

Research article

Evaluating the quantitative and qualitative contribution of zoos and aquaria to peer-reviewed science

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Abstract

The EU Council Directive relating to the keeping of wild animals in zoos, as well as major global and regional zoo associations, calls upon zoos and aquaria to support biodiversity conservation and research. However, assessments of the scientific contribution of zoos remain scarce to date. This paper, therefore, evaluates for the first time the quantitative research productivity of the 71 members of the Association of Zoological Gardens (Verband der Zoologischen Gärten, VdZ) and analyses aspects of its qualitative outcome. Between 2008 and 2018, VdZ members produced or contributed to 1,058 peer-reviewed and mostly ISI Web of Science (WoS)-listed publications, with productivity rates increasing over time. They did so either as (co-)authors or by supporting external research teams with access to animals, data or biological samples deriving from their respective ex-situ animal collections. The publications resulted in 8,991 citations appearing in 284 mostly not zoo-related journals. These findings, plus the large range of subject areas and animal species focused on, suggest a broad audience group reached. It is concluded that VdZ member zoos and aquaria make valuable contributions in certain fields of peer-reviewed science of which benefits might accrue for evidence-based ex-situ and in-situ conservation planning and management.

Introduction

For all zoos and aquaria in member states of the European Union the “EU Council Directive 1999/22/EC of 29 March 1999 relating to the keeping of wild animals in zoos” (hereafter “EU Zoos Directive”) constitutes the basic legal document for all operations. The Directive’s requirements define and strengthen the role that zoological gardens and aquaria (hereafter “zoos”) play in the conservation of biodiversity in accordance to Article 9 (“ex-situ conservation”) of the Convention on Biological Diversity (United Nations 1992) as well as to in-situ conservation. Amongst the most prominent and widely acknowledged tasks outlined in the EU Zoos Directive in support of biodiversity conservation are the promotion of

public conservation education, the provision of information about species and their natural habitats and the management of ex-situ breeding programmes for endangered animal species. However, the EU Zoos Directive also calls upon zoos to participate in research that benefits species conservation and/or to exchange information relating to species conservation. Accordingly, the call for research and publication of results is also firmly embedded in the Research Strategy of the European Association of Zoos and Aquariums, EAZA (Reid et al. 2008) and the World Zoo and Aquarium Conservation Strategy of the World Association of Zoos and Aquariums, WAZA (Barongi et al. 2015). Both strategies correctly point out that, over the past decades, zoos have generated vast amounts of scientific data and made meaningful contributions to the knowledge of species, including life history, reproduction, genetics,

behaviour, cognition, group dynamics, parasitology, veterinary medicine, husbandry, breeding of small wildlife populations and many more (Stoinski et al. 1998; Anderson et al. 2008; Conde et al. 2019; Mendelson et al. 2019; Perdue 2019; Rose et al. 2019). This applies in particular to certain aspects of the biology of animal species that had remained unknown from studies in natural habitats (Conde et al. 2019; Ludwig et al. 2019; O'Brien et al. 2019; Perdue 2019; Schmitt 2019; Schiffman and Clauss 2019; ZIMS 2020). The benefit to conservation of such zoo-generated data has been discussed (Rees 2005). Many authors however, acknowledge its value for evidence-based ex-situ and in-situ conservation planning and management (Gusset and Dick 2010; Conde et al. 2011; Pritchard et al. 2012; Byers et al. 2013; Hauswaldt et al. 2013; Strauss et al. 2013; Murphy and Gratwicke 2017; Schwartz et al. 2017; Ziegler et al. 2018; Conde et al. 2019; Traylor-Holzer et al. 2019). Nevertheless, due to the steadily growing number of animal species and natural ecosystems requiring scientific support to thrive (Pimm et al. 2014; IUCN 2020), zoo associations like EAZA or WAZA urge all members to enhance their research engagement for the ultimate goal of conserving biodiversity.

