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# Global trends in research output by zoos and aquariums

**Nora Escribano**[1] | **Arturo H. Ariño**[1,2] | **Andrea Pino-del-Carpio**[1] | **David Galicia**[1,2] | **Rafael Miranda**[1,2]

[1] Department of Environmental Biology, Universidad de Navarra, Pamplona, Spain

[2] Biodiversity and Environment Institute, Pamplona, Spain

**Correspondence**
A. H. Ariño, Department of Environmental Biology, Universidad de Navarra, 31080 Pamplona, Spain.
Email: artarip@unav.es

**Article impact statement**: Research led by zoos has exploded over the last decade, particularly research on conservation and genetics.

**Abstract**

Zoos and aquaria, often regarded as preservation-cum-entertainment enterprises, are also actors in the effort to curb the biodiversity crisis: raising awareness, supporting conservation, and conducting research. We assessed trends in zoo and aquaria research topics and study organisms over time worldwide. For the zoos and aquaria registered in the Species360's Zoological Information Management System and the World Association of Zoos and Aquariums, we compiled metadata on their research published in the peer-reviewed literature indexed in Scopus and carried out a keyword frequency analysis. The production of scientific papers by zoos increased at a much faster rate than the average accrual of scientific papers in the literature. Evolution of research themes ran parallel to that of biological sciences (e.g., development of molecular genetics or increased awareness about conservation). The focus of 48.5% of zoo-led research was on vertebrates, of which mammal research was 33.7%. Whether zoos are effectively contributing to conservation may still be debatable, but our results highlight their institutional efforts to increase knowledge about the species in their care.

**KEYWORDS**

biodiversity conservation, history of zoos, literature analysis, role of zoos, scientific production, Scopus, text mining

Tendencias Mundiales en la Producción Investigativa de los Zoológicos y Acuarios

**Resumen:** Los zoológicos y los acuarios, con frecuencia considerados empresas de conservación y entretenimiento, también son actores en el esfuerzo por reducir la crisis de la biodiversidad al crear conciencia, apoyar a la conservación y llevar a cabo investigaciones. Evaluamos las tendencias en los temas de investigación y los organismos de estudios en los zoológicos y los acuarios en todo el mundo a través del tiempo. Compilamos los metadatos de las investigaciones realizadas en los zoológicos y acuarios registrados en el Sistema de Manejo de Información Zoológica de Species360 y en la Asociación Mundial de Zoológicos y Acuarios que han sido publicadas en la literatura revisada por pares indexada en Scopus y realizamos un análisis de frecuencias de palabras clave. La producción de artículos científicos por zoológicos se incrementó a una tasa mucho más rápida que la acumulación promedio de artículos científicos en la literatura. La evolución de los temas de investigación fue paralela a la de las ciencias biológicas (p. ej.: desarrollo de la genética molecular o incremento en la conciencia por la conservación). El enfoque del 48.5% de las investigaciones conducidas por los zoológicos estuvo sobre los vertebrados. De este 48.5%, el 33.7% fueron investigaciones sobre mamíferos. Todavía puede debatirse si los zoológicos están contribuyendo efectivamente a la conservación, pero nuestros resultados

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resaltan sus esfuerzos institucionales por incrementar el conocimiento sobre las especies bajo su cuidado.

**PALABRAS CLAVE**
análisis de la literatura, conservación de la biodiversidad, historia de los zoológicos, minería de textos, papel de los zoológicos, producción científica, Scopus

## INTRODUCTION

Biodiversity is under threat, and the scientific community, policy makers, and the public are aware of it (Lotze et al., 2018). Early steps to counteract biodiversity loss included establishment of the Convention on Biological Diversity in 1992, formulation of the 2010 Biodiversity Target in 2002 (CBD, 2002), the Strategic Plan for Biodiversity 2011–2020, and the Aichi Biodiversity Targets in 2010 (CBD, 2011). In 2012, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, www.ipbes.net) examined the state, trends, and future prospects of biodiversity and the ecosystem services it provides. These platforms and plans stress the necessity of integrated cooperation of interested parties, including governments, the research community, conservation nongovernmental organizations, and the general public, to alleviate the biodiversity crisis. Zoos and aquariums (hereafter zoos) have also been established to contribute to the conservation of biodiversity (Conde et al., 2011; Funk et al., 2017).

