



Examining Evident Interdisciplinarity Among Prides of Lion Researchers

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Lions (*Panthera leo*) have experienced dramatic population declines in recent decades and today, inhabit just a fraction of their historic range. The reasons behind these declines are many, but conflict with humans, principally motivated by lion depredation of livestock, is among the most influential. Recent calls within the scientific community have identified that wicked problems like these should be addressed using interdisciplinary approaches. Here we examined the extent to which human-lion conflict research has been interdisciplinary. We conducted an extensive review of the literature and uncovered 88 papers, published between 1990 and 2015, that assessed human-lion interaction and the ecology of lions exposed to anthropogenic disturbance. While human-lion conflict research experienced near-exponential growth ($y = 8E-194e0.222x$, $R^2 = 0.76$) across this time period, the number of co-authors engaged in this research changed very little ($x = 3.28$, $se = 0.19$). Moreover, co-authors of this research tended to be affiliated with units from just three highly-related STEM disciplines (biology, wildlife management, and environmental science). Comparatively, co-authors affiliated with units in the humanities and social sciences occurred in <4% of all papers examined. Our analysis also presents a novel framework that positions human-lion conflict research as having not two dimensions, as has been commonly conceptualized, but five dimensions. These dimensions include not only the human and the lion dimensions, but also the livestock, wild prey, and environmental dimensions. None of the papers that we evaluated concurrently studied all five of these dimensions to determine their impact on human-lion conflict. Furthermore, despite the fact that human-lion conflict research was primarily developed by co-authors from STEM disciplines, the most common dimension evaluated was the human dimension which requires social science and humanities expertise. Our analysis indicates that interdisciplinarity among human-lion conflict research has

historically been low. These low levels of interdisciplinarity observed from 1990 to 2015 however, are not necessarily representative of the ongoing efforts to develop more inclusive research teams. Thus, we discuss the implications of this research for the development of sustainable solutions to conserve lions and preserve human well-being and identify potential avenues forward to create more interdisciplinary prides of lion researchers.

Keywords: conservation, human-lion conflict, interdisciplinary, lion, *Panthera leo*

INTRODUCTION

Lions (*Panthera leo*) are a highly enigmatic and charismatic species capable of capturing the attention of the scientific community and broader public alike. There is perhaps no better example of that capability than the societal response to the killing of Cecil the lion by a hunter in Zimbabwe in July of 2015. Less than a month later, stories in the editorial media describing this incident reached a peak of 12,000/day while hits on social media peaked at >87,000/day (Macdonald et al., 2016). Thus, in the twenty-first century, in large part due to their iconic and integral role (i.e., fundamental to the trophic systems in which they reside), lions are a species of unusually special conservation concern (McNeely, 2000; Dickman et al., 2011; Lindsey et al., 2012; Ripple et al., 2014; Macdonald et al., 2015). Once common across all of Africa, as well as portions of Europe and Asia, lions are restricted to fragmented populations in sub-Saharan Africa and one very isolated population in west India (Riggio et al., 2013; Henschel et al., 2014; Meena et al., 2014; Bauer et al., 2015). Lions now occur in just 8% of their historic range and have experienced an estimated 43% population reduction in the past 20 years (Bauer et al., 2015). Predictions suggest there are now ~25,000 lions in Africa with only ~500 individual lions remaining in India (Singh and Gibson, 2011; Bauer et al., 2015). Further, within the next 20 years, lions could decline by an additional 50% in Western-Central and East Africa, positioning the species itself on the cusp of extinction (Henschel et al., 2014; Bauer et al., 2015).

The reasons behind these declines are many including habitat loss, climate change, hunting, disease, and human conflict (Loveridge et al., 2016; Macdonald, 2016). Although all of these elements have contributed to the 1996 downgrading in conservation status of lions (i.e., from *near threatened* to *vulnerable* by the International Union for the Conservation of Nature—IUCN; Bauer et al., 2015), there is one element, in particular, that will determine whether lions continue to inhabit wild places in future. That element is human-lion conflict. Conflict, whereas the term is reductive and unsatisfactorily narrow in its depiction of just a portion of human-wildlife interaction (Conover, 2002; Madden, 2004; Nyhus, 2016), is illustrative of an important part of that interaction. Threats to human security and competition for resources can promote human-carnivore conflict (Millspaugh et al., 2015) with implications for carnivore conservation and human well-being. This is an age-old problem with clear evidence that human evolution itself, has been shaped by conflict with

carnivore species such as lions (Bunn and Ezzo, 1993; Treves and Naughton-Treves, 1999; Camarós et al., 2016).

Conflict between humans and carnivores often involves competition over prey species, whether they be wild-living or domesticated (Patterson et al., 2004; Graham et al., 2005; Dickman, 2010). In the present day, this conflict tends to derive from real or perceived depredation of livestock. Lions, for instance, prey upon a variety of domestic livestock including cattle, goats, sheep, and donkeys and can attack during both daytime (when livestock are often on the grazing lands) and nighttime (when livestock are typically herded together in livestock enclosures, i.e., bomas, kraals, corral, or stockade) periods (Ogada et al., 2003; Kissui, 2008). The current range of lions primarily overlaps with developing nations where livestock-keepers are particularly dependent upon, and vulnerable to, the loss of livestock (Thornton et al., 2002; Bank, 2009; Thornton, 2010). Thereby, livestock depredation can be fearsome, dispiriting, and economically crippling (Treves and Karanth, 2003; Inskip and Zimmermann, 2009; Miller, 2015). Experiences of this type foster soundly negative perceptions of lions among affected human communities (Treves and Karanth, 2003; Woodroffe and Frank, 2005; Kissui, 2008; Dickman, 2010; Dickman et al., 2014). Rapid increases in meat production (a tripling between 1980 and 2002 in developing nations) likely intensifies the potential for lion-livestock interaction (Thornton, 2010; Bauer et al., 2015). Thus, developing solutions for human-lion conflict is of paramount importance for the conservation of lion populations and the improvement of human well-being.

