JZAR JOURNAL OF ZOO AND AQUARIUM RESEARCH
www.jzar.org

JZAR Research article
OPEN ACCESS

Research article

Status of animal welfare research in zoos and aquariums: Where are we, where to next?

Sally Binding[1], Holly Farmer[2], Laura Krusin[2] and Katherine Cronin[3]

[1]European Association of Zoos and Aquaria, Plantage Kerklaan 38 4, Amsterdam 1018 CZ
[2]Wild Planet Trust, Paignton Zoo, Totnes Rd, Paignton, Devon, TQ4 7EU
[3]Lincoln Park Zoo, 2001 N Clark St, Chicago 60614

Correspondence: Katherine Cronin, email: kcronin@lpzoo.org

Keywords: animal welfare, aquariums, research, zoos

Article history:
Received: 10 Oct 2019
Accepted: 28 Feb 2020
Published online: 31 Jul 2020

Abstract

Research into the conditions that promote good animal welfare is essential to equip zoos and aquariums with the knowledge to create environments in which animals thrive. In order to collate the empirical information that is available regarding animal welfare in zoos and aquariums with regard to topics, methods and species, a systematic literature review was conducted of the primary peer-reviewed journals publishing zoo-based and welfare-based research. Journals included *Animal Welfare, Animals, Applied Animal Behaviour Science, International Zoo Yearbook, Journal of Applied Animal Welfare Science, Journal of Zoo and Aquarium Research*, and *Zoo Biology.* The literature review spanned 2008–2017 and revealed that 7.6% (n=310) of reviewed publications (n=4,096) in these journals were zoo- or aquarium-based and animal-welfare focused. The main topics studied included enrichment, social conditions and enclosure design, while understudied topics included the welfare of ambassador animals, and the welfare impacts of sound and light. Behaviour was by far the dominant welfare parameter used and the use of hormonal measures declined over this period. Taxonomic representation in these publications was notably skewed. Mammals were the focus of 75% of studies, and 82% of studies were vertebrate-focused (great apes being the dominant taxa). This study considers potential reasons for these patterns and highlights research areas for future emphasis that could serve to fill gaps in current knowledge regarding zoo and aquarium animal welfare, including more research into affective states that underlie an animal's welfare status.

Introduction

Animal welfare is increasingly recognised as a high priority for modern zoos and aquariums. The predominant framework for understanding animal welfare in the international zoo community is the Five Domains model (Mellor and Beausoleil 2015), adopted by the World Association of Zoos and Aquariums (Mellor et al. 2015). This framework emphasises the role that positive and negative subjective experiences have on characterising an animal's welfare status. The subjective experiences of the mental domain are influenced by the physical/functional domains that include the animal's nutrition, environment, physical health and behaviour (Mellor and Beausoleil 2015). Engaging in husbandry practices that promote good animal welfare not only helps zoos satisfy ethical considerations, but also helps institutions reach their goals of being centres for conservation, education and research, as animals experiencing good welfare often serve these missions more effectively (Powell and Watters 2017).

Assessment of animal welfare is becoming regular practice in zoos and aquariums in multiple geographic regions. For example, the European Association of Zoos and Aquariums (EAZA) references assessment of animal welfare in numerous locations in their Standards for the Accommodation and Care of Animals in Zoos and Aquaria (EAZA 2019) and has created a publicly available Animal Welfare Assessment Library and decision making tool to assist institutions in this capacity (EAZA 2020). Related, the British and Irish Association of Zoos and Aquariums (BIAZA) has released a Welfare Toolkit designed to assist BIAZA members in achieving high welfare standards. The

Table 1. Information coded from publications meeting criteria.

Category	Options	Definition
Taxonomic class	Mammal	Broad taxonomic classification at genus level, or species if provided
	Bird	
	Reptile	
	Fish	
	Amphibian	
	Invertebrate	
Topic	Social influences	The impact of conspecifics in the same or nearby enclosure (excluding reproduction)
	Light	Lighting and UV available within an enclosure
	Visitor activity/presence	Presence, activity, or noise of visitors at an enclosure
	Sound (non-visitor)	Exposure to sound in a zoo environment, excluding visitor sound
	Ambassador/show/ education animal	Housing, handling, or human exposure of animals involved in specific educational or guest experiences
	Keeper-animal interactions	Formal or informal interactions between an animal and the caregiver, including animal training
	Transportation	The transfer of animals between institutions
	Reproduction	Mating, production of offspring, or use of contraceptives
	Nutrition	Provision of diet, change to a diet, or diet itself
	Enrichment	Objects or practices intended to serve as stimulation, or identified as 'enrichment' by original authors
	Health	The physical health of the animal, may include disease, overall body condition
	Enclosure design	Physical layout, location, composition or characteristics of an enclosure
	Other	Any topic not covered above (actual topic was entered as a comment), examples included genetics, housing access, personality
Welfare parameter	Hormones	Measurement of glucocorticoid and/or glucocorticoid metabolite concentrations or other hormones
	Behaviour	Measurement of animal behaviour including enclosure use, social behaviour, interaction with enrichment, abnormal behaviours, activity budgets, play, preferences, latency to approach, etc.
	Body condition	Measurement of visible disease presence, injury, coat/scales/skin/feather condition, and body condition scoring
	Other	Any parameter not covered above (actual parameter was entered as a comment), examples included breeding success, breathing rates, keeper surveys

primary accrediting body for North America, the Association of Zoos and Aquariums (AZA), requires welfare assessments on all animals in accredited institutions as of 2017. The representative body for zoos, aquariums and sanctuaries in Australasia, the Zoo and Aquarium Association (ZAA), has developed the ZAA Welfare Assessment as part of their member accreditation process. Supporting these processes, guidance on assessing animal welfare has been considered in a number of recent publications (e.g., Honess and Wolfensohn 2010; Draper and Harris 2012; Kagan et al. 2015; Sherwen et al. 2018). With the increased focus on welfare assessments in many regional organisations, it is an opportune time to identify areas in need of additional research to support evidence-driven welfare assessment processes.

