.

Although HWC is a globally relevant problem, the actual level of conflict varies greatly depending on the social, economic and geographical contexts. There are many problems that occur due to differences in socioeconomic development between countries in the global North and global South, and HWC is not an exception. "People in developing countries are vulnerable to HWC," as Seoraj-Pillai and Pillay (2017) point out in their study in which they compared HWC perspectives in South Africa and globally. There are many causes for this vulnerability. A 20-year study from 1990 to 2010 in Congo showed that war and civil conflict had greatly increased poaching and environmental degradation (Nackoney et al., 2014). Studies in Tanzania have shown that an increase in the elephant population, which is due to effective protection measures, has resulted in crop damage that threatens the lives and livelihoods of local farmers. The increase in the human population and the need for economic development have led to a higher chance of conflict (Chang'a et al., 2016). These examples show that HWCs are often considered existential and substantial problems in developing countries. Whether certain species are under protection is also a significant factor limiting possible mitigation measures (Woodroffe, Thirgood, & Rabinowitz, 2005). For species that are under strict protection, lethal control is not an option and CS methods have to focus on technical solutions (e.g., chili fences in the case of elephants in Tanzania) (Chang'a et al., 2016). For species that can be hunted, determining whether or the extent to which to apply lethal control could be a part of a decision-making process involving citizens (e.g., wolf management decided by citizens only in the United States) (Todd, 2002).

While HWCs also occur in urban areas (Mueller, Drake, & Allen, 2019), a larger part is concentrated in rural areas, as it represents the original and suitable habitat for wild animals. Rural conflicts are also more likely to have greater impact on specific individuals by directly affecting the livelihoods of local residents, which results in a lower tolerance toward wildlife in rural population compared to the urban population (Dickman, 2010; Klevien, Bjerke, & Kaltenborn, 2004; König et al., 2020). This polarization among the urban and rural residents can affect how ready the public is to participate in CS approaches for monitoring and managing wildlife (Dickman, 2010; Kansky, Kidd, & Knight, 2014), thus is an important factor to consider when planning a CS project.

The Global and Local Geographic (GLG) model presented in Figure 3 combines these two polarizations: the vertical axis shows the polarization between the developed countries and developing countries, while the horizontal axis represents the urban–rural polarization. Although HWC is a far more complex problem which involves a multitude of factors, this model can be applied as the first step to find an effective CS approach, according to the economic, social and ecological backgrounds of each problem.

In the case of elephants (*Elephas maximus*) in Africa, finding non-lethal solutions is essential, as these species are under strict protection. Practical CS methods such as chili fences maintained by locals have shown significant effect in Tanzania (Chang'a et al., 2016). The SMART (Spatial Monitoring And Reporting Tool) software used in Cameroon has also been successful in creating risk maps which are applied to avoid interaction and mitigate damage on both sides (Farfána et al., 2019). For coyotes (*Canis latrans*) in North America, it is insufficient to apply CS merely as a monitoring tool, as management of these urban carnivores is influenced by differently positioned groups in the public (Mueller et al., 2019). In this case, it is necessary to apply a CS method that involves citizens not only in the data gathering but also in the planning and evaluating process of conservation and management measures (Ceaușu et al., 2015).

The limiting factors for CS projects to be successfully applied vary according to the social, economic and geographical backgrounds of each HWC. As an example, the availability of digital tools could be a great challenge for developing countries. However, a large part of the public is equipped with a multifunctional high-tech device that could close this gap to a certain extent: the smartphone. The GLG model explained in this section can provide a

