An evaluation of the role of "biological evidence" in zoo and aquarium enrichment practices

Running title: *Evidence use in zoo enrichment*

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Abstract

Evidence-based approaches are key to advancing all areas of zoo and aquarium practice. Output from empirical study must be disseminated to those within the industry so that results can support changes to husbandry and management for individual species. Information on enrichment techniques is published in a range of sources, including papers in the peer-reviewed and 'grey literature' (i.e. professional but non-reviewed publications). To investigate how evidence is implemented into enrichment practices, we sampled all enrichment studies identified in one online repository of peer-reviewed papers and two grey literature publications across an 11-year period. We recorded whether the enrichment was supported with biological evidence (whether it was developed using published enrichment-focussed research for that species and/or with the species' ecology and behaviour information) alongside analysis of the type of enrichment used and the chosen study species. Enrichment articles were more likely to be supported by biological evidence in peer-reviewed than grey literature. Taxonomic differences in the use of evidence were noted; for example, enrichment provided to carnivores and parrots was more likely to be supported with biological evidence compared to that used for penguins. Of the five enrichment types, nutritional enrichment was most often based on biological evidence. Multi-category and physical enrichment types were more common across all literature sources whereas social enrichment was less common, suggesting barriers to implementation of all enrichment types in zoological facilities. Our research suggests that zoo and aquarium professionals are considering species-specific welfare needs by ensuring that enrichment protocols are supported by biological evidence. However, opportunities to diversify the enrichment types being offered and species being researched are identified.

Keywords: Animal welfare; Environmental enrichment; Evidence-based approaches; Zoo animal management; Zoo research

1. Introduction

The concept of evidence-based captive animal management has been gathering momentum in recent years (Melfi 2009; Kaufmann et al 2019; Rose et al 2019a) and zoological facilities are increasingly using empirical study to inform their husbandry practices. One of the underpinning roles of modern animal collections is to uphold practices that promote animal welfare. Evidence from zoo literature can inform professionals about successful or relevant management techniques, which can provide support for the development of more advanced, species-specific husbandry approaches (Shyne 2006). A key area of captive animal husbandry where application of evidence is integral to improving welfare (and ameliorating poor welfare) states is the use of species-appropriate environmental enrichment (EE).

EE is described as the provision of novel stimuli into an animal's environment (Swaisgood & Shepherdson 2005) and its use has been identified as an important component of good husbandry for many captive-housed species (Fernandez et al 2019). While animal enclosures may sometimes be sufficiently stimulating that EE is not necessary, EE can provide numerous benefits for animals including cognitive challenge (Meehan & Mench 2007; Hopper et al 2016), opportunities to express natural behaviour, reduction of abnormal repetitive behaviour (Mason et al 2007), improvements to physical and psychological health and enhanced behavioural flexibility (Swaisgood & Shepherdson 2005). Since its development as a husbandry practice during the 20th century, the body of literature on EE has grown such that researchers can initiate structured analysis of EE topics to further refine its application to the zoo and aquarium (Riley & Rose 2020; Shyne 2006; Swaisgood & Shepherdson 2005).

All taxa may benefit from an enriched captive environment that allows performance of behavioural diversity and that promotes positive affective states (Rose et al 2017a, 2017b, 2019a). As some taxonomic groups are particularly susceptible to the development of abnormal repetitive behaviour when housed in captivity, EE has often been implemented as a preventative or treatment strategy (Shyne 2006). Focus on the necessity of EE for big cats (Felidae), bears (Ursidae) and primates (Regaiolli et al 2019; Fernandez & Timberlake 2019) shows the importance of empirical study of EE techniques to improve and enhance animal welfare at the species and individual level. Taxa such as primates and Carnivora have received more research attention in response to an increased likelihood of performing abnormal behaviour in the zoo (Clubb & Mason 2003; Mason et al 2007). Behavioural indicators of good welfare may be easier for welfare researchers to interpret for such taxa, as a bias towards the study of mammals in pure and applied behavioural science suggests a greater familiarity with their ecology (Melfi 2009; Mather 2019; Rose et al 2019a), therefore increasing the research attention they receive.

Inference of welfare state in reptiles, amphibians, fish or invertebrates appears more challenging than for endotherms. This challenge may be because outward visible signs of welfare state are often subtle and environmental variables (such as temperature) strongly influence activity levels and behaviour (Burghardt 2013; Bashaw et al 2016; Rose et al 2017, 2017b). If key welfare indicators are unknown or hard to identify, the difficulties for researchers in their attempts to identify effective EE strategies are increased (Greenway et al 2016). An animal's personality may also influence the way in which it interacts with EE (Pich et al 2019). Personality dimensions are not well studied in many taxa (Pich et al 2019) so the requirements of some taxonomic groups for EE complexity may be underestimated (Riley & Rose 2020).

1.1. Increasing the impact of EE research and applying evidence more widely.

A key aim of published EE literature is to inform practitioners of its effectiveness in enhancing animal welfare (Rose et al 2019a). Reports on effective and ineffective EE strategies have merit as they both inform practitioners on the suitability of current EE techniques (Claxton 2011). Any improvement and diversification of EE can be measured in the scientific literature; for example, Lutz and Novak (2005) proposed the use of several forms of EE for primates, including touch-screen technology. At the time of publication, touch-screen technology was relatively novel and its use for non-human primates had rarely been proposed. At the time of writing, Lutz and Novak's 2005 paper has received 159 citations, several of which have applied touch-screen computers to non-human primates (e.g. Ritvo & Allison 2017; Wooddell et al 2019; Huskisson et al 2020). This shows how EE concepts, once communicated within the scientific literature, may be developed, modified and shared globally with practitioners.

Evidence for EE practices that enhance animal welfare can be obtained from the literature and implemented into animal husbandry techniques. The sharing of EE research can allow practitioners to adapt existing EE techniques to novel subjects (Rose et al 2016). For example, auditory EE, which had originally been trialled for use in kennel-housed domestic dogs *(Canis lupus familiaris)* and primates can be successfully repurposed to use for parrots and great apes (Ritvo & Macdonald 2016; Williams et al 2017). Such work provides a foundation for further EE research to fully realise the welfare benefits of evidence-based EE.