Engagement for scientific research is also firmly embedded in the constitution of the Verband der Zoologischen Gärten (VdZ) e.V. (Association of Zoological Gardens, www.vdz-zoos.org) and, thus, amongst the key conditions for gaining VdZ membership. Founded in 1887 and now based in Germany's capital Berlin, VdZ is the oldest zoo association worldwide and currently represents 71 zoos in Germany (56), Austria (6), Switzerland (8) and Spain (1), all of which welcome more than 43 million visitors annually. In addition to their research activities, VdZ member zoos contribute in other ways to conservation, such as participating in and managing ex-situ breeding programs, providing animals and substantial financial and logistic support for in-situ conservation projects, offering nature-related education for the public and involving zoo staff in specialist groups of the IUCN Species Survival Commission (VdZ 2019).

It is difficult to evaluate the effectiveness of these manifold conservation measures undertaken by zoos and other conservation organisations (Stem et al. 2005; Ferraro and Pattanayak 2006; Falk et al. 2007; Weiler and Smith 2009; Gusset and Dick 2011; Loh et al. 2018). Regarding scientific research, the question arises how to evaluate the present or future use (or lack of use) of data and its benefits (or irrelevance) to the scientific community and conservation. As a first step to measuring the scientific output of zoos, it is possible to capture their research productivity: defined as the number of publications in peer-reviewed literature to which a zoo contributed. This metric approach allows quantitative comparisons over time and across organisations (Grant et al. 2007; Carpenter et al. 2014; Moed and Halevi 2015; Loh et al. 2018). It does not, however, allow conclusions to be drawn regarding the quality of the scientific output. To do so, it is possible to analyse additional factors, such as impact factors and diversity of peer-reviewed journals chosen for publications, subject areas as well as the various types of contributions zoo staff and the respective ex-situ animal collections provide for scientific research.

Regarding the research productivity of zoos, there are two recent publications of interest: the British and Irish Association of Zoos and Aquariums stated that out of their 105 members, 24 institutions published 159 papers in peer-reviewed journals in 2011 (Hartley 2013). Likewise, Loh et al. (2018) summarised and characterised the research productivity of the 228 members of the Association of Zoos and Aquariums (AZA) which are mainly located in the United States of America. The authors found that 5,175 articles were published by AZA members in peer-reviewed journals between 1993 and 2013 with publication output increasing over time. The majority of the journals chosen for publication by AZA members referred to the subject categories of

zoology (31.9%) and veterinary science (31.7%) with the Journal of Zoo and Wildlife Medicine (500 publications) and Zoo Biology (330 publications) being the two most frequently chosen journals. Furthermore, the study identified factors potentially favouring a high research productivity of single institutions, amongst them being the inclusion of "research" in the mission statement, large financial assets and a non-profit structure.

Rather than focusing on factors determining a single institution's level of engagement for research, this study aimed to determine the overall contribution of VdZ member zoos to peer-reviewed science. In order to do so, the following aspects were specifically looked at: (a) the peer-reviewed research productivity of all 71 VdZ zoos between 2008 and 2018; (b) the publications' citation rates; (c) the animal classes focused on; (d) the broadness of the audience group potentially reached according to the types of journals and subject categories attended to; and (e) the various ways in which ex-situ animal collections of VdZ members contributed to science.

Overall the study defines the baseline for quantitative and qualitative aspects of the contribution of VdZ zoos to peer-reviewed science. It also provides evidence for the level of implementation of the EU Zoos Directive regarding its research requirements as well as of the calls from WAZA, EAZA and VdZ for zoos to actively conduct and support research. Furthermore, this report underlines the value of ex-situ animal collections for science and identifies potential to increase future scientific output of zoos.

Methods

In order to quantify the research productivity of VdZ member institutions, in terms of the number of publications and their respective citations, publications were selected that fulfilled three conditions: published (1) between 2008 and 2018; (2) in a peer-reviewed scientific journal; and (3) by or with participation of one or more of the 71 VdZ member institutions. This recent 11-year period reflects the actual research productivity and content alignment and thus provides a detailed picture of current trends in scientific research. All publications included in the analysis were obtained using one of two different strategies. (1) Comparable to Loh et al. (2018), articles and citations were extracted from the Thomson Reuters ISI Web of Science (WoS) database and (2) VdZ member institutions were asked to provide lists of publications. These lists were checked against the results of the WoS database to avoid duplication. Furthermore, any publication not found in WoS was checked for a peer-review process conducted by the respective journal through its listing in the SCImago Journal Rank (SJR, Colledge et al. 2010). All journals not listed in WoS or SJR were excluded from the analysis with one exception: The zoo-specific, peer-reviewed Journal of Zoo and Aquarium Research (JZAR) which is published by the European Association of Zoos and Aquaria (EAZA) was not yet listed in WoS during data collection. This rigid selection of publications inevitably excludes some publication types produced by VdZ members but provides an applicable and standardised method for the analysis and comparisons.

