FACETS
a multidisciplinary open access science journal

RESEARCH ARTICLE

Peer-reviewed scientific contributions from Canadian zoos and aquariums

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Abstract

With the widespread loss of biodiversity, zoos and aquariums are striving to become leaders in biodiversity conservation and research. Canada's Accredited Zoos and Aquariums (CAZA) is a nonprofit organization created to represent its members, including as agencies of conservation and science. However, the contribution of CAZA members to conservation and science has not been quantified. We used research productivity in the form of peer-reviewed publications to systematically quantify biodiversity conservation engagement by CAZA institutions. We extracted publications from the ISI Web of Science database and found that the annual number of publications increased over time. CAZA members published most in the area of veterinary science, with few publications in biodiversity conservation. Organization age, research-orientated mission statements, and financial assets were significant predictors of research productivity. CAZA institutions also published significantly less ($\overline{X} = 12.5 \pm 5.52$ SE) than members of the Association of Zoos and Aquariums ($\overline{X} = 24.27 \pm 5.08$ SE), based in the United States. Zoos and aquariums are important resources in mitigating biodiversity loss, and are increasing their research output in this area. Nonetheless, only a small proportion of publications were in biodiversity conservation, and the majority of all publications occurred in zoo-centric journals.

Key words: zoos, conservation, publications, bibliometrics

Citation: Pyott BE and Schulte-Hostedde AI. 2020. Peer-reviewed scientific contributions from Canadian zoos and aquariums. FACETS 5: 381–392. doi:10.1139/facets-2019-0052

Handling Editor: David Lesbarrères

Received: September 18, 2019

Accepted: February 19, 2020

Published: June 4, 2020

Published by: Canadian Science Publishing

Introduction

Over 26 500 known and evaluated species are at risk of extinction worldwide at various levels and time scales (IUCN 2018), and biodiversity losses and extinction rates have increased considerably because of the widespread degradation of global ecosystems caused by humans (Johnson et al. 2017). The conservation of these species often requires that many organizations and institutions work together. Zoos and aquariums are becoming increasingly involved in the conservation of species at risk (Hutchins and Smith 2003). The World Association of Zoos and Aquariums (WAZA) is a global organization of zoos and aquariums that aims to promote cooperation among its members (waza.org). WAZA has helped develop the World Zoo Conservation Strategy that encourages zoological institutions to participate in biodiversity conservation efforts as well as providing guidance on how to reach these goals (IUDZG and CBSG 1993). Canada's Accredited Zoos and Aquariums (CAZA) is a nonprofit organization founded in 1974 (caza.ca) that currently has 30 institutional members. CAZA states that zoos and aquariums play a critical role in preserving biodiversity, and this is reflected in their accreditation standards that ensure high-quality animal care, education, and research at their institutions. CAZA maintains these standards through its inspections and policies and protocols.

CAZA members participate in Species Survival Programs and captive breeding and reintroduction programs, while also collaborating with government and nongovernment organizations to preserve species in Canada and abroad (Galbraith and Rapley 2005). However, quantifying the contribution of zoos and aquariums to conservation-related activities is extremely difficult (Ferraro and Pattanayak 2006; Loh et al. 2018). Research productivity in the form of peer-reviewed publications has been used to systematically quantify this contribution for members of the Association of Zoos and Aquariums (AZA), CAZA's counterpart in the United States (Loh et al. 2018). Peer-reviewed publications are important contributions to scientific knowledge that can be shared with other practitioners and thus aid in the formulation of informed conservation management decisions (Loh et al. 2018). However, not all conservation-relevant research will result in peer-reviewed publications, but research productivity of zoos and aquariums can still be related to overall conservation activity, as has been done for universities (Grant et al. 2007; Loh et al. 2018). Thus, research productivity provides a foundation with which to assess the conservation contributions of these organizations.

