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Husbandry and management interventions for the conservation and welfare of captive animals – a systematic evidence map

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Abstract

Zoos and aquariums are poised to play increasingly important roles in mitigating the global biodiversity crisis. However, the ultimate success of ex-situ conservation depends on animal welfare and effective husbandry and management practices. As such, an empirical understanding of 'what works' in zoo management is crucial for guiding success and embedding cost-effective practices. Here, we present the first systematic evidence map for husbandry and management interventions used in zoos and aquariums. We identified and extracted 1,070 articles spread across 45 journals, and examined patterns within taxonomic, spatial, temporal, and thematic categories. Studies originated from 516 institutions in 69 countries, and focused on 637 species. We listed 424 husbandry and management interventions used by ex-situ managers, based on a pilot study, consultations with an advisory board of expert practitioners, and the published literature. We found published evidence for the effectiveness of 90% of those interventions, with some (e.g. diet modification and enclosure enrichment) being more studied than others (e.g. animal behaviour management and visitor management). Clear biases were observed in the spatial and taxonomic focus of studies, with evidence being principally generated from institutions in Western Europe, North America, and Australia (77.4% of included studies), and most evidence (65.2% of included studies) focusing on mammals. Evidence from standalone aquariums was particularly scant. This article (and linked database) provides practitioners with a systematic and comprehensive resource detailing evidence-based studies of zoo management interventions to inform their decision-making. It also identifies opportunities for prioritising evidence synthesis and clear evidence gaps for future investigation.

Introduction

Global biodiversity loss, and its likely intensification in the coming decades, are predicted to be severe enough to represent a sixth 'Anthropocene' mass-extinction event (Barnosky et al. 2011; IPBES 2019; Cowie et al. 2022). Zoos, aquariums, and other ex-situ facilities (henceforth 'zoos') are well-placed to make important contributions towards mitigating this biodiversity loss through captive breeding and associated reintroduction and reinforcement programmes (Conde et al. 2011; Funk et al. 2017; Bolam et al. 2023). This is especially true when these are undertaken as integrated components of broader conservation strategies (Byers et al. 2013), and with respect to the other important societal contributions zoos provide, such as education and advocacy (Powell and Watters 2017). Recently, the IUCN Species Survival Commission produced a Position Statement highlighting the "significant contributions made by botanic gardens, aquariums, and zoos in their critical mission of conserving wild animals, fungi, and plants" and urging such institutions to achieve their potential in species conservation (IUCN SSC 2023). However, the ultimate success of ex-situ conservation programmes is dependent on effective husbandry and management (Swaisgood 2007; Dolman et al. 2015) (henceforth 'management'), and a poor understanding of these factors can lead to captive breeding failures (Michaels et al. 2014) and significant wasted resources. Additionally, ensuring positive welfare is an ethical obligation and legislative requirement (Wolfensohn et al. 2018; Lemasson et al. 2020; Spooner et al. 2023). Indeed, ensuring high welfare standards is a top priority for zoos, and has been linked to success in achieving broader conservation, education and research goals (Powell and Watters 2017; Binding et al. 2020). However, such success is dependent on effective management. Conversely, poor husbandry and ineffective conservation practices are detrimental to public support (Woods 2015) and can severely undermine the role of captive facilities in conservation. This is particularly relevant in the context of discussions about wider roles and public perception of zoos, evolving from menageries with animals displayed for entertainment into modern facilities of ex-situ conservation, education and major conservation funders (Conde et al. 2011).

Zoos have a rich history of scientific research and record keeping. Previous reviews have found that the publication rate of studies conducted in zoos has increased markedly over recent decades (Loh et al. 2018; Welden et al. 2020), including those with a specific focus on animal welfare (Binding et al. 2020). The standardised record keeping undertaken by zoos is also an important source of evidence for conservation management with the Zoological Information Management System maintained by Species360, which contains records for over 10 million individuals from 22,000 species (Conde et al. 2019). Existing literature and global datasets are available to inform management through husbandry guidelines such as the Animal Care Manuals of the Association of Zoos and Aquariums and the Best Practice Guidelines of the European Association of Zoos and Aquaria. However, the research potentially underpinning such guidelines is not always available and has rarely been collated in a systematic way.