At the coarsest resolution, human-lion conflict can only occur where lions and people interact. However, spatio-temporal patterns of human-lion conflict are considerably more complex than that. Evident variation in hotspots of human-lion conflict illustrate that the factors that promote conflict are highly complex (Baker et al., 2008; Kissui, 2008; Dickman et al., 2014; Miller, 2015). This complexity problematizes efforts to prescribe robust interventionist practices meant to alleviate that conflict. Close examination of human-carnivore conflict broadly, and human-lion conflict more specifically, reveals there are five, not two (as the phrase implies), dimensions that play a role. Spatio-temporal patterns of conflict depend not only on humans and carnivores, but also on livestock, wild prey, and environmental factors. The five dimensions of human-carnivore conflict are (**Figure 1**):

- 1) the carnivore (hereafter referred to as the “lion”) dimension - including information relating to the distribution, abundance, and behavior of carnivores



FIGURE 1 | Human-carnivore conflict broadly, and human-lion conflict more specifically, is an inherently interdisciplinary issue with five dimensions that broadly determine the intensity of conflict.

- 2) the livestock dimension
 - including information relating to the distribution, abundance, and behavior of livestock
- 3) the wild prey dimension
 - including information relating to the distribution, abundance, and behavior of wild prey
- 4) the human dimension
 - including information on human perceptions/attitudes, practices, finances, and policies
- 5) the environmental dimension
 - including information relating to weather, seasonality, and land cover.

Given that five dimensions contribute to spatio-temporal patterns and intensity of human-lion conflict, this ecological phenomena is inherently multidimensional.

Recent calls among the scientific community have identified the fundamental need to address multidimensional, or *wicked*, problems via multidisciplinary and interdisciplinary research (Mascia et al., 2003; White and Ward, 2010; Ledford, 2015; Rylance, 2015). Indicative of the importance of these approaches the journal *Nature* devoted an entire issue to explorations of multi-, inter-, and trans-disciplinary research in 2015 (volume 525, issue 7569). Multidisciplinary research is often defined as research that incorporates scholars and methods from multiple disciplines to study a problem or system, but the different disciplinary perspectives remain largely distinct; moreover, one discipline typically dominates the others (Eigenbrode et al.,

2007; Miller et al., 2008). Interdisciplinary research is often defined as incorporating deeper integration between different perspectives, such that investigators develop greater appreciation for each other's methodological approaches and sometimes develop new questions and methods (Eigenbrode et al., 2007; Miller et al., 2008). Transdisciplinary research involves the deepest integration of disciplinary perspectives, such that the individual disciplines are ultimately transcended and researchers develop new, unifying epistemological perspectives (Eigenbrode et al., 2007; Miller et al., 2008).

It remains to be seen whether completely new epistemological frameworks and categories will arise (thereby generating transdisciplinary research), but it seems unlikely that the complexity of the problems generated by human-lion conflict can be solved without interdisciplinary research that extensively incorporates and integrates insights from multiple disciplinary perspectives to confront the ecological and social components of the problem (Macdonald et al., 2010; White and Ward, 2010; Suryawanshi et al., 2013; Soh et al., 2014; Redpath et al., 2015; Angelici, 2016; Pooley, 2016; Macdonald and Chapron, 2017). Within this context, our study objectives were to:

- i) Examine the extent to which research on human-lion conflict has been interdisciplinary by deploying an extensive review of the literature on this topic published between 1990 and 2015.
- ii) Discuss the potential consequences of the observed levels of interdisciplinary on lion conservation and human livelihood improvement.

- iii) Use the information garnered from this review to codify the manner in which human-lion conflict research could be shaped to be more interdisciplinary in future.

Evaluations of this type are important because they can quantify existing approaches to research and present the ways in which solutions are framed. Lions are among the most conspicuously social species within the family *Felidae* (Macdonald et al., 2010). That extreme in behavior, and doubtless their remarkable charisma (Macdonald et al., 2015), has attracted extensive study. Thus, our intent was to examine whether the willingness to be interdisciplinary among prides of lion researchers mirrors the gregariousness of their study species.

MATERIALS AND METHODS

Literature Review

We conducted an extensive search of the related literature in January of 2016. We carried out this search among four databases including Web of Science (WoS) Core Collection, Scopus, Wildlife and Ecology Studies Worldwide (WESW), and the search engine Google Scholar. We engineered our search across multiple databases to ensure that the results were representative of the literature output as a whole. Each database was searched a total of three times (primary, secondary, and tertiary searches), with each subsequent search introducing additional search terms to further narrow the results. The search structure and terms remained consistent across searches in the three commercial databases, but the searching limitations inherent in Google Scholar required additional restrictions to the exact search parameters used.

Searches within the WoS, Scopus, and WESW databases were limited to title, keyword, and abstract. Identical search terms were used in the same sequence across the three databases. The primary search terms used were “human lion livestock” AND “panthera leo.” The second search added the term “conflict” to the initial terms and the tertiary search added “depredation” to the already used terms. The primary terms used for the Google Scholar search were “human lion conflict” as a phrase search to limit the results to those featuring that exact phrase. The secondary and tertiary searches built on the baseline by adding “panthera leo” and then “depredation” respectively. Due to the broad range of results provided from the Google Scholar searches and the lack of limiting functionality, we curated the results to remove non-peer-reviewed and abstract-only objects, duplicates, and annotated bibliographies.