A search was conducted for the institution name, including abbreviations, with asterisks (e.g., "Zool*" instead of "Zoologischer") and alternative spelling and names (e.g., "Nürnberg" and "Nuremberg"), in the "Address" field using "Basic Search" within the WoS Core Collection from 2008 to 2018. For each publication authorship, title and abstract, the journal's title and the times cited were saved. For papers without an explicit authorship of zoo staff, the types of contribution the zoo made in order to support the publication was determined. To complete the database, further information was added, such as location of data collection (in-situ/ex-situ/combined/others), classes of animals

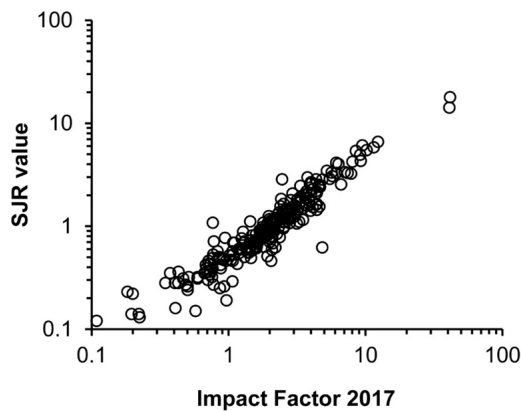


Figure 1. Comparison of the SCImago Journal Rank (SJR value) and Journal Impact Factor (IF 2017). The analysis of 248 journals revealed a highly significant correlation between SJR and IF 2017 (Pearson's correlation coefficient $r=0.966$, $P<0.01$, two-sided test). Data points are plotted on a logarithmic scale to obtain a better resolution.

focused on and subject categories. For the latter, subject categories were assigned to all WoS-listed articles using the subject category assigned to the respective journals by the WoS database. It was noted that 49.9% of the publications were assigned to more than one WoS subject category, hence overlap occurs. Nevertheless, this standardised approach allows a direct comparison with other studies (Loh et al. 2018) and is consistent with similar procedures for academic organisations (Keville et al. 2017).

Additionally, the relevant metrics (2017 and 5-year impact factors) and the JCR Category in the "View Journal Impact" field were selected during data collection. Based on the publication lists provided by the VdZ member institutions, the database was completed by adding the SJR value as a further impact measure. The SJR value weights citations according to the importance of the journal in which the citation occurs, thus reflecting more precisely the journal's prestige rather than its popularity (Colledge et al. 2010). An analysis of the 2017 impact factor and the SJR value of the respective journals showed a highly significant correlation between both parameters (Figure 1). Hence, the SJR value was used for comparison purposes in regard to publication impact throughout the study.

Results

Research productivity and types of contribution

Between 2008 and 2018, VdZ members produced or contributed to a total of 1,058 publications in 284 journals which resulted in 8,991 citations. The majority of these publications (78.6%) are listed in the WoS database (Table 1). Fourteen out of 71 VdZ members did not publish or contribute to any peer-reviewed paper since 2008. On average, those 14 members register around 239,000 visitors annually (VdZ 2019). The 10 zoos with the highest research productivity register on average around 1,491,000 visitors per year (VdZ 2019).

A more detailed analysis of articles published in the period 2008–2016 shows that only 18.7% of the publications were not cited, whereas 47.8% reached between one and nine citations and 33.5% were cited more than 10 times. Citations of articles published in 2017 and 2018 were not included in this detailed analysis as citations may be underestimated due to recentness.

Table 1. Journals, articles and citations of peer-reviewed publications to which VdZ zoos contributed (period 2008–2018).

