




## Human–wildlife coexistence in a changing world

Hannes J. König <sup>1</sup>, Christian Kiffner <sup>2</sup>, Stephanie Kramer-Schadt <sup>3,4</sup>, Christine Fürst <sup>5</sup>, Oliver Keuling <sup>6</sup>, and Adam T. Ford <sup>7</sup>

<sup>1</sup>Junior Research Group Human-Wildlife Conflict & Coexistence, Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Str. 84, Müncheberg, D-15374, Germany, email hkoenig@zalf.de

<sup>2</sup>Center for Wildlife Management Studies, The School for Field Studies (SFS), PO Box 304, Karatu, Tanzania

<sup>3</sup>Department of Biology, Technische Universität Berlin (TUB), Rothenburgstr. 12, Berlin, D-12165, Germany

<sup>4</sup>Department of Ecological Dynamics, Leibniz Institute for Zoo- and Wildlife Research (IZW), Alfred-Kowalke-Straße 17, Berlin, D-10315, Germany

<sup>5</sup>Institute for Geosciences and Geography, Dept. Sustainable Landscape Development, Martin-Luther University Halle (MLU), Von-Seckendorff-Platz 4, Halle (Saale), D-06120, Germany

<sup>6</sup>Institute for Terrestrial and Aquatic Wildlife Research (ITAW), University of Veterinary Medicine Hannover, Bischofsholer Damm 15, Hannover, D-30173, Germany

<sup>7</sup>Department of Biology, The University of British Columbia (UBC), 1177 Research Road, Kelowna, BC, V1V 1V7, Canada

**Abstract:** Human–wildlife conflict (HWC) is a key topic in conservation and agricultural research. Decision makers need evidence-based information to design sustainable management plans and policy instruments. However, providing objective decision support can be challenging because realities and perceptions of human–wildlife interactions vary widely between and within rural, urban, and peri-urban areas. Land users who incur costs through wildlife argue that wildlife-related losses should be compensated and that prevention should be subsidized. Supporters of human–wildlife coexistence policies, such as urban-dwelling people, may not face threats to their livelihoods from wildlife. Such spatial heterogeneity in the cost and benefits of living with wildlife is germane in most contemporary societies. This Special Section features contributions on wildlife-induced damages that range from human perspectives (land use, psychology, governance, local attitudes and perceptions, costs and benefits, and HWC and coexistence theory) to ecological perspectives (animal behavior). Building on current literature and articles in this section, we developed a conceptual model to help frame HWC and coexistence dimensions. The framework can be used to determine damage prevention implementation levels and approaches to HWC resolution. Our synthesis revealed that inter- and transdisciplinary approaches and multilevel governance approaches can help stakeholders and institutions implement sustainable management strategies that promote human–wildlife coexistence.

**Keywords:** agricultural landscapes, conceptual framework, human–wildlife interaction, methods and tools for human–wildlife research, protected areas, transboundary challenges

Coexistencia Humano – Vida Silvestre en un Mundo Cambiante

**Resumen:** El conflicto humano – vida silvestre (HWC) es un tema muy importante para la investigación agrícola y de la conservación. Los tomadores de decisiones necesitan información basada en evidencias para diseñar planes de manejo sustentable e instrumentos políticos. Sin embargo, proporcionar un apoyo objetivo para las decisiones puede ser un reto ya que las realidades y percepciones de las interacciones humano – vida silvestre varían enormemente entre y dentro de las áreas rurales, urbanas y peri-urbanas. Los usuarios de terrenos que incurren en costos debido a la vida silvestre argumentan que las pérdidas relacionadas a la vida silvestre deberían ser compensadas y que la prevención debería estar subsidiada. Es probable que quienes apoyan las políticas de coexistencia entre humanos y vida silvestre, como los habitantes de zonas urbanas, no enfrenen una amenaza a su medio de

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subsistencia debido a la vida silvestre. Dicha heterogeneidad espacial en el costo y beneficio de cohabitar con la vida silvestre es relevante en la mayoría de las sociedades contemporáneas. Esta Sección Especial presenta contribuciones sobre daños inducidos por vida silvestre que van desde las perspectivas humanas (uso de suelo, psicología, gobierno, actitudes y percepciones locales, costo y beneficio y la teoría del conflicto y la coexistencia humano-vida silvestre) hasta las perspectivas ecológicas (comportamiento animal). A partir de los artículos y la literatura actuales en esta sección desarrollamos un modelo conceptual para ayudar a estructurar los alcances del HWC y de la coexistencia. El marco de trabajo puede usarse para determinar los niveles y estrategias de implementación de la prevención del daño a la solución del conflicto humano - fauna. Nuestra síntesis reveló que las estrategias inter- y transdisciplinarias y las estrategias de gobierno multiniveles pueden ayudar a que los actores y las instituciones implementen estrategias de manejo sustentable para promover la coexistencia entre los humanos y la vida silvestre.