It is likely that EE is implemented for a wider array of species than appear in peer-reviewed literature (Rose & Riley 2020). There may be barriers that prevent practitioners from publishing their work with EE in peer-reviewed journals, for example time to write up outside of their working day. Other platforms may be more commonly utilised for sharing EE concepts and their effectiveness. Such platforms document case studies on specific populations or individual animals and provide valuable assessment of EE efficacy (Hoy et al 2010) because they showcase the strategies most commonly used by animal keepers to implement and assess EE, and they provide information on welfare assessment strategies across taxa. To further bridge the gap between EE theory and EE practice, first identified by papers such as Shyne (2006), investigation of what the gap currently is would be beneficial.

Papers published in the grey literature (e.g. non-peer-reviewed articles written by professionals or subject specialists for publications such as the *Shape of Enrichment* https://theshapeofenrichmentinc.wildapricot.org/ or *Wild Welfare* https://wildwelfare.org/) may provide an overview of the current state of practice for EE use in zoos and aquaria, as such platforms may be more accessible to animal keepers to both submit their work and to gain ideas and knowledge. Other forms of non-peer reviewed literature available to zookeepers include zoo association magazines and the proceedings from relevant symposia and workshops. All of these sources are noted as containing information on EE usage across zoo-housed taxa.

In order to determine how relevant EE is for improving husbandry standards and welfare states in zoo and aquarium housed species, this research evaluates the extent that EE is informed by evidence from available literature. We summarised the current trends in published research regarding types of EE investigated and the taxonomic groups most commonly investigated/provided with EE. We also investigated the use of such published studies by other researchers, evaluating the impact (based on citations of a specific piece of work) of peer-reviewed EE-focussed science. We analysed the prevalence of EE studies in (zoo-specific) “grey literature” to determine whether EE practices are being informed by existing research output.

2. Materials and methods

EE papers from 1 January 2008 to 31st December 2019 were Sourced from three repositories: the database Web of Science©, *Ratel* (the journal produced by the Association of British and Irish Wild Animal Keepers, ABWAK 2020), and *Animal Keepers’ Forum* (the journal of the American Association of Zoo Keepers, AAZK 2020). Web of Science represents peer-reviewed literature, whereas Ratel and the Animal Keeper’s Forum represent more practical information available to keepers and aquarists, which is referred to throughout the course of the paper as grey literature.

Results were first categorised by the animal Class studied in each paper (mammal, bird, reptile, amphibian, fish and invertebrate). A final category, “multi”, consisted of papers with a focus on more than one taxonomic group. Next, the number of papers using each type of EE as per Bloomsmith et al’s (1991) five categories, which are nutritional, occupational, physical, sensory and social (Table 1). Two further categories, training and multi, were identified. Debate amongst authors (Melfi 2013; Westlund 2014) stipulates that operant conditioning and positive reinforcement training in the zoo can be EE but should be provided alongside of conventional EE techniques for the specific species.

Table 1. Enrichment categories and examples.

Enrichment category	Example	Reference
Nutritional	A novel food source or different feed presentation type, requiring the animal to spend more time processing its meal.	Wooddell et al 2019

Occupational	A puzzle or task provided to an animal that requires it to solve a problem.	Field and Thomas 2000
Physical	Enclosure features (fixed or temporary) that require the animal to exert effort, such as climbing ropes.	Bloomsmith et al 1991
Sensory	A scent trail, using herbs or spices to guide animal around exhibit.	Resende et al 2011
Social	Visual and auditory contact with conspecifics that the animal is not normally exposed to.	Reinhardt et al 2013
Training	Use of a stick (target) to guide an animal around its exhibit, using food rewards for positive reinforcement.	Melfi 2013
Multi	Use of multiple forms of enrichment, such as when comparing the use of a puzzle feeder and a scent trail.	Swaisgood and Shepherdson 2005

For all suitable articles, irrespective of their Source, the species, Order, Family, Aim and Outcome were recorded. Consideration was also given as to whether EE had been developed in light of the species' natural behaviour and biology. Biological evidence (BE) was defined as the use of natural history and behavioural ecology evidence when developing EE. Use of BE was determined when the EE described in a paper was based on behavioural ecology and/or on previous empirical study of EE usage for that species. An example would be EE that enabled naturalistic foraging behaviours for captive parrots being based on key natural history information (Field & Thomas 2000). Papers that described EE that did not clearly explain natural history or encourage natural behaviours (e.g. use of submerged disco balls for penguins with no link to the encouragement of natural behaviour) were classed as non-BE.

The Aims (i.e. the point of doing the EE research) and Outcomes of the article were identified, as specified by each paper's authors. These Aims and Outcomes were then categorised as per Rose et al (2019a). The Aim categories used for this study were Behaviour, Cognition, Husbandry & Training, Nutrition, Veterinary Medicine, or Methods (how to collect data in a specified situation). Where a study had multiple Aims, the primary aim (as stated by the paper's author) was used.

Outcomes were described as suggested consequences of the paper. The categories for Outcomes were Animal and Ecosystem Health, Husbandry and Welfare, Pure Biology and Scientific Validity (Rose et al 2019a). The Outcome gains were categorised as advancing knowledge or practical application, either at a specific (single population or species) or general level.

2.1. Web of Science®

Raw data were used retrospectively from a previous study published in Palgrave Communications in 2019 (Rose et al 2019b) where the dataset for this paper is publicly available (https://doi.org/10.24378/exe.1903). To collect these data, Web of Science was searched from 2008 to 2019 using the key words of either "zoo" or "aquarium", followed by the term "enrichment". Additionally, the terms "mammal OR bird OR reptile OR amphibian OR fish OR invertebrate" were added to "zoo enrichment" or "aquarium enrichment", to ensure that all relevant papers were identified. Papers were included in the dataset if their focus was on some form of EE in animals held in zoos, aquariums or wildlife parks. Purely theoretical papers and reviews were also included within the dataset. From each relevant paper, the species or taxa being covered was included, in addition to the year, journal, journal's impact factor, the number of citations that the article has received, and the number of times other authors used the article to develop further EE studies.