Zoos may increasingly engage in conservation as their role shifts from places born to entertain the public to conservation-oriented facilities (Fa et al., 2014; Hutchins et al., 2018). Zoos are no longer regarded as "Noah Arks" (Balmford et al., 2003) but as institutions supporting conservation through pursuit of an integrated approach, including education of the public, support of in situ and ex situ programs and scientific research (Traylor-Holzer et al., 2019), of which a wide range is conducted on their stock and in the wild (Wilson et al., 2019), and collaboration with other institutions studying basic biology (Conde et al., 2019).

The end of the 2011–2020 Plan and the Aichi Targets seems an appropriate time to review the contribution of zoos to research. Until recently, assessment of research activity by zoos was limited to a few cases (Wemmer et al., 1997; Anderson et al., 2008; Melfi, 2009). Over the past 2 years, though, new research has explored contributions by specific zoos (Loh et al., 2018; Kögler et al., 2020; Welden et al., 2020), and a current work by Rose et al. (2019) involved examining a set of keywords in the Web of Science related to zoo-housed animals. We expanded their review framework by including all indexed peer-reviewed articles by researchers at zoological institutions worldwide. We used text-mining techniques and exploratory data analysis from an unbiased, agnostic starting point. We identified hot topics and highly studied taxa in zoo-led research, unraveled their trends through time, and mapped their relationship to each other. This enabled us to explore how research carried out by zoos has evolved over time and how it contributes to the development of their current conservation role.

## METHODS

We compiled a list of zoological institutions included in the Species360's Zoological Information Management System (Species360, 2019). This database contains data from over 1000 institutions, ranging from aquariums, zoos, and breeding centers to universities and animal sanctuaries. Although Species360 constitutes one of the most comprehensive databases of zoological institutions worldwide, we completed these data by adding zoos belonging to the World Association of Zoos and Aquariums (WAZA).

We classified institutions into 11 categories (association, company, institution, museum, protected area, research or conservation center, sanctuary, university or college, wildlife park, zoo or aquarium, and other). We first searched for institutions with the words *zoo* or *aquarium* in their names. For other institutions, we explored their websites and classified them according to their aims and mission. Because we aimed at analyzing the scientific production of zoos specifically, we filtered out other institutions, such as universities and research and breeding centers unless their zoological facilities are known under another name (e.g., articles originating from Antwerp Zoo use as affiliation the Royal Zoological Society of Antwerp, so we retained those articles). When an institution managed both zoos and separate research-oriented facilities, we considered the zoos separately from their parent institutions. If the research-oriented facilities could not be clearly separated from their zoo counterparts, we included those articles as well as long as they contained zoo-related keywords (e.g., Zoological Society of London). The final list contained 909 zoos.

We used the Scopus database to retrieve information about research papers published by the selected institutions. Its coverage mainly focuses on research articles rather than other types of outputs, such as books, conference proceedings, or gray literature (Mongeon & Paul-Hus, 2016).

For each institution, we retrieved the Scopus affiliation identifier (ID) through the Scopus Application Program Interface (API). In several cases, Scopus had multiple IDs for a single institution. To make sure that we included only our target institutions, we manually verified these entries in multiple ways (e.g., checking that the country of each institution matched the country tag as registered in Species360 database and making sure that the IDs resolved to the correct institution). Once we compiled the institutions' IDs, we retrieved metadata from all their indexed documents with the Scopus API. We finished the queries on 17 July 2020.

To explore the popular topics of research conducted in zoos, we performed a word frequency analysis with the titles and author keywords in the dataset. Analyzing the keywords and titles of an article provides a meaningful and unbiased way to obtain a broader view of the research trends in a given area (González et al., 2018). We preprocessed authors' keywords and titles with common text-mining procedures. We removed strings containing only digits, stop words, and punctuations. We split titles into single words and consecutively concatenated pairs or trios of words to generate bigrams and trigrams, respectively, and converted all the strings to lowercase letters.