Evaluating the Dimensions of Human-Lion Conflict Research

We then reviewed this literature to determine the applicability of each paper to human-lion conflict research. We recorded the stated research objective for each paper and excluded those papers that were not relevant to human-lion conflict research. After this exclusion process, we read each paper in detail. We documented the country where the study took place and then recorded whether the paper addressed each of the five dimensions of human-lion conflict. We documented whether

the paper studied each dimension (0, 1). In cases where that dimension was studied, we recorded the exact research technique used. Multiple research techniques could be used for studying any given dimension. We then calculated a Spearman rank correlation matrix to determine the degree of relatedness among the tendency for researchers to address multiple dimensions in a given paper.

Popular Literature

We also conducted a search of the popular literature in December 2016. The search was carried out in the database LexisNexis Academic. The subject was limited to the *All News* setting and the advanced search option source type was set to include the following categories: newspapers, major world publications, magazines, wire services, blogs, business and industry news, university newspapers, U.S. newspapers, and webnews. The date range for the search was limited to 1990-2015. The search terms were modified to broaden their scope given the lack of standardized vocabulary usage in popular writing. The terms that we used were “human lion conflict Africa.”

Co-author Analyses

We next conducted co-author analyses to determine the level of interdisciplinarity and multidisciplinary among the papers addressing human-lion conflict. Co-author analyses are an ideal method for calculating interdisciplinarity and multidisciplinary since these measures primarily address research practice rather than the content of a paper (Schummer, 2004). We excluded all theses, dissertations, and technical reports from this part of the study given a lack of co-author information. Co-authors from non-governmental organizations (NGOs), private industry, and in some cases governmental organizations, were difficult to place into a single discipline strictly using co-author affiliations. Thus, for NGOs and the private industry, we additionally used internet searches to determine a statement of purpose for each organization so as to facilitate the placement of co-authors into a given discipline. As governmental organizations often perform research on a variety of disciplines, we required a department to be stated within the co-author affiliation so as to place that co-author within a specific discipline. If this information was missing, we excluded that co-author from the disciplinary analyses. Additionally, when multiple affiliations were given for a single author we strictly recorded the primary affiliation. However, if the primary affiliation was ambiguous, we used additional affiliations to clarify geography, institution, and/or discipline.

To measure multidisciplinary, we developed a count of the number of disciplines represented in each paper, as determined by the co-author affiliations (see Schummer, 2004). We used this information to calculate a Multidisciplinary Index (M), observing the stated threshold of 5% (Schummer, 2004). This technique facilitates comparisons of the number of disciplines involved among the co-authorship in $\geq 5\%$ of human-lion conflict literature. This metric is created via the following equation:

$$M^{0.05} = \text{count } [c_i] \text{ if } c_i > 0.05 \tag{1}$$

$$c_i = n_i/N$$

where c_i was the relative size of the i th discipline. The number of papers having at least one co-author in the i th discipline was denoted by n_i , and the total number of papers was represented by N . Next, the relative size of the largest discipline (c^{max}) can be calculated by:

$$c^{max} = \text{Max } [c_i] \tag{2}$$

To calculate the level of interdisciplinarity, we assessed the number of papers that were co-authored by individuals from more than one discipline. We calculated this metric for papers having co-authors that hailed from ≥ 2 disciplines (I^2) and again for papers having co-authors from ≥ 3 disciplines (I^3). Herein:

$$I^2 = \frac{\text{the number of papers co-authored by individuals from } \geq 2 \text{ disciplines}}{N} \tag{3}$$

$$I^3 = \frac{\text{the number of papers co-authored by individuals from } \geq 3 \text{ disciplines}}{N} \tag{4}$$

Next we built an interdisciplinarity matrix which displayed all possible combinations of the collaborating disciplines. Here, $n_{i,k}$ represents the number of papers that included at least one co-author from the i th and k th disciplines. We then calculated bi-disciplinarity coefficients ($c_{i,k}$) for each combination of disciplines as a function of:

$$c_{i,k} = n_{i,k}/N \tag{5}$$

It is worth noting that the diagonals of the resultant interdisciplinarity matrix represent the relative number of monodisciplinary papers for each respective discipline. Lastly, we can determine how often each discipline participates in interdisciplinarity collaboration when conducting human-lion conflict research (si_i) using the following equation:

$$si_i = \sum_{k \neq i} c_{i,k}/c_i \tag{6}$$

In addition to evaluating the country in which the field research on human-lion conflict occurred, we also assessed the geographic location of each co-author's affiliation to get a sense of the degree of apparent cross-regional collaboration. While indicative of the co-author's geographic institutional affiliation at the time that the paper was published, this information does not in any way account for a co-author's country of origin.

Finally, we conducted a keyword analysis to determine the ways in which co-authors of human-lion conflict research describe their papers. We developed a database of all of the keywords used among the resultant human-lion conflict literature. Then using word cloud techniques we graphically represented the results of this analysis where the size of the keyword represented the intensity with which it was used across the literature.

RESULTS

We returned 158 unique lion research papers from our primary, secondary, and tertiary searches of literature published between 1990 and 2015 (Figure 2A). These papers derived from examination of four different search engines including Google Scholar, WoS, Scopus, and WESW (Figure S1). The baseline search terms (“human,” “lion,” and “livestock”) generated the largest number of papers for each search engine with the number decreasing as subsequent search terms were added in secondary (baseline + “panthera leo”) and tertiary searches (baseline + “panthera leo” and baseline + “panthera leo” + “depredation”; Figure S1). Google Scholar returned the largest number of papers, followed by WoS, Scopus, and finally WESW (Figure 1).

Among this set of papers, 70 were not specifically applicable to human-lion conflict research. We excluded papers when their stated research objectives were inconsistent with human-lion conflict. These papers tended to explore aspects of lion ecology irrespective of their relationship with people. We also excluded papers if they were pure reviews, primarily assessed trophy hunting of lions, examined lions in the paleological record, or mentioned lions but the focus was another species (e.g., hyenas, leopards, cheetahs). After removing these 70 papers, we retained 88 papers for examination of human-lion interaction and lion ecology in relation to sources of anthropogenic disturbance.

