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Words matter: how ecologists discuss managed and non-managed bees and birds

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Abstract

Effectively promoting the stability and quality of ecosystem services involves the successful management of domesticated species and the control of introduced species. In the pollinator literature, interest and concern regarding pollinator species and pollinator health dramatically increased in recent years. Concurrently, the use of loaded terms when discussing domesticated and non-native species may have increased. As a result, pollinator ecology has inherited both the confusion associated with invasion biology's lack of a standardized terminology to describe native, managed, or introduced species as well as loaded terms with very strong positive or negative connotations. The recent explosion of research on native bees and alternative pollinators, coupled with the use of loaded language, has led to a perceived divide between native bee and managed bee researchers. In comparison, the bird literature discusses the study of managed (poultry) and non-managed (all other birds) species without an apparent conflict with regard to the use of terms with strong connotations or sentiment. Here, we analyze word usage when discussing non-managed and managed bee and bird species in 3614 ecological and evolutionary biology papers published between 1990 and 2019. Using time series analyses, we demonstrate how the use of specific descriptor terms (such as wild, introduced, and exotic) changed over time. We then conducted co-citation network analyses to determine whether papers that share references have similar terminology and sentiment. We predicted a negative language bias towards introduced species and positive language bias towards native species. We found an association between the term *invasive* and bumble bees and we observed significant increases in the usage of more ambiguous terms to describe non-managed species, such as *wild*. We detected a negative sentiment associated with the research area of pathogen spillover in bumble bees, which corroborates the subjectivity that language carries. We recommend using terms that acknowledge the role of human activities on pathogen spillover and biological invasions. Avoiding the usage of loaded terms when discussing managed and non-managed species will advance our understanding and promote effective and productive communication across scientists, general public, policy makers and other stake holders in our society.

Keywords Invasion biology · Sentiment analysis · Wild · Native · Introduced · Bibliometric analysis

Introduction

Promoting the stability of critical ecosystem services involves the control of introduced species that damage the environment. One step forward is to regulate human practices, such as the management of domesticated species, that may transform harmless species into harmful ones by inducing their geographic expansion, overgrowth and potentially becoming parasite hubs for spillover. Given the interdisciplinary nature of management, researchers in ecology and evolutionary biology need standard and descriptive terminology to ensure effective communication among scientists, funding agencies, law makers, land managers, and the general public (Lyall et al., 2013; MacLeod, 2018; Mennes et al., 2019; Olson et al., 2019). If the terminology used does not reflect a shared context or are associated with strong sentiments (negative or positive), such terms may increase confusion and misunderstanding within and among different fields (Kueffer & Larson, 2014). This is the case for terms with multiple meanings between daily life and scientific use in different disciplines (Wear, 1999). For example, the words *alien* and *exotic* have multiple colloquial meanings that differ from their definitions in ecology and evolutionary biology. Both mean *non-native* when referring to species in ecological literature, but in everyday parlance they can refer to something that is unfamiliar/extraterrestrial (*alien*) or striking/attractive (*exotic*). Similarly, the terms *wild* or *feral,* which refer to non-domesticated species in a biological context, have very different meanings in the general vernacular (Box 1). The use of these words may perpetuate confusion or imply judgement because the connotations of the terms (and hence their sentiment) may differ depending on context and audience.

Many terms used to refer to managed and non-managed species (i.e., those whose reproduction, growth, and survival are or are not controlled by human practices, respectively) have been adopted from invasion literature. Since its inception, invasion ecology has employed some militaristic or pejorative terms to describe and identify the processes and possible consequences of the establishment of introduced species (Davis, 2006; Larson, 2005). While these terms may successfully evoke action to control the introduced species, some of these terms, such as *alien,* may imply much stronger negative connotations in comparison to non-invasive terms, such as *native* (Box 1). In the last two decades, there has been a concerted effort to recognize and resolve these terminological ambiguities and move toward a unified framework (e.g., Blackburn et al., 2011; Chew & Laubichler, 2003; Lockwood et al., 2013; Warren et al., 2017; Young & Larson, 2011). While a standardized terminology is beneficial, it does not address the issue of the impact of loaded term usage when describing managed and non-managed species.

With the recent explosion of research interest in native bees and other pollinators, a perceived divide has arisen between native bee (non-managed, wild) and managed bee scientists. This potential conflict is apparent in the popular press (e.g., MacDonald, 2019; McAffee, 2020) and the scientific literature alike (Pritchard et al., 2021; Smith & Saunders, 2016), where honey bees can be somewhat vilified in native bee-focused pieces, while the importance of native bees may be downplayed in honey bee-centric pieces. In contrast, the avian literature discusses managed (poultry) and non-managed (all other birds) species with less obvious issues arising from terminology use. Furthermore, the use of loaded language employed by ecologists to discuss managed and non-managed species may be context dependent. For instance, the words used to refer to honey bees in the literature related to pollination services could hold different sentiments (negative, positive, or neutral) in comparison to the words used to describe these insects in papers related to diseases and pathogen spillover (Box 1). Importantly, in both groups of animals (bees and birds), managed species have escaped cultivation to establish populations in natural environments (e.g., Callaway, 2016; Marcelino et al., 2022). Honey bees' demographic history and establishment in natural areas is well-documented (Cridland et al., 2017, Moritz et al. 2007). For chickens, reports of feral populations are most well documented in the media (e.g., Buckley, 2004; Dorson, 2011, AP 2008, Honolulu Star-Advertiser, 2022), particularly in many subtropical and tropical areas such as Bermuda (Ferrairo et al., 2017), Florida (Vice News, 2021), Hawaii (Gering et al., 2015; Koopman & Pitt, 2007) and Norfolk Island (Langford et al., 2013). One of the most well-studied cases is on Kauai (HI, USA), where the hurricanes in 1982 and 1992 led domesticated chickens to escape their enclosures to establish populations in nature (Callaway, 2016). Given that bees and chickens establish populations in natural environments where they can overgrow and potentially have undesired consequences, we delved into the literature to assess patterns in term usage over time. We applied a bibliometric approach to investigate how scientists actively refer to honey bees (*Apis* spp.), bumble bees (*Bombus* spp.), bees (i.e., all other bees), chickens (*Gallus gallus* and *Gallus domesticus*), and birds (i.e., all other birds) in ecology and evolutionary biology publications from 1990 to 2019. Specifically, we investigated (i) if and how word usage changed over time, (ii) which terms changed the most, and (iii) how the use of a term varied among bee and bird groups. We then used co-citation networks to (iv) detect different knowledge areas, and (v) evaluate how the terminology and sentiment varied within and among them.