**Palabras Clave:** áreas protegidas, interacción humano, fauna, marco de trabajo conceptual, métodos y herramientas para la investigación humano, fauna, paisaje agrícola, retos transfronterizos

**摘要:** 人类与野生动物的冲突是保护研究和农业研究的一个重要问题。决策者需要基于证据的信息来设计可持续的管理计划和政策工具。然而,由于农村、城市和城郊之内或之间的人类与野生动物相互作用的现实情况和观念存在很大差异,因此提供客观的决策支持也面临着挑战。因野生动物而遭受损失的土地使用者认为,与野生动物相关的损失应该得到补偿,且实施保护措施也应得到补贴。人与野生动物共存政策的支持者,如城市居民,则可能不会面临野生动物对生计的威胁。这种与野生动物共存的成本和收益的空间异质性普遍存在于多数当代社会。本专题包含介绍野生动物所造成破坏的系列文章,研究的角度从人类视角(土地利用、心理、管理、当地态度和观念、成本和收益、人类与野生动物的冲突和共存理论)到生态视角(动物行为)。基于已有文献和本专题的文章,我们设计了一个概念模型来为人类与野生动物共存及共存的维度制定框架。该框架可用于确定预防野生动物造成破坏的实施水平及解决人类与野生动物冲突的方法。我们的综合分析表明,跨学科和多级管理方法可以帮助利益相关者和机构实施可持续管理策略,促进人类与野生动物的共存。【翻译:胡怡思; 审校:聂永刚】

**关键词:** 人与野生动物相互作用, 人与野生动物研究的方法和工具, 概念框架, 农业景观, 跨境挑战, 保护地

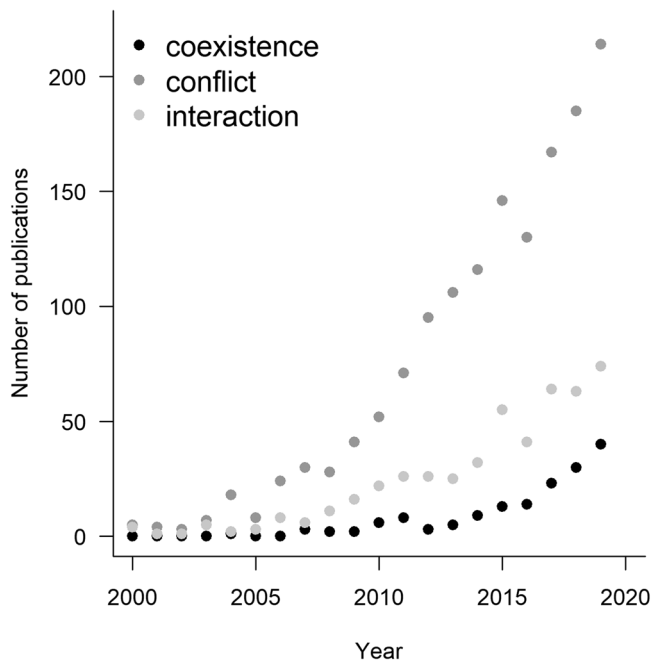
## Introduction

Human-wildlife conflicts (HWCs) are common near agricultural and other production landscapes, such as urban and peri-urban areas or near protected areas (PAs). Human-wildlife conflicts is defined as interactions between wildlife humans with a negative outcome (Madden 2004). From an anthropocentric perspective, such conflicts may occur when wildlife damage crops, injure or kill domestic animals, or threaten or kill people. Because this is a reciprocal process, humans and animals are negatively affected by the conflict, and HWC is one of the most complex and urgent issues facing wildlife management and conservation (Frank et al. 2019), especially outside PAs (Woodroffe et al. 2005). Scholars are seeking ways to refocus policy-relevant conflict research on finding pathways toward human-wildlife coexistence (Marchini et al. 2019) and coadaptation (Carter & Linnell 2016).

