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GAPs in the Study of Zoo and Wild Animal Welfare

Vinícius D. Goulart, Pedro G. Azevedo, Joanna A. van de Schepop, Camila P. Teixeira, Luciana Barçante, Cristiano S. Azevedo, and Robert J. Young*

Conservation, Ecology and Animal Behaviour Group, Belo Horizonte, Minas Gerais, Brazil

To investigate the science of animal welfare for zoo and wild animals in the period from 1966 to 2007, we conducted a bibliometric analysis of abstracts downloaded from *The Web of Science*© database using the keyword combination "Animal welfare, Zoo* and wild" in the topic field. In total we downloaded 1,125 abstracts, which were classified into the following categories: year of publication; environment of the study (e.g., zoo) or theoretical; area of knowledge (e.g., conservation in situ); number of experimental animals used; species; addresses of authors; taxonomic classification; publication language; journal name; number of citations received. Since 1990, there has been a rapid increase in the number of articles published in this area of animal welfare. One worrying result was that published articles were predominately of a theoretical nature (58.65%, $N = 563$). Most of the articles were published by authors either in Europe (47.43%, $N = 480$) or North America (37.65%, $N = 381$) and written in English (87.71%, $N = 971$). The majority of experimental studies were conducted with mammals (75.92%, $N = 391$), and had small sample sizes ($N = 7$ for zoo-based studies). In terms of impact factor (IF), the journals in this study had a median factor equivalent to that for the area of biological sciences (median IF = 1.013). Little knowledge cross-over from farm animal welfare was found (only four articles) in this study. In conclusion, zoo and wild animal welfare as a science may benefit from a greater interaction with farm animal welfare. Zoo Biol 28:561–573, 2009. © 2009 Wiley-Liss, Inc.

Keywords: animal well-being; GAP analysis; wild animal; zoo animal

*Correspondence to: R. J. Young, Conservation, Ecology and Animal Behaviour Group, Prédio 41, Mestrado em Zoologia, Pontifica Universidade Católica de Minas Gerais, Av. Dom José Gaspar, 500 Coração Eucarístico, 30535-610 Belo Horizonte, Minas Gerais, Brazil. E-mail: robyoung@pucminas.br

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INTRODUCTION

A recent study showed that research into environmental enrichment, as measured by a bibliometric analysis, has been increasing rapidly in the last 20 years [Azevedo et al., 2006]. This no doubt reflects the greater concern with which human societies have about animal well-being, this being particularly pertinent for animals with which the general public have contact, such as zoo animals [Young, 2003]. Despite this increase in research and increased public interest in animal welfare, scientists involved in animal welfare research have still not reached a consensus on a definition of animal welfare. Animal welfare can be defined as the state of an animal as it attempts to cope with its environment [Fraser and Broom, 1990]. In a more complete definition, such as the one proposed by a group of Edinburgh University students, animal welfare is the state of well-being brought about by meeting the physical, environmental, nutritional, behavioural and social needs of the animal or groups of animals under the care, supervision or influence of people [Appleby, 1996]. Nowadays, the concept of animal welfare takes into account the physical and mental health of the animal and how the environment influences it [Webster, 2005].

At the same time that human societies have become more concerned about animal welfare—they have also become conscious of the conservation crisis [Galindo-Leal, 2000]. At times, animal welfare and animal conservation pull against each other in that animal welfare is concerned with the individual, whereas animal conservation is concerned with populations [Young, 2003]. This conflict is, therefore, particularly pronounced for zoo animals. For example, when an individual of a wild species becomes completely adapted to captivity, it may experience the highest level of animal welfare, but such an adaptation could result in animals that would be of little or no value to conservation programmes.

Studies focusing on the welfare of animals are increasing in number since the last decade, in different areas, such as farmed and production animals [Bennet, 1996; Fraser and Broom, 1990; Heleski et al., 2004], laboratory [Baumans, 2005; Bayne, 2007; Swami et al., 2008], zoo [Jordan, 2005; Wickins-Dražilová, 2006; Linhart et al., 2008] and wild animals [Mulcahy, 2003; Hawkins, 2004; Jordan, 2005], as well as pets [Odendaal, 2005]. Ethics, economics and societal demands are the main reasons for this increase [Appleby and Hughes, 1997; Webster, 2005; Dawkins, 2006].