	Web of Science-listed	Only SJR-listed	JZAR	Total
Journals	254	29	1	284
Articles	833	201	24	1.058
Citations	8.572	391	28	8.991

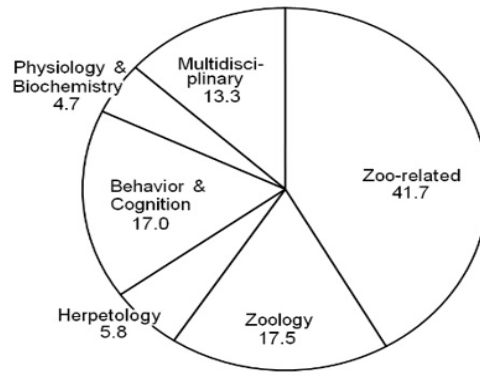
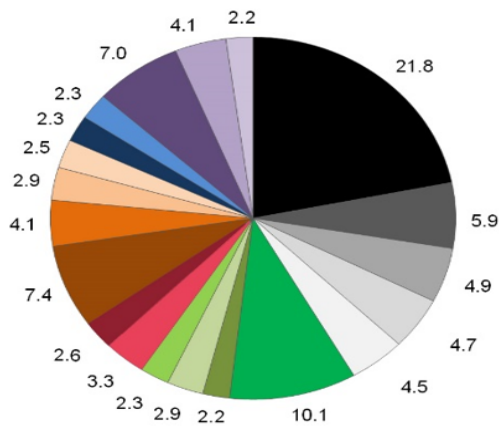
In most cases (69.8%), staff of VdZ members are the authors or co-authors of the publications. For the remaining 30.2% of publications, VdZ members contributed by providing external research teams with bio samples, access to zoo animals for non-invasive studies, funding or information from databases. Regarding data collection, 68.2% of all articles derive from research undertaken on zoo animals (ex situ) whereas 23.8% comprise data collected in the wild (in situ). 4.9% of the publications use combined ex-situ and in-situ data whilst 3.1% build upon theoretical approaches.

Type of journals and citation rates

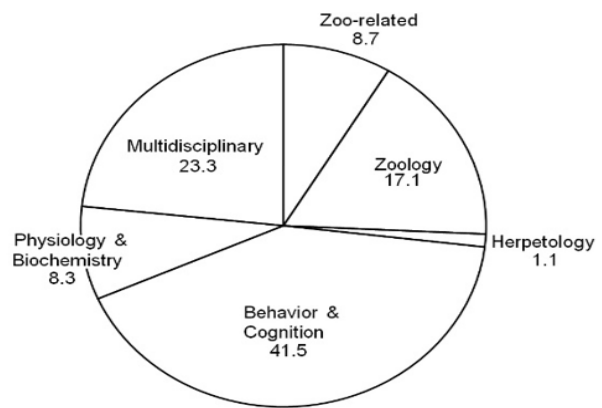
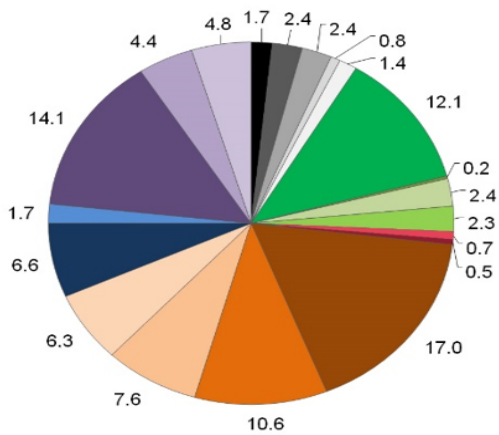
The majority (79.2%) of the 1,058 articles are published in 279 journals. According to the journals' thematic focus (compare Table 2) they can be summed up in five clusters: 'herpetology', 'zoology', 'physiology and biochemistry', 'behaviour and cognition', and various other disciplines ('multidisciplinary'). The remaining 20.8% of all publications appear in merely five journals, which form the sixth thematic cluster: 'zoo-related'.