Box 1: Glossary

Defined below are the 24 descriptor terms used in this study categorized by cultivation status, biogeographical origin, or an assessment of its impact on economies or ecosystems. We included meanings found in different sources (e.g., texts, dictionaries and scientific literature). We selected terms a priori that (1) are used to describe managed and unmanaged birds and bees in ecological literature, and (2) represent a range of negative, neutral, and positive connotations that we assigned. Neutrality of terms is indicated in parentheses to the right of the word as – (negative), + (positive), or 0 (neutral). Only one term (peridomestic) was not present in the dataset. Some terms have multiple definitions: some references may use some terms interchangeably, while other references point out specific nuances in their definitions.

Agriculture/Cultivation

1. *Backyard* (0): located or occurring in a backyard (Merriam-Webster, 2022); [bees] honey bee hives in backyard of residential property managed for honey or other services (Bonney, 2012; Messner et al., 2014); [chickens] chickens in backyard of residential property managed for eggs or as pets (Elkhoraibi et al., 2014; Pollock, 2012; Pollock et al., 2012).
2. *Commercial* (0): suitable or prepared for commerce (Merriam-Webster, 2022); animals managed at large scale to make a profit (bees: Martin & McGregor, 1973; chickens: Mburu et al., 2006; Aho, 2002)..

3. *Domesticated* (0): adapted over time (as by selective breeding) from a wild or natural state to life in close association with and to the benefit of humans (Merriam-Webster, 2022); [animals] that are in regular contact with humans and whose behaviour or environment has been considerably influenced by this close contact (Piggins & Phillips, 1998); [bees] bees living in man-made hives and wild colonies as those living in natural sites (Crane, 1984).
4. *Feral* (–): having escaped from domestication and become wild (Merriam-Webster, 2022) or now existing in a wild state (Simberloff & Rejmanek, 2011); not domesticated or cultivated (Merriam-Webster, 2022; bees: Crane, 1984); domestic animals from the domestic environment and their return to natural conditions (Henriksen et al., 2018).
5. *Free-range* (+): animals allowed to range and forage with relative freedom (Merriam-Webster, 2022); animals allowed to access the outdoors (Kijlstra et al., 2009).
6. Managed (0): describing an animal (e.g., domestic livestock, domestic pets, or other animals) whose environment is strictly controlled by humans (Ohl & van der Staay, 2012); [bees] social and solitary bee species that are managed by humans (Klein et al., 2018).
7. *Peridomestic* (0): concerned with human habitations and their surroundings (Bezerra et al., 2014).
8. *Wild* (+): living in a state of nature and not tame or domesticated (Merriam-Webster 2022); uncontrolled, violent, or extreme (Cambridge, 2022); [bees] not managed by humans (Mallinger et al., 2017; Winfree, 2010).

Origin/Distribution

9. *Alien* (–): belonging to another place (OED, 2022); non-native (Lockwood et al., 2013; Pysek et al. 2020; Falk-Petersen et al., 2006).
10. *Endemic* (+): native species restricted to a certain locality or region (Merriam-Webster, 2022; Falk-Petersen et al., 2006); found in and restricted to a particular geographical area (Simberloff & Rejmanek, 2011).
11. *Exotic* (+): not native to the place where found (Merriam-Webster, 2022); Non-native or alien (Falk-Petersen et al., 2006); introduced species (Simberloff & Rejmanek, 2011); Unusual an exciting because of coming from far away, especially a tropical country (Cambridge, 2022).
12. *Foreign* (0): of, from, belonging to, or characteristic of some place other than the one under consideration (Merriam-Webster, 2022).
13. *Indigenous* (+): originating or occurring naturally in a particular place (Merriam-Webster, 2022) and whose presence does not result from human activity (Simberloff & Rejmanek, 2011); native (Falk-Petersen et al., 2006).
14. *Introduced* (0): Individuals of a species moved from their native range to a new location outside of their native range (Simberloff & Rejmanek, 2011); organism moved directly or indirectly by humans from its native past or present range to a range outside its distribution potential (Falk-Petersen et al., 2006).
15. *Native* (+): occurring within its natural past or present range/dispersal potential (Falk-Petersen et al., 2006); living or growing naturally in a particular region (Merriam-Webster, 2022); indigenous (Simberloff & Rejmanek, 2011).
16. *Naturalized* (+): to become established as if native (Merriam-Webster, 2022); Non-native species that is self-sustaining (Falk-Petersen et al., 2006); Describing or