Research on human-lion conflict grew dramatically from 1990 to 2015 (Figure 2A), a trend that was consistent regardless of the search engine used (Figure S1). An exponential model of these temporal trends ($y = 8E-194e0.222x$) yielded a close fit to the data ($R^2 = 0.76$), suggesting growth in this research area was near-exponential from 1990 to 2015. All search engines demonstrated that research on the topic of human-lion conflict was virtually non-existent in the 1990's. Lions were downgraded by the IUCN Red List from threatened to vulnerable in 1996. Yet, it was not until the mid-2000's and into the 2010's that the research effort substantially expanded (Figure S1). For example, from 2013 to 2015, an average of 13.3 papers addressing human-lion conflict were published annually.

We found that the growth of research on human-lion conflict corresponded with growth in the popular literature coverage of conflicts between people and lions (Figure 2B). Furthermore, despite the research effort and corresponding media attention, the global population of lions continued to decline rapidly across this time period (Figure 2C). While these are admittedly coarse population estimates, between 1990 and 2015 lion populations reduced by almost half (Bauer et al., 2015; Figure 2C). Across

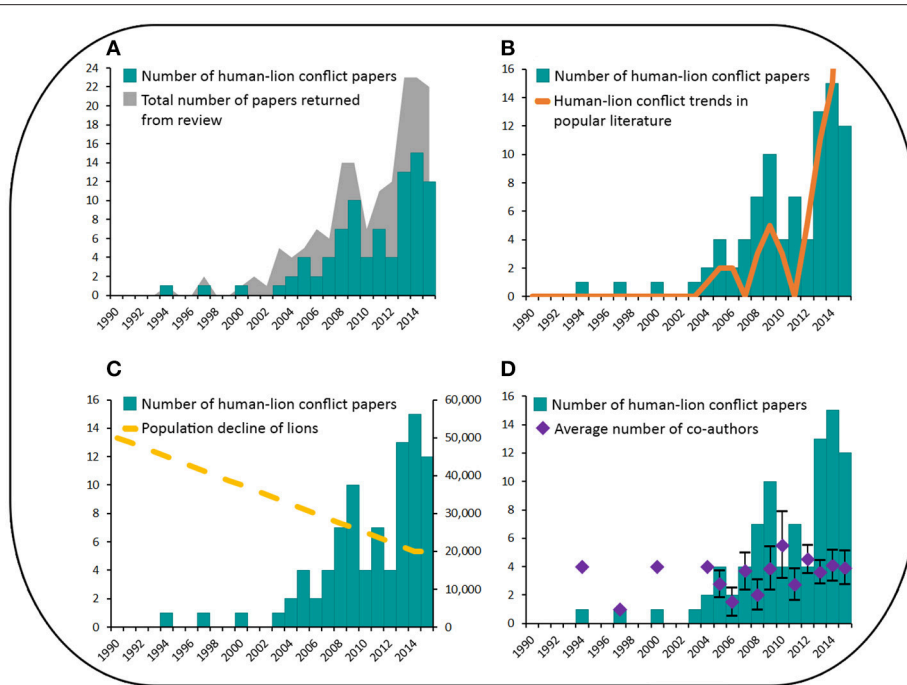


FIGURE 2 | Temporal trends in the number of human-lion conflict papers from 1990 to 2015 in relation to (A) the total number of papers returned from our extensive literature review, (B) trends in human-lion conflict in the popular literature, (C) the downward trajectory of lion (*Panthera leo*) populations, and (D) the average number of co-authors of associated with those papers.

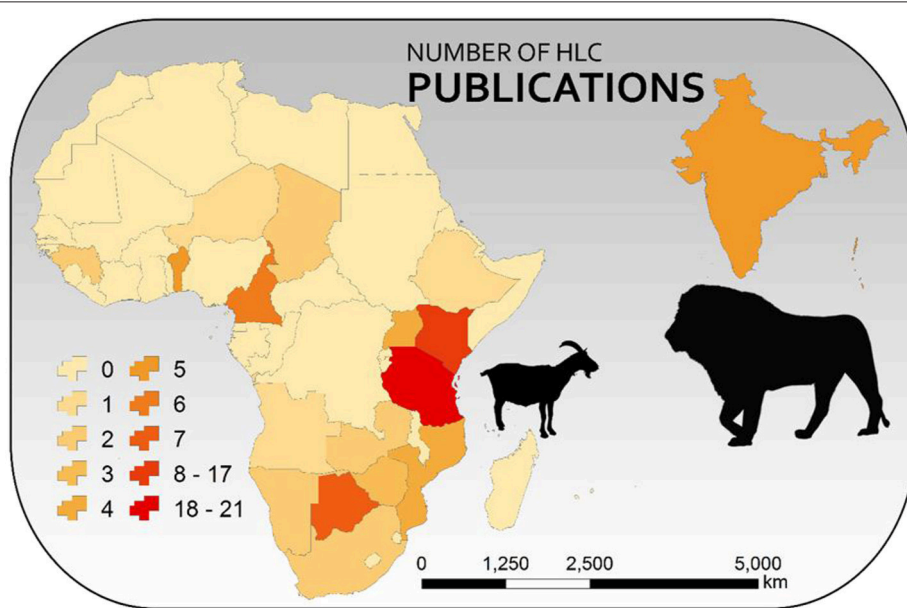
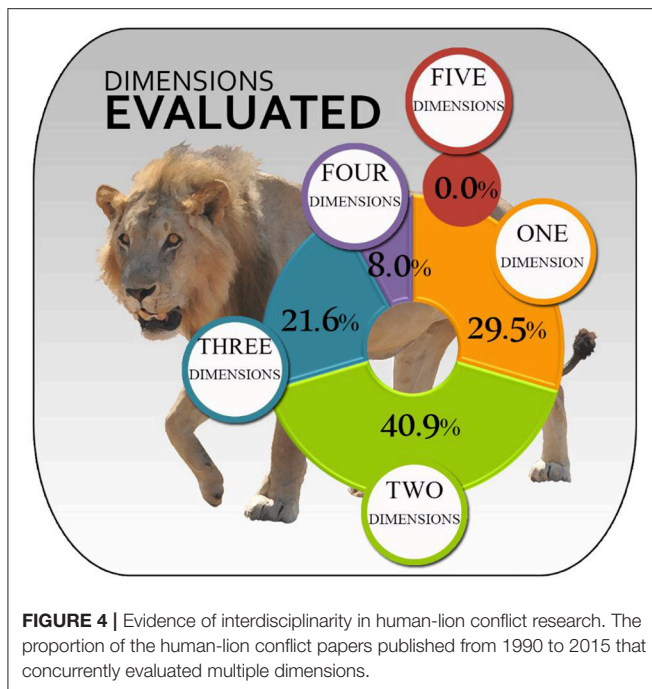