The literature on HWCs, interaction, and coexistence has grown exponentially in the last 20 years (Fig. 1), and work on conflict (based on a keyword search) outpaces work on interactions and coexistence 3-fold. This may be because scholarship on human-wildlife interactions has focused mainly on conflict (i.e., negative outcomes for people, wildlife, or both) (Chapron & López-Bao 2020 [this issue]) or because new ways of thinking about these interactions now include a paradigm of

coexistence. Most published studies were conducted in the biological sciences (approximately 45%), followed by the agricultural sciences (approximately 35%). Work in the social sciences and humanities (approximately 12%) warrants greater attention and integration (Bennett & Roth 2019; Frank et al. 2019).

*Coexistence* is defined as a dynamic but sustainable state in which humans and wildlife coadapt to living in shared landscapes, where human interactions with wildlife are governed by effective institutions that ensure long-term wildlife population persistence, social legitimacy, and tolerable levels of risk (Carter & Linnell 2016). Although this term has only recently been used by researchers, scientific focus on human-wildlife coexistence emerged much earlier (Herrero 1970). In 2003 a Special Section in *Conservation Biology* was published: “Human-Carnivore Conflict: Local Solutions with Global Applications” (Treves & Karanth 2003). The guest editors of the section highlighted the need for multidisciplinary research in HWC and for involving policy makers and managers. The importance of stakeholder participation in environmental decision making is increasingly being recognized, and multiple attempts have been made to implement participative processes (Reed 2008). With this Special Section on HWC, we sought to broaden the scope by considering multiuse agricultural landscapes and species ranging from native carnivores (e.g., lions [*Panthera leo*], spotted hyena [*Crocuta crocuta*], and



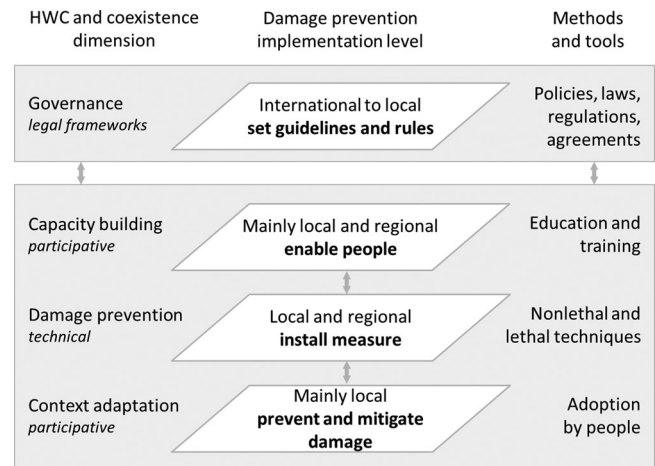
**Figure 1.** Number of peer-reviewed articles on human-wildlife conflict, interaction, and coexistence published from 2000 to 2019 based on literature search in the Scopus database. Search strings are “human-wildlife coexistence,” “human-wildlife conflict,” and “human-wildlife interaction.”

wolves [*Canis lupus*]) and herbivores (e.g., elephants, wild boar [*Sus scrofa*], and Japanese macaque [*Macaca fuscata*]) to invasive species (e.g., camels, feral pigs, and rabbits).

Examples in the section showcase wildlife disturbed and threatened by agricultural practices and, in contrast, wildlife that thrive in agricultural lands (i.e., have net growth rates  $>1$  and able to exploit anthropogenic resources). The 11 contributions to this section include comprehensive reviews, essays, and innovative case studies from Africa, Asia, Europe, and North America, where HWC and coexistence challenges differ.

Contributors were asked to address 3 critical questions related to HWC and coexistence: What are the key challenges of social-ecological models used to promote coexistence? Which methodological and biological considerations determine the effectiveness of mitigation measures that can facilitate coexistence? And, which dimensions, instruments, and levels of governance determine the outcome of HWC and coexistence (Fig. 2)?