A more detailed journal-specific analysis reveals that VdZ members published frequently (more than 10 articles per journal) in 20 journals (7.0% of 284) (Figure 2A). Within those 20 most frequently chosen journals, the five zoo-related journals comprise 41.7% of the articles ($n=214$) whilst 58.3% of the articles ($n=299$) were published in 15 journals with a non-zoo-specific focus. To gain further insight into the journal-specific outcome of those 20 frequently chosen journals, the respective journal impacts were calculated as a product of the number of articles published and the times those articles were cited (Figure 2B). According to this measure, the 214 articles in zoo-related journals make up only 8.7% of the total outcome with 319 citations. Their average citation rate (citations per article) is also rather low and lies between a minimum of 0.55 (Der Zoologische Garten) and a maximum of 3.52 (Zoo Biology). Contrary to that, the four zoological journals (Zootaxa, Revue Suisse de Zoologie, Bonn Zoological Bulletin, and European Journal of Wildlife Research) account for 17.1% of the outcome with a total of 90 articles and 628 citations. Here, the citation rate varies between 0.82 (Revue Suisse de Zoologie) and 8.58 (Zootaxa). The two more specialised herpetological journals reveal a total of 30 articles accounting for only 1.1% of the outcome. With 42 citations in total, their citation rates are low, ranging from 1.31 (Russian Journal of Herpetology) to 1.47 (Herpetology Notes). The two physiological/biochemical journals, also featuring 30 articles, show a higher impact (8.3%) with 306 citations and citation rates ranging from 5.17 (Journal of Animal Physiology and Animal Nutrition) to 20.33 (Comparative Biochemistry and Physiology A). The four journals focusing on behaviour and cognition (Animal Cognition, Journal of Comparative Psychology, American Journal of Primatology, and Animal Behavior) obtain by far the highest impact (41.5%) due to a total of 87 publications resulting in 1,527

A Research productivity



B Impact



Zoo-related

- Der Zoologische Garten
- Journal of Zoo and Wildlife Medicine
- Zoo Biology
- Journal of Zoo and Aquarium Research
- International Zoo Yearbook

Zoology

- Zootaxa
- Revue Suisse de Zoologie
- Bonn Zoological Bulletin
- European Journal Of Wildlife Research

Behavior & Cognition

- Animal Cognition
- Journal of Comparative Psychology
- American Journal of Primatology
- Animal Behavior

Herpetology

- Herpetology Notes
- Russian Journal of Herpetology

Physiology & Biochemistry

- Comparative Biochemistry and Physiology A
- Journal of Animal Physiology and Animal Nutrition

Multidisciplinary

- PloS One
- Scientific Reports

Figure 2. Journal-specific analysis. 2A: Research productivity in the 20 most frequently used journals, shown as percentages of articles published. 2B: Impact of the 20 most frequently used journals, measured as the product of the number of articles and citations. On the left side, the percentages of each journal are given whereas on the right side the respective percentages are shown for the six thematic clusters of journal types.

citations. Here, the citation rates are high throughout and range from 16.5 to 18.53. The 68 articles in the three multidisciplinary journals (PloS One, Proceedings of the Royal Society B Biological Sciences, and Scientific Reports) also reveal high citation rates between 7.71 and 15.91 (857 citations) resulting in the second highest impact of 23.3%.

Subject categories

The analysis reveals that the majority of publications (n=832) are assigned to the subject categories zoology (25.1%) and veterinary sciences (13.9%; Figure 3). The four subject categories environmental science and ecology, behavioural sciences, science and technology and biodiversity and conservation are also rather

Table 2. Number of articles in the WoS subject categories in 2-year intervals (period 2008–2017)

	2008/09	2010/11	2012/13	2014/15	2016/17
Zoology	57	71	73	77	76
Veterinary sciences	29	32	42	43	52
Environmental sciences and ecology	13	16	21	27	25
Behavioural sciences	21	14	21	20	20
Science and technology	0	9	12	19	29
Biodiversity and conservation	15	11	15	16	13
Life Sciences and biomedicine	11	11	8	12	10
Reproductive biology	17	12	10	7	5
Evolutionary biology	5	4	16	13	9
Psychology	18	9	7	11	6
Marine and freshwater biology	1	5	4	12	9
Others	11	19	30	28	42
Total	198	213	259	285	296

prominent with percentages between 5.2% and 7.6%.

The research productivity of VdZ zoos rose over time by one third, revealing an overall positive trend (n=198 in 2008/09; n=296 in 2016/17; Table 2). At all times, the output remained highest in the subject categories of zoology and veterinary sciences, accounting for 39% of all publications listed in WoS. Likewise, there was a noticeable increase in the subject categories environmental sciences and ecology, science and technology as well as marine and freshwater biology. Research productivity in behavioural sciences, biodiversity and conservation, life sciences and biomedicine, and evolutionary biology remained relatively stable while productivity in reproductive biology and psychology decreased over time. Interestingly, whereas no publication in the subject category education and educational research (in category ‘others’) was published between 2008–2013, six publications appeared in the period 2014–2017.