FIGURE 3 | The country location of the field component of human-lion conflict research. The figure depicts spatial variation in the number of papers evaluating human-lion conflict from 1990 to 2015.

that same period however, the number of co-authors engaged in human-lion conflict research changed very little (Figure 2D). While the range in the number of co-authors engaged in human-lion conflict research was between one and nine, the mean was

3.28 with a relatively narrow standard error on the estimate (se = 0.19), demonstrating consistency over time (Figure 2D).

The human-lion conflict field research was positioned across 16 countries in sub-Saharan Africa as well as India. The majority



of that research occurred in East Africa (Figure 3). Tanzania ($n = 21$) had the highest number of human-lion conflict papers with Kenya following in second position ($n = 17$). Thereafter the number of human-lion conflict papers declined rapidly with no one country recording greater than seven total papers from 1990 to 2015 (Figure 3).

The dimension that was most commonly evaluated was the human dimension ($n = 46$, 52.3% of the papers). The lion dimension was next ($n = 42$, 47.7%) followed by the environmental dimension ($n = 38$, 43.2%), and then the livestock dimension ($n = 33$, 37.5%). Finally, the dimension that was least likely to be assessed was the wild prey dimension ($n = 24$, 27.3%). The vast majority of these papers evaluated only one ($n = 26$) or two ($n = 36$) of the human-lion conflict dimensions at a time (Figure 4). Far fewer papers concurrently evaluated three dimensions ($n = 19$) and a small minority of papers assessed four dimensions ($n = 7$; Figure 4). No paper that we reviewed assessed all five dimensions of human-lion conflict concurrently (Figure 4). Furthermore, we detected no correlation among the dimensions that were evaluated (Table S1). The most likely tendency ($|r| = 0.59$; Table S1) was to study the human dimension and the lion dimension in the same paper.

Within each dimension, the exact research technique used also varied (Figure 5). There were seven primary techniques used to study the lion dimension, five for the livestock dimension, nine for the wild prey dimension, five for the human dimension, and three for the environmental dimension (Figure 5). The majority of papers that evaluated the lion dimension used telemetry to track movement and map the habitat/resource selection of lions (Figure 5). Other techniques included spoor surveys, call-up surveys, continuous follows, camera traps, examinations of lion dental records, and human surveys gauging lion ecology. The most common technique used to assess the livestock

dimension was surveys (aerial, head counts, reports/interviews of number of livestock owned) of livestock herds, followed by examination of depredation locations, participatory mapping of livestock movement, telemetry, and literature surveys to reveal information about livestock ecology (Figure 5). There were a diversity of techniques used to assess the wild prey dimension and no single one was predominant (Figure 5). The human dimension and the environmental dimension were considerably more consistent. Though the human dimension was evaluated using camera traps, reported data on human populations, structured survey designs, and human space use mapping, by far the most common technique was semi-structured human surveys (Figure 5). Finally, to study the environmental dimension, co-authors mapped climate/weather/seasonal conditions, evaluated land cover characteristics, and calculated proximity metrics (e.g., distance to features of interest including, but not limited to, protected area boundary, water sources, and habitat edges; Figure 5).

Co-authors of these human-lion conflict papers derived from a set of nine total disciplinary categories (Table 1). Three disciplines (biology/ecology/zoology, wildlife management/conservation, and environmental science) clearly had the largest relative size (Table 1). Biology/ecology/zoology had a relative size of 53.3%, wildlife management/conservation had a relative size of 36.0%, and environmental science had a relative size of 33.3%, respectively. Comparatively, social-science and humanities-based disciplines were underrepresented (Table 1). For example, social sciences, political science/policy, philosophy, anthropology, and geography each yielded a relative size of <4.0% (Table 1). Overall, we found that less than a quarter ($I^2 = 22.7$) of human-lion conflict papers had co-authors that derived from two or more disciplines and even fewer ($I^3 = 10.7$) had co-authors from three disciplines. Calculation of an interdisciplinary index ($M^{0.05} = 3$), revealed that this interdisciplinarity occurred between and among co-authors from biology/ecology/zoology, wildlife management/conservation, and environmental science, three inter-related STEM fields.

Co-authors conducting human-lion conflict research were affiliated with four primary types of institutions (academic, NGOs, governments, or private foundations/industries). Those from academic institutions were the most common co-authors of human-lion conflict research, occurring in 86.0% (relative size) of all papers. Co-authors from NGOs were the second-most common (occurring in 28.0% of all papers), followed by co-authors from governments (21.0%), and finally those from private foundations/industries (4.0%). Collaboration of co-authors across these institutional groups was also not uncommon but only tended to involve authors from two or more of these groups ($I_1^2 = 34.7$) and very rarely from three or more of these groups ($I_1^3 = 5.3$). The most frequent collaboration occurred among co-authors from academic institutions and NGOs. This type of collaboration was observed in 13.3% of all papers.