GAP analysis is a tool used for the guidance of future research in a particular scientific area; it consists of a complete and extensive bibliometric evaluation of a certain theme that helps to understand the evolution of knowledge across time [Azevedo et al., 2006]. It has been used in conservation programs to indicate geographic areas to be preserved or even species that need to be conserved [Lipow et al., 2004; Oldfield et al., 2004; Yip et al., 2004; Shaffer and Costa, 2006; Trisurat, 2007]. This concept of preservation and conservation could equally be applied to other areas such as animal welfare. Azevedo et al. [2006] undertook a bibliographical GAP analysis' of the literature related to environmental enrichment, and were able to identify some main areas of concerns, such as experimental design.

The aim of this article is not only to be a theoretical review of animal welfare, but instead to analyse statistically the subject area to make recommendations about how to fill the GAPs in our knowledge as specifically related to zoo and wild animal welfare. In order to do this, it is necessary to determine what research has already been conducted (e.g., geographical distribution of research and the nature of

research conducted), and to quantify all aspects of this research, including issues such as research quality.

MATERIALS AND METHODS

The scientific articles database, *The Web of Science*©, was used for data gathering in this study. This database was chosen as it is widely used by academics around the world in their search for scientific articles. From *The Web of Science*© it is possible to obtain full articles, abstracts and bibliographical references. Moreover, the available journals have been analyzed by the *Journal of Citation Reports*, an authority that evaluates the quality of scientific journals globally [Thomson Scientific, 2005]. The database has truly international coverage of publications, something that is important as national databases show biases toward particular types of research [Melfi, 2005]. We searched this database using the following three combinations of keywords: ''Animal welfare, Zoo* AND wild,'' ''Animal welfare AND Zoo*'' and ''Animal welfare AND wild'' for the 41-year period from 1966 to 2007. The selection of keywords emphasized research on zoo and wild animals, but did not totally exclude studies on farms or in laboratories that had relevance to zoo or wild animal welfare. For example, Young et al. [1994] published an enrichment study on the behaviour of housed pigs on farms, which as the authors themselves noted, has relevance to zoo animal welfare. Our initial search found 1,355 references to articles, which we then downloaded (including their abstracts) to a reference manager software (Endnote 5©). We then individually read each abstract to confirm that they were indeed about our subject, and subsequently rejected 230 articles from our database. These articles were rejected using the following criteria: (1) articles that only mentioned animal welfare in passing; (2) articles that were repetitions; (3) articles that did not have an abstract and whose titles were not obviously related to animal welfare.

The data in this article therefore refer to the contents of 1,125 abstracts downloaded from *The Web of Science*© on May 1, 2008. Although, it would obviously be preferable to use complete articles, this proved to be logistically impossible. We considered the use of abstracts to be a good compromise, because in general they contain all the information we required (see below), and allowed us to have a statistically large sample size. There were of course occasions when abstracts did not have all of the required information, and in these cases we scored the data as ''unknown'' and have presented them as such in our results.

Using a checksheet, we recorded the following items from each abstract: (1) year of publication; (2) environment where animals were maintained (i.e., zoo, laboratory, farm and ''other'' (pets or human studies) or if it was a theoretical study; (3) area of knowledge (i.e., conservation in situ, ex situ, physiology, ethics, health, behaviour, environmental enrichment, molecular biology); (4) number of experimental animals used; (5) species of animal study; (6) addresses of authors (by country and institution); (7) higher taxonomic classification (i.e., mammal, bird, fish, reptile, amphibian, invertebrate); (8) language of the publication; (9) name of the journal (with its impact factor in 2007); and (10) number of citations received. Categories listed in items 2 and 3 were chosen by the authors as they can cover all possibilities in the study of animal welfare. Articles that could be classified into more than one category were classified into their main subject according to the content of

their abstract; for example, if an article was about behavior and enrichment, its abstract was read and the most important category, as indicated by the author, was chosen. If the article had multiple authors from different institutions, we used the corresponding author and his/her institution in the analysis.