Despite the clear importance of employing evidence-based management practices in zoos, similar to the broader field of conservation, there remains an incomplete understanding of which practices are effective, and which are not (Melfi 2009). This is compounded by various research biases, barriers to evidence access, and obfuscation by management practices based on subjective traditions and 'folklore' rather than empirical data (Melfi 2009; Arbuckle 2013; Lemasson et al. 2020). While some studies have attempted to collate information on management interventions conducted in zoos (e.g., Swaisgood and Shepherdson 2005), these have not been completed using a systematic evidence-map approach, and have tended to be restricted in both scope and sample size. This makes it difficult for practitioners to identify provenely effective (or indeed provenely ineffective) management interventions for a given situation, and also to identify relevant research gaps to investigate. Resolving these limitations may become critical in the near-to-medium-term future as intensification of biodiversity loss could make effective ex situ programmes increasingly important for averting extinctions (Bowkett 2009; Martin et al. 2014a; Bolam et al. 2021).

To address these knowledge gaps, and following previous calls for an evidence-based framework of management interventions for captive animals (Melfi 2009), we present here the first systematic map of research evidence for the effectiveness of management interventions used in zoos. Systematic maps - also referred to as evidence maps or scoping reviews - have rapidly gained popularity in recent years and are collections of primary research and reviews aiming to collate and describe the available published research evidence on a topic using a repeatable, unbiased and transparent methodology (James et al. 2016). We present this map as a resource for ex situ care and conservation practitioners and summarise the associated metadata to identify knowledge clusters particularly rich or lacking in evidence-based zoo research, as well as notable taxonomic, spatial, temporal, and thematic biases.

Methods

Objective of the map (primary and secondary research questions)

The principal objectives of this map, as set out in the published protocol (Lemasson et al. 2020), are to examine:

i) Which studies have measured the effects of any management and/or husbandry interventions/practices on the conservation and welfare of captive (kept in zoos, aquariums, or other captive facilities) animals?
ii) Which husbandry interventions/practices and outcomes have been well-studied (knowledge clusters) and which ones are lacking published evidence?
The study also has a secondary objective of examining the distribution and frequency of studies between outcomes/metrics, species or species groups, countries/facilities, and years (Lemasson et al. 2020).

Advisory board and compilation of the management intervention list

At the start of this study, we formed an expert advisory board to help us shape our research questions and advise on management interventions used in zoos (see Lemasson et al. 2020). The board expanded slightly since the protocol was published to comprise 26 international experts (Appendix Table 1). Our original list of management interventions was supplemented by those highlighted during previous pilot synthesis work (Jonas et al. 2018) and those identified as part of our systematic literature search. Although the list is comprehensive, additional interventions may exist that were not identified in the literature or considered by our advisory panel. Interventions were grouped into 10 thematically broad categories (level 1), with each broad category being divided into more specific sub-categories (level 2). We identified 29 level 2 categories in total (with between one and nine level two categories nested within each level 1 category) (Appendix Table 2).

Literature sources and search strategy

A complete methodology for the construction of our evidence-based map can be found in Lemasson et al. (2020). We followed the systematic methodology and the standards set out by the Conservation Evidence group based at the University of Cambridge (Sutherland et al. 2019). We briefly summarise key points here and highlight any deviations from the original protocol.

We systematically searched the published scientific literature for relevant research testing zoo management interventions. We supplemented the list of literature sources presented in the protocol (Lemasson et al. 2020) by adding the Journal of Zoological and Botanical Gardens; a highly relevant publication first published in December 2020. The final list of sources searched comprised 28 core academic journals in which every article was scanned (Appendix Table 3a), as well as 337 potentially relevant studies identified during systematic searches of an additional 99 English-language academic journals and nine report series

(Appendix Table 3b) by the Conservation Evidence team as part of their subject-wide evidence synthesis methodology (Sutherland et al. 2019).