Participating in research is mandated by CAZA for a zoo or aquarium to obtain and maintain accreditation (CAZA 2008). However, for Canadian zoos and aquariums, few studies have explored their contribution to biodiversity conservation efforts and research productivity in general. Olive and Jansen (2017) conducted interviews of CAZA's four largest and oldest zoos, and determined they were all involved in hands-on conservation programs. Galbraith and Rapley (2005) used surveys to provide insight into the role of research at CAZA institutions, but received only eight responses. The responses received indicated that research was prevalent at the majority of these institutions (Galbraith and Rapley 2005). Although these studies attempted to quantify the roles conservation and research play at CAZA institutions, the scope of their analysis was limited. To our knowledge, no one has yet quantified the contribution of CAZA organizations to biodiversity conservation efforts in a systematic manner. Understanding patterns of research productivity among CAZA members is important for understanding the contributions zoos and aquariums bring to conservation at large, and this information could be important for CAZA and its members in their strategic planning to identify areas for investment in their programs.

We used research productivity (defined as the number of peer-reviewed publications) to characterize the contribution of Canadian zoos and aquariums to scientific discovery, with a specific focus on publications relevant to biodiversity conservation, in the same manner as Loh et al. (2018). We use the term "publications" when referring to peer-reviewed publications. Hence, we quantified the number of publications produced by CAZA members, as well as determined the journal outlets and subject areas of these publications. We expected that the number of publications produced by CAZA members would increase over time because of the contemporary transition of zoos and aquariums from sources of entertainment to science centers (Hutchins and Smith 2003) and that inter-organizational variation between institutions will affect the magnitude of publications produced by each member. These organizational factors include age, organization type, organization size, and the inclusion of the term research in the organization's mission statement. We expected that older and financially larger institutions would publish more because of their greater resources relative to younger and smaller zoos and aquariums. We also expected nonprofit organizations and those that include research in their mission statement to publish more, as these factors are indicative of an environment that prioritizes research (Loh et al. 2018). We expected that generally CAZA members would produce fewer publications than their AZA counterparts because the AZA has older and larger institutions than CAZA. Likewise, we expected that CAZA members would produce fewer publications related to biodiversity conservation than AZA members because of the relatively large number of AZA members that have research institutes devoted to conservation (e.g., Smithsonian Conservation Biology Institute, San Diego Zoo Institute for Conservation, Lincoln Park Zoo's Conservation & Science Department) compared with what is found in Canada.

Materials and methods

Characterizing publication trends

We followed Loh et al. (2018) and quantified research productivity by CAZA members using the Thomas Reuters ISI Web of Science (WoS) database. We recognized that by relying solely on the WoS database some publications may be excluded, but we assumed that the proportion of publications that were excluded for each institution was roughly constant; therefore, WoS provided a standardized source to compare institutions (Loh et al. 2018). Additionally, WoS was used to search for authorship by institutions and provided bibliometric measures, such as *h*-indices and subject areas, that are not available using other databases (e.g., Google Scholar). Our methods are consistent with Loh et al. (2018). Thirty CAZA institutions were searched for by name, using abbreviations and alternate spellings, in the WoS Core Collection in the "Address" field using "Basic Search". Using the search parameter "Address" produced all publications in which at least one of the author's addresses was listed as a zoo or aquarium. Two searches were conducted, one from 1993 to 2013, the same time period as Loh et al. (2018) to compare AZA and CAZA members, and one from 1993 to 2017 to include more recent data on the research productivity of CAZA members.