referring to an introduced organism that reproduces without human help and that may or may not spread further (Simberloff & Rejmanek, 2011).
17. *Non-native* (−): living or growing in a place that is not the location of its natural occurrence (Merriam-Webster, 2022); species moved outside their normal geographic ranges due to human activities regardless of their impacts on native ecosystems (Lockwood et al, 2013); occurring outside its natural past or present range/dispersal potential (Falk-Petersen et al., 2006); introduced species (Simberloff & Rejmanek, 2011).
Impact
18. *Beneficial* (+): favorable or advantageous; producing good results or helpful effects (Merriam-Webster, 2022); species from which humans derive direct or indirect benefit (Alford, 2019).
19. *Damaging* (–): causing damage (Merriam-Webster, 2022); injuring or having a detrimental effect on (OED, 2022).
20. *Destructive* (–): causing great harm or damage (Merriam-Webster, 2022).
21. *Detrimental* (–): obviously harmful (Merriam-Webster, 2022);.
22. *Harmful* (–): causing or likely to cause harm (Merriam-Webster, 2022).
23. *Invasive* (–): Alien/non-native organism that have established a new area and expanding their range (Falk-Petersen et al., 2006) usually to the detriment of native species and ecosystems (Merriam-Webster, 2022); an introduced/non-native species that causes [or is likely to cause] negative ecological, economic or environmental harm or spreads aggressively (Lockwood et al., 2013; Beck et al., 2008).
24. *Pest* (–): a destructive organism that attacks crops, food, livestock, etc. (OED, 2022). Organisms harmful to humans or human activities (Falk-Petersen et al., 2006; Merriam-Webster, 2022); A species possessing characteristics that are considered hazardous or unwanted by humans (Simberloff & Rejmanek, 2011)

Methods

Literature search

We conducted a search of the ecological and evolutionary biology literature between the years 1990 and 2019 using the Web of Science database (Clarivate Analytics, USA) on 14 July 2020. We conducted topic searches for all pairwise combinations of five animal groups (honey bees, bumble bees, non-managed bees, chickens, and non-managed birds) and 24 descriptor terms (Box 1), for a total of 139 separate searches (Table S1.1 Appendix S1). In each search, we specified the topic terms (animal-descriptor term combination) in titles, abstracts, author keywords, and KeyWords Plus in articles (Document = "article") in the fields of ecology or evolutionary biology (Category = "ecology or evolutionary biology") published in English (Language = "English") between the years 1990 and 2020 in the Science Citation Index Expanded™. Out of 139 total searches, 108 searches representing 23 descriptor terms returned at least one paper (i.e., 1 of the 24 descriptor terms retrieved no results), yielding a total of 17,236 papers including duplicate articles (Table S1.2 Appendix S1). We further classified each of the 24 descriptor terms based on their connotation as negative, positive, or neutral (Box 1).

Filtering search results

To assess if an article resulting from our searches legitimately met our criteria, one of 10 authors manually reviewed each entry. We included an article in our dataset if the descriptor term was an active modifier of the animal term in titles, abstracts, and/or one of the author's keywords (Table S1.3). For example, for the descriptor term wild, if the abstract had the phrase "wild bumble bee" we included the article in our dataset, whereas we excluded a paper with the phrase "bumble bees visit wild flowers". In addition, we performed two quality controls (see Appendix S1) to ensure filtering accuracy. After filtering, 3614 valid records remained, representing 80 different animal-descriptor combinations (i.e., 59 of our original animal-descriptor combinations that returned results in Web of Science yielded no articles legitimately using the terms). For each term used in more than 10 papers, we conducted chi-square tests to compare usage across animal groups. We then assessed whether it was significantly more or less likely to be used for each animal group by calculating standardized residuals. All analyses were conducted in R v. 3.6.3 (R Core Team, 2021).

Time series analysis

For this analysis, we limited the dataset to complete years (e.g., 1990–2019) to identify trends in publication by year. We standardized the number of papers to account for increased publication of ecology and evolutionary biology manuscripts. We calculated standardized proportions by dividing the number of papers in each search by the total number of papers published in ecology and evolutionary biology by year for each taxonomic group. In a second analysis, we examined only terms for which there were at least 100 papers: *managed*, *wild*, *endemic*, *native*, *invasive*, *exotic*, and *introduced*. For these seven terms, we analyzed the standardized proportions across taxonomic groups for bees and for birds using linear models (package *lme4*, Bates et al., 2015), with year, animal, and year*animal interaction as fixed effects. We used the function *lstrends* to calculate the slope and function *pairs* to compare slopes in package *emmeans* (Lenth, 2019). We report full model results and post-hoc tests in Appendix S2 (Tables S2.1–2.2). We used the *streamgraph* package (Rudis, 2015) to visualize these results (Fig. 1).

Bibliometric network analysis

For each animal group, we created co-citation networks between the papers included in our database and their references using the function *NetMatrix* from the *bibliometrix* package (Aria & Cuccurullo, 2017). In co-citation networks, papers represent nodes and two papers are linked if they have at least one reference in common. In this sense, the more references two papers share, the more connected they are (Aria & Cuccurullo, 2017; Kessler, 1963). Such analysis enabled us to explore whether different studies in a field rely on the same intellectual influences (Nettle & Frankenhuis, 2019).