We considered why integrated research, based on a combination of socioeconomic, socioecological, and basic ecological research methods, is needed to understand and overcome the challenges of HWC and to transform them into coexistence. We also examined theories, concepts, and challenges of HWC and coexistence and devised a conceptual framework to structure HWC and



**Figure 2.** Conceptual framework of human-wildlife conflict (HWC) and coexistence that can be used to determine damage prevention implementation levels and approaches to human-wildlife conflict resolution.

coexistence into different dimensions, damage prevention implementation levels, and methods and tools. We applied our framework to the case of gray wolves (*Canis lupus*) returning to Germany, although the framework is generic enough to be transferrable to other conflict scenarios. We also explored HWC challenges posed by the decoupling of policy jurisdictional boundaries and transboundary movement of wildlife.

In our synthesis of the Special Section contributions, we sought to present a clear path to conflict solving: a holistic perspective that objectively considers and weighs diverging arguments of stakeholder groups to provide the evidence base required to cope with the diverse and challenging facets of HWC and coexistence.

We considered the role of holistic and interdisciplinary (joint research among different scientific disciplines) science in generating new knowledge about HWC and coexistence and in facilitating transdisciplinary work with stakeholders that bridge the gaps between science, policy making, and practice. By *transdisciplinary*, we mean coproduction of knowledge as boundary work by policy makers and managers in research activities in support of identifying solutions to a problem (von Wehrden et al. 2019).

## Call for Governance Structures

The underlying reasons for HWCs are manifold. The unprecedented magnitude of natural resource use by humans (Turner et al. 2007) is fueled by a population approaching 8 billion people, many of them in systems that depend on persistent economic growth. The need to produce food (Godfray et al. 2010) is accompanied by high rates of land-use changes, which typically transform

natural or seminatural areas to urbanized and agricultural areas (Foley et al. 2005).

Current HWC and coexistence research focuses primarily on large mammals (Nyhus 2016), perhaps because such species can pose a risk to human safety and livelihoods. This anthropocentric view of wildlife leads to classifying species as good or bad, without considering their intrinsic value. Human activities (e.g., land conversion, harvesting, and introduction of non-native species), however, constantly affects species' presence (Sala et al. 2000), but species may respond differently to those human activities (Brashares 2010). Hence, due to the finite nature of natural resources, agricultural and human-dominated landscapes are increasingly becoming arenas for human-wildlife interactions. Source-sink dynamics attracting wildlife to human food sources and the magnitude of conflict may be context dependent, yet conflicts frequently attract considerable attention where wildlife is perceived to negatively affect people's well-being or livelihoods (Kansky et al. 2016).

Moreover, human-wildlife interactions often translated into conflicts between people or groups of people with divergent interests (Redpath et al. 2015). For example, conflicts arise between farmers, who focus on economic production, and conservationists, who seek to maintain natural areas.

The institutional structures that shape interactions between humans and wildlife are diverse and vary by region. For example, European approaches to coexistence are often formalized through international regulatory processes, and these may differ from processes in rural areas in the global South, where more informal and community-driven approaches typically provide the context for coexistence (e.g., Broekhuis et al. 2018). The effectiveness of international conservation agreements in shaping human-wildlife coexistence remains largely untested. The consensus is principally that coexistence can be achieved only through a holistic perspective in which socioeconomic and ecological aspects are given full consideration (Nyhus 2016; Hill et al. 2017).

A key challenge in managing human-wildlife interactions is to design and implement sustainable governance mechanisms (Morzillo et al. 2014; Soulsbury & White 2015). People and most wildlife species have extensive learning abilities, complex social life histories, and their own agendas and strategies on how to access and use resources. Instruments for spatial planning and development at multiple scales are needed to manage human-wildlife interactions sustainably to avoid or reduce conflicts (Seijger et al. 2017) and to ensure a sustainable coexistence (Woodroffe et al. 2005).

To make progress toward human-wildlife coexistence, a better understanding and objective testing of assumptions about the causes of wildlife-induced damages from various perspectives, including wildlife ecology, human perceptions and behavior, and legal

frameworks (Chapron & López-Bao 2020; Treves & Santiago-Ávila 2020 [this issue]; Wilkinson et al. 2020 [this issue]) is essential. This is particularly important in landscapes where people have modified nature in such a way that agriculture provides habitat to some (protected) species and where novel governance models are needed to balance shared land use between people and wildlife.