It is also important to understand the current state of knowledge in order to ensure that care for animals promotes good animal welfare. Melfi (2009) argued that guidelines on animal husbandry and welfare often emerge from "tradition and myth." EAZA member institutions manage studbooks for 398 species (EAZA 2019) and Best Practice Guidelines, the detailed documents that provide husbandry knowledge, are published for 125 species (including both studbook and non-studbook managed species). Melfi (2009) suggested that instances of lack of content regarding animal welfare guidelines may be due to limitations in evidence-based scientific knowledge for many species. Veasey (2017) reached a similar conclusion in his analysis of AZA Animal Care Manuals, documents analogous to EAZA's Best Practice Guidelines.

The challenge of having enough research to guide practices that promote good animal welfare is exacerbated by the diversity of species, the degree of individual differences within species, and the need for multiple measures of welfare within a species. Zoos and aquariums house a diverse range of taxa for which knowledge on how to influence and measure animal welfare is required (e.g., Brando and Buchanan-Smith 2018; Clegg 2018; Salas et al. 2018; Sherwen et al. 2018), and in many cases different taxa have a distinct set of needs that must be met in order to optimise their welfare (Wolfensohn et al. 2018). Even within the same species, individual animal welfare can differ in response to the same care, dependent upon developmental history, temperament or coping style (e.g., Koolhaas et al. 1999; Boissy and Erhard 2014). Finally,

Table 2. Number of publications reviewed in each journal, and percentage of welfare-related publications per journal.

Journal title	Number of publications reviewed (n=4,096)	Percentage of zoo- and aquarium-based welfare-related publications
Journal of Zoo and Aquarium Research	119	26.9%
Zoo Biology	617	17.8%
Journal of Applied Animal Welfare Science	307	16.6%
International Zoo Yearbook	213	9.4%
Animal Welfare	563	5.0%
Applied Animal Behaviour Science	1825	3.7%
Animals	452	0.4%

many welfare scientists agree that multiple, complementary measures of welfare are ideal when attempting to characterise an individual's welfare status (e.g., Broom et al. 1991; Scott et al. 2003; Butterworth et al. 2011), making the amount of research required even greater.

Previous authors have summarised the current state of knowledge in the field. Rose et al. (2019) recently characterised the zoo-themed research output of the past ten years, demonstrating the breadth of zoo-related research encompasses welfare, biology, cognition, health and other topics. Walker et al. (2014) provided a broad review of publication trends in animal welfare science over the preceding 20 years, considering agricultural, laboratory, zoo and domestic animals. These authors reported that zoo animal research generated a consistent number of publications over the time period. However, the overall amount of publication effort lagged far behind farm animals, which were the subject of more than four times as much published research. Walker et al. (2014) predicted that, due to the diversity and large number of species in human care in zoos and aquariums (estimated to be approximately 7 million, Frynta et al. 2013), zoo- and aquarium-based welfare research would increase in the coming years.

Identifying what information is currently available, and where there are gaps in available research, can shape priorities for research programmes that will have maximal impact on the welfare of animals in zoos and aquariums (Melfi 2009; Walker et al. 2014). Likewise, understanding where there is a depth of knowledge can help ensure that best practices are being developed in response to knowledge. Therefore, in order to gain a better understanding of current zoo and aquarium animal welfare science, a systematic literature review was conducted of peer-reviewed, scientific publications focusing on animal welfare research conducted within zoos and aquariums, over a 10-year period (2008–2017, inclusive). A 10-year retrospective window from the start of this project was chosen to quantify the specific questions and methods that have garnered recent research interest. This study is not hypothesis-driven, but rather quantifies the content of welfare-related publications over the time period, considering the taxonomic groups that have served as a focus, the questions that have received attention, and the welfare parameters measured.

Methods

This study systematically reviewed the published content of the following peer-reviewed journals: *Animal Welfare, Animals, Applied Animal Behaviour Science, International Zoo Yearbook, Journal of Applied Animal Welfare Science, Journal of Zoo and Aquarium Research*, and *Zoo Biology*. Journals were preliminarily identified by the authors, and the selection was confirmed via a Thomson Reuters Web of Science search (7 May 2019) that indicated over 85% of papers that fit the search criteria (below) were published in these journals. Taxa-specific journals (e.g., *American Journal of Primatology*) were not included to maintain a manageable scope. All journal issues published between 1 January 2008 and 31 December 2017 were considered. For two journals, the first issue was published after January 2008, therefore the material between the first issue date and 31 December 2017 was included (first issue of *Animals* was in 2011 and the first issue of *Journal of Zoo and Aquarium Research* was in 2013).

Each table of contents was systematically reviewed for publications concerning zoo or aquarium animal welfare by one of the authors. Decisions were based upon the title, unless ambiguous, in which case abstracts and/or full texts were considered using the following rules. First, the words 'welfare', 'well being' or 'wellbeing (hereafter collectively referred to as welfare) were used at least once in the title, abstract, keywords or main body of text, and with direct relevance to the topic of the paper. Publications that only made passing mention of welfare (e.g., in the last paragraph of the discussion) were not included. Second, the research was conducted in a zoo or aquarium, used data generated from animals cared for in a zoo or aquarium, or discussed zoo or aquarium animals as the primary subject matter. Third, review articles meeting the previous two criteria were only included if they presented additional information, analyses or theories beyond a summary of current literature. Book reviews, letters to editor and errata were excluded. Publications considered ambiguous in terms of meeting the criteria were considered by at least two authors and a consensus was reached for inclusion in the review. For example, a study on how dietary changes can improve gastrointestinal functioning may have welfare implications, but if a relationship to welfare was not specifically drawn by the publishing authors, it was not included.