Publications, citations, and *h*-indices were extracted for each institution from the WoS database to determine their research productivity (**Supplementary Material S1**). Publications extracted included peer-reviewed journal articles, book chapters, and conference proceedings. The *h*-index is a citation index defined by the number of publications per organization with at least *h* citations (Hirsch 2005). Redundant publications that were produced jointly by multiple zoos were removed from total publications, but were counted for each individual zoo. To verify that the increase in publications from 1993 to 2017 was not just a result of time, as researchers are publishing now more than ever before (Bornmann and Mutz 2015), we collected the total number of publications by all researchers in 1993 and in 2017, using the "Year Published" field in WoS. Percent increase was then calculated for both total global publications and total publications by CAZA members from 1993 to 2017. Journal outlets and their corresponding subject areas were also extracted from WoS to characterize popular journals and research areas. Journals were often assigned to more than one subject area, but we categorized each into one subject area using the ranking system provided by WoS. This approach provided a standardized classification of topics in which CAZA institutions are publishing (Loh et al. 2018), as has been done for other organizations such as universities (Keville et al. 2017).

Organizational factors affecting research productivity

To determine the characteristics that may affect research productivity at individual institutions, their age, organization type, organization size, and their mission statements were determined using their website and other online sources. Age was determined relative to 2017 by finding the year the institution was founded. Organization type was divided into four categories: for profit, nonprofit, government run, and government nonprofit hybrids. Mission statements that included the word research or research-affiliated terms were identified. Organization size, in the form of net assets, was obtained from the Canada Revenue Agency website (canada.ca/en/revenue-agency.html) for nonprofits only, as financial information for government and for-prof1it organizations was often unavailable or inconsistent. Data were obtained from 2017. To quantify the growth of CAZA nonprofit institutions over time, net assets were also obtained for 2003 from charitydata.ca, which was the furthest year back on record. This could not be obtained from the CRA website as they only have financial data dating back 5 years. The growth of CAZA institutions was then related to research productivity over time.

Statistical analysis

All statistical analyses were conducted in R (RStudio Team 2016). The first analysis regressed total publications with year using a linear model to determine research productivity over time. Total publications were $\log_{10}$ transformed to obtain normality. The second analysis modeled total publications and total citations with age, mission statement, and organization type using a negative binomial model (*MASS* package; Venables and Ripley 2002). Pseudo-R^2 values were calculated using the *pscl* package to determine model fit (Jackman 2017). We chose to use a negative binomial model, contrary to Loh et al.'s (2018) linear model, because the data follow a negative binomial distribution. Mission statements were coded as 0 (research did not appear) or 1 (research did appear). In the case of organization type with four levels, nonprofits were coded as the reference variable in all cases. Nonprofits were chosen as the reference variable because they were the organization type we were interested in, per our predictions; therefore, we could compare all other organizations types with nonprofits. This is again contrary to Loh et al.'s (2018) methods, who used government nonprofit hybrids as the reference variable. A subsequent analysis was performed with only nonprofit organizations to test for the effect of organization size, as nonprofits were the only organization type we could obtain financial data for. For nonprofit organizations, total publications and total citations were analyzed using a linear model against organization size, age, and mission statement. Total publications, total citations, and organization size were $\log_{10} + 1$ transformed to achieve normality. Lastly, analyses were performed to compare CAZA and AZA members. The Mann–Whitney test was used to compare the mean number of total publications and mean number of biodiversity conservation publications per institution between AZA and CAZA members, as the data were nonparametric even after transformation. There were five CAZA members that were also AZA members at the time of Lohs et al.'s (2018) data collection in 2013. These institutions were removed from the AZA data set for all comparisons between the AZA and CAZA. A Mann–Whitney test was also used to compare mean age between organizations and an independent Welch's *t* test was performed on net assets ($\log_{10}$ transformed) to compare mean organization size. All data used for analysis pertaining to the AZA were taken from the supplementary material of Loh et al. (2018).