2.2. Ratel and Animal Keeper's Forum

Archived copies of ABWAK's magazine *Ratel*, and the AAZK's *Animal Keeper's Forum* were manually searched for articles investigating the use of EE. All issues were searched from January 2008, to December 2018, resulting in 10 years of data for each Source. Articles were included if the title or methods included consideration of the use of EE.

2.3. Data Analysis

Data were analysed in Minitab v.19 (www.minitab.com/en-us/products/minitab/). A total of 295 data entries were generated from the three different Sources of EE literature: Web of Science (167, 56.61%), *Ratel* (45, 15.25%) and *Animal Keeper's Forum* (83, 28.13%).

To analyse the number of papers that used BE for the EE documented, a binary logistic regression was run that compared BE in the peer-reviewed and grey literature across time. Age of the paper (years), taxonomic Class, type of EE described and Source (i.e. peer-reviewed or grey literature) were predictors of use of BE. The consideration (1) or lack (0) of BE in each type of publication (peer-reviewed or grey literature) was the Outcome variable.

To investigate the predictors of 'Aim category', a nominal logistic regression was run. The Aim categories of Behaviour, Husbandry & Training and Welfare were used in the model and any remaining categories were excluded as they were not found in both literature types. The Outcome variable was the 'Aim category' of each paper, and the predictors were the age of paper (years), paper Source (peer-reviewed or grey literature), BE, taxonomic Class, and type of EE described.

To analyse the predictors of a paper's total number of citations (i.e. the number of times a paper was cited in other peer-reviewed Sources), a Poisson regression was run. The outcome variable was the paper's total number of citations, and the predictors included were age (years), taxonomic Class, type of EE and the journal's Impact Factor. The interaction between the age of a paper and its impact factor was also included as a predictor as impact factor changes over time. This analysis was run only on the peer-reviewed literature, as citation numbers were not available for grey literature.

For models where multiple P values were compared, a corrected level of significance was calculated using the Bejamini-Hochburg method to test for any false discovery of significance (Benjamini & Hochberg 1995). Based on this corrected significance level, new probabilty values were calculated (Q values) and presented alongside of the original P values. Significant Q values in all cases are highlighted with the asterisk symbol. In each case, model fit was determined using generated r^2 values.

3. Results

3.1. *Biological evidence*

The output of the binary logistic regression revealed that a paper's Source (i.e. the repository where the paper was found) and the type of EE were significant predictors of whether or not a paper used BE enrichment, whereas paper age and taxonomic Class were not ($\chi^2(286) = 271.15$, $r^2 = 13.31\%$, P = 0.004). P values for each predictor were compared to a corrected alpha level of 0.03 and significant Q values are marked with a * (Table 2). Papers published in Web of Science were more likely to contain EE based on evidence compared to those published in AKF.

Table 2. Output of binary logistic regression on use of BE for documented EE practices.

Predictor	**Variable**	**Estimate**	**Standard error**	**DF**	**P value**	**Q value**
Age (years)	1	0.480	0.769	10	0.131	0.0375
	2	0.391	0.675			
	3	-0.235	0.664			
	4	-0.176	0.704			
	5	0.972	0.771			
	6	0.011	0.698			
	7	1.209	0.821			
	8	0.621	0.733			
	9	1.387	0.743			
	10	-0.532	0.680			
Class	Amphibian	19	0.197	7	0.506	0.05
	Bird	10	0.197			
	Fish	8	0.197			
	Invertebrate	21	0.241			
	Mammal	9	0.197			

	Reptile	11	0.279			
Source	Web of Science	1.357	0.324	2	<0.001	0.0125*
	Ratel	0.773	0.455			
	Animal Keeper's forum	-0.578	0346			
Type of enrichment	Nutritional	0.626	0.507	7	0.003	0.025*
	Occupational	-1.146	0.731			
	Physical	-0.050	0.418			
	Sensory	-0.554	0.452			
	Social	-0.350	0.708			
	Training	-2.221	0.581			

The number of papers with BE enrichment was tracked across time for both peer-reviewed and grey literature (Figure 1). EE papers in peer-reviewed literature were more likely to have a biological basis. Whilst taxonomic Class was not a significant predictor of BE use, there were differences apparent in the publication trend for different taxonomic Orders (Figure 2) with some species (e.g. Sphenisciformes, penguins) showing no use of BE and others (e.g. Phoenicopteriformes, flamingos, and Accipitriformes, birds-of-prey) showing that all described EE in a paper was based on BE.

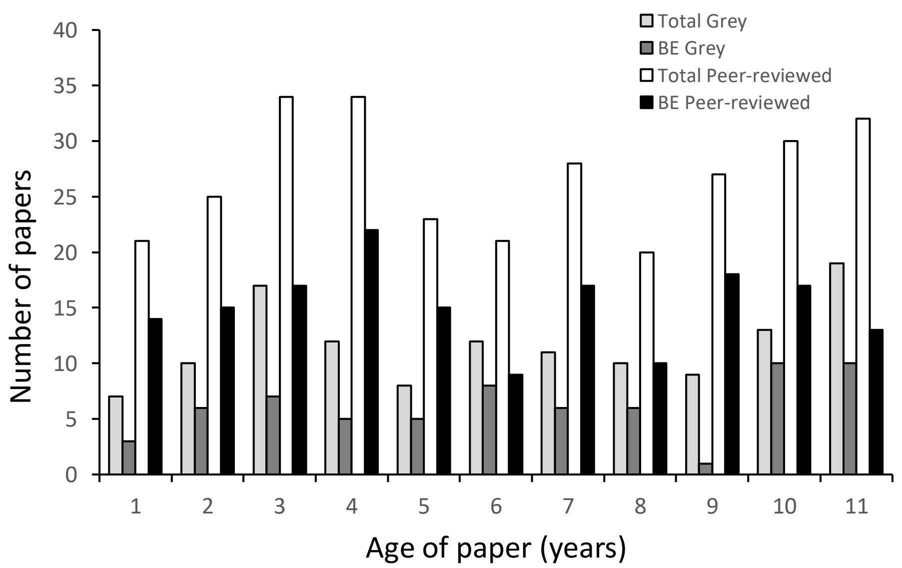

Figure 1. Total number of papers per year for grey and peer reviewed literature, and the number of papers that use BE EE. The 'total grey' and 'total peer-reviewed' boxes show the total number of papers published per year on enrichment for these sources. The 'BE grey' and 'BE peer-reviewed' boxes show the number of papers that used BE enrichment in that year.