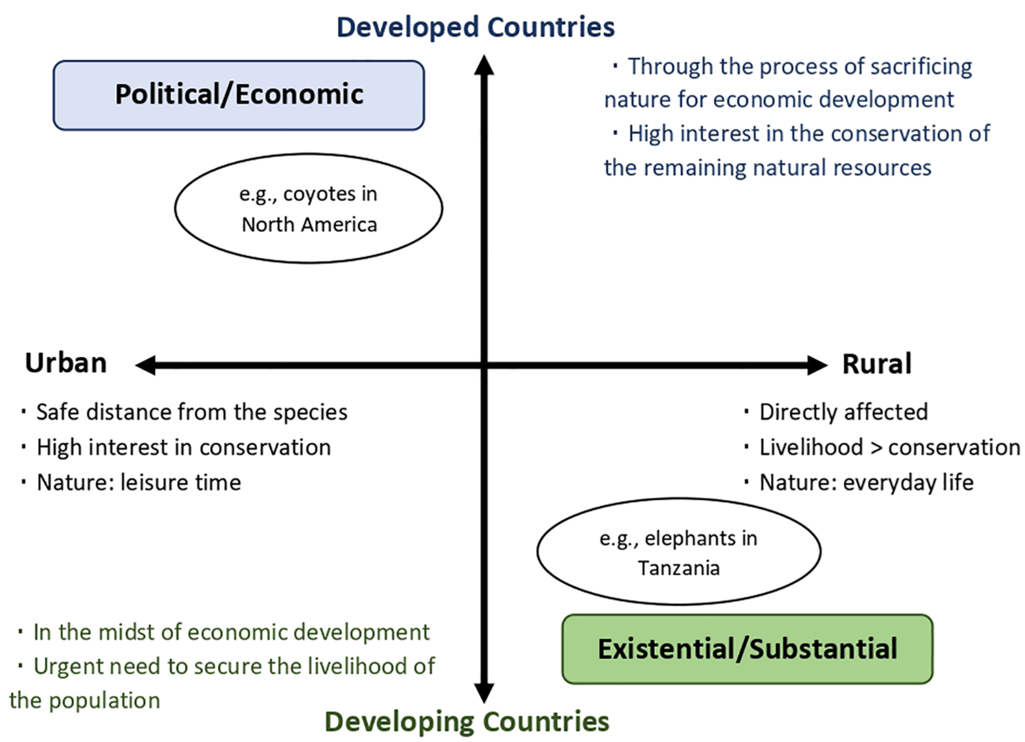

FIGURE 3 The Global and Local Geographic (GLG) model explaining different levels of HWC according to social, economic, and geographical backgrounds

guideline for determining which CS approach is appropriate for practical application.

3.6 | Leveraging social capital

Promoting human–wildlife coexistence and sustainability strategies in conservation should explicitly address the needs of future generations. Education, which is one of the four interdisciplinary fields CS links (Figure 1), has the potential to foster a new environmentally friendly generation that will be better informed about environmental issues and more cooperative in finding sustainable measures for mitigating HWCs (Soanes et al., 2020).

CS greatly contributes to the education of participating citizens by increasing their confidence in science and improving their understanding of the research field (Haywood & Besley, 2014; Roche & Davis, 2017; Shirk et al., 2012). In this section, however, the focus will be on CS approaches targeting children and students, such as projects in cooperation with kindergarten and schools, which in some cases are part of the educational program (Weckel, Mack, Nagy, Christie, & Wincorn, 2010).

There have been many CS approaches in the field of wildlife monitoring that have involved children and students in their studies, such as the "Green wave project" or "Nature Watch," which invited school children, among other citizens, to record phenology data on plants, insects and birds (Donnelly, Crowe, Regan, Begley, & Caffarra, 2014). Frigerio et al. (2018) provide an overview of three Austrian projects that targeted children and students to monitor and document animal abundance and behavior.

Although some scientists have greater concern about the reliability of data, it has been proven that the data gathered by children and students are as reliable as the data gathered by professionals if the appropriate training is provided (Frigerio et al., 2012). In the study of Galloway, Tudor, and Vander Haegen (2006) children had difficulty in subjective assessment or tended to over report rare species, while the probability of a sample proving positive nearly doubled when children under 12 years collected them in a study monitoring a deadly fungus on amphibians in northern coastal California (Pope, Wengert, Foley, Ashton, & Botzler, 2016). Thus, by understanding these strengths and weaknesses and designing CS projects accordingly, data collected by children and students can contribute to effective monitoring and novel scientific findings.