These data were typed into a spreadsheet, and then statistically analysed in Minitab 13 for Windows. Anderson–Darling tests were applied to test if the data met the requirements for parametric statistics, which they did not; therefore, all statistical tests used were nonparametric, and, where appropriate, we have presented medians instead of means. The number of analysed cases varied in accordance with the information available in the abstracts, and therefore, our N was usually less than the total number of abstracts analysed (1,125). Where appropriate, we analysed specific subsets of our data; for example, area of knowledge. In general, linear trends in our data were analyzed using Spearman rank correlations, and differences between sub-categories of variables were analyzed using χ^2 analysis. Where appropriate, significant χ^2 analyses were subjected to standardized residual analysis to detect differences between specific sub-categories.

RESULTS

The number of articles published in this area of animal welfare has grown rapidly in the last 17 years (see Fig. 1): showing a strong significant positive correlation between year and number of articles published ($r_s = 0.916$; $N = 17$; $P < 0.001$). Most of the articles were published in Europe (47.43%, $N = 480$) and North America (37.65%, $N = 381$); Central/South America (1.58%, $N = 16$) and Africa (2.37%, $N = 24$) published the least number of studies. The difference between these Continents was highly statistically significant ($\chi^2 = 770$; DF = 3; $P < 0.001$). Standardised residual analysis showed that Europe and North America were publishing significantly more of the articles than expected, whereas Central/South America and Africa were publishing significantly less than expected. The United States and England were the countries that produced most articles addressing zoo/wild animal welfare (30.13%, $N = 339$; 15.64%, $N = 176$, respectively). In total 56 different countries were recorded in our data.

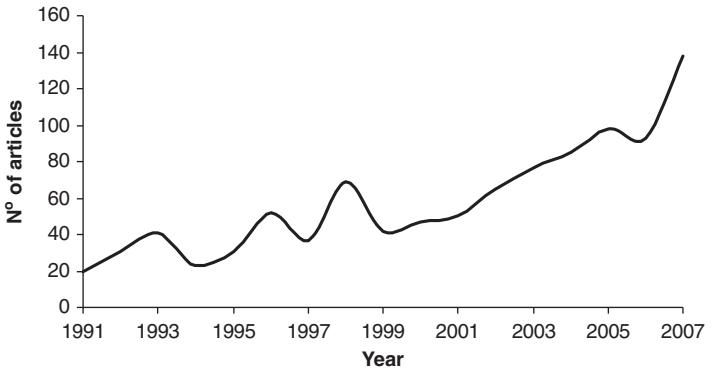

Fig. 1. Number of articles present in *The Web of Science*© database between 1991 and 2007 for the animal welfare science.

Before 1991, less than 20 articles were published per year on the subject of zoo/wild animal welfare according to our research, and we considered a yearly sample of less than 20 articles to be inadequate to analyse publishing trends. The problem with using less than 20 articles is that one researcher publishing five studies on the effects of environmental enrichment on the welfare of the maned wolf would heavily bias apparent publication trends, for example. Therefore, in terms of analysing subject area we have limited our analysis to the period from 1991 to 2007 ($N = 999$).

According to *The Web of Science*©, the five most prominent areas of knowledge published in this field were: Ethics (24.70%, $N = 245$), ex-situ conservation (19.56%, $N = 194$), in-situ conservation (14.72%, $N = 146$), animal health (14.31%, $N = 142$) and animal physiology (11.49%, $N = 114$); the numbers of articles published in these areas differed significantly ($\chi^2 = 63.5$, DF = 4; $P < 0.001$). Standardised residual analysis showed that significantly more studies were published about ethics than expected, and significantly fewer studies than expected were published about animal health and physiology.

In general, studies were predominately theoretical (58.65%, $N = 563$), and experimental studies were slightly more likely to be conducted in nonzoo environments (12.40%, $N = 119$ vs. 10.52%, $N = 101$; for nonzoo vs. zoo environments, respectively). Studies conducted in the wild (10.31%, $N = 99$) and in laboratories (6.15%, $N = 59$) generated the smallest number of publications. In zoos the two most important subject areas were ex-situ conservation with 31.38% ($N = 59$) and environmental enrichment with 36.23% ($N = 25$) (Table 1). In laboratory environments most of the researchers analyzed the welfare of the animals in terms of their physiology (30.84%, $N = 33$) (Table 1). In wild studies, 32.87% of articles ($N = 47$) evaluated aspects of animal welfare in relation to in-situ conservation efforts (Table 1). Theoretical studies focused mainly on ethics ($N = 219$, 92.41%). Studies conducted in sanctuaries, veterinary hospitals and on farms were rare ($N = 10$, 4 and 4, respectively) and they tended to evaluate aspects of animal health or ex-situ conservation as measures of animal welfare (Table 1).