We also found that co-authors of human-lion conflict research had affiliations with institutions based in North America, Europe, Africa, and Asia. Co-authors with affiliations in Africa were most common (occurring in 54.7% of all papers) followed closely by co-authors in Europe (46.7%) and in North America (45.3%).

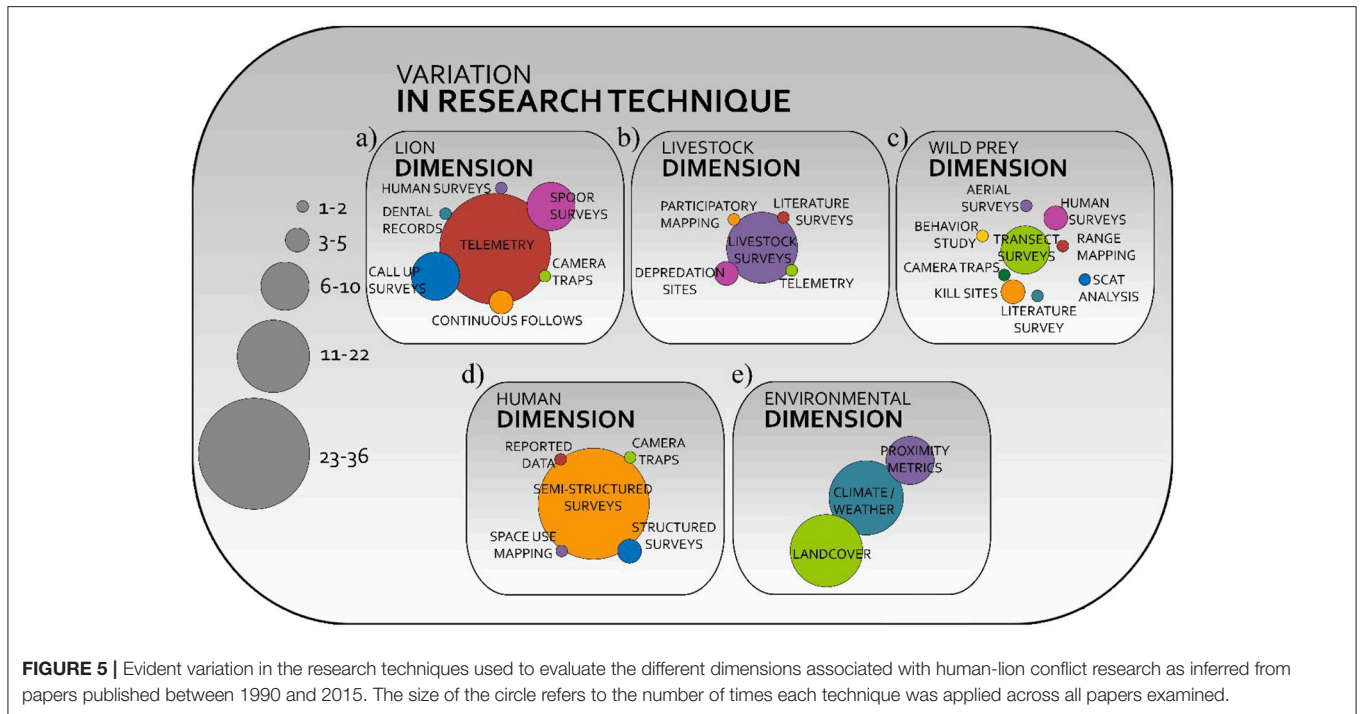


FIGURE 5 | Evident variation in the research techniques used to evaluate the different dimensions associated with human-lion conflict research as inferred from papers published between 1990 and 2015. The size of the circle refers to the number of times each technique was applied across all papers examined.

Co-authors from Asia occurred in just 6.7% of all papers. Our geographic collaboration index indicated that 45.3% of papers were published by co-authors from two or more geographic regions. These geographic collaborations tended to occur most frequently between Europe and Africa, comprising ~23% of all papers.

Finally, with respect to our keyword analysis, there were 21 papers that we excluded from this assessment given that they did not provide keywords. The number of keywords per paper ranged from four to 10 and averaged 5.98 (se = 0.22). The most frequently used keyword was “lion” followed by “human-wildlife conflict,” “*Panthera leo*,” “African lion,” and “livestock depredation” (Figure S2).

DISCUSSION

Research on human-lion conflict and corresponding coverage of this issue in the popular literature experienced near-exponential growth from 1990 to 2015. The vast majority (89%) of the papers were published across a 10-year period from 2006 to 2015. For instance, there were more papers published per year in 2013, 2014, and 2015 on human-lion conflict than the total number of papers published from 1990 to 2006 (Figure 2A). Despite the growth in the research area and the coverage of that research in the popular literature (Figure 2B), the global lion population has continued to decline (Figure 2C). This questions whether the research relating to human-lion conflict is effectual at conserving lions. We do highlight that scientific research is often reactive (Groves et al., 2002) and thereby, we should anticipate lag effects between publication of research papers and the potential

conservation benefits on the species of interest (e.g., Brooks et al., 1999). Thus, given the intensity of human-carnivore conflict research in recent years, it is likely still too soon to see the impacts of that research on the recovery of lion populations.

But the trends that we present here are also part of a broader discussion relating to the divide between human-carnivore conflict research and policy formation (see Macdonald et al., 2010, 2015). Just 2.7% of the papers had co-authors affiliated with units in the political science/policy discipline. Of course, it is not only the policies themselves that are important, but the adoption and implementation of management action at a local level. That point brings us back to the human communities bordering the protected areas where lions typically reside. Lion researchers have made great strides in centering the development of conflict solutions in these communities (e.g., Woodroffe et al., 2007; Hazzah et al., 2014; Loveridge et al., 2017). Thus, co-authors of human-lion conflict research may focus on implementing management strategies deriving from their research rather than endeavoring to inform policy. Moving forward, we suggest that more robust incorporation of experts from political science and policy (see Macdonald et al., 2010; Posner et al., 2016) and adaptive co-management among teams of interdisciplinary researchers and human communities (Berkes, 2004) will be necessary to position conservation efforts into practice (Groves et al., 2002; Redpath et al., 2013). Recent movements (e.g., the Oxford Format) have made efforts to do just that by convening experts from within and, importantly, beyond, the fields of biology/ecology/zoology, wildlife management/conservation, and environmental science to develop new lion conservation approaches (Macdonald and Chapron, 2017).