The engagement of children in wildlife research through CS not only opens new research possibilities but also contributes to raising a new, environmentally aware generation (Soanes et al., 2020). The decision-making of young people on biological conservation is greatly based on their formal school education (Grace & Ratcliffe, 2002), and it has been repeatedly pointed out that a new approach in scientific education is needed to prepare future generations to tackle global issues such as climate change (Hodson, 2003). The participatory approach of CS fosters scientific thinking (Trumbull, Bonney, Bascom, & Cabral, 2000) enhances scientific understanding, and in some cases even increases students' interest in pursuing careers in natural resource management (Pitt & Schlutz, 2018). Additionally, participation in CS projects can lead to value changes (Maund et al., 2020; Turrini et al., 2018) and willingness in changing behavior toward the environment among participants (Dean, Church, Loder, Fielding, & Wilson, 2018). Especially in case of HWC, participatory CS formats can help participants to understand the values of others, plurality of actors and the complexity of the problem. Therefore, integrating CS into formal school education could be one approach to realize this goal.

Children and students can also become amplifiers of CS in their families and communities. A survey on human coyote interaction in the United States succeeded in covering a large geographic area by distributing a survey via school children (kindergarten to grade 12) as part of a voluntary class assignment (Weckel et al., 2010). Children acted as the connecting link between scientists and the public by interviewing their family and community members and reporting the results. This also makes it possible to reach a wider range of the public than usual CS project, where participants tend to be biased positively toward wildlife or have higher conservation interests (Maund et al., 2020).

This section has highlighted the importance of engaging children and youth in CS activities not merely as valuable and reliable sources of data but also as amplifiers in their communities; moreover, children and youth represent the future generation that has to deal with the increasing challenges of biodiversity loss and conservation. Having opportunities to have direct contact with scientists at a young age could also help young people develop a trustful relationship with science.

4 | CONCLUSION

This study reviewed CS approaches in the field of HWCs, and has assessed its potential of mitigating conflicts and finding strategies for a better coexistence. A large part of the theories and models in the field of HWC address humans, analyzing how experience, knowledge, emotion and other factors, such as social relationships and intergroup dynamics, influence attitude, behavior, acceptance and tolerance toward a species (Table 1). Due to its interdisciplinary characteristics, CS enables a holistic approach to HWCs; it not only considers scientific findings and solutions but also involves fields such as education, society and communication by linking them together (Figure 2). CS is not only (1) an effective method to gather wildlife data (Table 2) which contributes in mitigating the primary conflict between humans and wildlife (Figure 1) but also (2) a tool to engage citizens in the research and management of wildlife, which can contribute in mitigating the following conflicts between differently affected humans (Figure 1). Digitalization has been a key driver of CS by introducing novel tools and systems for faster, easier, and more accurate data collection—which is especially relevant for wildlife research—and by lowering barriers for participation through the internet. Although there are numerous factors influencing the complexity of HWCs, the GLG model proposed in this study can be applied as a first step to find effective CS methods according to the diverse social, economic and geographical backgrounds of each conflict. CS can also contribute to the sustainable conservation of wildlife species by laying the foundation for environmentally aware and responsible future generations.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Emu-Felicitas Osterman-Miyasita has conceptualized and developed the idea of the essay under the supervision of Hannes J. König. Nadja Pernat and Hannes J. König have contributed to the discussion of the manuscript with their respective expertize in citizen science and human–wildlife conflict.

DATA AVAILABILITY STATEMENT

Use of secondary published information (literature cited). No primary data were collected for the current study.

ETHICS STATEMENT

No ethics review was required for this manuscript as no primary data was collected.

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