Results

Comparing AZA and CAZA institutions

Both AZA and CAZA institutions published most often in the *Journal of Zoo and Wildlife Medicine* and published most in the category of veterinary science. AZA members ($n = 223$) published significantly more than CAZA members from 1993 to 2013 ($W = 4240$, $p = 0.015$, AZA $\overline{X} = 24.27 \pm 5.08$ SE, CAZA $\overline{X} = 12.5 \pm 5.52$ SE). For comparison, from 1993 to 2013, AZA's top publishing member produced 650 publications (Loh et al. 2018), whereas CAZA's top publishing member produced 127 publications. However, there was no significant difference in the mean number of biodiversity conservation publications produced by AZA and CAZA institutions ($W = 3627.5$, $p = 0.288$, AZA $\overline{X} = 1.26 \pm 0.35$ SE, CAZA $\overline{X} = 0.43 \pm 0.28$ SE). The proportion of AZA members that produced publications (52.8%) was higher compared with CAZA members (36.7%). AZA institutions were also found to be significantly older ($W = 4602.5$, $p = <0.001$, AZA $\overline{X} = 65.11 \pm 2.51$ SE, CAZA $\overline{X} = 39.30 \pm 4.50$ SE) and significantly larger in terms of assets ($t = 2.31$, df = 9.80, $p = 0.044$) than CAZA institutions. AZA nonprofit's mean net assets were $111 911 260 CAD ($n = 89$), whereas CAZA nonprofit's mean net assets were only $27 876 610 CAD ($n = 10$).

Characterizing publication trends

From 1993 to 2017, 30 CAZA institutions published 536 times with 9077 total citations (**Table 1**). The number of publications increased significantly over time, with 10 publications in 1993 and 53 publications in 2017 ($p < 0.001$, adjusted $R^2 = 0.824$; **Fig. 1**). This increase in the number of

Table 1. Top research-productive CAZA members ranked by total publications.

Organization	Publications	Citations	*h*-index	*h*-index rank[a]
Toronto Zoo	182	1772	22	3
Vancouver Aquarium	151	3413	29	1
Montreal Biodome	75	2012	25	2
Calgary Zoo	63	1130	11	4
African Lion Safari	22	186	9	5
Granby Zoo	14	303	8	6
Assiniboine Park Zoo	14	95	7	7
Quebec Aquarium	8	92	3	8
Zoo Sauvage de St. Felicien	4	60	3	9
Cochrane Polar Bear Habitat	1	4	1	10
Edmonton Valley Zoo	1	1	1	11
Wye Marsh	1	1	1	11
Ecomuseum Zoo	1	0	0	12

[a]If two or more Canada's Accredited Zoos and Aquariums (CAZA) members had the same *h*-index the better rank was awarded to the organization with a higher number of total publications (Loh et al. 2018). If two or more CAZA members had the same *h*-index ranks and the same number of total publications, the higher ranks was given to the organization with a higher number of total citations. If two or more CAZA members had the same *h*-index, total publications, and total citations, a tie was awarded to those organizations.

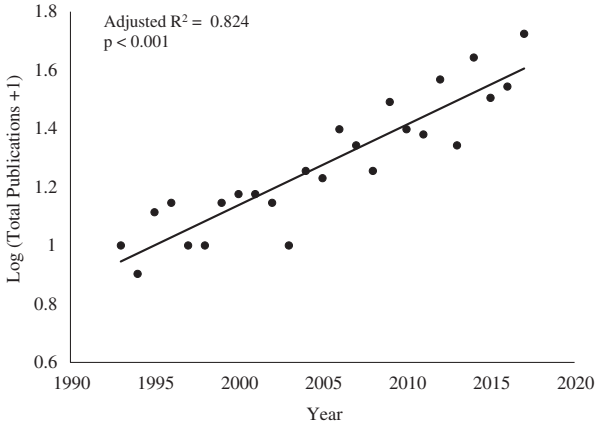

Fig. 1. The total number of publications produced by Canada's Accredited Zoos and Aquariums members per year from 1993 to 2017.

peer-reviewed publications among CAZA members was greater than the overall increase in the number of peer-reviewed publications in the WoS database over the same time period (1993—1 103 679 publications, 2017—2 985 155; CAZA members: 1993—9, 2017—47; increase of 170.5% vs. 422.2%). CAZA members published in 213 different journals. They published most often