Each publication that met the above criteria was coded based on taxonomic class(es), research topic and welfare parameter(s) (behaviour, hormones, body condition, other) (Table 1). When more than one species, topic(s) and/or parameter was reported, all were coded except for cases of superficial mention. A person blind to the aims of this review coded a random selection of 20% of the selected articles; average percent agreement for

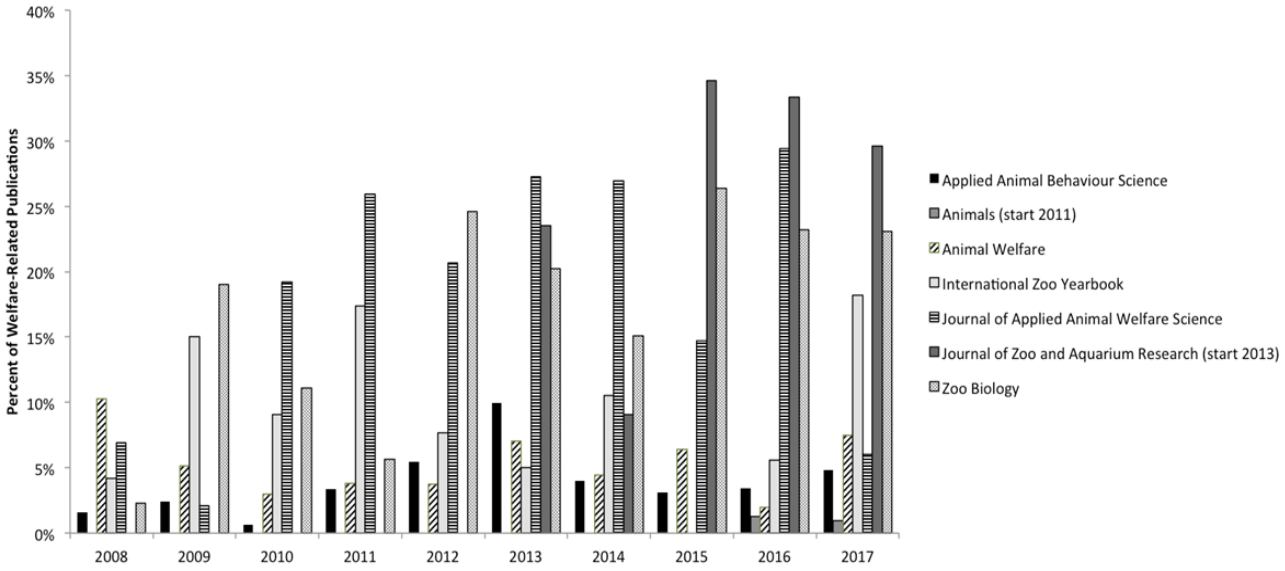

Figure 1. Percentage of zoo- and aquarium-based animal welfare publications per year in each of the seven journals reviewed (2008–2017).

research topic was 93% (range 76% to 100%) and average percent agreement for welfare parameter was 90% (range 84% to 97%).

Information was entered, summarised and analysed with basic descriptive statistics in Microsoft Excel to understand relative research emphasis on different taxonomic groups, topics and parameters, and to summarise changes over time. Raw data are available upon request and all coded publications are included in the Reference section.

Results

A total of 4,096 publications were reviewed, of which 310 (7.6%) were determined to have satisfied the above criteria as zoo- or aquarium-based welfare research. Within each journal, the percentage of publications that satisfied the criteria ranged from 0.4-26.9% (Table 2). There was a positive relationship between year and the average percentage of publications that satisfied the criteria across journals, indicating that the emphasis on zoo

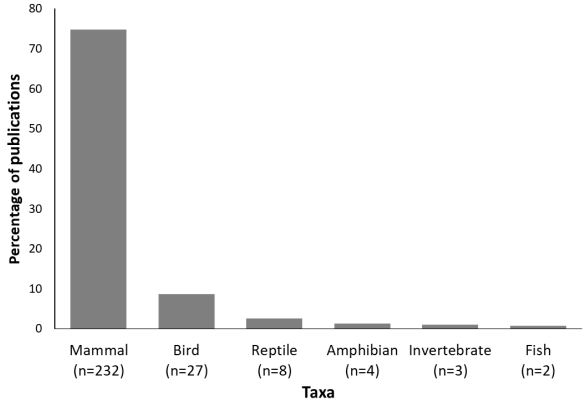

Figure 2. Taxonomic representation in zoo- and aquarium-based animal welfare publications from 2008–2017.

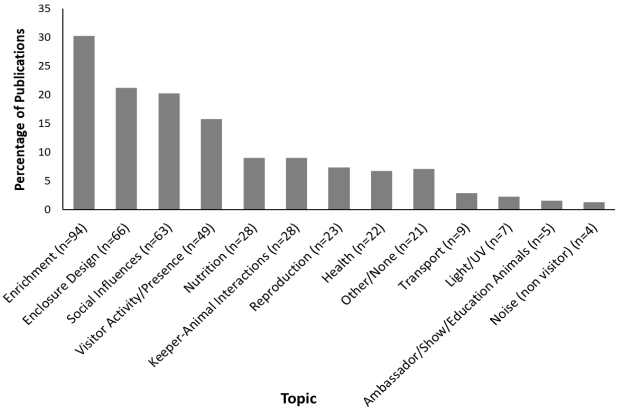

Figure 3. Topics studied in zoo- and aquarium-based animal welfare publications from 2008–2017. Some publications studied more than one topic, hence percentages sum to more than 100%.