Next, we carried out a lemmatization of the metadata, building a corpus of lemmas (i.e., units of lexical meaning) and their different inflected forms that appeared in the list of preprocessed keywords (i.e., author keywords, bigrams, and trigrams all together) so they could be analyzed as single items. For example, *species distribution modeling* can also appear in its abbreviated form (*SDM*) and in different languages. Because lemmatization is context dependent, it is more time intensive but also more meaningful than stemming (i.e., reducing a word to its word stem), which in our case would have been less desirable because we were also working with taxonomic names for which information could be lost by stemming.

The list of keywords exceeded 20,000 unique entries. We checked and normalized the most frequent keywords, setting the threshold at 10 occurrences in the corpus. We also looked for inflected forms of the most common keywords in the remaining set of words appearing fewer than 10 times and harmonized and simplified spelling differences (e.g., British vs. U.S. English, plural to singular form). For example, we lemmatized *reproduction*, *breeding*, and *sexual reproduction* as a single keyword. Nevertheless, we took a highly conservative approach and made few assumptions when normalizing keywords. For example, we kept *breeding*, *captive breeding*, and *inbreeding* separate because they have different meanings.

Finally, we identified taxonomic names across the remaining non-normalized keywords and validated them against the GBIF backbone taxonomy (GBIF Secretariat, 2019). First, we used GBIF's API (https://www.gbif.org/developer/summary) to match taxa names to the backbone. Then, we screened all remaining keywords looking for vernacular names and giving them the highest taxonomic resolution possible. For example, *common bottlenose dolphin* refer to the species *Tursiops truncatus*, whereas *bottlenose dolphin* refers to the genus *Tursiops*.

Once we built the corpus of lemmas and identified taxonomic names, we performed a word frequency analysis. Each document was characterized by a batch of words that included the author keywords and the bigrams and trigrams that resulted from processing the titles. We removed the duplicates that arose from analyzing author keywords and titles together. We identified the most popular topics and most studied taxa over the complete temporal coverage and investigated their temporal trends (Westgate et al., 2015). We next explored the relationship between frequent words (defined as those occurring in at least 0.15% of the literature corpus) through a co-occurrence analysis. For each keyword, we quantified how often each other keyword in the list appeared together in the same paper and represented their probability of co-occurrence through the Pearson's $\varphi$ coefficient. Finally, we tabulated the conservation status of the species studied in zoos based on the IUCN Red List of Threatened Species (IUCN, 2020).

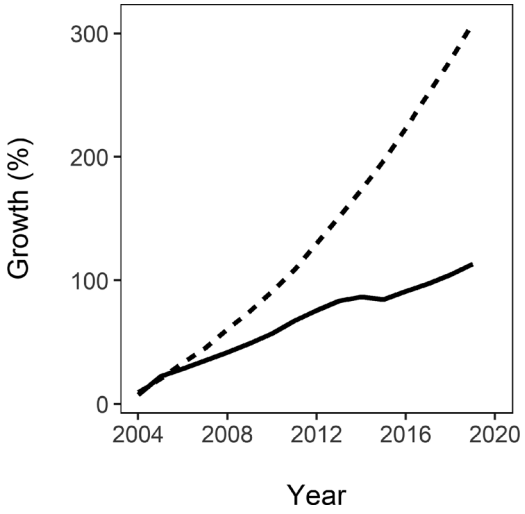


**FIGURE 1** Increase (cumulative growth as percentage of 2003 production) in published papers written by researchers at zoos (dotted line) and overall increase in the Scopus database for all fields (solid line)

We used *R* to perform all analyses (R Core Team, 2019) and Inkscape software for the final graph modifications (The Inkscape Team, 2019). See Appendix S1 for the complete references of the *R* packages we used.

## RESULTS

We found 15,246 documents published over a century by 447 zoological institutions (49.2% of the final list). The cumulative output showed exponential growth ($R^2 = 0.99$). Although 4030 articles had been published by 2003, twice as many (8362, a 107% increase) had been published by 2011. During the next 8-year period, 7993 new articles brought the cumulative total to 16,355, a 305% increase over 16 years. The yearly rate of increase was 9.15% (SD 0.85) (Figure 1).