From the co-citation networks, we first identified unique modules–subsets of papers that share more references with each other than with the papers outside of that module (Girvan & Newman, 2002)—employing the Louvain algorithm (Blondel et al., 2008). Second, we determined a paper's influence level by calculating betweenness centrality, which represents how many times each paper acts as a bridge between two other papers. Thus, papers with higher betweenness centrality connect different publications and enhance

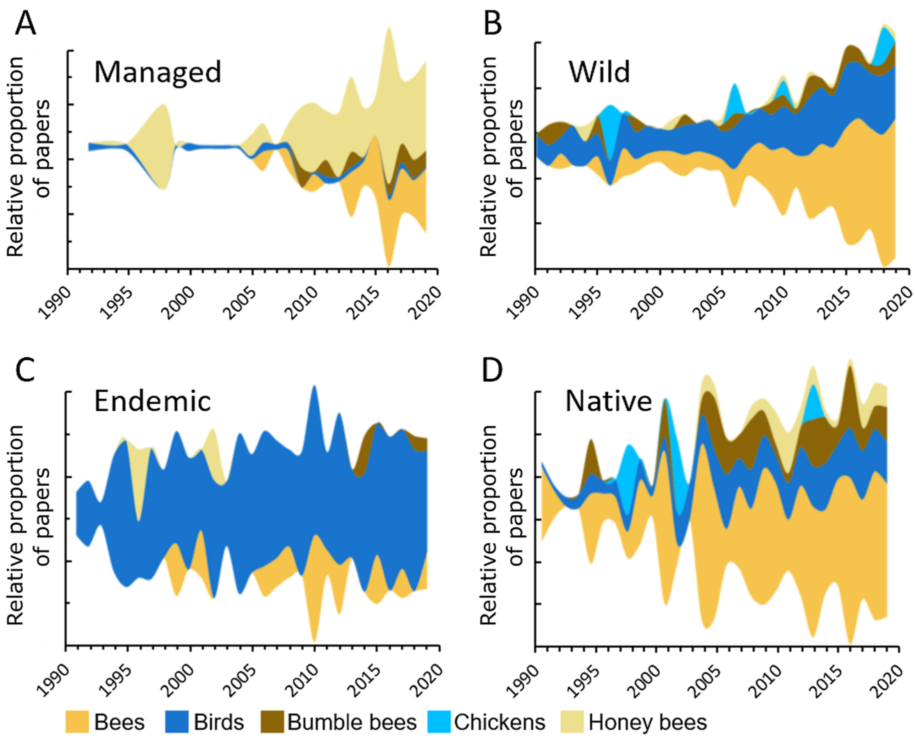

Fig. 1 Streamgraphs depicting changes in the relative proportion of papers using terms **A** *managed,* **B** *wild*, **C** *endemic*, and **D**) *native* over time by animal group

multidisciplinary research in the co-citation network (Diallo et al., 2016). Finally, we examined each module's knowledge structure by reading the titles, abstracts, and keywords of the 10 papers with the highest betweenness centrality per module. To compare modularity among networks, we created 99 null models for each co-citation network of our five organisms. We used the *nullmodel* function in the *vegan* package (Oksanen et al., 2015) to randomize citations while maintaining the total number of citations in each network and then calculated the modularity z-score for each network.

Sentiment analysis

To determine patterns in loaded language in the dataset, we assessed sentiment using the *sentiment_by* function in the *sentimentr* package (Rinker, 2017). This package calculates a sentiment score for each sentence within an abstract and then computes an average sentiment value from these scores for each journal article abstract. Sentiment values range from −1 to 1, with −1 being attributed to sentences with the most negative sentiments, 0 representing neutral sentences and 1 associated with the most positive sentences (see Appendix S1). These sentiment scores are indicative of how the general public may perceive the use of language in scientific publications. From the modularity analysis of the co-citation networks (see above), we first selected the largest four modules in each of the organisms' networks. We excluded chicken papers from this analysis due to small sample size ($N < 10$ papers per module). We used a Kruskal–Wallis test to assess whether abstract sentiment varied significantly by network module within each animal group. Lastly, to test for differences in abstract sentiment across animals in the full dataset, we again used a Kruskal–Wallis test and included all papers in the database in this analysis. Where appropriate, we conducted post-hoc tests using Wilcoxon rank-sum tests with false discovery rate adjustment for multiple comparisons (Benjamini & Hochberg, 1995).

Results

Our searches retrieved 3614 articles using our terms of interest that were produced by 9464 authors and published between 1990 and 2019. The descriptor terms that were more frequently used than expected are *wild* for bees, *managed* for honey bees, *commercial* for bumble bees, *endemic* for birds, and *domesticated* for chickens (Table 1). Honey bees exhibited higher than expected associations with terms for 9/16 terms, while bees in general were less associated than expected for 8/16 terms overall in our dataset.