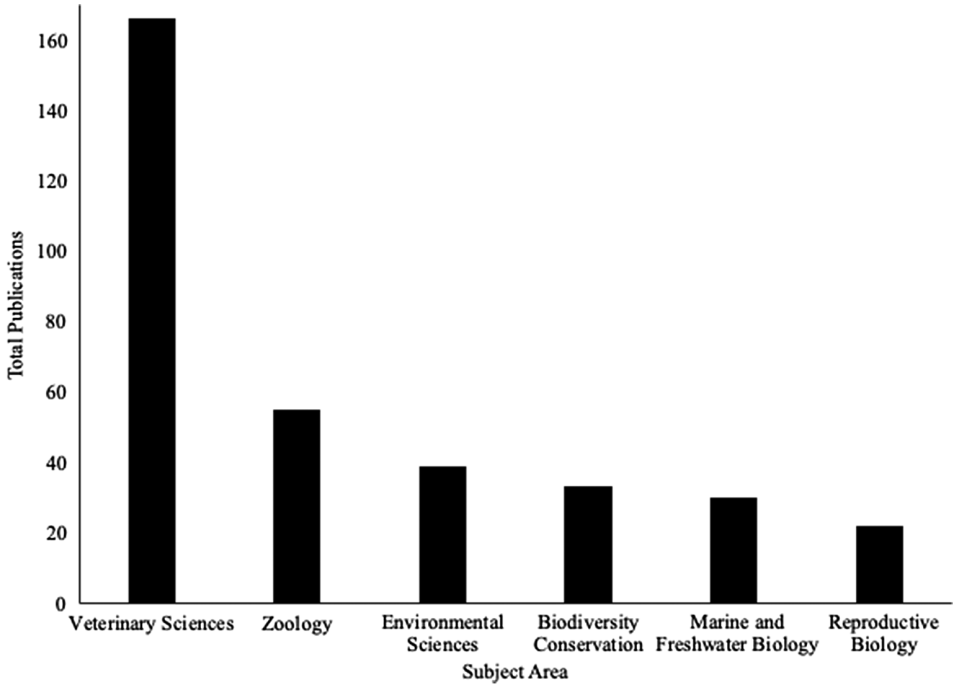

Fig. 2. Total number of publications of the top six subject areas Canada's Accredited Zoos and Aquariums members published from 1993 to 2017.

in the *Journal of Zoo and Wildlife Medicine* (53 publications), *Zoo Biology* (29 publications), *Theriogenology* (18 publications), *Biology of Reproduction* (15 publications), and the *Archives of Environmental Contamination and Toxicology* (11 publications). CAZA members published in a total of 46 subject areas. The top subject areas, as identified by WoS, were veterinary sciences (166 publications), zoology (55 publications), environmental sciences (39 publications), biodiversity conservation (33 publications), marine and freshwater biology (30 publications), and reproductive biology (22 publications) (Fig. 2). The top publishing and most cited institutions were the Toronto Zoo, Vancouver Aquarium, Montreal Biodome, Calgary Zoo, and African Lion Safari (Table 1). Only 13 of 30 members produced publications.

Organizational factors affecting research productivity

Age and mission statement were the only significant predictors of total publications and total citations for CAZA members (Table 2). Organization type had no significant effect on the number of publications or citations produced by CAZA institutions, with the exception of government nonprofits having significantly fewer citations than nonprofits ($\overline{X} = 295.5 \pm 295.3$ SE and $\overline{X} = 418.2 \pm 287.8$ SE, respectively; Table 2). The models for both total publications and total citations explained little of the variation in number of total publications and total citations (McFadden's pseudo $R^2 = 0.069$ and 0.054, respectively). The analyses conducted strictly on nonprofit organizations to examine the effects of organization size showed that larger organizations published more and were cited more often than smaller organizations (Fig. 3), but mission statement and age had no effect on either (Table 3). The linear models including the effects of size, for only nonprofit organizations, explained a moderate amount of the variation in the number of total publications and total citations (adjusted $R^2 = 0.717$ and 0.782, respectively). Average net assets increased from $8 774 377 CAD in 2003 to $33 039 078 in 2017. During this same time period, total publications increased from 10 to 53.