Animal classes

Publications focusing on mammals constituted the majority (58.7%). Articles on reptiles (16.8%), birds (10.5%), amphibians (6.5%), invertebrates (4.3%) and fish (3.2%) are also present but to a much lesser extent. In order to understand whether the animal class referred to in a publication influenced the overall outcome of a publication, the relationship between the SJR value of the publishing journal and the number of citations a publication received was examined. Figure 4 shows that the number of citations rose in accordance with a higher SJR value. Most publications (43.2%) focusing on mammals are published in journals with an SJR value of 1 or more (up to 17.87) whereas this applies to only 12.9–33.6% of the articles dealing with the other vertebrate classes or invertebrates. Thus, articles dealing with mammals seem to achieve better results in regard to citations. Nonetheless, some publications in journals with a low or medium SJR value also achieved frequent citation (i.e. Zootaxa with a SJR

of 0.26 and 8.58 citations per article, or Comparative Biochemistry and Physiology with a SJR of 0.84 and the highest citation rate of 20.3 within the frequently used journals). Additionally, some publications dealing with reptiles were cited more than 30 times despite a SJR value as low as 0.26 (i.e. Geissler et al. 2009; David et al. 2011; Nazarov et al. 2012).

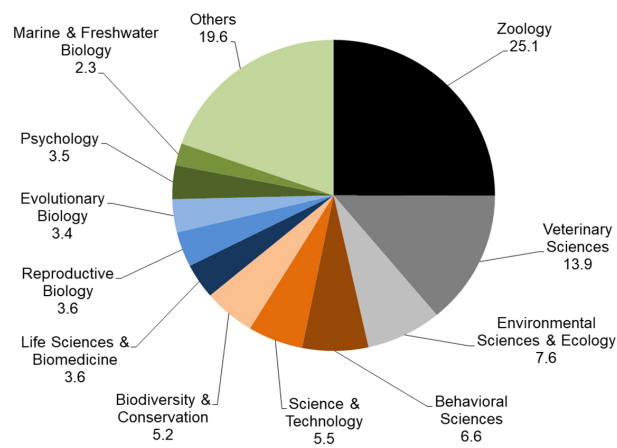


Figure 3. Percentages of publications in regard to the WoS subject areas (categories may overlap, see Methods)