Table 1 Number of papers in the final dataset that used the term of interest to describe each animal group

Term	Bees	Honey bees	Bumble bees	Birds	Chickens	Chi-square
Alien	4 (−)	0 (−)	11 (+)	59	0	$X^2_4 = 28.61$, $P < 0.0001$
Backyard	0	0	0	3	5	$X^2_4 = 227.39$, $P < 0.0001$
Beneficial	5	4 (+)	6 (+)	3 (−)	0	$X^2_4 = 52.15$, $P < 0.0001$
Commercial	6	19 (+)	22 (+)	8 (−)	14 (+)	$X^2_4 = 391.89$, $P < 0.0001$
Damaging	2	0	0	3	0	$X^2_4 = 3.03$, $P = 0.55$
Destructive	0	0	0	1	0	$X^2_4 = 0.36$, $P = 0.99$
Detrimental	2	4 (+)	2	5	0	$X^2_4 = 18.42$, $P = 0.0010$
Domesticated	1 (−)	10 (+)	2	22 (−)	13 (+)	$X^2_4 = 264.48$, $P < 0.0001$
Endemic	21 (−)	2 (−)	3 (−)	718 (+)	0 (−)	$X^2_4 = 200.76$, $P < 0.0001$
Exotic	17	15	10	103	2	$X^2_4 = 6.64$, $P = 0.16$
Feral	6 (−)	39 (+)	4	45 (−)	6 (+)	$X^2_4 = 203.46$, $P < 0.0001$
Foreign	0	1	1	0	0	$X^2_4 = 17.38$, $P = 0.0016$
Free-range	0	0	0	2	6	$X^2_4 = 329.44$, $P < 0.0001$
Harmful	0	0	0	3	0	$X^2_4 = 1.07$, $P = 0.90$
Indigenous	0 (−)	5	0	33	9 (+)	$X^2_4 = 121.91$, $P < 0.0001$
Introduced	22 (−)	62 (+)	21	237	2	$X^2_4 = 95.92$, $P < 0.0001$
Invasive	5 (−)	17 (+)	15 (+)	115	1	$X^2_4 = 29.60$, $P < 0.0001$
Managed	41 (+)	79 (+)	9	36 (−)	0	$X^2_4 = 531.98$, $P < 0.0001$
Native	249 (+)	31 (-)	54	986	3 (−)	$X^2_4 = 63.76$, $P < 0.0001$
Non-native	5	13 (+)	8 (+)	45	0	$X^2_4 = 28.71$, $P < 0.0001$
Peridomestic	0	0	0	1	0	NA
Pest	0 (−)	0	0	41	0	$X^2_4 = 14.64$, $P = 0.0055$
Wild	332 (+)	13 (−)	52 (−)	1226	6 (−)	$X^2_4 = 136.73$, $P < 0.0001$
Total	718	314	220	3695	67	

For terms used in more than 10 articles, (−) indicates that a term was significantly less used than expected and (+) indicates that a term was significantly more used than expected based on standardized residuals following Chi-square tests

Time series analysis

The use of each descriptor term followed different trajectories across time. We found that certain terms were more commonly used to describe certain animal groups and that the use of some terms increased more rapidly than others (Table S2.2 in Appendix S2). Specifically, the use of the term *managed* increased at a faster rate for honey bees than for any other animal group (Fig. 1A). The term *wild* exhibited a unique growth pattern in its usage across years (Fig. 1B), increasing at a faster rate to refer to bees than to any other animal group. The term *endemic* was used to describe birds more than any other animal ($F_{4,135}=173.94$, $P<0.001$; Fig. 1C), and usage also increased most rapidly for birds (Table S2.2 in Appendix S2). Furthermore, the use of *native* over time increased at a steeper rate for bees than all other animal groups (Table S2.2 in Appendix S2; Fig. 1D). The term *invasive* also had a significant increase in usage over time ($F_{1,100}=4.26$, $P=0.042$) and a significant effect of animal ($F_{4,100}=4.30$, $P=0.003$), where *invasive* was more commonly used for bumble bees than bees or chicken. However, slopes (i.e., changes over time) did not differ in the usage of the word *invasive* across animal groups ($F_{4,100}=0.67$, $P=0.61$). The use of the term *exotic* was consistent across animal groups ($F_{4,110}=0.14$, $P=0.96$), and years ($F_{1,110}=1.19$, $P=0.28$). Similarly, the proportion of papers using the term *introduced* was consistent over time ($F_{1,140}=0.56$, $P=0.46$) with no interaction of animal by year ($F_{4,140}=0.49$, $P=0.74$). However, there were differences among animal groups ($F_{4,140}=9.20$, $P<0.001$), such that *introduced* was used significantly more often overall for honey bees than bees, bumble bees, and chickens. We did not detect any change in usage of any of our focal terms with regard to chickens in the time series analysis.

Bibliometric analysis

Most of the scientific articles in our database were published by corresponding authors affiliated with institutions in the United States (28.6%), the United Kingdom (13.16%), Australia (7.5%,), New Zealand (4.8%), and Germany (4.4%). Considering all animal groups, the dataset contains publications from 169 different journals, from which *Biological Conservation* was the most popular journal (6.7% of all the publications in our dataset; Table S3.1). The bird group had the highest number of publications (2,760), authors (7,289), and corresponding author's countries (77). After birds, the next most abundant animal group in terms of the total number of publications was bees, followed by honey bees, bumble bees, and chickens (Table S3.2 in Appendix S3). Multi-authored publications were most common in the chicken group, with an average of 5.47 authors per article, as compared to average number of authors in all other animal groups (Table S3.2).

The papers in our dataset contained a total of 110,486 cited references. The number of modules identified varied by animal group (Table 2). The co-citation network for birds was the most modular (z-score = 56.23), which demonstrates that bird networks exhibit fewer connections among the different knowledge areas in comparison to other animal groups. The co-citation network for honey bees, in contrast, was the least modular of all animal groups, with more connections among the different knowledge areas (Table 2).