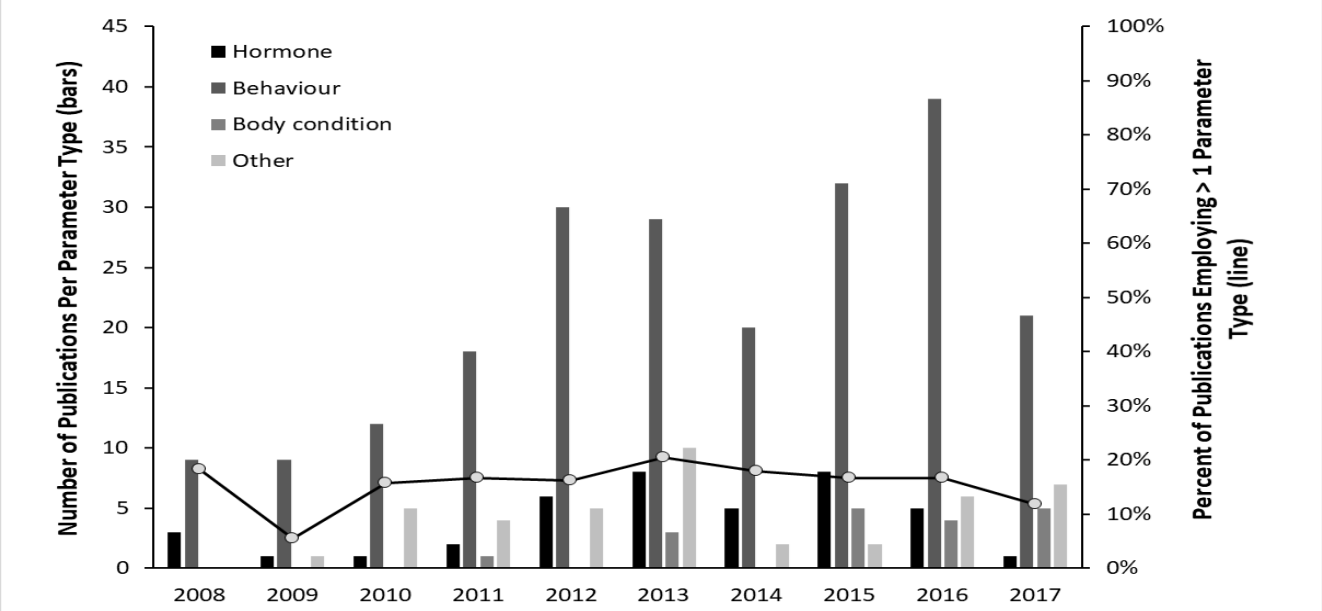

Figure 4. Welfare parameters measured in zoo- and aquarium-based animal welfare publications per year (2008–2017). The primary y-axis shows the number of publications per year that relied on each type of parameter. The secondary y-axis shows the percent of publications per year that incorporated more than one type of parameter.

and/or aquarium-related welfare research increased over time in these journals (Spearman rank order correlation, n=10, r_s=0.806, P=0.005). Figure 1 shows the percentage of publications meeting criteria annually for each journal.

When examining taxonomic representation in publications, an emphasis on mammals was identified (Figure 2). The top five taxonomic families represented in welfare-related publications over the time period were Hominidae (great apes, 13.5%, n=42), Elephantidae (elephants, 9.4%, n=29), Felidae (cats, 7.1%, n=22), Delphinidae (dolphins, porpoises and certain whales, 3.2%, n=10) and Ursidae (bears, 2.9%, n=9). At the species level, the African bush elephant *Loxodonta africana* garnered the most publications (7.7%, n=24), followed by western lowland gorilla *Gorilla gorilla gorilla* (6.5%, n=20), Asian elephants *Elephas maximus* (5.2%, n=16), chimpanzees *Pan troglodytes* (4.2%, n=13) and bottlenose dolphins *Tursiops truncatus* (2.6%, n=8); all of which are mammals. Outside of mammals, the two most studied species were the greater rhea *Rhea americana* and the greater flamingo *Phoenicopterus roseus*, with 1.0% of publications each.

The questions of interest in publications were wide-ranging. Enrichment was the most frequently addressed welfare topic (30.3%, n=94), followed by enclosure design (21.3%, n=66) and social influences (20.3%, n=63). Topics that received the least attention included lighting (2.3%, n=7), the welfare of animals classed as ambassadors, involved in shows or as part of education presentations (1.6%, n=5), and the impact of non-visitor sound (1.3%, n=4; Figure 3).

The majority of publications (90%, n=279) identified at least one specific parameter to measure welfare. Behaviour was by far the most common (81.0%, n=226), followed by 'other' (e.g., keeper surveys, fecundity, respiration rates, or not specified; 17.6%, n=49), hormones (15.1%, n=42) and body condition (7.5%; n=21). More than one welfare parameter was used in 17.9% of publications (n=50), more than two parameters were used in only 1.1% of publications (n=3). The reliance on different parameters over the 10-year period is shown in Figure 4.

Discussion

Over the 10-year period, the number of publications focused on zoo and aquarium animal welfare has more than doubled. This increase in attention to animal welfare science corresponds with the establishment of several welfare-focused groups within regional zoo organisations (e.g., EAZA Animal Welfare Working Group in 2015; British and Irish Association of Zoos and Aquariums (BIAZA) Animal Welfare Subgroup in 2017) and the integration of welfare assessments into the ZAA and AZA accreditation processes. Considered together, the publication trends and additional emphasis in the zoo community indicate an increased awareness by the community on the need for objective assessment and improvement of animal welfare.

Taxonomic emphases

This study found a strong bias towards research on mammals. Results may have differed had the study included taxon-specific journals; however, previous work has reached the same conclusions considering different sources as well as different time frames (e.g., Wemmer et al. 1997; Anderson et al. 2008). The current analysis, based on a more recent time frame and a broader journal scope, reveals nearly the same proportional emphasis on mammals.

The emphasis on mammals in welfare research is disproportionate to the representation of mammals in zoos and aquariums worldwide. According to a recent review of species housed in zoos and aquariums that use the global animal records database (Species360 Zoological Information Management System 2019), there are more than twice as many bird species housed in zoos than mammals. An obvious recommendation from this review is to diversify the taxonomic focus of evidence-based welfare research so that information is available to enhance welfare for more species in human care. One could also argue that, given that modern zoos serve an important role as conservation organisations, there should be an increased focus on species with higher conservation threat, which would shift focus away from

many mammals (Conde et al. 2013).

The taxonomic bias may be a result of the widely-recognised sentience of mammals as public and scientific opinion both generally agree upon their ability to feel and therefore experience positive or negative welfare states (Proctor 2012). Furthermore, mammals, particularly the large, charismatic megafauna, arguably receive the greatest attention from the public (i.e., Carr 2016). The species found to be the most common focus of welfare publications (elephants, gorillas, chimpanzees and dolphins) were rated within the top 20 most charismatic animals by western countries (Albert et al. 2018). The increased emphasis on studying the welfare of these publicly preferred species may be driven by greater public and media-driven pressure to invest more effort into the species of public interest.

Welfare topics

There was a great deal of diversity in the types of questions researchers asked regarding zoo and aquarium animal welfare. Publications evaluating the impact of environmental enrichment on welfare were the most common. Providing environmental enrichment is widely considered one of the most effective strategies for promoting psychological well-being (Swaisgood and Shepherdson 2005; de Azevedo et al. 2007; Makecha and Highfill 2018); therefore, this emphasis may not be surprising. The taxonomic focus of enrichment studies has historically been biased toward large, charismatic species (Swaisgood and Shepherdson 2005) although recent work has begun to expand welfare evaluations of environmental enrichment to lesser studied taxa, such as reptiles and amphibians (e.g., Burghardt 2013; Bashaw et al. 2016). It seems likely that a focus on enrichment will remain a cornerstone of zoo and aquarium research moving forward as technology continues to develop and expand the scope of potential enrichment approaches, including for example tablet computers for apes or automated feeders coupled with motion detection for giraffes (e.g., Kim-McCormack et al. 2016; Krebs and Watters 2016; see also Clay et al. 2011; Clark 2017).