Of those documents, 13,569 (89%) were research articles that we analyzed further. The distribution of articles among institutions was uneven; 60% were authored by researchers from just 15 zoos (Appendix S2). Five journals (0.34%) published 21% of all articles, mainly within the Scopus subject areas of Agricultural and Biological Science, and Environmental Science. The top 3 journals were specifically zoo oriented in scope (Appendix S3).

*Breeding* (340 documents), *conservation* (283), *captivity* (256), *genetic diversity* (242), *endangered species* (223), *sexual hormones* (209), *mitochondrial DNA* (*mtDNA*) (200), *behavior* (166), *microsatellites* (165), and equating *nutrition* and *animal welfare* (154) were the top 10 keywords and were used in 17.6% of total keywords (Appendix S4). The popularity and persistence of keywords changed over time (Figure 2). *Breeding* was the most persistent keyword over the years, and *conservation* came up in the 2000s and rapidly became the dominant keyword (Figure 2).

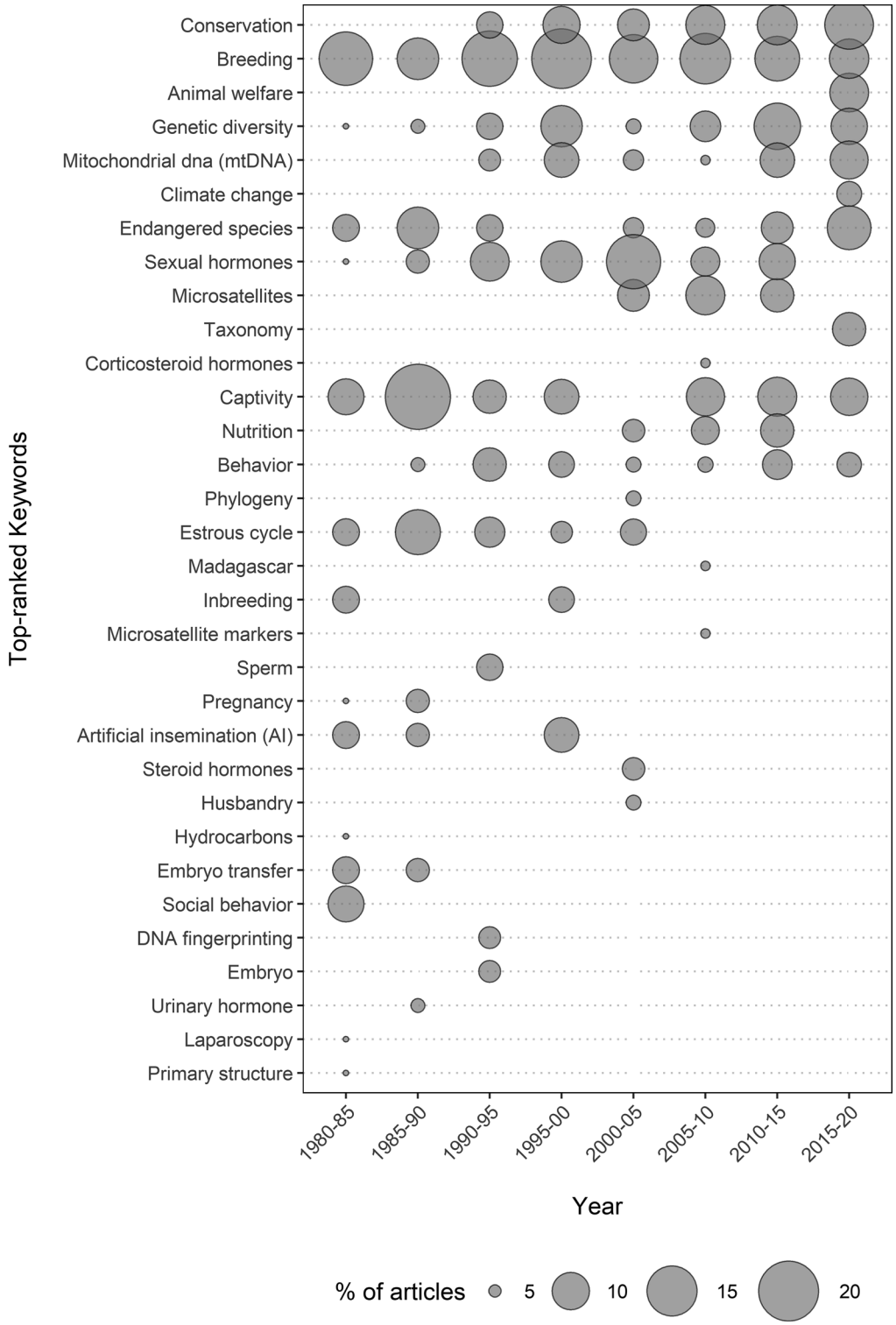


**FIGURE 2** Emergence, persistence, and decline of the top-ranked keywords in published papers written by researchers at zoos from 1980 to 2019. For each 5-year period, circle size is relative to keyword frequency (counts for each keyword divided by the total number of articles available for that period)

Research led by zoos concentrated on vertebrates. Mammals were the most studied class (33.7% of papers), followed by birds (6.4%), reptiles (4%), fish (2%), and amphibians (1%). Among invertebrates, anthozoans were dominant (1.5%, Figure 3). The most frequent (Appendix S5) species names included *Tursiops truncatus* (304 documents), *Pan troglodytes* (211), *Canis lupus* (185), *Gorilla gorilla* (181), *Felis catus* (173), *Panthera leo* (169), *Elephas maximus* (165), *Loxodonta africana* (147), *Phascolarctos cinereus (116)*, and *Ailuropoda melanoleuca* (112).