## Agriculture and Conservation Interface

Confronted with returning carnivores, such as gray wolves and brown bears [*ursus arctos*] in Europe (Chapron et al. 2014), governance (i.e., how to manage conflicts or turn them into sustainable coexistence) is challenged when conflicts become political (Treves et al. 2017). Ideally, finding solutions includes participatory and stakeholder-inclusive approaches in which all regulatory agencies and community members codevelop programs that can collectively evaluate possible trade-offs related to wildlife management goals (Dorresteijn et al. 2016; Martin et al. 2020). However, scant quantitative research addresses how best to derive such a participatory process in the context of human-wildlife coexistence.

In this Special Section, 2 conflict areas appear of major concern: agricultural landscapes that provide habitat for wildlife (Carter et al. 2020 [this issue]; Denninger Snyder & Rentsch 2020 [this issue]; Perry et al. 2020 [this issue]; Rees et al. 2020 [this issue]; Tsunoda & Enari 2020 [this issue]; Wilkinson et al. 2020) and transboundary PAs and areas surrounding PAs (Jordan et al. 2020 [this issue]; Martínez-Jauregui et al. 2020 [this issue]; Salerno et al. 2020 [this issue]), where wildlife species damage mainly subsistence farms and where effective implementation of conservation laws has resulted in increased wildlife populations. For people lacking access to governance over wildlife management, informal actions, such as retaliatory killing or poaching, may occur at high rates outside PAs and can have negative consequences for wildlife inside PAs (Kahler et al. 2013). Such uncoordinated and often illegal lethal management can have cascading effects on the species' distribution, abundance, and long-term population viability (Woodroffe et al. 2005). In other cases, lethal control can unintentionally increase damage occurrences (Eklund et al. 2018; van Eeden et al. 2018). Due to the often illegal, and thus cryptic, nature of these informal responses, the magnitude and effects of poaching on wildlife species are rarely monitored directly (Liberg et al. 2012). Although strong governance may help shape coexistence, formalized governance is not a panacea for coexistence. For example, heavily subsidized predator control programs in the United States are aimed explicitly at reducing carnivore populations rather than at contributing to human-carnivore coexistence (Bergstrom 2017).

Perhaps a formal and objective accounting of farmers' perceptions about wildlife-related damages and establishing effective means for quantifying economic losses and costs (i.e., transaction and opportunity costs) (Carter et al. 2020; Jordan et al. 2020; Rees et al. 2020; Salerno et al. 2020) can improve transparency in this controversial topic. We conclude that conservation needs to focus especially on multiuse landscapes, such as agricultural areas, where the interface between humans and wildlife occurs.

## Conceptual Framework and an HWC Example with Wolves

Transforming HWC to sustainable coexistence requires holistic and integrative approaches. Building on existing literature and contributions to this section, we developed a conceptual framework for structuring different dimensions of HWC, damage prevention implementation levels, and methods and tools (Fig. 2). We considered the case of gray wolves (*Canis lupus*) in Germany to illustrate how the framework can be applied to a specific context. The framework applies mostly to conflicts that are damagerelated, and less to those that are political.

Gray wolves returned to Germany in 2000, and by 2019 there were 105 packs and 25 pairs and 13 individuals (approximately 700 individuals total [www.dbb-wolf.de]). Livestock owners perceived and experienced diverse direct and indirect economic losses due to the presence of wolves and the subsequent need to adapt to the new situation.

### Governance

In response to the increasing wolf numbers, a strictly protected species under the EU directive, Germany's parliament approved in 2019 (Bundestag 2019) an amendment to the Nature Conservation Act that relaxes lethal control of wolves (Kiffner et al. 2019). Adjustments were justified mainly to establish legal options (e.g., killing injured and "problematic" wolves [i.e., wolves that have repeatedly breached wolf-proof fences and killed livestock]). Federal states must implement the law. For example, Brandenburg (where most of the wolves live in Germany) developed a state-specific regulation that provides guidelines on when, how, and under what circumstances wolves can be killed (Brandenburg 2019).

### Capacity Building

Multiple stakeholder groups are directly and indirectly affected by wolves. This includes livestock farmers, state agencies that implement wolf monitoring and formally handle livestock losses due to predation, private hunters who perceive loss of prey, and wildlife managers who cull problematic wolves. Capacity building (e.g., how

to build fences and apply for funding for fences or for compensation) is carried out by legal authorities or nongovernmental organizations and mainly targets farmers who keep livestock.