Table 2. Regression table for organizational factors related to research productivity for Canada's Accredited Zoos and Aquariums members from 1993 to 2017.

	Total publications (pseudo $R^2 = 0.068$)			Total citations (pseudo $R^2 = 0.054$)		
Factor	Regression coefficient	SE	*p*	Regression coefficient	SE	*p*
Age	0.120	0.024	<0.001*	0.261	0.034	<0.001*
"Research" in mission statement	5.121	1.201	<0.001*	9.682	1.625	<0.001*
For profit	0.088	1.529	0.954	1.244	2.101	0.554
Government	−0.059	1.728	0.973	0.701	2.349	0.765
Government nonprofit hybrid	−2.302	1.247	0.065	−4.971	1.649	0.003*

Note: Nonprofits are not included in the table because they were used as the reference variable for the analysis. Therefore, the results presented for all other organization types (for profit, government, and government nonprofit hybrids) are a comparison with nonprofits. SE, standard error; *, $p < 0.05$.

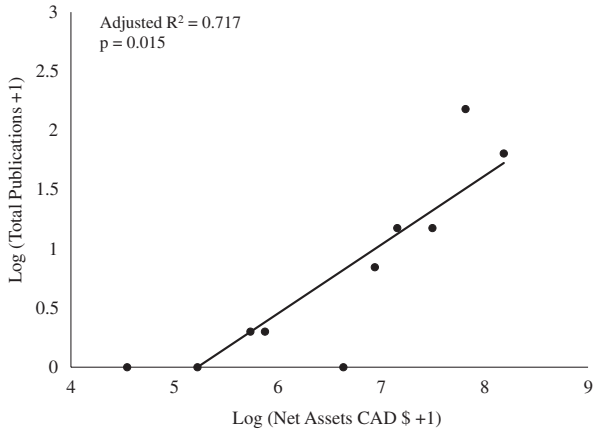

Fig. 3. Net assets related to total publications by Canada's Accredited Zoos and Aquariums nonprofit members from 1993 to 2017. Net assets were obtained from 2017.

Discussion

The total number of publications produced by CAZA members increased significantly over time, demonstrating that CAZA members are increasingly participating in research, as per the mandate of CAZA. This increase in CAZA research productivity is not simply a correlate of the general increase in peer-reviewed publications at large. The subject areas and journals that CAZA members published in most often demonstrated a strong research focus on the veterinary sciences, with only a small proportion of biodiversity conservation publications produced (6.12%). In addition, the journals that most publications appeared in (*Journal of Zoo and Wildlife Medicine* and *Zoo Biology*) are specialist journals with readership predominantly limited to the zoo community, indicating that scientific discourse is primarily among zoo and aquarium personnel (Lawson et al. 2008; Loh et al. 2018). Karesh and Cook (1995) argued that veterinary science can be integrated into conservation projects to assess and monitor the health of wild populations, train others how to properly handle wildlife, and to evaluate the success of these projects. Nonetheless, zoos and aquariums may consider publishing in journals with a wider audience base to facilitate knowledge sharing among various organizations, specifically those engaged in biodiversity conservation (Loh et al. 2018). The number

Table 3. Regression table for organizational factors relating to research productivity for Canada's Accredited Zoos and Aquariums nonprofit members from 1993 to 2017.