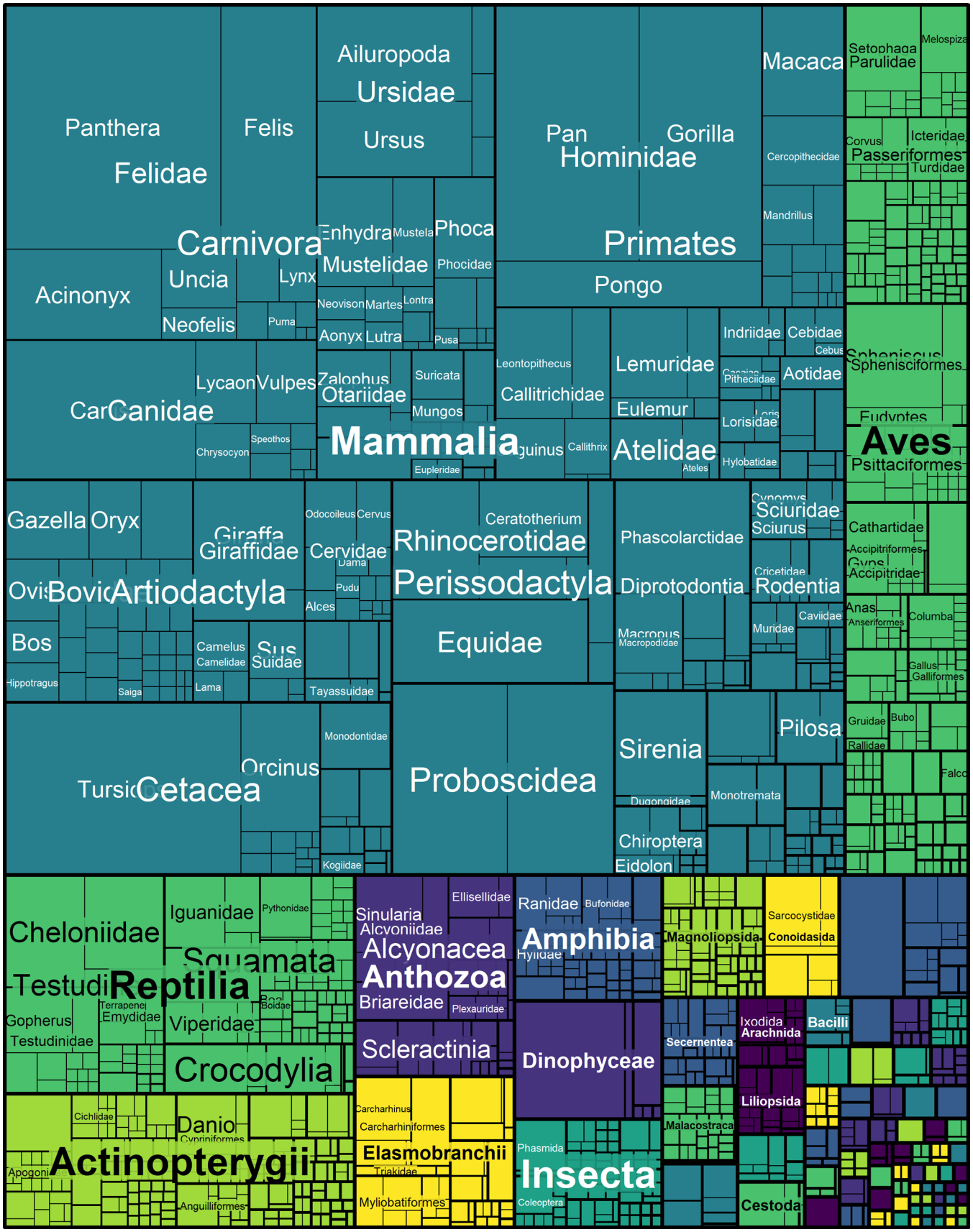


**FIGURE 3** Proportional number of articles by zoo researchers by taxonomic group

Least concern (LC) was the most represented IUCN species category (30.9% of species studied), followed by vulnerable (VU) (23.1%) and endangered (EN) (17.5%) (Appendix S5). These proportions seemed rather stable over time; there was no significant trend up or down (Appendix S8). Although some highly studied species had low IUCN ratings (e.g., *T. truncatus*), the top studied species included mostly EN and VU species (Appendix S7) (e.g., *G. gorilla*, *P. troglodytes*, and *E. maximus* [Appendix S7]).

Clusters of keywords, describing broad research interests became evident in our co-occurrence analysis. *Captivity* was the most connected keyword with 270 links, of which *breeding*, *primates*, and *Gorilla gorilla* were the most frequent co-occurrences. *Breeding* was also highly connected (202 links) to *captivity, endangered species*, and *conservation*. *Endangered species* was the third-ranked keyword (37 links) connected to *conservation, genetic diversity*, and *captivity*, among others (Figure 4). Although well-defined clusters were found (e.g., *Karenia brevis* + *harmful algal bloom* + *brevetoxin* + *Florida red tide*, or *genetic markers* + *microsatellites* + *mitochondrial DNA* + *genetic diversity*) (Figure 4), most common words were generally not highly correlated to each other (Appendix S9). Some even showed slightly negative correlations, meaning that those pairs appeared together less probably than by chance alone (e.g., *captivity* and *Tursiops truncatus* [Appendix S9]).