We assessed all relevant literature for studies that tested the effects of interventions published on captive animals between January 1980 to December 2021. This represents a two-year extension from the original range of years proposed in Lemasson et al. (2020). An additional modification to the protocol is that we excluded articles published before 1980. Although zoo management studies were published as early as the 1950s (Hediger 1950), literature before this period was frequently inaccessible, especially in digitised formats. Additionally, the 1980s saw the emergence of zoo management as a distinct discipline, with various legislation being passed to ensure good practices (Melfi 2009; Powell and Watters 2017), and the establishment of the first journal dedicated to the science of ex-situ care and conservation (Zoo Biology, first published in 1982).

Article screening, study selection and criteria for inclusion

Article screening, study selection and criteria for inclusion are listed in Lemasson et al. (2020). Briefly, publications were screened in two stages as normal for systematic mapping: (1) using titles and abstracts and (2) using full texts. At each stage, we decided whether to include or exclude each publication from the map, based on whether the described study (or studies – note that one article may contain one or more individual intervention) met the eligibility criteria (which were defined using 'PICO/PECO' terminology: P=populations/subjects, I=interventions/E=exposures, C=comparators, O=outcomes - as detailed in the protocol and in Sutherland et al. 2019). Two authors (TEM and AJL) completed the article screening. Prior to screening, both completed consistency and accuracy tests whereby sets of preliminary decisions on article inclusion were compared with decisions by the experienced core Conservation Evidence team using a Cohen's Kappa test (Cohen 1960), until agreement scores of K >0.61 ('substantial'; the threshold used by Conservation Evidence) were achieved for both authors. Due to the logistical limitations that became apparent when identifying the vast volume of literature that needed to be scanned, we excluded non-English literature searches as per the protocol.

Eligible Populations

Populations included all taxa (vertebrates and invertebrates) of captive animals. Studies on domestic species were excluded even if kept in zoos and aquariums (e.g. domestic rabbits or goats kept as part of a petting zoo). This remains unchanged from the protocol detailed in Lemasson et al. (2020).

Eligible Interventions/Exposures

We retained articles describing studies that tested one or more of the management interventions listed in Appendix Table 2. Studies undertaken in farms, laboratories and aquaculture facilities on species that are also kept in zoos and aquariums, and for which the intervention studied could be implemented in a zoo or aquarium (e.g. object enrichment for laboratory primates), were included. In agreement with the advisory board and due to the magnitude of the veterinary intervention literature as well as the different requirements for veterinary staff in a zoo setting, it was decided to exclude articles related to clinical treatment of injury and disease or physical restraining techniques (see Lemasson et al. 2020). However, we did include a large number of health focused interventions in a zoo or aquarium setting (e.g. the many interventions relating to variations in diet - see Appendix Table 2).

Eligible Comparators

Unchanged from the protocol (see Lemasson et al. 2020)., but briefly, in order to be included studies must have included a comparison or a counterfactual, either in time (i.e. monitoring change over time, typically before/after the intervention was implemented), or space using an experimental control (for example comparing sites or enclosures with and without the intervention). Alternatively, a study was included if it compared one specific intervention (or implementation method) against another. Wild populations also represented suitable comparators. We made an exception for some studies relating to the success of captive breeding that lacked a non-breeding situation as a comparator.

Eligible Outcomes

Unchanged from the protocol (see Appendix Table 4 in Lemasson et al. 2020), and essentially consisting of any reported outcomes or metrics.

Meta-data extraction and study coding

Each study was given a unique identifier. Meta-data from each study were extracted and coded to form our map, using 19 categories based on the PICO/PECO components described above. The protocol listed 18 categories (presented in Table 5 in Lemasson et al. (2020)); for each of these we coded meta-data relating to the study (e.g. study year, study site at two geographical levels, taxa at two taxonomic levels, study design, and intervention at two category levels), as well as meta-data relating to the publication (bibliographic information such as article reference; year of publication; journal or report name). We also included one extra category named "Institution type" that specifies the type of research facility the study was undertaken at: 1) Zoo/Aquarium/Wildlife Park, 2) University/Research Institution, 3) Rescue Centre/Shelter, or 4) Private Company (e.g. commercial aviculturists).

Data mapping, analysis, and visualisation

The systematic map is presented as a coded Microsoft CSV file (Appendix Table 5) that allows filtering and searches.