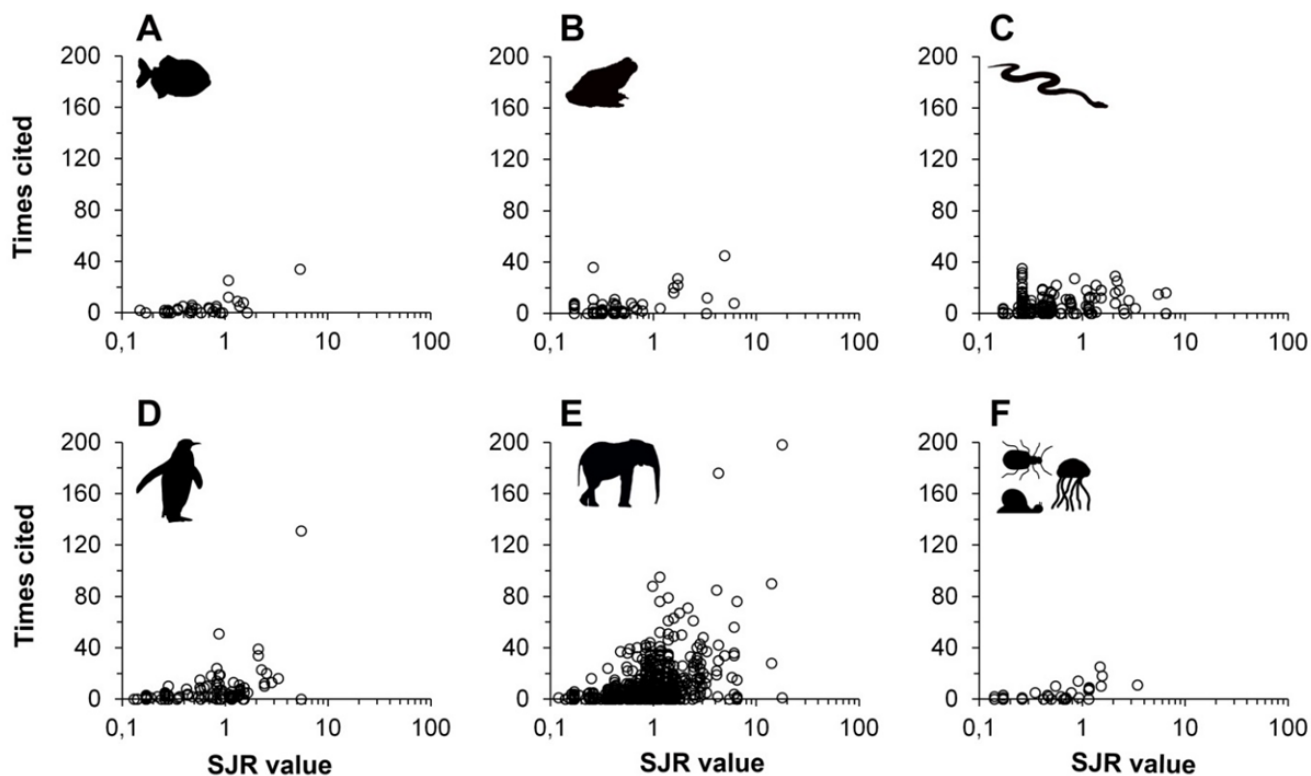


Figure 4. Correlation between the citation frequency and the SCImago Journal Rank (SJR value). The publications were assigned to the respective vertebrate classes (A–E) or invertebrates (F). Data points are plotted on a logarithmic scale to obtain a better resolution.

Discussion

VdZ member zoos produced or contributed to a large volume of peer-reviewed publications between 2008 and 2018, with the majority being WoS-indexed and resulting in a respectable amount of citations. The magnitude of research productivity plus the trend of increasing numbers of publications over time support findings of other studies (Loh et al. 2018; Rose et al. 2019) and indicate a substantial contribution of VdZ zoos to certain fields of science. Besides these quantitative results, this study also highlights three lesser-known facts that underline the value of ex-situ animal collections for science: 1) VdZ zoos regularly provide external research teams with access to animals, biological data or biomaterial samples derived from their animal collections, which result in numerous peer-reviewed publications. By doing so, VdZ zoos continuously contribute to the Aichi Biodiversity Target 19 which aims at improving the conservation-related science base and the sharing of relevant data (Convention on Biological Diversity 2016). This said, it is assumed that additional publications may not have been captured in the present study, due to external research teams not always explicitly mentioning a zoo's contribution and zoos not always following up. It is, therefore, suggested that zoos more closely track the outcome of their contributions to external research as this is likely to raise their overall research productivity in future assessments. 2) VdZ zoos do not restrict their research efforts to ex-situ data collection only. About one-fifth of the

publications are based on data gathered in natural habitats (in-situ) with some resulting in high-impact publications such as the discovery and description of new species (i.e. Ziegler et al. 2008; Geissler et al. 2009; David et al. 2011; Nguyen et al. 2011; Nazarov et al. 2012; Van Schingen et al. 2016; Greenbaum et al. 2018). Whilst in the present study, only a few publications combined zoo-based data and data from the field, it is predicted that the ongoing merging approaches to in-situ and ex-situ population and conservation management will favour such combined research methods in the future (Byers et al. 2013; Schwartz et al. 2017; Ziegler et al. 2018). 3) Numerous unpublished bachelors, masters and PhD theses that are carried out in VdZ zoos with crucial support and supervision of zoo staff were not taken into account in this study. Yet, those hands-on experiences are also in support of science as they provide early career researchers with practical and affordable wildlife research experience. As an indication of the magnitude of such opportunities provided through the existence of ex-situ animal collections, Hartley (2013) points out that in BIAZA member zoos a total of 848 projects at undergraduate level and 212 projects at postgraduate level were completed in 2011, resulting in 289 publications of which only 159 appeared in peer-reviewed journals.