## DISCUSSION

We found a prominent increase in the rate of scholarly publication by researchers at zoos, widely and globally confirming specific trends found by Rose et al. (2019) in Web of Science and by Welden et al. (2020) for the European zoos. This increase was accelerated, clearly surpassing the average rate of increase in general science. The research production indexed by Scopus over all fields rose 85% from 2003 to 2013 (1.3–2.4 million published papers) (Plume & Van Weijen, 2014), whereas our results showed a 150% increase over the same period for the zoo-led output (Figure 1). The increase was strongly driven by specific topics, such as breeding, conservation, and captivity (Figure 2) and taxonomic groups, such as mammals and birds (Figure 3).

The emergence, persistence, and decline of keywords in research articles led by zoo researchers revealed a shift in their focus, compatible with observed trends in science. For example, in the early 1980s and 1990s, the top 10 keywords were mostly terms related to veterinary and ethology (Figure 2), which makes sense for institutions that hold captive animals. The new millennium brought an explosion of DNA-based methods (Taylor & Harris, 2012) and increased awareness about the biodiversity crisis (Jenkins, 2003). These shifts were reflected in the research conducted by zoos. We observed that popular topics in the 20th century gave way to keywords related to conservation and genetics (Figure 2), which were prominent starting in 2000 (Appendix S4).