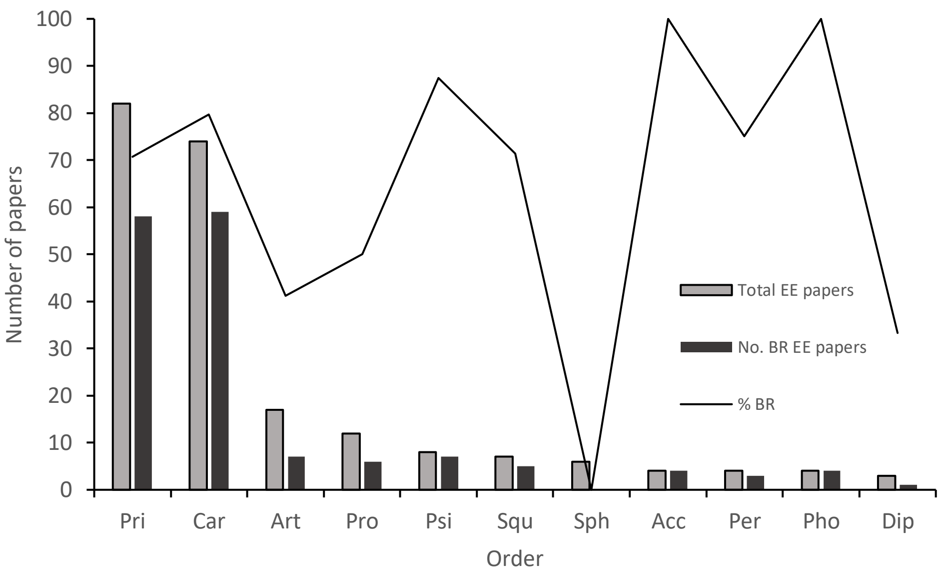

Figure 2. Total number of papers for the most frequently investigated taxonomic orders (as defined by any order that has been the focus of three of more papers), and the number of papers which included BE enrichment. Key: Pri = Primates, Car = Carnivora, Art = Artiodactyla, Pro = Proboscidaea, Psi = Psittaciformes, Squ = Squamata, Sph = Sphenisciformes, Acc = Accipitriformes, Per = Perissodactyla, Pho = Phoenicopteriformes, Dip = Diprotodontia.

3.2. Characteristics of peer-reviewed and "grey" literature

The "husbandry and training" category was the most common aim for EE papers, irrespective as to whether they were from peer reviewed or grey literature sources (Table 3). Similarly, the "husbandry and welfare" category was the most common output for EE studies regardless of their source.

Table 3. Number of papers with each Aim and Outcome category for all sources of information.

	Category	Animal Keeper's Forum number of papers (%)	Ratel number of papers (%)	Web of Science number of papers (%)	Total number of papers (%)
Aim	Behaviour	4 (1.36)	2 (0.68)	10 (3.39)	16 (5.42)
	Cognition	0	0	2 (0.68)	2 (0.68)
	Husbandry & training	63 (21.36)	34 (11.53)	139 (47.12)	236 (80.0)
	Methods	0 (0)	0 (0)	9 (3.05)	9 (3.05)
	Physiology	0 (0)	0 (0)	3 (1.02)	3 (1.02)
	Visitor studies	1 (0.34)	0 (0)	2 (0.68)	3 (1.02)
	Welfare	15 (5.08)	9 (3.05)	2 (0.68)	26 (8.81)
Outcome	Behaviour change (Human)	0 (0)	0 (0)	1 (0.34)	1 (0.34)
	Conservation & sustainability	0 (0)	0 (0)	5 (1.69)	5 (1.69)
	Husbandry & welfare	81 (27.46)	45 (15.25)	151 (51.19)	277 (93.90)
	Pure biology	0 (0)	0 (0)	6 (2.03)	6 (2.03)
	Scientific validity	2 (0.68)	0 (0)	4 (1.36)	6 (2.03)

The results of the nominal logistic regression investigating the predictors of Aim category indicated that only the source, Web of Science, was significant with all other predictors non-significant ($\chi^2(243) = 327.192$, $P = 0.007$) (Table 4). However, once multiple P values were inputted into a Benjamini-Hochburg correction factor to check for false discovery at a new significance level of 0.019, this significant value for Web of Science now only approaches significance.

Table 4. Output of nominal logistic regression on the Outcome of Aim categories of Behaviour, Husbandry & Training, and Welfare.

Predictor	Variable	Estimate	Standard error	DF	P value	Q value
Age (years)	1	-1.307	1.466	10	0.373	>0.05
	2	-1.773	1.313		0.177	>0.05
	3	19.117	0.676		0.998	>0.05
	4	-1.994	1.418		0.160	>0.05
	5	-2.177	1.386		0.116	>0.05
	6	18.515	0.783		0.998	>0.05
	7	-1.309	1.530		0.393	>0.05
	8	-2.303	1.453		0.113	>0.05
	9	-0.176	1.668		0.916	>0.05
	10	-0.480	1.441		0.760	>0.05
Class	Amphibian	-24.166	65760.7	7	1.000	>0.05
	Bird	21.626	0.461		1.000	>0.05
	Fish	-21.273	0.461		1.000	>0.05
	Invertebrate	-1.023	0.065		1.000	>0.05
	Mammal	21.225	0.461		1.000	>0.05
	Reptile	22.571	0.461		1.000	>0.05
Source	Web of Science	2.514	0.837	2	0.003*	0.002
	Ratel	-0.480	0.648		0.526	>0.05
	Animal Keeper's forum	-0.492	0.624		0.459	>0.05
Type of enrichment	Nutritional	-17.498	0.109	7	0.761	>0.05
	Occupational	34.930	0.055		0.999	>0.05
	Physical	0.191	1.899		0.106	>0.05
	Sensory	17.945	0.611		0.509	>0.05
	Social	4.101	1.693		0.110	>0.05

	Training	-16.5543	0.756		0.841	>0.05
Biological basis	Yes/No	0.831	0.576	1	0.149	>0.05

3.3. Predictors of citations in peer-reviewed literature

Results of the Poisson regression ($\chi^2(155) = 629.58$, $r^2 = 63.32$ $P < 0.001$) indicated that taxonomic Class, impact factor, type of EE and the interaction between impact factor and age of paper were significant predictors of total citation number (Table 5). For each predictor, multiple P values were compared to a corrected alpha level of 0.04 and significant Q values highlighted. Whilst not a significant factor under the corrected alpha level for this model, the model estimates for age show an increase in the number of times a paper is cited over time. Species representation is similar across the study period with the exception of Psittaciformes (parrots), which only appeared in more recent (<6-year-old) papers.