We completed a series of exploratory analyses to examine the nature and distribution of evidence, as well as to identify knowledge clusters and gaps. Specifically, we assessed the spatial coverage (geographical distribution) of evidence, as well as the extent to which different interventions, taxonomic groups, and outcome categories have been studied.

First, to examine spatial patterns and associated bias of studies in the systematic map on a global scale, we plotted the location of country/countries in which each study was completed on a World map, standardising names to the list of 241 countries and territories provided in South (2017). The map was produced using a Behrmann equal area cylindrical projection (Yildirim and Kaya 2008) and the R packages ggplot2, ggthemes, tidyverse,sf, readxl, rnaturalearth and rnaturalearthdata (Wickham 2016; South 2017; Pebesma 2018; Wickham et al. 2019a,b; Arnold et al. 2021). We also noted the top 10 institutions appearing most frequently in the systematic map, as well as the frequency with which different institution types appear. For this latter analysis, as an additional output, we also noted the frequency of studies produced from specialist aquariums, as a subset of the "Zoo/Aquarium/Wildlife Park" category excluding aquariums that are part of larger zoos or wildlife parks (these institutions listed in Appendix Table 4).

To examine the extent to which different interventions were studied, we calculated the percentage of listed interventions for which at least one study was identified and listed in the map. This also allowed us to determine the proportion of interventions for which we found no published evidence. We also examined the frequency at which interventions were tested, at both level 1 (broad category) and level 2 (sub-category). Similarly, we examined the frequency with which level 1 and level 2 outcomes appeared in the map (as detailed in Lemasson et al. 2020).

To examine patterns of taxonomic representation and bias within the systematic map, we tabulated the number of level 1 intervention categories tested within studies for each taxonomic class. Non-vertebrate classes were grouped as “invertebrate spp” for these analyses. We also noted the top 10 most frequently appearing species in the map, and plotted the number of studies published per year for each taxonomic order (as well as the total number of studies published per year), along with the proportion of studies comprised by each order per year.

Finally, given recently highlighted concerns regarding the impacts of delays in the publication of conservation data (Christie et al. 2021a), we examined the lag time between when studies testing interventions were conducted and when they were published by calculating the mean average difference between study year and year of publication for all studies in the map. Where studies were conducted across multiple years, the most recent year was used for this analysis.

Results

Our systematic map (Appendix Table 5) is populated with meta-data from 1,070 studies that met our extraction criteria (from an overall pool of 27,705 scanned articles from our 28 core journals and the 99 journals and nine report series in the Conservation Evidence database). These studies came from 516 institutions in 69 countries and focused on 637 different species.

Distribution of evidence by country

There are strong spatial biases regarding where the studies listed in our systematic map were undertaken. Of the 241 countries and territories listed in South (2017) only 69 (28.6%) have at least one study in our map (Figure 1). Of these, the vast majority (77.4%) were undertaken in Western Europe, North America, or Australia. Two countries in particular are over-represented in the map – the USA (47.6% of all studies) and the UK (11.9%). This over-representation is also visible in Table 2a, which shows that nine of the top 10 institutions where studies were undertaken are from these two countries (seven in the USA and two in the UK), with only one – Melbourne Zoo (Australia) – being located elsewhere.

While the majority (55.5%) of studies found were undertaken in zoos, aquariums, and wildlife parks, many were undertaken in universities and research institutions (37.5% of studies), with the remaining 7% of studies undertaken by private companies and rescue centres. Notably, only 4.2% of studies were completed in dedicated aquariums (Appendix Table 4).

Distribution of evidence by intervention type and outcome variables

We found evidence for 381 (90%) of the 424 interventions listed in Appendix Table 2 (where the intervention had at least one study). Research effort was not equally distributed between intervention types. Some differences between taxonomic groups notwithstanding, management interventions focusing on diet and feeding modification (376 studies), enclosure modification (335 studies) and population management (249 studies) are very well represented (Figure 2). On the other hand, management interventions focusing on animal-keeper interactions (44 studies), visitor management (21 studies), and transport and handling (17 studies) are comparatively poorly represented (Figure 2). We found no published evidence for the remaining 43 interventions (10%) (Table 1). The average number of studies per intervention was 2.7, excluding those with no evidence in the map.