	Total publications (adjusted $R^2 = 0.717$)			Total citations (adjusted $R^2 = 0.782$)		
Factor	Regression coefficient	SE	p	Regression coefficient	SE	p
Age	0.002	0.007	0.774	0.004	0.011	0.705
"Research" in mission statement	−0.366	0.295	0.261	−0.762	0.463	0.151
Organization size	0.572	0.170	0.015*	1.038	0.267	0.008*

Note: SE, standard error; *, $p < 0.05$.

of publications in biodiversity conservation has increased substantially in the last 4 years, from 13 publications in 2013 to 33 in 2017. This suggests that zoos and aquariums are increasing their engagement in biodiversity conservation research, as has been the goal of WAZA (IUDZG and CBSG 1993). Anecdotal information suggests that CAZA members are hiring increasing numbers of permanent conservation scientists, so this upward trend in publication rates is expected to continue and may explain differences in the proportion of publications in the subject areas of veterinary sciences and biodiversity conservation.

We also examined the organizational factors that contributed to research productivity of CAZA members. Organization type was not a significant predictor of research productivity, which was contrary to our expectations and inconsistent with AZA members (Loh et al. 2018). We expected nonprofit organizations to publish the most because of institutional attitudes that tend to value biodiversity conservation at these organizations (Loh et al. 2018). However, there were no significant differences among organization types. This could be due to the relatively low number of publications overall, making it difficult to detect differences. Consistent with Loh et al. (2018), both mission statement and age significantly affected publications produced. Organizations with research-affiliated terms in their mission statement published more than those without, and age was positively related to the number of publications produced. Mission statements that pledged to contribute to scientific knowledge may be an indicator of organizational attitudes that prioritize and value research (Loh et al. 2018). Older organizations have had more time to acquire resources, such as money, partnerships, and community engagement, allowing them the flexibility to conduct more research. It can also be postulated that older organizations would be able to acquire more expertise within their staff.

In the analysis of nonprofit organizations, larger organizations produced more publications than smaller organizations, consistent with AZA members (Loh et al. 2018). Smaller organizations may be constrained by their size and limited in what research they are able to perform, whereas large organizations may have the resources to take on many projects. AZA institutions produced significantly more publications per member than CAZA members, based on a comparison of our results and Loh et al. (2018), additionally, proportionately more AZA members produced publications relative to CAZA members. This pattern may be the result of the generally older and larger organization size of AZA members. The AZA and CAZA differ in terms of age—the AZA was founded in 1924 whereas CAZA was founded in 1975. The AZA also has considerably more assets than CAZA (AZA—$24 331 211 CAD; IRS 2017 vs. CAZA—$119 434 CAD; CRA 2017). It is also worth noting that CAZA's top publishing institutions (Toronto Zoo, Vancouver Aquarium, Montreal Biodome, and Calgary Zoo) have all been AZA members, and they are also some of Canada's oldest and largest zoos. This supports the idea that older and larger organizations have higher research

outputs because of increased resources. Interestingly, there was no difference between AZA and CAZA in the number of publications per member in biodiversity conservation. This furthers the narrative that there is a strong research focus on the veterinary sciences across North America, as both CAZA and AZA institutions produce high volumes of publications in this area compared with relatively low numbers of biodiversity conservation publications.

There are a number of reasons why zoos and aquariums should seek to enhance the production of peer-reviewed publications, particularly in biodiversity conservation. First, it facilitates knowledge sharing among the community of conservation practitioners, whether zoos, academic, government, or nongovernment organizations. Second, the process of peer-review ensures some standard in the science being produced. Finally, the credibility of zoos as conservation organizations can only be enhanced by the production of peer-reviewed science in this field. One way that has been proposed to increase zoos' and aquariums' research productivity is by increasing collaborations with academic institutions (Fernandez and Timberlake 2008). Zoos and aquariums and academic institutions often have common goals regarding animal biology and conservation, such as understanding behaviour, the conservation and propagation of species, and education (Fernandez and Timberlake 2008). Therefore, it is puzzling that collaborations between these groups are rare (Maple 2008). Often zoos and aquariums have different research interests than academic institutions, with the former being more focused on programs to promote the well-being of their animals and the latter focused on the biology and behaviour of frequently used species (Mellen and MacPhee 2001; Fernandez and Timberlake 2008). However, zoos and aquariums and academic institutions can combine these interests for mutual benefit (Fernandez and Timberlake 2008). Academics can use the unique environment zoos and aquariums provide for studying species, whereas academic research based on field observations may increase the success of reintroduction efforts led by zoos and aquariums (Fernandez and Timberlake 2008).