In total, our database had 236 different species or subspecies present. Most of the studies were conducted on mammals (75.92%, $N = 391$), with chimpanzees (*Pan troglodytes*, Primates, $N = 18$) and red deer (*Cervus elaphus*, Artiodactyla, $N = 12$) being the most common species. Birds were the second most-studied group of animals, with 13.40% of published articles ($N = 69$), but no one species dominated these studies. Reptiles were in third place with 4.08% of studies ($N = 21$). Amphibians were the group of vertebrates with the least number of studies (1.17%, $N = 6$) and the invertebrates appeared only in 1.36% of articles ($N = 7$), five of them with arthropods as experimental subjects; fish were not present in our data set. In-situ conservation was the most frequent subject area for articles published on birds (32.26%, $N = 20$) and invertebrates (33.33%, $N = 2$), although for invertebrates it coincided with health studies (Table 2). These differences between groups of study animals were highly significant ($\chi^2 = 808.16$; DF = 3; $P < 0.001$). Standardised residual analysis showed that significantly more articles were published about mammals than expected, and all other groups were significantly less than expected. Ex-situ conservation was the subject area of most of the studies for mammals (28.14%, $N = 103$) and reptiles (27.78%, $N = 5$), and for reptiles it also coincided with physiology (Table 2). Physiology was the prominent area of study for amphibians (50%, $N = 2$), but ex-situ conservation and ethics appeared in second

TABLE 1. Numbers of studies conducted in the different subject areas (in %) across different environments (the percentages refer to columns and the numbers in brackets below are *N*)

	Behav.	Ex-situ	In-situ	Enrich.	Ethics	Physio.	Health	M.B.
Zoo	4.05 (3)	31.38 (59)	0.70 (1)	36.23 (25)	–	11.21 (12)	–	–
Laboratory	6.76 (5)	–	0.70 (1)	5.80 (4)	0.84 (2)	30.84 (33)	8.00 (10)	66.67 (4)
Farm	–	–	–	–	–	–	3.20 (4)	–
Captive	14.86 (11)	15.95 (30)	3.50 (5)	33.33 (23)	2.53 (6)	37.38 (40)	2.40 (3)	–
Vet hospital	–	1.06 (2)	0.70 (1)	–	0.42 (1)	–	4.80 (6)	–
Wild	4.05 (3)	9.04 (17)	32.87 (47)	–	3.80 (9)	10.28 (11)	8.80 (11)	–
Sanctuary	–	1.60 (3)	–	–	–	0.93 (1)	–	–
Theoretical	70.27 (52)	40.96 (77)	61.54 (88)	24.64 (17)	92.41 (219)	9.35 (10)	72.80 (91)	33.33 (2)
N total	74	188	143	69	237	107	125	6

Behav., Behaviour; Ex-situ, ex-situ conservation; In-situ, in-situ conservation; Enrich., environmental enrichment; Physio., physiology; M.B., molecular biology; *N* total varied between the subject areas due to the inability to identify these informations in some of the abstracts evaluated. Owing to many small cell counts in the above table it was not possible to analyze its contents by χ^2 tests.

TABLE 2. Percentages of studies of animal welfare for different taxonomic groups published between 1991 and 2007 (the percentages refer to rows and the numbers in brackets below are *N*)

	Behav.	Ex-situ	In-situ	Enrich.	Ethics	Physio.	Health	M.B.
Bird	9.68 (6)	19.35 (12)	32.26 (20)	8.06 (5)	6.45 (4)	14.52 (9)	9.68 (6)	0 (0)
Fish	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Invert.	0 (0)	0 (0)	33.33 (2)	0 (0)	0 (0)	16.67 (1)	33.33 (2)	16.67 (1)
Mammal	5.74 (21)	28.14 (103)	14.75 (54)	12.02 (44)	10.93 (40)	21.04 (77)	7.10 (26)	0.28 (1)
Reptile	11.11 (2)	27.78 (5)	11.11 (2)	11.11 (2)	11.11 (2)	27.78 (5)	0 (0)	0 (0)
Amphibian	0 (0)	25.00 (1)	0 (0)	0 (0)	25.00 (1)	50.00 (2)	0 (0)	0 (0)