### Damage Prevention

Implementation of damage prevention measures includes fences built to a minimum standard height and voltage and livestock guarding (Reinhardt et al. 2012). Preventive killing of wolves is illegal. However, in the event of repeated predation events, private hunters and wildlife managers are allowed to kill individual wolves or entire packs until local predation has stopped.

### Context Adaptation

Adoption of effective mitigation strategies (Denninger Snyder & Rentsch 2020) is key to effective damage prevention and HWC and coexistence. Because one-size-fits-all strategies to reduce HWC are ineffective (Eklund et al. 2018), adaptation to specific HWC situations is required. By considering legal frameworks (laws), knowledge, and technical equipment (capacities and capabilities), stakeholders (e.g., livestock keepers) may choose their own damage prevention measures (e.g., fencing and guard dogs) to cope with wolves.

### Challenges

Although this governance approach appears relatively straightforward, the seamless integration of local actors affected by wolves remains a challenge. For example, payment routines for carnivore damages are subject to bureaucratic processes, delayed access to funds, and unresolved claims (Morehouse et al. 2018). For some stakeholders, whose dominant belief system focuses on the existence and intrinsic value of wolves on the landscape (Boman & Bostedt 1999), the expansion of carnivore populations to new areas challenges the utilitarian value of people's livestock. The current model lacks an explicit system to evaluate the effectiveness of the implemented mitigation methods and even an assessment of the benefits that the return of an apex predator will yield, such as dilution of pathogens or reduction of browsing damage (Ripple et al. 2014). We suggest such an evidence basis is a necessary step in effective damage prevention. In this case, wolf predation behavior, landscape and governance structures, and farm management ideally inform a holistic and integrated assessment.

## Management Options for Coexistence

It is a general management challenge when humans and wildlife live in transboundary areas. Although we are aware that people and wildlife have always had lethal and nonlethal interactions, there are emerging frontiers

where HWC is unfolding in novel ways. These frontiers are driven by deliberate movement (i.e., translocation, introduction, or reintroduction) of wildlife by people into novel habitats (such as urban areas); natural spread of restored populations; climate-change-induced shifts in tolerance of wildlife by people; intrusion of people into areas with abundant wildlife; and emergence of zoonotic diseases. Renewed efforts to bring wildlife back to areas from which they were extirpated, from wolves in Yellowstone (Fortin et al. 2005) to bison in Canada (Steenweg et al. 2016), to European Bison in western Poland (Kuemmerle et al. 2018), bring to light the issue of governance. Who is funding rewilding and to what extent do people living in the rewilded areas have a say in how the new species are managed?

Wildlife also are naturally moving (e.g., dispersing) into areas where they were formerly extirpated—possibly because of changes in climatic regimes or adjusted levels of tolerance by residents. For example, Common Cranes (*Grus grus*) are benefiting from milder winters and changing cropping patterns in northern Europe (Nilsson et al. 2016). Grizzly bears (*Ursus arctos horribilis*) have been moving back to North American prairies after more than a century of active suppression outside their mountain redoubt (Morehouse et al. 2020). The so-called return of grizzly bears in this agriculturally dominated prairie landscape builds on technologies and incentives—supported by landowner willingness—that are making the landscape increasingly safer for bears as they spread farther east.

Climate change is altering seasonal weather patterns and the biogeoclimatic envelope for wildlife. As a result, new combinations of species are interacting at times of the year and in places where people may be unprepared to tolerate or mitigate interactions with wildlife (McRae et al. 2008). For example, to cope with droughts in central Kenya, pastoralists moved livestock to areas with more abundant forage. These areas include wildlife ranches and ecotourism properties, where wildlife conservation is a priority and lands are managed accordingly (Blair & Meredith 2018). As a result, the needs of livestock, human livelihoods, and wildlife were brought into conflict. As people adapt to climate-change-induced weather patterns, such novel interactions are expected to rise (White & Ward 2010; Svenning et al. 2016).