Research productivity is not a perfect measure of zoos' and aquariums' contribution to biodiversity conservation because of the research-implementation gap often observed in the field of conservation biology (Knight et al. 2008; Arlettaz et al. 2010). Often conservation research is not implemented in the field, so research is not always indicative of conservation action (Knight et al. 2008; Arlettaz et al. 2010). Zoos and aquariums also engage in biodiversity conservation in ways that may not be captured by the metric of research productivity. Zoos and aquariums are centers for education about wildlife and their conservation (Miller et al. 2004). Annually, more than 700 million people visit zoos and aquariums around the world, providing a unique opportunity to educate the public about conservation (Gusset and Dick 2011). Zoos and aquariums also contribute to conservation initiatives by providing funding to biodiversity conservation organizations; worldwide, zoos and aquariums are among the main providers of conservation funding in relation to major international conservation organizations (Gusset and Dick 2011). They also participate extensively in captive breeding programs to preserve endangered species for possible reintroduction (Conde et al. 2011; Harding et al. 2016). It is recognized that captive populations are necessary to avoid the loss of many species (Mallinson 2003). For instance, the population of Vancouver Island marmots (*Marmota vancouverensis*), an endemic mammal, dropped to approximately 30 individuals in 2003, prompting a zoo-based recovery strategy to be put in place (Roach 2017). Owing to the joint captive breeding and reintroduction program led by the Toronto Zoo and Calgary Zoo, as of 2017 a conservative estimate of 140–190 marmots exist in the mountains of British Columbia (Roach 2017).

Zoos and aquariums present unique opportunities to study animals in ways that are not possible in the wild and are therefore invaluable for the conservation of species (Hutchins and Conway 1995). As conservation is a mandate of CAZA (CAZA 2008), the production of peer-reviewed publications may be one way to assess the growth of conservation research at zoological institutions. By identifying size and age of organizations as significant predictors of research productivity, as well as the inclusion

of research-focused wording in the strategic plans of zoos and aquariums, CAZA and their members can make strategic decisions to either prioritize research at the larger and older institutions or support the conservation research activities of smaller and younger organizations. Further work should examine patterns of research productivity of zoos and aquariums across other jurisdictions (e.g., European Association of Zoos and Aquaria, the Australasian Zoo and Aquarium Association). Other factors that can impact the research productivity of zoos should also be analyzed including the taxonomic composition of the collection of zoos (e.g., Rose et al. 2019), the background changes in the publication landscape including the overall increase in research output by the scientific enterprise at large, and any differences in the publication cultures of veterinary sciences and biodiversity conservation. Importantly, it is also worth examining the other significant aspect of the modern zoo—conservation education. Examining patterns of organizational characteristics related to the productivity and efficacy of education programs of zoos using tools such as that described by Barriault and Rennie (2019) would give further insight into the continued evolution of zoos and aquariums.

Acknowledgements

Thanks to D. Edwards for help with statistical analysis and G. Mastromonaco for discussion.

Author contributions

AIS-H conceived and designed the study. BEP performed the experiments/collected the data. BEP analyzed and interpreted the data. AIS-H contributed resources. BEP and AIS-H drafted or revised the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Data availability statement

All relevant data are within the paper and Supplementary Material.

Supplementary material

The following Supplementary Material is available with the article through the journal website at doi:10.1139/facets-2019-0052.

Supplementary Material 1

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