Fish are not presented as no published studies were in our data-set.

place, both with only one article published (25%, $N = 1$ for both subjects) (Table 2). Obviously, the results of the above analyses with small sample sizes needed to be interpreted cautiously.

One-hundred-and-twenty-eight experimental studies reported sample sizes, producing a mean sample size of 867. However, this result relied on one study on urban domestic cat welfare, which had a sample size of 103,643. The median number of animals used in experiments was 18—showing that sample sizes in general were relatively small. The median sample size for zoo-based studies was seven, which was lower than all other captive categories (e.g., laboratories, etc.).

The majority of the articles were published in the journals Applied Animal Behaviour Science (9.69%, $N = 109$), Animal Welfare (7.91%, $N = 89$), Journal of the American Veterinary Medical Association (7.86%, $N = 88$), Deutsche Tierarztliche Wochenschrift (5.36%, $N = 60$), Veterinary Records (5.36%, $N = 60$) and Zoo Biology (5.16%, $N = 58$). The differences between observed and expected were significant for this sub-set of journals ($\chi^2 = 28{,}8$; DF = 5; $P < 0.001$) (Table 3). Standardised residual analysis showed that significantly more articles were published in Applied Animal Behaviour Science than expected, and significantly less than expected in Zoo Biology. In total, the articles were published in a total of 254 different journals. Therefore, the majority of journals published less than five of the articles in our data.

We measured the importance, and to some extent the quality, of research published about animal welfare by analysing the impact factors of the journals where articles were published, and their median number of citations. The top eleven journals, in terms of the number of articles published, had a median impact factor of 1.013 (see Table 3), and the number of citations varied between 0 and 333, with a mean number of citations of 5.67. Analyzing only the articles with 0–20 citations

TABLE 3. The number and percentage of papers published by the top eleven ranked journals in terms of articles in our database (1948–2007)

Journal name	IF[a]	Total	%	RI
Applied Animal Behaviour Science	1.404	100	8.94	2
Animal Welfare	0.714	89	7.95	4
Journal of the American Veterinary Medical Association	1.820	88	7.86	1
Veterinary Records	1.087	60	5.36	3
Deutsch Tierarztliche Wochenschrift	0.469	60	5.36	7
Zoo Biology	0.564	58	5.18	6
Journal of Wildlife Diseases	1.013	23	2.06	8
Wildlife Society Bulletin	0.952	23	2.06	9
Journal of Wildlife Management	1.528	16	1.43	10
Ilar Journal	2.319	16	1.43	5
Australian Veterinary Journal	0.595	16	1.43	11
Total	1.013[b]	549	49.06	–

[a]Impact factors refer to 2007 (most recent available); Total, total number of articles (N) published about animal welfare (1948–2007); %, per cent of total data-set of articles ($N = 1119$); RI, rank of influence for environmental enrichment (RI = Rank (IF∗Total)) [for more details, see Azevedo et al., 2006].
[b]Median not total.

(94.32%, $N = 1{,}060$ of the articles), the mean number of citations decreased to 3.16. The most cited article, which was about the physiology of anhydrobiosis and its role in human well-being, had received 333 citations. The top-five cited articles addressed different aspects of animal welfare, such as animal behavior (291 citations), theoretical basis of animal welfare (163 citations), veterinary science (113 citations), environmental enrichment (110 citations) and physiology of stress (106 citations). Taking into account only the number of articles published, the journal Applied Animal Behaviour Science appeared in first place ($N = 100$), but when we also took into account impact factor, the Journal of the American Veterinary Medical Association became the most important journal (Table 3) (i.e., multiplying impact factor by the number of articles).