These 4 frontiers of HWC and coexistence are exacerbated by fragmentation in cultures and policies. Communities living adjacent to PAs, for example, may experience spillover effects of wildlife intrusions into their farms and villages (Martínez-Jauregui et al. 2020). Urban deer are not perceived and experienced equally by all members of the community; some people feed or encourage deer and others seek to mitigate damages. Polish bison are moving into eastern Germany with potential benefits for grassland ecosystems (Koerner et al. 2014), conservation, and tourism and potential risks for farmers,

foresters, and motorists. Be it across a city street or an international boundary, issues of fragmented policies and heterogeneity in tolerance for wildlife underlie many HWC situations. The mechanisms of this conflict also have an ecological basis because landscape connectivity (i.e., animal movement) across policy boundaries drives the interaction between people and wildlife.

With emerging challenges to coexistence in the coming decade, we urge a reconsideration of traditional approaches to coexistence. Fencing large areas, such as PAs, shooting wildlife, excluding stakeholders from the decision process, and not redistributing wildlife-related costs and benefits are increasingly considered unsustainable practices. Two relatively new concepts serve as model regions for a sustainable development. Peace Parks (Schoon 2013) and UNESCO-Biosphere Reserves (Schultz et al. 2011) aim to promote sociocultural activities and economic development while dedicating space for strict habitat protection and conservation. Some countries make intentional attempts to restore wild areas through rewilding (Pereira & Navarro 2015; Perino et al. 2019), whereas other countries, such as Japan, experience undeliberate range expansion and population size increases in multiple wildlife species in abandoned farmland and forest areas (Tsunoda & Enari 2020). However, in some cases, coexistence may remain difficult to realize. For example, in regions with social conflicts and war, mass migration of people may trigger HWC, such as the amplified human–elephant conflict around Rohingya refugee settlement in Bangladesh (Mukul et al. 2019).

## New Perspectives from Special Section Contributions

Anthropocentrism, treating nature as utilitarian without intrinsic value, ignoring future generations rights (human or nonhuman), and preferring consensus over contests of ideas are just some of the value judgments identified in this Special Section. Coming from a general conservation and policy point of view, Chapron and Lopez Bao (2020) point to the need to critically reflect on the status and role of nature in HWC studies. They attempt to uncover and deconstruct the normative assumptions behind contemporary conservation conflict studies. They argue that by framing conservation conflicts as conflicts between people about nature, such studies ensure that nature often comes second and this may do a disservice to conservation. Finally, they point to the problems conservation faces if conservation goals are always subordinate to human goals, a situation that could be minimized through a radical and provocative proposal: recognizing nature has the “right to exist.”

Jordan et al. (2020) emphasize that wildlife species outside PAs may be perceived as “pests” and that there is a growing risk of conflict if benefits and costs are disproportionately and unequally shared among

stakeholders, societies, and the global North and South. They stress critical aspects related to intolerance and how attitudes and behavior toward wildlife vary with social and cultural norms.

Treves and Santiago-Avila (2020) reflect on the evolution of the concept of HWC and the newer concept of coexistence. They discuss 4 assumptions: neutrality of scientists, participation as a means to achieve fairness and consensus, an increase in wildlife threats to human interests, and the additivity of wildlife damages to other sources of damages. They conclude that only the latter 2 assumptions are testable and that progress in the scholarship and practice of HWC and coexistence requires explicit testing of assumptions to ensure scientific integrity.

Tsunoda and Enari (2020) deal with the phenomena of rural depopulation and its implications for wildlife management and conservation. The authors describe a case study of a depopulation scenario in rural Japan. In this area human population decline coincided with increases in Sika deer, wild boar, and Japanese macaque, which now occupy farm land and cause damages to agriculture. Instead of increasing human pressure on these species through, for example, lethal control, the authors suggest land-use planning that considers a combination of land sharing and sparing.

Denninger Snyder and Rentsch (2020) developed a framework to assess mitigation strategies for African and Asian elephant-induced crop damage. They point to the need for effective of crop-mitigation strategies that must incorporate measures of effectiveness and rates of adoption among target users. Their framework includes 3 principal components, including local attitudes and perceptions, sustainability (as a means for local capacities), and scalability (i.e., limitations or requirements to support wider adaptation of an approach).

Rees et al. (2020) employed a framework to assess co-benefits that derive from alternative conservation strategies based on the feasibility, as well as associated costs, and benefits to both threatened species and agriculture. They consider the case study of the Australian Lake Eyre Basin in which several invasive wildlife species are in conflict with native species and agricultural production. They conclude that quantifying costs and benefits and prioritizing them can be a straightforward process to increase support for a conservation strategy and to identify potential investment partnerships.