Module structure and sentiment analysis

The modules were related to different knowledge areas within the scientific literature of each animal group studied (Table 3), and also exhibited sentiment values that significantly

Table 2 Co-citation network analyses: For each animal group, we report the total number of publications, total number of references from these publications, the number of modules that these papers formed and the modularity score

Animal group	Number of publications	Number of references	Number of modules	Modularity (z-score)	Isolated papers
Bees	589	17,401	4	0.24 (−223.25)	4
Honey bees	250	8,440	5	0.53 (−14.29)	1
Bumble bees	142	4,957	4	0.50 (−23.01)	2
Birds	2760	89,757	12	0.61 (56.23)	31
Chickens	54	2,204	NA	NA	NA

Isolated papers refer to the number of publications that had no reference in common with the other papers in the network. We excluded chickens from the module detection analysis due to low sample size

differ within animal groups (Fig. 2, Table S4.1). For bees, all modules had positive sentiment scores, and publications related to the role of environmental stressors on bee conservation (module 1) had the lowest relative sentiment scores of the top four modules (Fig. 2A). In contrast, the bumble bee module encompassing pathogen spillover from managed bumble bees to their non-managed counterparts (module 1) exhibited a significantly lower sentiment score than the other three, representing the only bumble bee module with a negative average sentiment (Fig. 2B). For honey bees, publications related to honey bee health (module 4) comprised the only module with a negative average sentiment for honey bees and had a significantly lower sentiment score than the other three modules (Fig. 2C). Finally, all four bird modules had positive sentiment scores, even the module related to biological invasions (module 4) (Fig. 2D). Overall, we detected significant variation in sentiment across animal groups (Table S4.2; Fig. 2E). Sentiment was highest for non-managed bees followed by honey bees when compared to all other animal groups analyzed.

Discussion

In the past 3 decades, ecologists and evolutionary biologists have used different terms to describe study organisms based on their management and origin. The terms *wild*, *endemic*, *native*, *managed*, and *invasive* all increased in use during this time period. In fact, the use of the terms *wild* and *native* increased significantly faster in the bee literature than in the bird literature (Fig. 1). The popularization of the word *wild* for bees may be linked to the recognition of colony collapse disorder in managed colonies of honey bees (Cox-Foster et al., 2007), the subsequent increasing interest in alternative pollinators, and the enactment of pollinator protection initiatives (e.g., the Pollinator Partnership Action Plan in the United States and the EU Pollinators Initiative). While ecologists may use *wild* to indicate non-domesticated species growing in their natural environment (Fig. S2.1), the general public and scientists from other disciplines may interpret the same term as fierce organisms growing without regulation or control (Box 1). To minimize confusion and promote objectivity, we suggest that future studies should clearly define *wild* and/or include additional descriptors such as *non-domesticated* or *non-managed.* Such clarification could help to shift the general public

Table 3 Knowledge area of the top four modules detected by each animal group

Animal group	Module's number			
	1	2	3	4
Bumble bees	Pathogen spillover from managed bumble bees to their non-managed counterparts	Role of environmental stressors, especially pesticide exposure	Foraging behavior and resource preference	The effect of introduced bumble bees on pollination services
Honey bees	The importance of managed honey bees as pollinators in natural areas	The competition and coexistence dynamics of honey bees inside and outside their native ranges	Measure of honey bee colony density and other population demographics	Honey bee health (including microbiota, viruses, diseases, and the pathogen spillover phenomena)
Bees	Role of environmental stressors (e.g., pesticides, parasites, and climate change) on bee conservation	The effect of urbanization on bee communities and populations	The effect of landscape on diet breadth and foraging habits of bees	Invasion ecology, specifically regarding the role of *Apis mellifera* and/or *Bombus terrestris* on other bees
Birds	Genetic diversity, gene flow, and population divergence of non-managed birds	The risks that urban bird populations face (such as lead exposure, competition, and food limitation)	Challenges for conservation and reintroduction of bird populations (especially diffuse competition and predation)	Invasion ecology and bird-bacteria associations

Given the small sample size for chickens, we excluded the module detection analysis

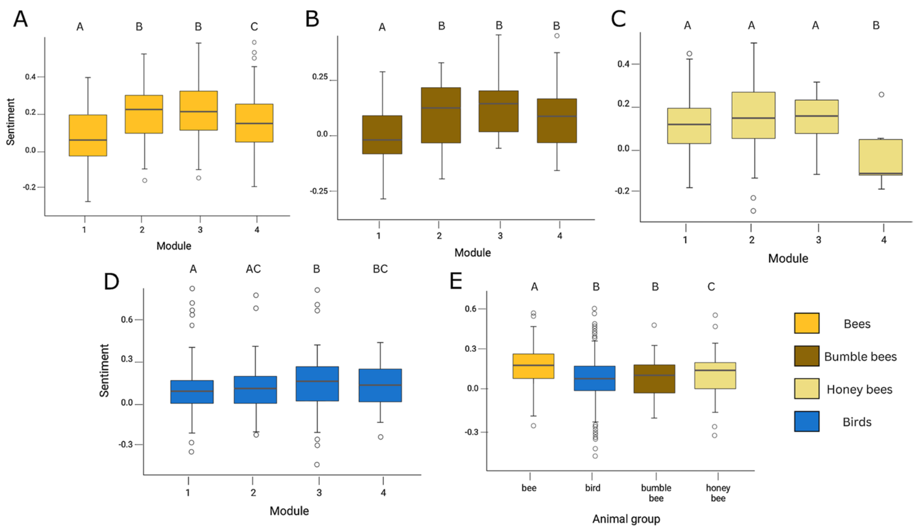

Fig. 2 Box plots representing how sentiment (median ± 95% CI) varies among scientific abstracts belonging to different modules for **A** bees, **B** bumble bees, **C** honey bees, **D** birds, and **E** by animal group. Sentiment scores are indicatives of how the public may perceive the use of language in scientific publications. Sentiment values range from -1 (most negative sentiments) to 1 (most positive sentiments). Scores of 0 indicate neutral sentences. Different letters represent significant differences ($P < 0.05$ after false discovery rate adjustment) among the median sentiments present in each module

perception of *wild* bees from uncontrolled stinging creatures to the intended meaning and to promote their conservation and/or study.