The analysis of keyword frequencies offers a perspective about a research field that can be enriched by exploring how keywords relate to each other. Some terms become popular and might end up being used as trade-defining words in author keywords and titles to bring the attention of potential readers. Titles and author keywords are often catchy and mimic the trends in their fields to elicit interest and, ultimately, entice reading. This might be the case for *breeding*, *conservation*, *captivity*, and *endangered species*, which were the most common keywords overall (Appendix S3) and the most connected (Figure 4), but they were not particularly associated with other, specific words (Appendix S9).

Zoos are known to be taxonomically biased, often focusing on large-bodied vertebrates and birds (Ward et al., 1998; Melfi, 2009; Rose et al., 2019) and less-threatened species (Martin et al., 2014). These charismatic species can often be more easily exhibited and are most appreciated by visitors (Landová et al., 2018; Ward et al., 1998). Melfi (2009) reported that 89% of papers focused on mammals (60% on primates) in British and Irish facilities, whereas Rose et al. (2019) found that 69% of zoo-related articles in the Web of Science dealt with mammals (40% on primates). Our much larger sample showed a similar (although less marked) bias toward mammals, particularly carnivores, primates, and cetaceans (Figure 3 and Appendices S5 & S6). Taxonomic bias is also common in other biodiversity-related fields (Rosenthal et al., 2017; Troudet et al., 2017).

Recently, zoos have shifted to more conservation-oriented missions (Barongi et al., 2015), so they should further engage in conservation of most threatened species (Miller et al., 2004). If such engagement occurs, species in high IUCN threat categories should receive a higher degree of attention. We found partial evidence of this. Almost one-half of articles published by zoo researchers dealt with species with threat levels above NT, although LC and VU species were the most represented (Appendices S5 & S7). For example, 2 of the top 3 studied species were *T. truncatus* and *C. lupus*, which are LC. However, the proportion of articles that dealt with threatened species has stabilized in recent years. Although we acknowledge that zoos cannot address all challenges in species conservation (Gippoliti, 2012), it should be expected that at least some of their research activity should prioritize the most endangered species in their care.

Zoos conduct research on a wide variety of topics dealing with breeding, conservation, and genetic issues. *Breeding*, *conservation*, *captivity*, *genetic diversity*, or *endangered species* were frequent words (Appendix S4). However, zoos are also supporting research in situ. For example, Florida red tides cause damage both to marine animals and humans. The keyword cluster defined by words related to *Karenia brevis* (Figure 4) is an example of how zoos are actively contributing to research on a specific issue.

Although research is often presented as one of the core elements of zoo missions (Hutchins & Thompson, 2008), labeling them now as research institutions is still debatable. Although a Ph.D. often marks the entry into a research career, it has been argued that less than one-third of the professionals conducting and coordinating research in North Amer-