Wilkinson et al. (2020) developed an ecological framework to contextualize carnivore–livestock conflicts. They took an ecological perspective of the relationship between predators and domestic prey in a case study of snow leopards (Asia) and wolves and cougars (*Puma concolor*) (North America), arguing that the mitigation of HWC requires understanding of ecological mechanisms. They conclude that applying established ecological concepts to human-managed systems can improve management of carnivore–livestock conflict.

Martinez et al. (2020) use a choice experimental approach (willingness to pay) to analyze attitudes and perceptions of citizens toward alternative management options to control “overabundant” ungulates (red deer) in 2 Spanish national parks. They found that a majority of the surveyed citizens believe it is acceptable to kill deer to maintain ecological functions of the parks. The authors highlight the risk of social conflicts that may arise from hunting activities. They conclude that the selection of tools to reduce wildlife impacts in parks is crucial to avoid conflicts in environmental-agenda planning.

Perry et al. (2020) conducted surveys in 3 areas of southern Kenya to analyze the role of psychology in determining human–predator conflict. They found that livestock management and prevention of human–predator conflict varied between and within communities and depended on normative beliefs and control beliefs regarding livestock management. They conclude that understanding the psychology of livestock management is key to determining the best wildlife–livestock conflict mitigation strategy.

Salerno et al. (2020) present a study on wildlife (mainly African elephant [*Loxodonta africana*]) impacts and vulnerable livelihoods in a transfrontier conservation landscape in southern Africa. They analyzed results of an interview-based survey of smallholders with a Bayesian multilevel model to quantify crop damage and alternative food-securing sources. They found that crop predation is widespread and affects over half of the sampled human population. The most vulnerable people are those who rely on gathering of food and welfare programs. Interestingly, these 2 livelihood strategies also buffer or reduce the harmful effects of predation by wildlife.

Carter et al. (2020) used a multi-agent modeling approach to investigate how human perception of risk from conflict-prone wildlife is transmitted among networks of farmers and affects wildlife populations through spatial feedbacks. In the model, farmers assess economic trade-offs and socially shared risk perception to decide how much labor to allocate to farming and whether and where to build fences on their farms to reduce risks from wildlife. In scenarios of high transmission of risk perception among farmers, fence building was widespread, resulting in decreased economic losses from wildlife damage but also in displacement of wildlife conflicts to new areas. They conclude that sharing risk perception in social networks alters spatial patterns of human–wildlife interactions, leading to emergent conservation outcomes such as spillover effects.

## Conclusions

HWCs have been and will continue to be a key topic in conservation and agricultural research. Conflicts

increasingly arise in agricultural landscapes and in relation to transboundary wildlife management, for example, where humans have modified nature in such a way that farmland provides new forms of habitat to species that are perceived as pests and where people and wildlife follow different systemic boundaries (e.g., agricultural land use vs. wildlife habitat, or administrative and political boundaries vs. wildlife home ranges). The role of research in understanding HWC and facilitating promotion and implementation of solutions for a sustainable coexistence requires different methods and tools. There is no one-size-fits-all solution. Based on our synthesis, we come to the following key conclusions:

People's perceptions are central to achieving coexistence and are ideally based on equitable participation among relevant stakeholders. Coexistence is not fixed, but can rather be understood as a dynamic process of continuing negotiations between the different stakeholder groups. Therefore, a holistic perspective that objectively considers and weighs the often diverging arguments between stakeholder groups can provide the evidence base required to cope with the diverse and challenging facets of HWC and coexistence.

A formal and objective accounting of stakeholders' perceptions about wildlife-related damages and establishing effective means for quantifying economic losses and costs (i.e., transaction and opportunity costs) can help bring greater transparency to this controversial topic. Therefore, we suggest such an evidence basis is a necessary step in contributing to effective damage prevention, considering that wildlife behavior, landscape and governance structures, and land management ideally inform a holistic and integrated assessment.

We suggest a more comprehensive integration of transdisciplinary science-stakeholder policy approaches into policy design and management, for example, by institutions that use evidence-based science and multistakeholder formats as the basis for their decisions.

Finally, we conclude that species conservation needs a special focus on multiuse landscapes, such as agricultural areas, that reflect the interface between humans and wildlife.

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