Similarly (and in some cases relatedly), outcome categories in our systematic map are not equally represented. In general, and again with some differences between taxonomic groups, studies investigating the effect of interventions on condition (414 studies) and breeding success (234 studies) are well-represented, while studies investigating impacts on population structure (15 studies), population genetics (four studies) and visitor number or behaviour (five studies) are poorly represented (Figure 3). Figure 4a and 4b provide detailed breakdowns of level 1 interventions and outcomes per taxonomic class, respectively.

Distribution of evidence by taxonomic group

Figure 4a and 4b and Figure 5 all show that strong taxonomic bias exists in our systematic map, with mammals being by far the most-studied taxonomic group (n=699, present in 65.3% of all studies), and primates in particular being well-studied (n=398, present in 37.2% of all studies). Birds (n=128, 12%) and

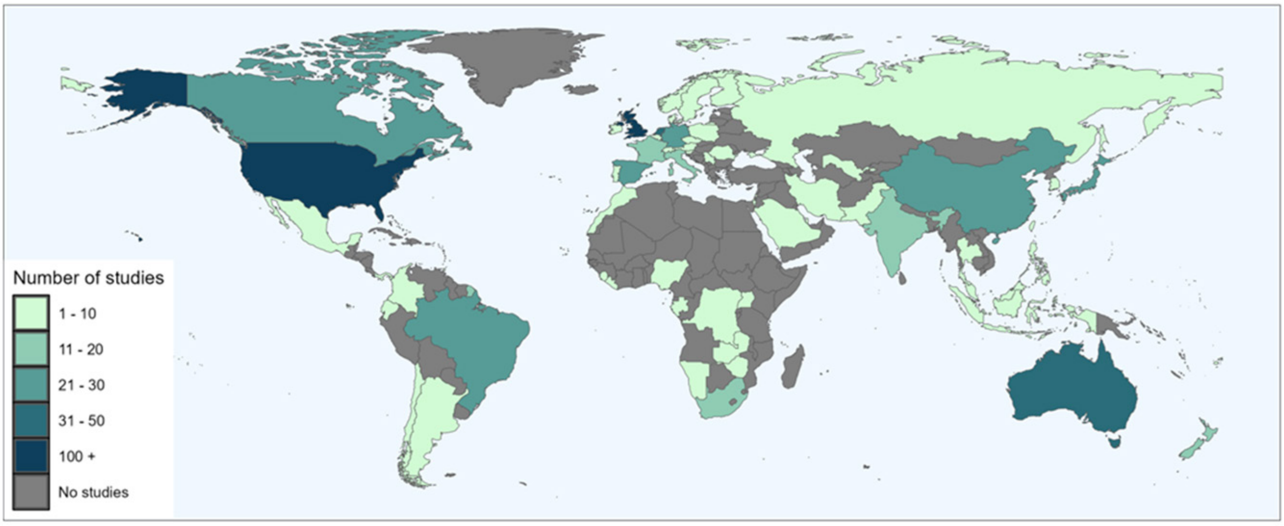

Figure 1. Global geographic heat map showing the number of studies undertaken in each country and territory, as listed in South (2017).

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Table 1. Specific zoo management interventions identified as being used in zoos, but for which no evidence is found in our systematic map. Level 1 and Level 2 categories for these unevidenced interventions are also indicated.