Table 5. Model output to identify significant predictors of the number of citations per peer reviewed paper.

Predictor	**Variable**	**Estimate**	**Standard error**	**DF**	**P value**	**Q value**
Age (years)	1	2.161	0.739	10	0.192	0.05
	2	2.761	0.726			
	3	2.709	0.728			
	4	2.589	0.735			
	5	3.469	0.733			
	6	3.864	0.725			
	7	3.726	0.729			
	8	3.546	0.725			
	9	3.866	0.725			
	10	4.237	0.726			

Class	Amphibian	0.046	0.165	5	<0.001	0.01*
	Bird	-1.910	0.215			
	Fish	0.455	0.169			
	Invertebrate	-2.14	1.02			
	Mammal	-1.111	0.0883			
	Reptile	-0.988	0.275			
Impact factor	Impact factor	1.43	0.496	17	<0.001	0.02*
Type of enrichment	Nutritional	-0.341	0.095	6	<0.001	0.03*
	Occupational	0.053	0.118			
	Physical	-0.453	0.088			
	Sensory	0.306	0.083			
	Social	0.436	0.093			
	Training	0.180	0.094			
Impact factor *Age	Interaction between predictors	0.1532	0.0172	10	<0.001	0.04*

3.4. Type of enrichment

Of the EE types, multi-category (109, 36.94%) appeared most frequently in this sample of the literature (109, 36.94%), followed by physical EE (56, 18.98%) nutritional (41, 13.89%), sensory (37, 12.54%), training (27, 9.15%), social (13, 4.4%) and occupational (12, 4.06%). The representation of each EE category also differed between the types of literature (Figure 3), with training studies appearing more frequently in grey literature.

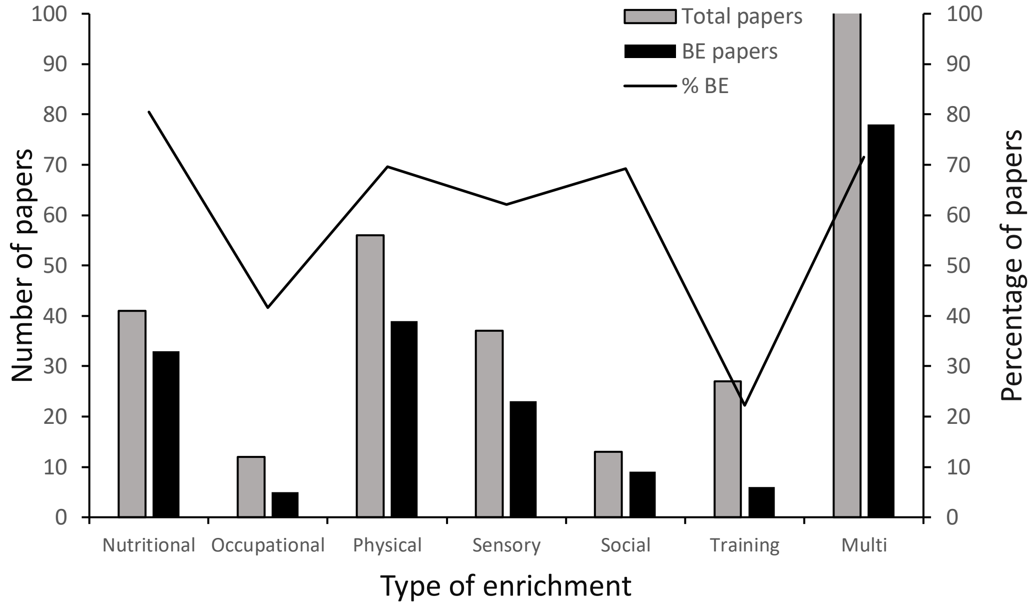

Figure 3. Total number of papers using each enrichment type for both grey literature and peer reviewed literature combined. The number of papers which contain BE enrichment are shown in black, and the percentage of papers that are biologically informed is shown as a line.

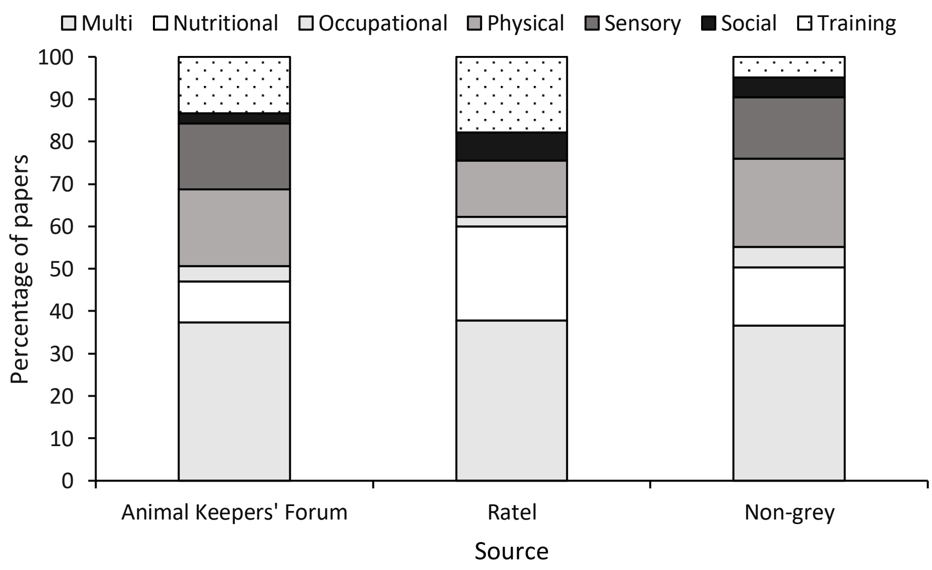

Figure 4. Percentage of papers covering each singular type of enrichment and multi (for papers that discussed several EE types).