Moreover, we found a strong association between the term *invasive* and bumble bees. This is likely due to the commercialization and introduction of these species for pollination services across the world and their subsequent spread in these introduced regions (Velthius and van Doorn, 2006). However, in invasion biology the term *invasive* most commonly describes a *non-native* species that causes significant ecological and/or economic harm (Lockwood et al., 2013). Therefore, we suggest employing more objective terms to reference *domesticated* and *introduced* species whose management represents a benefit for society and/or ecosystem services. However, when the management of domesticated and introduced species results in adverse economic and ecological effects (e.g., pathogen spillover; Box 2), we advise scientists to emphasize the causes of such species invasiveness when employing loaded terms. We also suggest that bee and bird ecologists continue to pay attention to their wording with the purpose of preventing the spread of terms with an implicit negative bias (Larson, 2005; Warren, 2007) and to only use strongly negative words when data support their usage.

While identifying a specific population as managed or non-managed is straightforward, not all species will fit into a native or non-native category, such as migratory species. As more migratory bird species have received attention than migratory insect taxa (Gao et al., 2020; Satterfield et al., 2020), it is perhaps unsurprising that there are definitions for what constitutes a native migratory bird. The US Congress considers a migratory bird species to be classified as *native* if it occurs in a region as "the result of natural biological or ecological processes" (Office of the Federal Register, 2019). What makes a migratory insect *native* is less clear with few species being referenced as *native* migratory insects in the literature (e.g., Monarch butterfly (Fortier et al., 2011), Fall armyworm (Gao et al., 2020)).

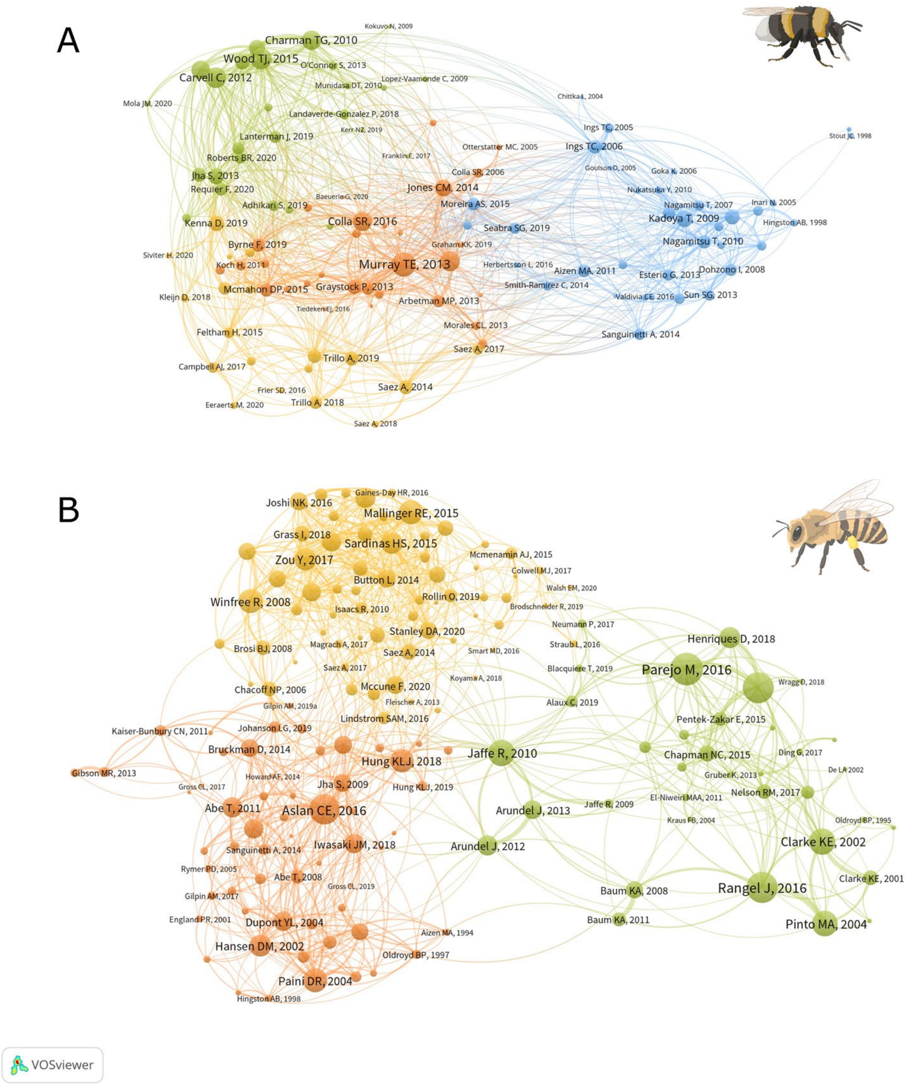

Fig. 3 Co-citation network for bumble bees (**A**) and honey bees (**B**). Each node represents a scientific publication and links among nodes indicate shared references. Modules are indicated by different colors. For bumble bees, module 1 (in orange) spans the literature linked to pathogen spillover, module 2 (in yellow) contains the literature related to pesticide exposure, module 3 contains (in green) the literature related to resource preference and foraging habits, and module 4 (in blue) shows the publications related to the effect of introduced bumble bees on pollination services. For honey bees, we only show the top three modules (those containing more than 10 scientific publications). Module 1 (in orange) contains the literature related to the importance of managed honey bees as pollinators in natural areas, module 2 (in yellow) exhibits the scientific publications linked to the competition and coexistence processes of honey bees inside and outside their original range of distribution, and module 3 (in green) shows the scientific literature related to the calculation of colony density and other demographics of honey bee populations. Refer to Table 3 for results for the other groups. (Colour figure online)