Level 1 Intervention category	Level 2 Intervention category	Specific untested intervention
Diet or feeding modification	Food enrichment and/or presentation	Add additional scents to food to make it more palatable
		Provide straw (as a chewable item)
		Feed animals in subgroups
		Hand-feed animals
	Diet supplementation and/or modification	Leave infertile eggs at spawn site as food for egg-eating larvae
		Provide live food that was exposed to UV
		Provide faecal bacteriotherapy/supplement
		Supplement the diet with nutraceutical
	Feeding schedule and/or location modification	Create or remove predictable signals of feeding times
		Feed at different visitor crowd levels
Object-related enrichment	Provide a toy or novel object	Introduce a model of a prey species
Enclosure or habitat modification or enrichment	Water	Change pool configuration
	Space size, access, or complexity	Provide pre-made burrows/tunnels
		Vary material or orientation of resting platform
	Temperature and humidity	Provide temperature-controlled nest boxes
		Vary enclosure humidity
	Sound/Auditory	Play music at a constant level to prevent other external noises alarming animals
		Use a different aeration type to provide a novel acoustic environment in aquarium tanks
	Scent/Olfactory	Vary olfactory proximity of predator or prey species
	Sight and/or visual enrichment	Allow views of predator/prey species in neighbouring enclosures
		Add images as visual enrichment within the enclosure
		Provide motion illusions
	Other sensory or enclosure enrichment	Provide natural nesting sites/environments (rather than artificial ones)
Social composition or group modification	Increase, decrease, or merge groups	Identify and breed a similar species to refine husbandry techniques prior to working with target species
	Change group social structure	Allow animals to choose social companions
		Place animals with impairments (such as blind or deaf animals) with healthy conspecifics
Population management	Population increase and/or natural reproduction	Allocate breeding pairs using DNA-based (genetic) relatedness coefficient rather than pedigree or kinship
		Genetically screen (barcode) animals to ensure species identity
		Provide objects which facilitate mating behaviour
	Incubation and rearing methods	Allow adults to attend to their eggs
		Vary parental incubation time before artificial incubation
	Artificial reproduction	Artificially select sex by sorting sperm
		Use artificial cloning from frozen or fresh tissue
	Population reduction and/or contraception	Alternate the type of contraceptive to avoid resistance
		Isolate ovulating females
Visitor management	Visitor-animal interaction	Use visitors as a source of stimulation
		Provide a refuge or "safe" area for animals during opportunities for visitors to interact with animals
		Vary the height of visitors above the animals
Animal-keeper interaction	Enclosure/exhibit cleaning procedures and husbandry disturbances	Vary frequency of enclosure cleaning
		Vary the amount of water changed during aquarium tank husbandry
		Vary enclosure cleaning schedule
Transport and handling	Transport	Regulate water quality during the transportation of aquatic animals
		Regulate temperature during transport

Table 2. A) List of the top 10 institutions contributing studies (by number of studies contributed) and the country they occur in, and B) List of the top 10 species (by number of studies they are the subjects of), along with their taxonomic order and class.

A)	Institution	Country	Number of studies
	University of Texas	USA	28
	Smithsonian National Zoo	USA	20
	Zoo Atlanta	USA	19
	Lincoln Park Zoo	USA	18
	Disney's Animal Kingdom	USA	17
	Yerkes Regional Primate Centre	USA	15
	London Zoo	UK	13
	Melbourne Zoo	Australia	12
	Bronx Zoo	USA	10
	Chester Zoo	UK	10

B)	Common name	Species name	Order	Class	Number of studies
	Chimpanzee	*Pan troglodytes*	Primates	Mammalia	82
	Western gorilla	*Gorilla gorilla*	Primates	Mammalia	58
	Rhesus macaque	*Macaca mulatta*	Primates	Mammalia	56
	Asian elephant	*Elephas maximus*	Proboscidea	Mammalia	25
	Common marmoset	*Callithrix jacchus*	Primates	Mammalia	22
	African savanna elephant	*Loxodonta africana*	Proboscidea	Mammalia	18
	Tiger	*Panthera tigris*	Carnivora	Mammalia	18
	Cheetah	*Acinonyx jubatus*	Carnivora	Mammalia	17
	Bornean orangutan	*Pongo pygmaeus*	Primates	Mammalia	15
	Black-capped capuchin	*Sapajus apella*	Primates	Mammalia	15

reptiles (n=120, 11.2%) are the next most studied groups, with all other taxa combined only constituting 12.1% of studies. The predominance of mammals in the systematic map is also reflected in Table 2b, which shows that all the top 10 species appearing as study subjects in our map are mammals (six of which are primates). Overall, there is a positive relationship between year and the number of studies produced (Pearson's correlation R=0.87) indicating that, overall, publication rates of studies testing interventions in captive settings are increasing (Figure 6a). This positive trend is also observed in all taxa except for invertebrate