3.5. Taxonomic representation

Mammals (227, 76.95%), birds (34, 11.52%) and reptiles (12, 4.07%) were the most frequently documented taxonomic Classes in this sampled literature. Amphibians (2, 0.68%), fish (1, 0.34%) and invertebrates (1, 0.34%) were the subject of fewer studies and 18 studies (6.10%) had a multi-taxa focus. Supplementary information on taxonomic representation is available in the appendix (Appendix 1, 2).

4. Discussion

This study has identified that biological evidence was significantly more likely to be found in peer-reviewed papers than in grey literature articles. Differences were noted in how BE was used for different categories of EE, with papers focussing on nutritional and multiple forms of EE more likely to be supported with BE. Some taxonomic groups, such as carnivores, primates, ungulates and elephants, were more often represented in this sample of EE literature compared to other taxa.

Husbandry and Training was the most common aim for papers, irrespective of their Source (Tables 3 and 4), which reflects the growing research output from zoological collections (Loh et al 2018) that is aimed at improving animal care standards (Barber 2009), which in turn advances animal welfare. A paper's Source (peer-reviewed or grey literature) was a predictor of aim category, with peer-reviewed literature showing a wider range of possible Aim categories (e.g. cognition, methods and physiology) which were not identified in grey literature. This difference in Aim categories is likely a reflection of the target audience, as grey literature sources targeted zoo professionals whereas peer-reviewed journal articles tended to target a more academic audience. Reviews of multiple EE strategies, and application of novel methods were more likely to appear in peer-reviewed sources, suggesting that larger meta-analyses or gap analyses, as well as papers documenting new ways of measuring or evaluating EE have a more theoretical rather than practical audience.

4.1. Biological evidence

Our research demonstrates that many published EE strategies are biologically relevant to the taxa they are used on, but there is scope for more widespread BE use in EE development. Nutritional EE was significantly more likely to be biologically informed (Figure 4), which likely reflects the push towards evidence-based zoo nutrition and a reduction in unhealthy or inappropriate dietary alternatives in zoo foods (Less et al 2014; Britt et al 2015). Likewise if nutritional EE aims to increase foraging or food handling and processing time, then knowledge of a species' behavioural and evolutionary ecology regarding feeding and foraging strategies will be needed for such EE to work successfully (Stoinski et a. 2000; Altman et al 2005).

Difference in BE usage across papers and EE categories may be a direct result of how EE is utilised for and the ease of providing EE to a given species. For example, it is more challenging to incorporate natural history information into training regimes or occupational EE. However, training, particularly when it is used to encourage species-specific behaviours, can be biologically informed. Training-based EE appeared frequently in the grey literature (Figure 1) and this may be a cause of a lower use of BE in these papers. Training studies have considerable value for sharing knowledge on good practice, animal management, and potentially may improve human-animal interactions (Melfi 2013; Ward & Melfi 2013). The greater occurrence of training research in the grey literature suggests that authors are targeting a specific audience (i.e. other zookeepers) to share important information on species-specific training techniques. Whilst the grey literature was less likely to contain articles that featured BE, it probably better reflected the actual use of EE within zoos and aquariums (i.e. written by zookeepers for zookeepers).

The grey literature is more difficult to systematically search for specific-subject content compared to peer-reviewed articles. Consequently, areas of EE practice that appear less frequently (and therefore might receive less attention) may have appeared in the scientific literature but indexing and cataloguing issues could limit their overall readership. A study of zoo and aquarium professionals noted that conference delegates considered EE to be essential for non-parrot birds, fish and invertebrates (Rose & Riley 2020) but our study revealed limited numbers of papers on these taxa. The positive attitude of zoo professionals to widespread use of EE, as stated by Rose & Riley (2020), suggests that EE may be commonplace throughout zoological collections but is not always being shared in or read from the literature.

There may be occurrences of when an EE provided is not based on BE but still provides positive welfare outcomes, for example the use of touch-screen computers for zoo-housed primates (Kim-McCormack et al 2016; Schmitt 2018) or the use of music as sensory stimulation (Ritvo & MacDonald 2016). Measurement of any positive behavioural indicators (for example play, exploration or enhanced positive social interaction) in conjunction with the use of the EE could be analysed and published to then provide situational or individual evidence for why this type of "non-BE" enrichment is actually relevant, beneficial for the welfare of zoo-housed species, and effective at providing an output for the performance of welfare positive behaviours. Clearly, the need for individual interaction with such forms of non-BE enrichment is crucial; research on mouse lemurs *(Microcebus murinus)* showed that as animals age, their interaction with touchscreen technology declined in comparison to younger animals (Joly et al 2014). This finding may be relevant to various BE enrichment methods too, and provides clear reasons for evaluation of EE (in any of its forms) so that it continues to be relevant to the animals it is provided to for all of their life stages.

4.2. Predictors of citations in peer-reviewed literature

Our research revealed that a paper's age, the animal's taxonomic Class, the interaction between age and journal Impact Factor, and type of EE were all significant predictors of total paper citation number. The significant interaction between the age of a paper and its impact factor in our study supports the idea that the longevity of an article enhances its value to others, particularly as journal impact grows over time as they are available for longer. The growth in open access scientific publishing is a helpful development that should bring high impact academic research to more zoo and aquarium researchers who may have struggled to reach such publications in the past. A positive correlation was noted between a paper's age and increasing citation rate in other disciplines (Tahamtan et al 2016), so it may take time for the findings from a paper to be digested and then applied to industry by others working on the topic of said paper.