Box 2: When sharing is not caring

Pathogen spillover events between domestic and wild, non-managed species of both bees and birds are well-documented, exemplifying the consequences of spillover on the new hosts. Agricultural animals play a particularly important role in spillover events because of agricultural intensification (e.g., high density production) (Jones et al., 2013; Sokolow et al., 2019). In such situations, the transmitting species (original host) is often described in negative terms as a threat to the receiving species (spillover host). However, the direction of spillover and strategies to prevent spillover differ between bees and birds.

Case Study #1: The European honey bee (Apis mellifera). Farmers have managed honey bees for centuries for their pollination services. However, modern beekeepers maintain large numbers of hives and rent out pollination services to farms. This often requires the long-distance movement of bees from farm to farm, following the bloom season of each crop. The human-mediated transport of honey bees has resulted in the increased exposure of other bee species to new parasites, pathogens, and diseases via spillover. For example, pathogen spillover from managed to non-managed bumble bees likely contributed to declines in native bumble bees in North America, Japan (Graystock et al., 2016), and Chile (Schmid-Hempel et al., 2014). However, the community-level consequences of these spillover events to non-managed bees have rarely been quantified. Pathogen spillover may undermine pollinator conservation efforts, resulting in significant ecological damage from insufficient pollination services. Additionally, these spillover effects may sow conflict between stakeholder groups as attitudes toward managed bees change.

Case Study #2: Chickens (Gallus gallus domesticus). Like bees, birds have a long history of human domestication (Read et al., 2015) resulting in large-scale farming of some species, such as chickens for meat and egg production (West & Zhou, 1988). Due to selective breeding, chickens have lost genetic diversity and may be particularly sensitive to diseases that are widespread in wild bird populations. In commercial chicken production, biosecurity is a high priority to keep chickens isolated from pathogens that occur in non-managed bird populations, such as endemic Newcastle disease virus or avian influenza. Outbreaks of disease devastate the poultry industry resulting in mass culling, quarantines, and trade restrictions. However, pathogen spillover from domestic poultry may contribute to wildlife decline, yet this remains largely unexplored. In particular, poultry may be an important contributor of pathogens and disease due to the increases in backyard and hobby flocks in urban areas, thus expanding the livestock-wildlife interface (reviewed in Ayala et al., 2020). Additionally, chickens may serve as important pathogen reservoirs. Poultry vaccination is a crucial component of modern production, but has not always blocked transmission, which has led to the evolution of more virulent strains (Read et al., 2015). Producers already face scrutiny for animal welfare concerns, and conflict among stakeholders will likely lead to greater acrimony unless pathogen spillover is more effectively addressed.

Migratory species are very rarely, if ever, described as *invasive* or *introduced* in the literature. The only exception, to our knowledge, involves invasive migratory fish or lamprey (e.g., Myles-Gonzalez et al., 2019). Thus it may not be surprising that most migratory bird and insect species do not receive the negative sentiment and connotation of a *non-native* or *invasive* species. Rather the migration behavior itself often makes the species special or helps attract interest of researchers and the public (Gao et al., 2020; Holland et al., 2006; Satterfield et al., 2020).

Our citation networks analyses further revealed that, in the absence of a shared terminology, different clusters of researchers use different terms that vary in both their connotation and sentiment. The modules we identified in the network analysis exhibited strong patterns in sentiment scores (Fig. 2). For instance, modules in bumble bees and honey bees related to diseases and host-associated microorganisms showed a negative sentiment score in both animal groups, whereas modules associated with pollination services showed a positive sentiment (Figs. 2 and 3). These patterns may reflect the negative effect that pathogen spillover may have on both biodiversity and the insect pollination industry. Similar to the terms associated to biological invasions, use of negative biased language may vilify the species involved in pathogen spillover instead of acknowledging the responsibility management practices may have on this process. Thus, we encourage the use of neutral terms such as *non-managed, managed* and *commercial* when referring to potential parasite hubs because these terms acknowledge that pathogen spillover is also linked to the quality of management practices.

Conclusions

Effective communication is fundamental for successful interdisciplinary research. Taking a bibliometric approach to examine literature on bees and birds, we described and quantified the changes in the terminology used to refer to managed and non-managed bees and birds. While we focused on systematically analyzing 30 years of scientific publications, our reflections are not limited to written publications, but also apply to verbal communication when teaching, presenting research, and mentoring students. Comparing the sentiment of scientific literature and that of popular press, for example, may help scientists make stronger contributions towards applied research and policy making. We hope that this study will help researchers to use terms that hold accountable our management practices and regulations on complex biological processes like pathogen spillover and biological invasions. To that end, we endorse the efforts to clearly define in publications and verbal communications the intended meaning when using loaded terms in ecological and evolutionary biology contexts.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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