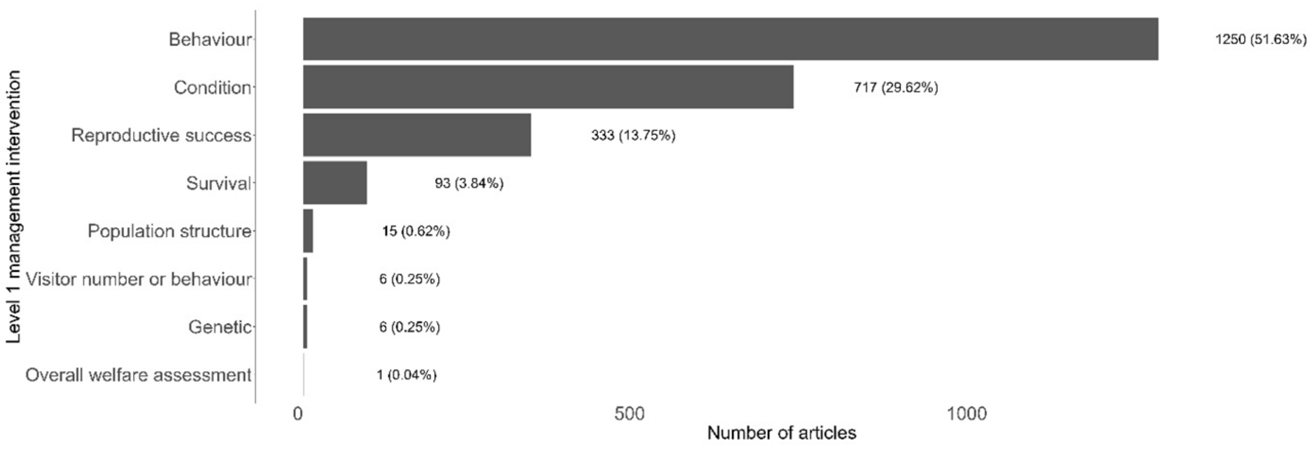

Figure 2. Number of studies identified by level 1 (broad category) outcome variables.

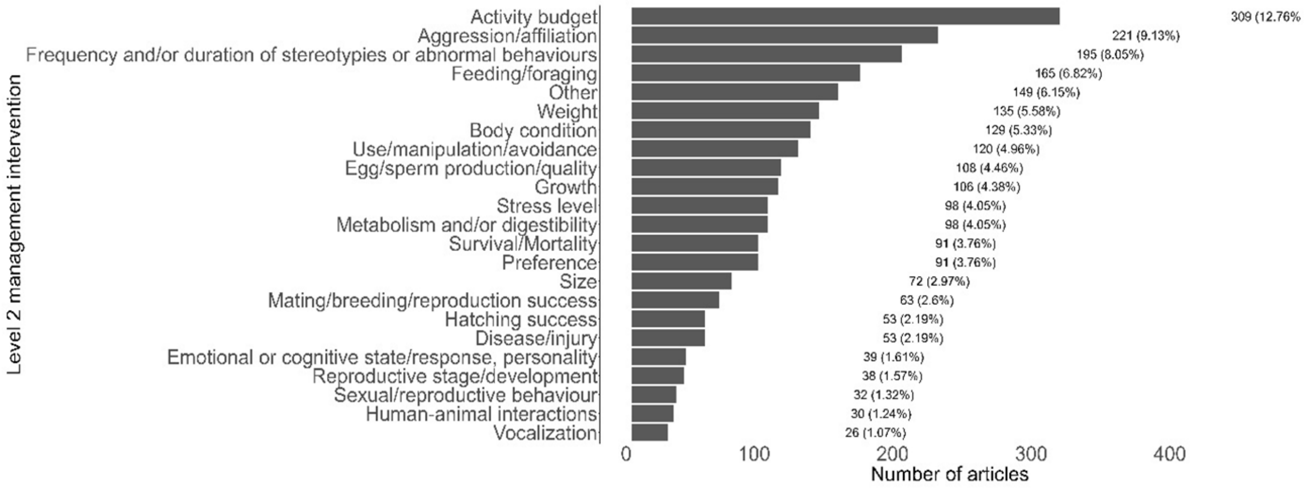

Figure 3. Number of studies identified by level 2 (subcategory) outcome variables.