The impact of environmental light and sound were among the least studied topics, and it is predicted that these questions will gain attention in coming years. Laboratory-based research has shown the impact that light intensity, duration and wavelengths have on psychological and physical well-being (reviewed in Wulff et al. 2010; Ross and Mason 2017). The impact of lighting is one area of work that is gaining traction across a wide range of species in zoos (e.g., Baines et al. 2016; Fuller et al. 2016; Ross et al. 2013; Benn et al. 2019). With the increasing accessibility of technology to monitor sound and light levels (Fuller 2014; Kardous and Shaw 2014), this area seems poised for additional development with the potential for a positive impact on welfare.

Another area that emerged as having received very little research effort was the welfare of animals used in educational or interactive programs. A recent review highlights the widespread prevalence of human-animal interaction programs in zoos and aquariums globally (D'Cruze et al. 2019) and calls for more research have been made (e.g., D'Cruze et al. 2019; de Mori et al. 2019). Given how common human-animal interaction programmes are, and how taxonomically and programmatically diverse they are (D'Cruze et al. 2019), this could be a massive investment of research efforts. Here, it is argued that research efforts should begin by acknowledging the relevant evidence-based knowledge already acquired in the laboratory and agricultural industries, and priorities should be set from that vantage point. For example, research from outside zoos and aquariums has largely demonstrated that transportation (e.g., Grandin 1997; Adenkola and Ayo et al. 2010) and handling by multiple people tend to negatively impact welfare (Meany et al. 1996; Nunez et al. 1996; Balbcombe et al. 2004; Meijer et al. 2007). Conversely, a sense of control and voluntary participation in activities tends to positively impact welfare (e.g., Hurst and West 2010; Perlman et al. 2012) and species with a history of domestication tend to experience less welfare compromise in repeated close contact with humans (e.g., Podberscek et al. 1991; Hemsworth et al. 1996; Rushen et al. 1999). This study recommends capitalising on this evidence when designing animal programmes and then developing research projects that build upon this knowledge base for applications in zoo and aquariums to be productive moving forward in this area.

Welfare parameters

The study found that behaviour was by far the most commonly used welfare parameter over the 10-year period. This prevalence may arise because data collection on an animal's behaviour is a non-invasive method of assessing animal welfare that can be done without advanced technology. Recently, freely available tools such as ZooMonitor (Lincoln Park Zoo 2020) have increased the ability of zoo and aquarium-based researchers to collect behavioural data and generate insights that may reflect changes in welfare (Wark et al. 2019). The dominance of behaviour as a welfare parameter may also be explained by recent increases in interest in abnormal behaviour from the general public and the zoo community, as well as more scrutiny applied to the relationship between these behaviours, actual welfare and publicly perceived welfare (Hill and Broom 2009; Miller 2012; Rose et al. 2017). Even as other parameters gain validation, it is expected that behaviour will remain a cornerstone of welfare research given its momentum, accessibility and proven value to date (see also Keeling 2019).

Accessibility may also explain the consistent use of body condition as a welfare parameter over the years. While this indicator is arguably less sensitive to subtle changes in welfare, measurements can typically be taken rather quickly and infrequently, without special equipment, and while animals are freely moving in their primary habitat. Body condition was used in studies across a wide range of taxa, yet rarely used as the only indicator. While this study does not recommend body condition as a primary indicator due to its potential lack of sensitivity to affective states underlying welfare (see also Veasey 2017), it does seem beneficial to continue using it alongside other parameters as the field strives to gain a handle on which measures are most practical and valid.

In contrast, the use of hormones as a welfare indicator appears to be decreasing in these journals. The vast majority of publications reporting on hormonal indicators relied on glucocorticoids. Glucocorticoid indicators gained in popularity from 2008, peaking in 2010, and dropping to a low in 2015. The peak of publications in 2010 was a year after a notable reduction in the number of publications focusing on behaviour as a welfare parameter. Activation of the stress responses system was optimistically regarded as an objective measure of welfare, yet over the last 10 years, its validity as a welfare indicator has been questioned through recognition of cortisol release during times of non-harmful excitement (Fraser 2008; Walker et al. 2014); for example, when interacting with enrichment and engaging in playful or sexual behaviour. Perhaps due in part to the difficulty of interpreting glucocorticoid levels in relation to welfare, there has been emphasis on the development of other physiological indicators that can be obtained non-invasively, such as the antibody immunoglobulin A (IgA) that may provide insights into levels of chronic stress (reviewed by Staley et al. 2018).

The most predominant parameter contributing to the 'other' category was caretaker surveys of perceived welfare. In many cases, the opinion of people who are familiar with the individual animals has been shown to be a useful indicator of welfare (Meagher 2009; Whitham and Wielebnowski 2009; Less et al. 2012). In practice, the information caretakers are filtering in

order to provide their opinions likely emerge from the other categories considered (behaviour, hormones, body condition) but may also capture more difficult to measure indicators like the animals' mood or changes in demeanour. There is long-standing consensus that multiple measures should be used to assess welfare whenever possible (e.g., Dawkins 2003; Butterworth et al. 2011; Mendl and Paul 2020), yet the percentage of studies relying on multiple parameters has remained relatively low and constant (Figure 4). Continuing to develop validated tools that caretakers can use to provide information about welfare may prove to be a practical way forward to gain multivariate accounts of welfare (see also Wemelsfelder 2007; Rose and Riley 2019).