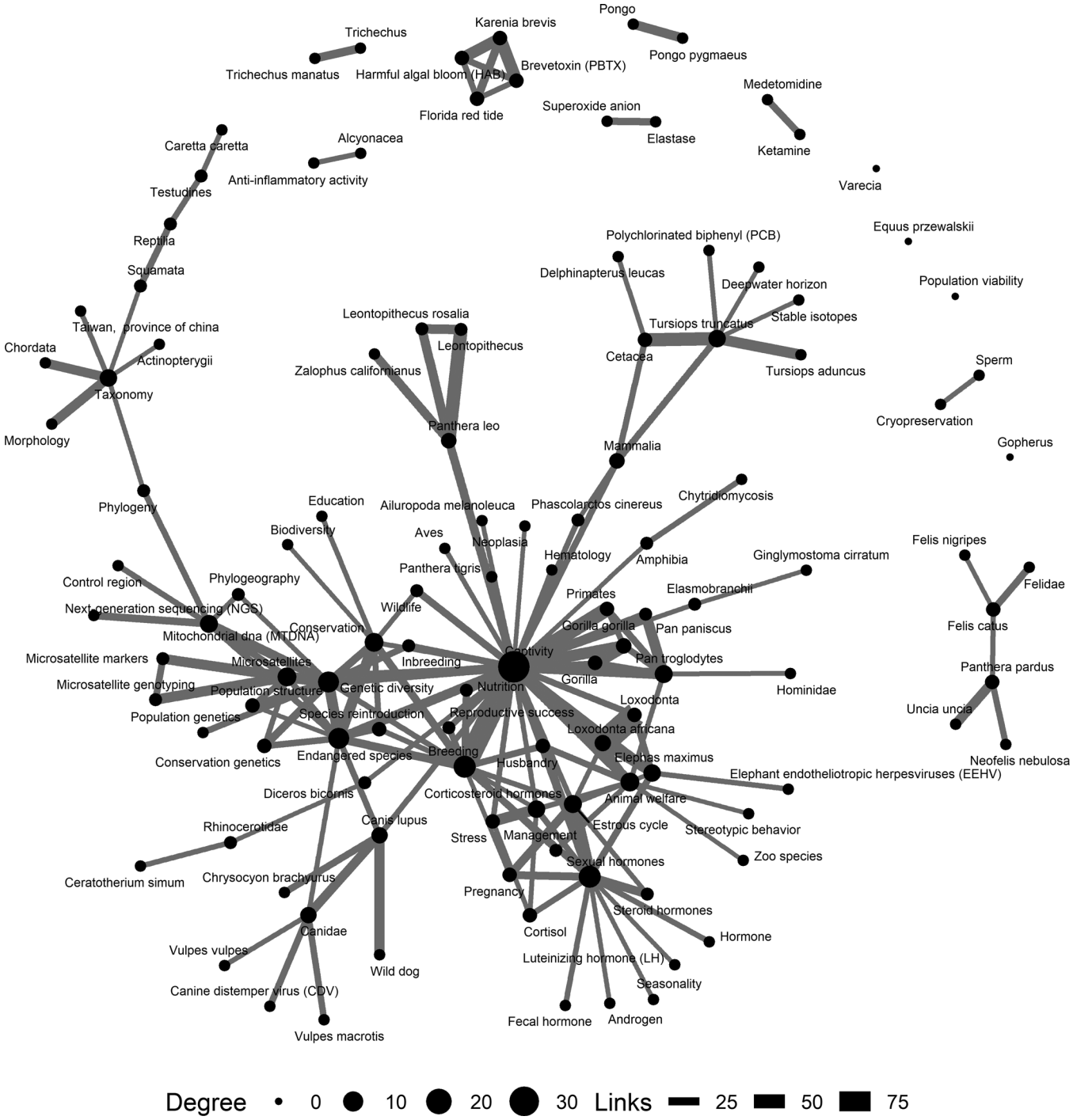


**FIGURE 4** Network of co-occurrence of keywords in published papers written by researchers at zoos (links, number of times 2 keywords appeared together in the same document; node size, number of edges connected to the keyword [i.e., degree of connection]). Keywords with fewer than 10 joint co-occurrences are not shown

ican zoos in the early 2000s had a doctorate and that few full-time research positions exist in zoos (Anderson et al., 2010). Still, zoos may be valuable allies in conservation science because they can provide information to fill data gaps to understand species biology (Conde et al., 2011, 2019), contribute to the environmental education of the millions of visitors they receive (Moss et al., 2015), and provide space, infrastructure, and expertise for the conservation of endangered species (Olive & Jansen, 2017).

The year 2020 was the deadline for the Aichi Biodiversity Targets and closed the decade on biodiversity. Whether zoos are effectively contributing to conservation or whether their efforts amount to a laundering of past practice may still be under debate, but the fact that they are increasingly producing research

seems no longer up for debate. Governments and society will now have an opportunity to factor in this enhanced role for zoos in their policies and perceptions, respectively.

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## ORCID

*Nora Escribano* https://orcid.org/0000-0002-7863-4463
*Arturo H. Ariño* https://orcid.org/0000-0003-4620-6445
*Andrea Pino-del-Carpio* https://orcid.org/0000-0001-8177-4005
*David Galicia* https://orcid.org/0000-0002-2585-9888
*Rafael Miranda* https://orcid.org/0000-0003-4798-314X

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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