Work on amphibians and fish were positive predictors of total citation number, whereas other taxonomic Classes were negative predictors. There may be a restricted pool of EE evidence for fish and amphibians, researchers are actively using the available content to write high-impact papers that are useful to those working with such species. The limited research evidence for some amphibians and fish might result in the papers that are available being cited extensively, particularly as practitioners and scientists work more closely on defining and examining welfare states and quality of life measurement for such species (Michaels et al 2014; Graham et al 2018).

4.3. Type of enrichment

Multi-category EE studies, in which several different EE types are featured, appeared most frequently in all forms of publication (Figure 4). Review papers that summarise and compare EE across situations and taxonomic groups (Swaisgood & Shepherdson 2005) may be especially useful for zoo professionals, enabling comparison of the effectiveness of EE types before a choice is made to apply EE to a specific species in the zoo or aquarium. Developing such review papers for understudied taxa (e.g. fish or invertebrates) may increase engagement with EE for such species as well as overcome some of the challenges with how it is used in this species that could be a barrier to EE being provided.

Of single category EE papers, the most commonly documented in all literature sources were physical, nutritional, sensory and training. Social and occupational EE were rarely included in EE articles. EE types are not mutually exclusive, and as such, social and occupational forms of EE may be covered in other ways. Introduction of new animals into an exhibit might be investigated under the topics of animal compatibility, breeding or social network analysis, and may not be labelled as EE. Similarly, group housing for social animal species may be enriching, yet this is often considered part of routine husbandry and is therefore not always covered as EE research (Rose et al 2016). Occupational EE, similarly, may either be provided as part of normal husbandry routines as well as by enclosure fixtures, fittings, planting and substrates. Consequently, the role of the enclosure itself as a form of occupational EE, with the associated welfare benefits that this brings, may be forgotten as it is not "given or provided" specifically to the animal as a form of EE, and may be constantly available to the animal.

Both occupational and social EE can be provided without nutritional rewards, allowing keepers to move away from food as EE in situations where dietary provision needs to be carefully monitored.

Social EE could be provided as opportunities to interact with individuals from another social group in a safe, controlled manner using appropriate barriers where necessary (Lutz & Novak 2005). Many sociable species are highly motivated to seek out social interaction (Hopper et al 2016) and therefore the natural behaviour of the animal could be manipulated and managed in conjunction with enclosure change or modification to enhance the enriching nature of the social environment provided (Rose et al 2016).

4.4. Taxonomic representation

Over 75% of papers focused on mammals (with primates and carnivores being especially popular research subjects); amphibians, fish and invertebrates were the focus of less than 1% of studies respectively. This taxonomic bias is represented in research fields such as general zoo science (Melfi 2009; Rose et al 2019a), animal behaviour (Rosenthal et al 2017), conservation (Bautista and Pantoja 2005; dos Santos et al 2020), and is also reflected in how popular such taxa are with the general public (Courchamp et al 2018).

Taxonomic Classes less common in this sample of the EE literature are well-represented in zoos and aquariums globally (Brereton & Brereton 2020) and therefore diversification of research output as well as the replication of EE experiments across institutions could be possible (Rose et al 2019a). Some of these taxa are featured in the literature but in other topics, such as conservation or breeding (Rose et al 2019a). Many Orders, such as the amphibians Caudata and Gymnophiona, and almost all fish Orders, were not represented in our dataset. Basic behavioural ecology knowledge of these Orders may be lacking, inhibiting the development of new research initiatives. There is evidence to suggest that some of the EE strategies are not yet appearing in the published literature, and therefore it is possible that EE for these taxa is more widespread than our literature search would suggest.

4.5. Extending this research question

Previous papers (Melfi 2009) and more recent journal special editions that have focussed on the use of evidence in the zoo (e.g. *Animals,* MDPI 2020) have illustrated gaps in husbandry knowledge for many taxa in the zoo and consequently still call for zoo animal management to be evidence based at the species-specific level. A requirement for using evidence to underpin practice is further emphasised by zoo and conservation organisations themselves as they implement changes to existing species management protocols. For example, the European Association of Zoos and Aquaria, EAZA (2020), Best Practice Guidelines and the IUCN's Conservation Planning Specialist Groups, CPSG (2020), One Plan Approaches can integrate management of species between the wild and zoo environments (Traylor-Holzer et al 2019). For such evidence to be available, it is important for zoos and academic institutions continue to work together to identify what research questions need to be posed, and where, to ensure that evidence gathered is credible and relevant to the practical application it links to. Our research on BE for EE provides examples of how evidence has been gathered on EE for particular species, as well as where more information is needed for specific taxonomic groups and EE styles. To further enhance evidence gathering on EE use (e.g. species relevance and application) surveys, workshops and training could be used to garner information on: how EE is decided upon, how it can be adapted for the promotion of key behavioural and ecological needs within a species, and how it can be reassessed and re-evaluated as a cyclic process of action research (Kirkey 2005) to audit its continued efficacy over time (Therrien et al 2007; Woods et al 2020). Increasing the understanding of what EE is and the capacity for its use by animal care staff can be successfully undertaken via the use of species-specific workshops, with learning objectives centred on linking species ecology with EE needs in the zoo (Melfi & Hosey 2011; Rose et al 2016). Research that investigates the best methodologies for systematic scoring and categorisation of "how much evidence was used to develop the EE" should be developed, trialled and analysed. Such scoring methods could rate the final EE output against a scale of evidence usage.

Such descriptors on a scale of this kind could be linked to a numeric score (e.g. a score of 0 for no BE at all; a score of 1 for no BE put the potential for its inclusion) to enable a full evaluation of all stages of EE design and application to a specific species within a specific animal collection. This approach would help with welfare auditing, provide useful information on the "normal characteristics" of the individual animals to support health and wellbeing records kept by vets or curatorial staff, and be useful for animal welfare policies and zoo licencing documentation.

Further extension of this research to develop and test a BE scoring system to assess the species-specific relevance of different EE types could also reduce the effect of any confounds to this research, notably the need for reference material and citations to be used within the peer-reviewed literature as a requirement of publishing in this medium. It may well be that EE devices documented in the grey literature were originally developed using information on species' ecology and behaviour but the lack of requirement for referencing means this information is lost from any final publication. Scoring the BE from each paper, in a Likert scale (where 1 and 5 equate to 'no consideration of BE' and 'full consideration of BE throughout development of EE' respectively) would provide greater depth on the integration of BE in enrichment provision.