Conclusions

Considering the trends observed in zoo- and aquarium-based welfare research, the following recommendations are given. First, efforts should be made to broaden the taxonomic focus to start gaining insights into underrepresented taxa. Some areas in need of focus are aquatic taxa outside of Delphinidae, and birds, reptiles, amphibians and invertebrates. Simply put, any focus outside of mammals will help increase the breadth of welfare knowledge in the community. Beyond that direction, whether efforts should be prioritised based on the number of individuals of a certain taxonomic group that are in human care, the number represented in managed breeding programmes, the capacity for experiencing emotions, or conservation status could be debated and will likely depend on institutional or regional priorities. For taxonomic groups with a history of welfare science, such as the apes, it is recommended that science continuing in this arena focuses on diversifying parameters and relying on the strong foundation of behavioural science in this work to begin validating new indicators. Integration of these findings into new policies and practices related to these well-studied taxa is also encouraged.

It is advised to focus on topics that have been understudied, such as the impact of light and sound on welfare, while encouraging zoo-based researchers to continually take advantage of knowledge gained in other industries, as explored above for animals involved in human-visitor interaction programmes. Regarding parameters, although a lofty request, a focus on accessible measures, if possible, would be extremely beneficial to the field. Measures that are either low cost, do not require specific equipment, and/or are possible while animals are freely moving about their primary habitat seem the most likely to gain traction in the zoo and aquarium communities.

Of course, the personnel employed by zoos and aquariums are limited in the time and expertise available to be contributing to zoo and aquarium welfare science. As others have recommended previously (Chiszar et al. 1993; Maple and Segura 2015), pursuing collaborations with academic partners and field researchers will allow the integration of modern approaches and the filling of gaps that may not otherwise be possible. Related, ensuring that the zoo and aquarium industry is capitalising on the decades of research available on farm, laboratory and companion animal welfare and prioritising research that builds on existing work, will expedite the rate of knowledge acquisition in this industry (Ward and Hosey 2019).

Acknowledgements

We thank the organisers of the Universities Federation for Animal Welfare 2017 Symposium for providing a stimulating meeting that led to the inception of this project. We thank Sarah Woody for assistance with coding. We thank Stephen R. Ross and Maureen Leahy for feedback on earlier versions of this manuscript,.

References

Adenkola A.Y., Ayo J.O. (2010) Physiological and behavioural responses of livestock to road transportation stress: A review. *African Journal of Biotechnology* 9(31): 4845–4856.

Albert C., Luque G.M., Courchamp F. (2018) The twenty most charismatic species. *PLOS One* 13(7): e0199149.

Anderson U.S., Kelling A.S., Maple T.L. (2008) Twenty-five years of Zoo Biology: A publication analysis. *Zoo Biology* 27: 444–457.

de Azevedo C.S., Cipreste C.F., Young R.J. (2007) Environmental enrichment: A GAP analysis. *Applied Animal Behaviour Science* 102(3–4): 329–343.

Baines F.M., Chattell J., Dale J., Garrick D., Gill I., Goetz M., Skelton T., Swatman M. (2016) How much UVB does my reptile need? The UV-Tool, a guide to the selection of UV lighting for reptiles and amphibians in captivity. *Journal of Zoo and Aquarium Research* 4(1): 42–63.

Balbcombe J.P., Barnard N.D., Sandusky C. (2004) Laboratory routines cause animal stress. *Contemporary Topics in Laboratory Animal Science* 43: 42–51.

Bashaw M.J., Gibson M.D., Schowe D.M., Kucher A.S. (2016) Does enrichment improve reptile welfare? Leopard geckos (Eublepharis macularius) respond to five types of environmental enrichment. *Applied Animal Behaviour Science* 184: 150–160.

Benn A.L., McLelland D.J., Whittaker A.L. (2019) A review of welfare assessment methods in reptiles, and preliminary application of the Welfare Quality® protocol to the pygmy blue-tongue skink, *Tiliqua adelaidensis*, using animal-based measures. *Animals* 9(1): 27.

Bethell E.J. (2015) A "how-to" guide for designing judgment bias studies to assess captive animal welfare. *Journal of Applied Animal Welfare Science* 18: 18–42.

Boissy A., Erhard H.W. (2014) How studying interactions between animal emotions, cognition, and personality can contribute to improve farm animal welfare. In Grandin, T. and Deesing, M.J. (eds). *Genetics and the Behavior of Domestic Animals*. Academic Press, 81–113.

Brando S., Buchanan-Smith H.M. (2018) The 24/7 approach to promoting optimal welfare for captive wild animals. *Behavioural Processes* 156: 83–95.

Broom D.M. (1991) Animal welfare: concepts and measurement. *Journal of Animal Science* 69(10): 4167–4175.

Burghardt G.M. (2013) Environmental enrichment and cognitive complexity in reptiles and amphibians: concepts, review, and implications for captive populations. *Applied Animal Behaviour Science* 147(3–4): 286–298.

Butterworth A., Mench J.A., Wielebnowski N. (2011) Practical strategies to assess (and improve) welfare. In Appleby, M.C., Mench, J.A., Olsson, I.A.S., Hughes, B.O. (eds). *Animal Welfare, 2nd Edition*. CAB International, 200–214.

Carr N. (2016) Ideal animals and animal traits for zoos: General public perspectives. *Tourism Management* 57: 37–44.

Chiszar D., Murphy J.B., Smith H.M. (1993) In search of zoo-academic collaborations: a research agenda for the 1990's. *Herpetologica* 49: 488–500.

Clark F.E. (2017) Cognitive enrichment and welfare: Current approaches and future directions. *Animal Behavior and Cognition* 4(1): 52–71.

Clay A.W., Perdue B.M., Gaalema D.E., Dolins F.L., Bloomsmith M.A. (2011) The use of technology to enhance zoological parks. *Zoo Biology* 30(5): 487–497.

Clegg I.L. (2018) Cognitive bias in zoo animals: An optimistic outlook for welfare assessment. *Animals* 8(7): 104.

Clegg I.L., Delfour F. (2018) Can we assess marine mammal welfare in captivity and in the wild? Considering the example of bottlenose dolphins. *Aquatic Mammals* 44(2): 181–200.

Conde D.A., Colchero F., Gusset M., Pearce-Kelly P., Byers O., Flesness N., Browne R.K., Jones O.R. (2013) Zoos through the lens of the IUCN Red List: A global metapopulation approach to support conservation breeding programs. *PLOS One* 8(12): e80311.