We found that East Africa (namely Tanzania and Kenya) was the center of human-lion conflict research (**Figure 3**). This is important because East Africa is home to the majority of remaining lions on the planet and four of the reported 10 last stronghold lion populations (those that inhabit protected areas and have >500 adult lions; Riggio et al., 2013; Bauer et al., 2015). Recent projections suggest that lions in East Africa may further reduce by 50% over the next 20 years (Bauer et al., 2015). This decline, along with predictions for Western-Central Africa, could position the species itself on the precipice of extinction throughout much of its range (Henschel et al., 2014; Bauer et al., 2015). Though spatial variation is evident, lion populations are primarily growing in highly-managed, often fenced, reserves in four southern African countries (Namibia, Botswana, South Africa, and Zimbabwe; Bauer et al., 2015; Riggio et al., 2015). There are additional elements at play, apart from fencing, including management philosophy, financial budgets and allocations to conservation efforts, prey abundance, and human population density. But the association between lion population growth and fencing has encouraged an avid debate about the role that fenced parks may play in the conservation of lions in the future (Creel et al., 2013; Packer et al., 2013; Watson, 2013; Pfeifer et al., 2014; Durant et al., 2015). Importantly, these discussions will need to be informed not only by insights from STEM fields but also by perspectives from the humanities and social sciences (e.g., human perceptions, behaviors, ethics, historic cultures and practices, future goals, and governance structures).

Little Evidence of Interdisciplinarity

Despite the rapid expansion in published human-lion conflict research and calls among the scientific community and funding entities for interdisciplinary research, the number of co-authors on resultant papers has changed little over time (**Figure 2D**). On average, there were 3.28 (se = 0.19) co-authors on any given human-lion conflict paper. A vast majority (86% relative size) of these papers featured co-authors with academic affiliations. Where co-authors of the same paper came from different institutions, the most common collaboration occurred between academicians and researchers from NGOs. Interestingly, the co-authors of human-lion conflict research predominantly derived from three STEM disciplines (biology/ecology/zoology, wildlife management/conservation, and environmental science). These three fields were the most highly related disciplines among the nine represented in our study (**Table 1**). Humanities and social-science disciplines, on the other hand, were greatly underrepresented in human-lion conflict research. Despite these results, we found that the most commonly-evaluated dimension in human-lion conflict research was the human dimension. This might suggest that researchers studying the human dimensions of human-lion conflict research were not disciplinary experts in the social sciences. We caution however, that the relative sizes presented here (**Table 1**) should be viewed as conservative estimates. There is limited information that can be garnered from interpretation of co-author affiliations. Thus, we suspect that there were instances in which a co-author's disciplinary affiliation was not descriptive of that individual's expertise

(e.g., a human dimensions expert that currently works as an academic in a Department of Zoology). Furthermore, we highlight the possibility that certain co-authors may have become competent in human-dimensions research without explicit disciplinary training (i.e., self-taught, short courses, and workshops). Nevertheless, given the obvious importance of human dimensions in human-lion conflict research, the low levels of integration of co-authors from fields such as philosophy, anthropology, and social science is troubling.

This point raises the concern that current research on human-lion conflict is unlikely to reflect genuine interdisciplinarity, which requires authentic integration of multiple disciplinary perspectives (Eigenbrode et al., 2007). Different disciplines emphasize distinct questions and ways of framing complex problems (Miller et al., 2008; Elliott, 2017). Conservation problems are almost always importantly complex, requiring multidimensional, rather than singular, solutions (Blaustein and Kiesecker, 2002; Hirsch et al., 2011). One of the major benefits of interdisciplinary research is that it brings these distinct approaches together to generate more comprehensive appreciations of complex problems (Daily and Ehrlich, 1999; Rhoten and Parker, 2004; Chapman et al., 2015). Unfortunately, even if research on human-lion conflict incorporates some co-authors with the ability to use methods from the social sciences, this research is unlikely to reflect a rich, interdisciplinary appreciation of the issues at play if it continues to originate primarily from STEM-dominated disciplinary questions and perspectives. In that case, robust solutions for human-lion conflict will continue to be elusive, problematizing efforts to conserve lions and improve human well-being. Furthermore, given the current disconnect between human-lion conflict research and policy formation, it seems particularly important to encourage research driven by perspectives from policy-oriented disciplines (i.e., Macdonald and Chapron, 2017).

These potential shortcomings however, are not exclusively attributable to lion biologists, zoologists, or ecologists. Lion researchers have made efforts to incorporate experts from the social sciences for many years (see Macdonald et al., 2007) and have, at times, found it challenging to get meaningful collaboration from social scientists and humanities experts (Macdonald et al., 2010, 2013). Thus, the burden of proof in interdisciplinary research falls upon the co-authors from each of the representative disciplinary domains (Campbell, 2005). We do see positive indications that research teams evaluating lion conservation problems are becoming increasingly interdisciplinary (Pooley, 2016; Macdonald and Chapron, 2017) and we expect that to be a trend that will only grow moving forward. Furthermore, the results that we present here should not be particularly surprising. Educational and career training systems are increasingly specialized and tend not to incentivize the development of broad interdisciplinary expertise (Dickman, 2010; Macdonald et al., 2013). This point presents the context for the relatively low levels of interdisciplinarity that we detected within human-lion conflict research and further emphasizes the need for robust interdisciplinary collaboration.