5. Animal welfare implications and conclusions

EE is considered integral to the improved welfare states experienced by many zoo-housed animals (Swaisgood & Shepherdson 2005). EE presented in both Source types showed the use of BE that demonstrates the value and relevance of the EE to the species receiving it. It appears that, as a general observation, zoos and aquariums are using an evidence-based approach to develop EE strategies for the animals in their care. Some EE types were referred to less frequently in the literature (e.g. social, occupational), and this could be an opportunity for zoos to diversify their EE strategies as newer BE becomes available to those guiding EE programmes, specifically for species whose welfare may be improved by use of social or occupational enrichment.

Not all EE types necessarily need to be supported by BE, and in such cases, attention should be paid to the intended welfare outcome for the animals involved. For example, training programmes are not always based on BE, yet they can provide measurable welfare benefits for animals involved by enabling coping mechanisms, reducing stress during husbandry and management or by enhancing the animal's feelings of autonomy over its current situation (Laule et al 2003; Westlund 2014). However, where possible an animal's natural history and behaviour should be taken into account to ensure that EE is biologically appropriate for that species; an especially important consideration for animals in conservation programmes where the promotion of adaptive traits, essential for survival of future generations in the wild, is a key requirement (Greggor et al 2018). Enhancing animal welfare outputs for individuals within conservation programmes is possible with the correct use of relevant EE (enabling "opportunities to thrive") and therefore the welfare relevance of our review, and our call to encourage more evidence gathering on how EE is developed, is applicable to the many roles of the zoo or aquarium's animal collection (Greggor et al 2018).

With some taxonomic groups appearing more frequently in the literature, there are opportunities for practitioners to diversify and adapt their EE strategies to new subjects. It is likely that a wide range of EE types are already being used for a much more diverse variety of taxa than is actually being published. As the actual scope of EE being practiced by the zoo and aquarium community is clearly challenging to measure, we encourage those practitioners already using novel EE strategies or who are conducting EE on under-represented taxa to consider sharing their findings. Increased dissemination of studies by animal care staff would provide more evidence for future work that aims to fill current gaps in knowledge relating to EE.

Active online social media groups, widely accessible to animal care staff, may allow new EE ideas to be shared more rapidly than via traditional media. There are benefits to the rapid sharing of information online but some sources may lack repeatability. Unlike information presented in the "grey literature" whose articles often require some evaluation of the suitability of EE (ABWAK 2020), the instantaneous communication within social media can reduce the changes of such important reflection and review of suggested practice. However, these online forums could provide greater insight into the EE strategies commonly used by animal care staff, particularly if they document EE targeted for welfare improvements in "poorly researched" taxa. Future research should include an assessment of the types of EE and species advertised in these media, with a comparison against what is being published in grey and peer-reviewed sources.

Given the scope for developing EE at the species-specific level, to enhance welfare using BE within the EE protocol, alongside the likelihood that relevant and useful EE approaches exist in the grey literature publications of many zoo organisations, we suggest that such professional zoo organisations consider how they share and archive the articles from their newsletters, magazines or journals. An enhanced, and searchable, online repository of past articles would increase the readership of information that has been submitted to the publication and, from a research standpoint, enable more vigorous assessment of the content and application of the results contained within these articles.

Overall, we have shown that key aspects of a zoo or aquarium animal welfare programme, notably the use of EE as a means of enhancing the lives of the animals at the institution, is more often than not, based on facets of ecological or biological evidence that relate to the species being enriched or the design or type of EE protocols being used to enhance welfare through behavioural means (i.e. the promotion of specific activities or behavioural events). Zoos need to consider increasing their research outputs to show the use of evidence for a wider range of species, and they should continue to re-evaluate current EE practices to ensure that they remain relevant to the animal's behaviour patterns and attainment of positive welfare states.

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Appendix:

Appendix 1. Table containing number (and proportion) of papers per taxonomic group from each literature Source

	Animal Keeper's Forum	**Ratel**	**Web of Science**	**Total**
Amphibian	0 (0)	0 (0)	2 (0.68)	2 (0.68)
Bird	8 (2.71)	13 (4.41)	13 (4.41)	34 (11.53)
Fish	1 (0.34)	0 (0)	0 (0)	1 (0.34)
Invertebrate	1 (0.34)	0 (0)	0 (0)	1 (0.34)
Mammal	64 (21.69)	25 (8.47)	138 (46.78)	227 (76.95)
Reptile	6 (2.03)	3 (1.02)	3 (1.02)	12 (4.07)

Multi	0 (0)	4 (1.36)	11 (4.75)	18 (6.10)

Appendix 2. Table of most represented taxonomic Orders in this enrichment literature

Class	**Order**	**Number of papers (proportion)**
Amphibians	Anura	2 (0.68)
Birds	Psittaciformes	8 (2.71)
	Sphenisciformes	6 (2.03)
	Accipitriformes	4 (1.36)
	Phoenicopteriformes	4 (1.36)
	Pelecaniformes	2 (0.68)
	Cathartiformes	1 (0.34)
	Galliformes	1 (0.34)
	Gruiformes	1 (0.34)
	Passeriformes	1 (0.34)
	Strigiformes	1 (0.34)
Fish	Perciformes	1 (0.34)
Invertebrates	Octopoda	1 (0.34)
Mammals	Primates	82 (27.80)
	Carnivora	74 (25.08)
	Artiodactyla	17 (5.76)
	Proboscidaea	12 (4.07)
	Perissodactyla	4 (1.36)
	Diprotodontia	3 (1.02)
	Chiroptera	2 (0.68)
	Pilosa	2 (0.68)
	Rodentia	2 (0.68)

	Cetartiodactyla	1 (0.34)
	Lagomorpha	1 (0.34)
	Macrosceliformes	1 (0.34)
Reptiles	Squamata	6 (2.03)
	Crocodilia	2 (0.68)
	Testudines	2 (0.68)
Multi-taxa		55 18.64)