Cronin K.A., Bethell E.J., Jacobson S.L., Egelkamp C., Hopper L.M., Ross S.R. (2018) Evaluating mood changes in response to anthropogenic noise with a response-slowing task in three species of zoo-housed primates. *Animal Behavior and Cognition* 5: 209–221.

Crump A., Arnott G., Bethell E.J. (2018) Affect-driven attention biases as animal welfare indicators: review and methods. *Animals* 8(8): 136.

D'Cruze N., Khan S., Carder G., Megson D., Coulthard E., Norrey J., Groves G. (2019) A global review of animal–visitor interactions in modern zoos and aquariums and their implications for wild animal welfare. *Animals* 9(6): 332.

Dawkins M.S. (2003) Behaviour as a tool in the assessment of animal welfare. *Zoology* 106(4): 383–387.

de Mori B., Ferrante L., Florio D., Macchi E., Pollastri I., Normando S. (2019) A protocol for the ethical assessment of wild animal–visitor interactions (AVIP) evaluating animal welfare, education, and conservation outcomes. *Animals* 9(8): 487.

Department for Environment, Food and Rural Affairs (DEFRA) (2017) Secretary of State's standards of modern zoo practice, Appendix 8 – Specialist exhibits, elephants, Section 8.8. Accessed at: assets.publishing.service.gov.uk

Draper C., Harris S. (2012). The assessment of animal welfare in British zoos by government-appointed inspectors. *Animals* 2(4): 507–528.

EAZA (2019) Available at: https://www.eaza.net/conservation/programmes/ [Accessed on 6 June 2019].

EAZA (2020) Available at: https://www.eaza.net/about-us/areas-of-activity/animal-welfare#AWAL [Accessed on 25 June 2020].

Fraser D. (2008) U*nderstanding Animal Welfare: The Science in its Cultural Context*. Ames, IA: Wiley-Blackwell, Oxford.

Frynta D., Šimková O., Lišková S., Landová E. (2013) Mammalian collection on Noah's ark: the effects of beauty, brain and body size. *PLOS One* 8(5): e63110.

Fuller G.A. (2014) *The night shift: lighting and nocturnal strepsirrhine care in zoos* (Doctoral dissertation, Case Western Reserve University).

Fuller G., Raghanti M.A., Dennis P.M., Kuhar C.W., Willis M.A., Schook M.W., Lukas K.E. (2016) A comparison of nocturnal primate behavior in exhibits illuminated with red and blue light. *Applied Animal Behaviour Science* 184: 126–134.

Grandin T. (1997) Assessment of stress during handling and transport. *Journal of Animal Science* 75(1): 249–257.

Hemsworth P.H., Price E.O., Borgwardt R. (1996) Behavioural responses of domestic pigs and cattle to humans and novel stimuli. *Applied Animal Behaviour Science* 50(1): 43–56.

Hill S.P., Broom D.M. (2009) Measuring zoo animal welfare: Theory and practice. *Zoo Biology* 28(6): 531–544.

Honess P., Wolfensohn S. (2010) The extended welfare assessment grid: a matrix for the assessment of welfare and cumulative suffering in experimental animals. *Alternatives to Laboratory Animals* 38(3): 205–212.

Hurst J.L., West R.S. (2010) Taming anxiety in laboratory mice. *Nature Methods* 7(10): 825.

Kagan R., Carter S., Allard S. (2015) A universal animal welfare framework for zoos. *Journal of Applied Animal Welfare Science* 18: 1–10.

Kardous C.A., Shaw P.B. (2014) Evaluation of smartphone sound measurement applications. T*he Journal of the Acoustical Society of America* 135(4): 186–192.

Keeling L.J. (2019) Indicators of good welfare. In Choe J.C. (ed). *Encyclopedia of Animal Behavior, 2nd Edition.* Academic Press, London, pp 134–140.

Kim-McCormack N.N., Smith C.L., Behie A.M. (2016) Is interactive technology a relevant and effective enrichment for captive great apes? *Applied Animal Behaviour Science* 185: 1–8.

Koolhaas J.M., Korte S.M., De Boer S F., Van Der B.J., Vegt C.G., Van Reenen H., Hopster I.C., De Jong, Ruis M.A.W., Blokhuis H.J. (1999) Coping styles in animals: Current status in behavior and stress-physiology. *Neuroscience and Biobehavioral Reviews* 23(7): 925–935.

Krebs B.L., Watters J.V. (2016) Using technology driven environments to promote animal well-being in zoos. *Proceedings of the HCI Goes to the Zoo.*

Less E.H., Kuhar C.W., Dennis P.M., Lukas K.E. (2012) Assessing inactivity in zoo gorillas using keeper ratings and behavioral data. *Applied Animal Behaviour Science* 137(1–2): 74–79.

Lincoln Park Zoo (2020) ZooMonitor (Version 3.2) [Mobile application software]. Available from https://zoomonitor.org.

Makecha R.N., Highfill L.E. (2018) Environmental enrichment, marine mammals, and animal welfare: A brief review. *Aquatic Mammals* 44(2): 221–230.

Maple T.L., Segura V.D. (2015) Advancing behavior analysis in zoos and aquariums. *The Behavior Analyst* 38(1): 77–91.

Meagher R.K. (2009) Observer ratings: validity and value as a tool for animal welfare research. *Applied Animal Behaviour Science* 119(1–2): 1–14.

Meany M.J., Diorio J., Francis D., Widdowson J., LaPlante P., Caldji C., Sharma S., Seckl J.R., Plotsky, P.M. (1996) Early environmental regulation of forebrain glucocorticoid receptor gene expression: Implications for adrenocortical responses to stress. *Developmental Neuroscience* 18: 49–72.

Meijer M.K., Sommer R., Spruijt B.M., van Zutphen L.F., Baumans V. (2007) Influence of environmental enrichment and handling on the acute stress response in individually housed mice. *Laboratory Animals* 41: 161–173.

Melfi V.A. (2009) There are big gaps in our knowledge, and thus approach, to zoo animal welfare: A case for evidence-based zoo animal management. *Zoo Biology* 28(6): 574–588.

Mellor D.J., Beausoleil N.J. (2015) Extending the 'Five Domains' model for animal welfare assessment to incorporate positive welfare states. *Animal Welfare* 24(3): 241–253.