TABLE 1 | Discipline categories for co-authors of human-lion conflict research papers published between 1990 and 2015.

DISCIPLINARY CATEGORIES OF CO-AUTHORS		
ABBREVIATION	DISCIPLINE	RELATIVE SIZE
B	BIOLOGY, ECOLOGY, ZOOLOGY	53.3
W	WILDLIFE MANAGEMENT / CONSERVATION	36.0
E	ENVIRONMENTAL SCIENCE	33.3
SS	SOCIAL SCIENCES	4.0
PS	POLITICAL SCIENCE / POLICY	2.7
P	PHILOSOPHY	2.7
A	ANTHROPOLOGY	2.7
S	STATISTICS	1.3
G	GEOGRAPHY	1.3

The relative size of the total co-authorship group presented by each discipline is also presented.

Limited Comparability of Research

While the human dimension (52%) was most commonly assessed, the lion dimension (48%) was a close second. Increasingly, human-wildlife conflict research is as much, or more, about people than wildlife (Treves et al., 2009; Redpath et al., 2010; White and Ward, 2010). Thereby, research on human-wildlife conflict has largely been envisaged as having two predominant spheres (involving humans and wildlife; Manfredi and Dayer, 2004; Redpath et al., 2004; Thirgood and Redpath, 2008) and our results reflect that central tendency. Subsequent expansion of this ideology has reframed these spheres into three domains represented by organisms, habitat, and humans (Decker et al., 2012). We found human-lion conflict research to have five dimensions. Following the human and lion dimensions, the environmental dimension (43%) and the livestock dimension (38%) were the next most-evaluated. The wild-prey dimension was comparatively understudied (27%). This result is interesting given that wild-prey depletion has been presented as a potential causal mechanism associated with lions switching from wild-prey to domestic livestock fueling human-lion conflict (Patterson et al., 2004; Gusset et al., 2009). Furthermore, loss of wild-prey species is one of the biggest concerns for lion conservation in future given that while there might be enough protected land to support lion populations, the utility of that land would be modest without adequate prey to support lion populations (Macdonald, 2016; Wolf and Ripple, 2016). We recommend that efforts be

made to increase research on the role of wild-prey in human-lion conflict and carnivore conservation, more broadly (see Wolf and Ripple, 2016).

Research across these different dimensions also showed a pattern of considerable variation in the methodological technique deployed (Figure 5). This was particularly evident in the wild-prey dimension where dramatic variation in the style of research should be expected to complicate efforts to compare results across studies, countries, and regions. Such variation is problematic in a number of different disciplines including predator-prey research (Lima and Dill, 1990; Weissburg et al., 2014), but is particularly obvious in research occurring in carnivore-ungulate systems (Moll et al., 2017). An area of potentially productive future research would be a social network analysis (see Nita et al., 2016; Rozyłowicz et al., 2017) of the interconnectedness of these prides of lion researchers. The application of social network analysis tools could, for instance, document existing webs of collaboration, chart the spread of research techniques throughout these networks, and identify those portions of the network that disproportionately contribute to research on human-lion conflict.

A New Pride of Lion Researchers

Human-lion conflict research has been much-needed, ground breaking (in many cases), and well-intentioned. However, we have pointed out areas where this research effort can

be strengthened. Examination of these areas facilitates an opportunity to synthesize existing information and codify a path forward. Thus, based on this review, we suggest that there is productive space available for the evolution of new prides of lion researchers to examine the different dimensions of human-lion conflict in a way that may be more forward-thinking and effective. Here we relay a series of specific recommendations deriving from our research effort. First, we recommend that researchers endeavor to simultaneously evaluate all five dimensions of human-lion conflict. Whereas it may be possible to partition particular dimensions of human-lion conflict among some research efforts, studying this problem in a holistic manner is necessary to document the factors that account for the most variation observed in spatio-temporal patterns of conflict, for instance. Such evidence is much-needed to prioritize interventionist activities capable of reducing that conflict (Treves et al., 2004; Atwood and Breck, 2012). Second, we recommend that researchers conduct interdisciplinary research (Pooley, 2016) involving full and meaningful integration of contributors from diverse backgrounds, expertise, and affiliations who can bring together multiple disciplinary methods and framings of the problem (Eigenbrode et al., 2007; Miller et al., 2008; Macdonald and Chapron, 2017). Of particular need in human-lion conflict research is the incorporation of experts from the social sciences and humanities. Third, we recommend that researchers increase efforts to study the wild prey dimension. While this dimension was most understudied in our assessment there is good reason to believe that factors associated with wild-prey (e.g., depletion, ecology, movement) are particularly relevant to conflict between people and lions. Thus, increasing research on this topic should improve efforts to conserve lion populations while preserving human interests. Fourth, we recommend that, as much as is possible, researchers assess the different dimensions of human-lion conflict using comparable research techniques. This step would facilitate robust comparisons across studies which could

lead to conservation actions that are applicable at broader, more regional scales. Finally, we recommend that research on human-lion conflict continue to make efforts to inform policy actions. Promoting more genuinely interdisciplinary research that is driven by scholars from fields like anthropology, sociology, law, and public policy is likely to help address the research-policy divide. Both the development and enactment of progressive policies will be necessary to sustain species such as lions while preserving the well-being of people in an increasingly anthropocentric world.

AUTHOR CONTRIBUTIONS

RAM was the project leader and contributed to every aspect of the study. KE, MH, SG, JM, SR, BK, DK, RJM, TM, AM, LA, JB, CH, CB, and DM reviewed literature returned from this review, wrote sections of the manuscript and edited the entire manuscript. ET lead efforts to access all of the literature comprising this review and wrote and edited section of the manuscript. All authors equitably contributed to the creation of this review and approve submission to Frontiers.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fevo.2018.00049/full#supplementary-material>

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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