Terry L. Maple, with 13 published papers (0.47%), David W. Macdonald with 11 published papers (0.39%) and Marian S. Dawkins with 10 published papers (0.36%) were the most productive authors in our database. A total of 2,295 different authors (all authors on a article) were presented in our database. The majority of were produced by researchers from the University of Oxford (2.59%, $N = 25$), the University of California, Davis (1.76%, $N = 17$), the University of Bristol (1.66%, $N = 16$) and the University of Cambridge (1.35%, $N = 13$). A total of 568 different institutions were presented in our database (which included: zoos, universities, NGOs and government research institutions). In terms of language 87.71% of articles ($N = 971$) were written in English, the rest being in German (9.57%, $N = 106$), Dutch (1.26%, $N = 14$) and French (0.72%, $N = 8$). The differences in language of publication was high statistically significant ($\chi^2 = 2374.47$; DF = 3; $P < 0.001$). Standardised residual analysis show that significantly more article than expected were published in English, and all other languages were used significantly less than expected.

DISCUSSION

Two major trends came out of our bibliometric analysis: (1) the number of articles being published about zoo/wild animal welfare is increasing and likely to do so for the foreseeable future; (2) the majority of published studies had a theoretical nature. Taking our first results, most researchers publishing in this area of science would consider this to be positive. However, it is unclear whether this result reflects increased interest and investment in this area of scientific research or simply that researchers are responding to increasing pressures to publish. Of course this argument is not unique to the subject area in question. The second major trend that we detected is more worrying, because animal welfare by its very nature is an experimental subject. Obviously, all areas of human endeavor can benefit from ethical and theoretical analyses, but it is surprising that this comprises the majority of articles. This may reflect: (1) more professionals in the area of ethics having an interest in zoo/wild animal welfare, or (2) a lack of funding for experimental work. In many countries it is difficult for researchers based in zoos to attract research council funding [Smith et al., 2007].

Of the published experimental articles the majority were related to environmental enrichment or ex-situ conservation efforts (Table 2). Only six other subject areas were found and these varied with type of environment, however, owing to small sample sizes in many categories it was not possible to analyse these data statistically by environment type. In terms of environment 95% of studies in our database were

conducted in captivity (unspecified), zoos, the wild or in laboratories (Table 1). Therefore, the impact of farm-based studies on our database was minimal. This may reflect the relative lack of cross-over between the two environments. Undoubtedly, far more animal welfare research has been conducted on farm animals than zoo animals [see Young, 2003], and arguably more scientific interchange between these two areas of animal welfare research would be profitable, especially for zoo animal welfare research. Presently, there are a few cross-over scientists, such as Kathy Carlstead, Robert Young and Chris Barber who all conducted their Ph.D. research on farm animals before moving on to conduct research into zoo animal welfare.

Many of the other results found by this study were expected. For example, a variety of studies have reported a bias towards conducting animal-welfare-type studies with mammals [Azevedo et al., 2006; Melfi, 2005], despite mammals not being the most common or threatened group of animals held in captivity. This bias probably therefore, results from people's innate attraction to mammals' physical characteristics as has been reported in a variety of zoo-visitor behavior studies [Hinde and Barden, 1985; Young, 2003]. Certainly, the most popular species in our database were those that have physical characteristics attractive to humans, such as large eyes and forehead (e.g., chimpanzees; [Sanefuji et al., 2007]). Having said this a wide variety of species were studied by authors in our database, but obviously with less than five publications per species. It is surprising that we found no articles concerning fish welfare, especially given that this subject has had some attention in animal welfare journals recently (e.g., Applied Animal Behaviour Science, 104(3–4): 2007). The result is all the more surprising as many zoos have aquariums. However, it may be that our combination of keywords did not permit the finding of relevant fish articles. Substituting the word "aquarium" for "zoo" in our keyword searches produced four articles about fish welfare that confirmed that there is a lack of research in aquarium-fish welfare. Scientific productivity on a particular species is something of a two-edged sword, as many articles on a particular species means that we understand its well-being better. However, as resources for research are limited, this may also mean that other species are ignored. Zoos presently house around 4,000 species of animals, which puts into perspective the 236 different species encountered in our database.