Mellor D.J., Hunt S., Gusset M. (eds.) (2015) *Caring for wildlife: the world zoo and aquarium animal welfare strategy.* Gland: WAZA Executive Office, 87 pp.

Mendl M., Paul E.S. (2020) Assessing affective states in animals. In McMillan, F.D. (ed.). *Mental Health and Well-being in Animals, 2nd Edition*. CAB International, 328–344.

Miller L.J. (2012) Visitor reaction to pacing behavior: Influence on the perception of animal care and interest in supporting zoological institutions. *Zoo Biology* 31(2): 242–248.

Núñez J.F., Ferré P., Escorihuela R.M., Tobeña A., Fernández-Teruel A. (1996) Effects of postnatal handling of rats on emotional, HPA-axis, and prolactin reactivity to novelty and conflict. *Physiology & Behavior* 60: 1355–1359.

Perlman J.E., Bloomsmith M.A., Whittaker M.A., McMillan J.L., Minier D.E., McCowan B. (2012) Implementing positive reinforcement animal training programs at primate laboratories. *Applied Animal Behaviour Science* 137(3–4): 114–126.

Podberscek A.L., Blackshaw J.K., Beattie A.W. (1991) The effects of repeated handling by familiar and unfamiliar people on rabbits in individual cages and pens. *Applied Animal Behaviour Science* 28(4): 365–373.

Powell D.M., Watters J.M. (2016) The evolution of the animal welfare movements in U.S. zoos and aquariums. *Der Zoologische Garten* 86: 219–234.

Proctor H. (2012) Animal sentience: where are we and where are we heading? *Animals* 2(4): 628–639.

Rose P.E., Nash S.M., Riley L.M. (2017) To pace or not to pace? A review of what abnormal repetitive behavior tells us about zoo animal management. *Journal of Veterinary Behavior* 20: 11–21.

Rose P.E., Brereton J.E., Rowden L.J., de Figueiredo R.L., Riley L.M. (2019) What's new from the zoo? An analysis of ten years of zoo-themed research output. *Palgrave Communications* 5(1): 1–10.

Rose P., Riley L. (2019) The use of Qualitative Behavioural Assessment to zoo welfare measurement and animal husbandry change. *Journal of Zoo and Aquarium Research* 7(4): 150–161.

Ross M.R., Gillespie K.L., Hopper L.M., Bloomsmith M.A., Maple T.L. (2013) Differential preference for ultraviolet light among captive birds from three ecological habitats. *Applied Animal Behaviour Science* 147(3–4): 278–285.

Ross M., Mason G.J. (2017) The effects of preferred natural stimuli on humans' affective states, physiological stress and mental health, and the potential implications for well-being in captive animals. *Neuroscience & Biobehavioral Reviews* 83: 46–62.

Rushen J., Taylor A.A., de Passillé A.M. (1999) Domestic animals' fear of humans and its effect on their welfare. *Applied Animal Behaviour Science* 65(3): 285–303.

Salas M., Manteca X., Abáigar T., Delclaux M., Enseñat C., Martínez-Nevado E., Quevedo M., Fernández-Bellon H. (2018) Using farm animal welfare protocols as a base to assess the welfare of wild animals in captivity—Case study: Dorcas gazelles (*Gazella dorcas*). *Animals* 8(7): 111.

Scott E.M., Fitzpatrick J.L., Nolan A.M., Reid J., Wiseman M.L. (2003) Evaluation of welfare state based on interpretation of multiple indices. *Animal Welfare* 12(4): 457–468.

Sherwen S., Hemsworth L., Beausoleil N., Embury A., Mellor D. (2018) An animal welfare risk assessment process for zoos. *Animals* 8(8): 130.

Species360 Zoological Information Management System (ZIMS) 2019 zims.Species360.org.

Staley M., Conners M.G., Hall K., Miller L.J. (2018) Linking stress and immunity: Immunoglobulin A as a non-invasive physiological biomarker in animal welfare studies. *Hormones & Behavior* 102: 55–68.

Swaisgood R.R., Shepherdson D.J. (2005) Scientific approaches to enrichment and stereotypies in zoo animals: What's been done and where should we go next? *Zoo Biology* 24(6): 499–518.

Thorpe S., Weiss A., Fletcher A., Garcia R., Farmer H., Pullen K. (2019) An introduction to the Great Ape Welfare group (GAWg) and consideration of how we can translate our research to ensure optimal outcomes for the wellbeing and conservation of captive and wild great apes. *Presentation at the joint meeting of the 8th European Federation for Primatology and Primate Society of Great Britain Winter Meeting Oxford UK* Sept 8–11, 2019.

Veasey J.S. (2017) In pursuit of peak animal welfare; the need to prioritize the meaningful over the measurable. *Zoo Biology* 36(6): 413–425.

Walker M., Diez-Leon M., Mason G. (2014) Animal welfare science: Recent publication trends and future research priorities. *International Journal of Comparative Psychology* 27(1): 80–100.

Ward S.J., Hosey G. (2019) The need for a convergence of agricultural/laboratory and zoo-based approaches to animal welfare. *Journal of Applied Animal Welfare Science* 1–9.

Wark J.D., Cronin K.A., Niemann T., Shender M.A., Horrigan A., Kao A., Ross M.R. (2019) Monitoring the behavior and habitat use of animals to enhance welfare using the ZooMonitor app. *Animal Behavior and Cognition* 6(3): 158–167.

Wemelsfelder F. (2007) How animals communicate quality of life: The qualitative assessment of behaviour. *Animal Welfare* 16: 25.

Wemmer C., Rodden M., Pickett C. (1997) Publication trends in Zoo Biology: A brief analysis of the first 15 years. *Zoo Biology* 16: 3–8.

Whitham J.C., Wielebnowski N. (2009) Animal-based welfare monitoring: using keeper ratings as an assessment tool. *Zoo Biology* 28(6): 545–560.

Wolfensohn S., Shotton J., Bowley H., Davies S., Thompson S., Justice W. (2018) Assessment of welfare in zoo animals: Towards optimum quality of life. *Animals* 8(7): 110.

Wulff K., Gatti, S., Wettstein J.G., Foster R.G. (2010) Sleep and circadian rhythm disruption in psychiatric and neurodegenerative disease. *Nature Reviews Neuroscience* 11(8): 589–599.