Despite the overall encouraging research productivity of most VdZ members, the findings also reveal that some members have not contributed to science since 2008. Those zoos might, however, have produced research outcomes which remained unpublished

or were not captured by the research methods used in this study. In addition to previous factors that were identified to predict the likelihood of scientific engagement of a zoo (Loh et al. 2017; Rose 2019), the results suggest that numbers of annual visitors can also impact research productivity. This said, not all zoos receiving lower numbers of visitors conduct little or no research, and not all institutions with millions of visitors express high levels of scientific engagement, so this aspect needs further investigation.

In regard to outreach and broadness of the target group, some authors (Rees 2005; Lawson et al. 2007; Loh et al. 2018) suggest that zoos preferably publish in zoo-related journals. The findings of this study instead indicate a rather large diversity of target groups potentially reached: VdZ zoos published in a remarkable total of 284 journals with nearly 80% of all publications appearing in not specifically zoo-related journals ranging from herpetology, physiology, biochemistry, behaviour, cognition, technology, conservation to education and others. When narrowing down the analysis to the 20 most common journals, publications appearing in the five zoo-related journals outnumbered those in the 15 non-zoo-related journals. The publications in zoo-specific journals also contribute rather little to the overall outcome in regard to citations. Possibly, this is caused by relatively fewer regular subscribers or topics appearing less relevant to non-zoo-specific groups of the scientific community. This phenomenon, however, is not restricted to zoo-related journals but also affects other areas of scientific expertise with a niche character. Overall, it can be asserted that the visibility and recognition of research engagement of zoos and the interdisciplinary exchange might be boosted if zoos increasingly published in non-zoo-specific journals in order to reach an even broader audience.

Comparable to Loh et al. (2018), a large proportion of VdZ zoo-based research can thematically be assigned to the subject categories zoology and veterinary sciences. These preferences may be attributed to the availability of relevant data under ex-situ conditions plus a tradition of zoos' interest in such fields and their constant ambition to improve animal husbandry (i.e. Miller and Fowler 2012; Murphy and Gratwicke 2017; Rose et al. 2019). Yet, the broad range of scientific fields to which zoos contribute is remarkable. Less traditional subject categories, such as education and educational research, are becoming relevant to the zoo research agenda, which might relate to the EU Zoos Directive's request for public conservation education and the subsequent call for its evaluation.

It is recognised that not all publications are likely to be utilised for evidence-based conservation. Contrary to previous criticism of most zoo-based research not being relevant to conservation (Lankard 2001; Rees 2005), and due to the complexity of present-day conservation projects, it is argued that publications in any subject category hold potentially crucial information for ex-situ or in-situ conservation (Ziegler et al. 2008; Saragusty et al. 2012; Murphy and Gratwicke 2017; Hildebrandt et al. 2018). This view is supported by a recent study (Conde et al. 2019) that demonstrates the conservation value of basic lifespan data that have been collected by more than 1,200 zoos and aquaria around the world on a daily basis and collated in the Zoological Information Management System (ZIMS 2020).

Regarding the animal classes chosen for research in the present study, more than half of the publications focused on mammals. Meanwhile, bird and fish species remain extremely underrepresented in zoo-based research compared to their abundance in zoological institutions. On average, each VdZ member keeps 52 species of mammals, 54 bird species and 34 species of fish (VdZ 2019). These findings underline the urgent call to extend research equally across all taxa (Melfi 2009; Rose et al. 2019). This applies even more so as the present results reveal that examining understudied animal classes neither excludes authors

from publishing in journals with medium or high impact factors or SJR values, nor from receiving respectable citation rates (i.e. Andreone et al. 2008; Wright et al. 2008; Day et al. 2013).

Against the background of the ongoing debate about the level of implementation of the EU Zoos Directive, this study provides quantifiable and qualifiable evidence of the important role that VdZ zoos play in the gathering of scientific knowledge, which partially benefits evidence-based ex-situ and in-situ conservation planning and management. It also highlights that animals in ex-situ collections can be of high scientific value, besides being important ambassadors for conservation education (Falk et al. 2007; Gusset and Dick 2011; Moss et al. 2015) and forming part of ex-situ insurance populations (Pritchard et al. 2012; Da Silva et al. 2019).

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