Our study also confirms the dominance of English as the language of science, which should not be a surprise as our database consists of peer-reviewed scientific articles. Unfortunately, there are no comprehensive databases of nonpeer-review articles. We suspect that many such articles would be published in the native language of the country where they were produced. However, a number of these journals have a wide international circulation and impact (e.g., *The Shape of Enrichment*) and these journals are published in English.

We argue that a median sample size of 18 animals should be considered small, especially as it was not possible for us to separate out cases where animals in a group were considered separately in statistical analyses (i.e., pooling fallacy). Looking specifically at zoos, the median sample size was seven ($N = 25$). A similar result was also reported by Azevedo et al. [2006], and this probably reflects the fact that individual zoos often keep limited numbers of each species. Zoo-based researchers are aware of this problem and have been countering it by conducting multiple-institution studies [e.g., Clubb and Mason, 2003]. However, such studies, while useful, often suffer from the lack of proper experimental controls, and tend to be expensive to conduct.

The geographical biases in publications were to be expected as this reflects the longer history and investment in scientific research by European and North American countries. Whether the species-rich developing countries in our database will increase their scientific productivity in this area is unclear, as many of these countries, rightly or wrongly, are giving priority to in-situ animal conservation studies [Common and Stagl, 2005]. Given these geographical biases, it is not a surprise that the universities and the researchers that have the greatest scientific productivity are from these regions. However, given the importance of zoological collections in species-rich developing countries and the importance of animal welfare suggest a need to stimulate more research in such countries. Since the year 2000, the Brazilian Zoo Association (*Sociedade Brasileira de Zoológicos*) Annual Conference has been offering courses related to animal welfare, showing that at least in a practical sense some developing countries are trying to improve zoo/wild animal welfare.

A wide variety of journals were used by a large number of authors in our database; this no doubt reflects the multidisciplinary and complex nature of zoo/wild animal welfare. Despite, the large number of journals, approximately 11 journals dominated the subject and they have a median impact factor that can considered to be an average for biological sciences [see Azevedo et al., 2006]. Therefore, as judged by impact factor, zoo/wild animal welfare can be considered to be an area of average scientific quality. It is perhaps surprising that the journal Zoo Biology was not more prominent in our database. However, this no doubt reflects our combination of keywords that allowed the inclusion of studies relevant to zoo animals, but not conducted with zoo animals. Zoo Biology may also have suffered, because of its relatively low impact factor, which prevents researchers from some countries from publishing in it (e.g., Brazil). For example, until recently, if Brazilian biologists published in Zoo Biology, the article did not count toward their scientific productivity as evaluated by the Brazilian Government. The number of citations that articles received in this area is in line with a similar bibliometric study on environmental enrichment [Azevedo et al., 2006]. Inevitably, a specialized area of research like zoo/wild animal welfare will have relatively few researchers, and this will result in low citation counts for articles. Having said this, a large number of different authors were present in our database ($>2{,}000$), but most only had a contribution to one article, and even leading authors in our database did not contribute large numbers of articles. Previously, Lotka [1926] showed that in most areas of scientific endeavor, a significant percentage of publications are produced by a small number of researchers, which is not what our data show.

CONCLUSION

In conclusion, although this study has shown that zoo/wild animal welfare is a growing area of science, it is not without its problems or limitations. It remains to be seen if these problems will be overcome: one possible solution would be a greater interchange of information between animal-welfare scientists working in all types of environments. *The International Conference on Environmental Enrichment* (see its conference proceedings, for example) has been dominated as its inception by zoo-based workers with little participation from researchers working in other environments. One new initiative by the Brookfield Zoo in 2008 was the hosting

of the first zoo animal welfare conference titled, ''Measuring Zoo Animal Welfare: Combining Approaches and Overcoming Challenges,'' which successfully brought together researchers from zoos and farms. It is to be hoped that this initiative will bear fruit in terms of improvements in zoo animal welfare.

Specifically, our analysis demonstrates GAPs in our knowledge concerning: (1) fish, amphibian, reptile and invertebrate welfare; (2) the link between health, physiology and zoo animal welfare; (3) the welfare of wild animals; (4) how to convert theoretical knowledge into practical solutions for zoo animal welfare; (5) how zoo environments affect animal welfare outside of Europe and North America; (6) the welfare of the majority of mammals species due to studies being focussed on only a few species (e.g., chimpanzees).

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