a)

Intervention	Actinopterygii	Amphibia	Aves	Chondrichthyes	Invertebrate spp.	Mammalia	Reptilia
Animal-keeper interaction	4 (8.9 %)	2 (3.5 %)	8 (4.6 %)	1 (6.2 %)	5 (9.6 %)	20 (2.2 %)	4 (2.8 %)
Behaviour management	1 (2.2 %)	1 (1.8 %)	6 (3.4 %)	0 (0 %)	0 (0 %)	70 (7.8 %)	2 (1.4 %)
Diet or feeding modification	11 (24.4 %)	16 (28.1 %)	45 (25.9 %)	2 (12.5 %)	15 (28.8 %)	256 (28.6 %)	33 (22.8 %)
Enclosure or habitat modification or enrichment	16 (35.6 %)	22 (38.6 %)	39 (22.4 %)	6 (37.5 %)	21 (40.4 %)	189 (21.1 %)	47 (32.4 %)
General enrichment interventions	0 (0 %)	0 (0 %)	1 (0.6 %)	0 (0 %)	0 (0 %)	8 (0.9 %)	0 (0 %)
Object-related enrichment	1 (2.2 %)	1 (1.8 %)	11 (6.3 %)	0 (0 %)	1 (1.9 %)	82 (9.2 %)	9 (6.2 %)
Population management	4 (8.9 %)	12 (21.1 %)	42 (24.1 %)	3 (18.8 %)	6 (11.5 %)	138 (15.4 %)	44 (30.3 %)
Social composition or group modification	8 (17.8 %)	3 (5.3 %)	12 (6.9 %)	3 (18.8 %)	3 (5.8 %)	108 (12.1 %)	4 (2.8 %)
Transport and handling	0 (0 %)	0 (0 %)	5 (2.9 %)	0 (0 %)	1 (1.9 %)	10 (1.1 %)	1 (0.7 %)
Visitor management	0 (0 %)	0 (0 %)	5 (2.9 %)	1 (6.2 %)	0 (0 %)	14 (1.6 %)	1 (0.7 %)
Total	45	57	174	16	52	895	145

b)

Outcome	Actinopterygii	Amphibia	Aves	Chondrichthyes	Invertebrate spp.	Mammalia	Reptilia
Behaviour	21 (35 %)	6 (9 %)	73 (42 %)	7 (46.7 %)	13 (15.7 %)	486 (58.3 %)	49 (26.2 %)
Condition	23 (38.3 %)	25 (37.3 %)	48 (27.6 %)	3 (20 %)	30 (36.1 %)	215 (25.8 %)	71 (38 %)
Reproductive success	8 (13.3 %)	22 (32.8 %)	35 (20.1 %)	3 (20 %)	19 (22.9 %)	106 (12.7 %)	41 (21.9 %)
Survival	7 (11.7 %)	14 (20.9 %)	15 (8.6 %)	2 (13.3 %)	19 (22.9 %)	21 (2.5 %)	13 (7 %)
Population structure	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	2 (2.4 %)	0 (0 %)	13 (7 %)
Visitor number or behaviour	0 (0 %)	0 (0 %)	3 (1.7 %)	0 (0 %)	0 (0 %)	2 (0.2 %)	0 (0 %)
Genetic	1 (1.7 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	3 (0.4 %)	0 (0 %)
Overall welfare assessment	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (0.1 %)	0 (0 %)
Total	60	67	174	15	83	834	187

Figure 4. a) Summary table showing number of level 1 interventions per taxonomic class. Darker blue cells indicate most studies; while red cells indicate fewest studies. *Numbers exceed the total number of articles (N=1,070) in the map due to multiple interventions being reported within a single study. 4b) Summary table showing number of level 1 response variables per taxonomic class. Darker blue cells indicate most studies; while red cells indicate fewest studies. *Numbers exceed the total number of articles (N=1,070) in the map due to multiple outcomes being reported within a single study.

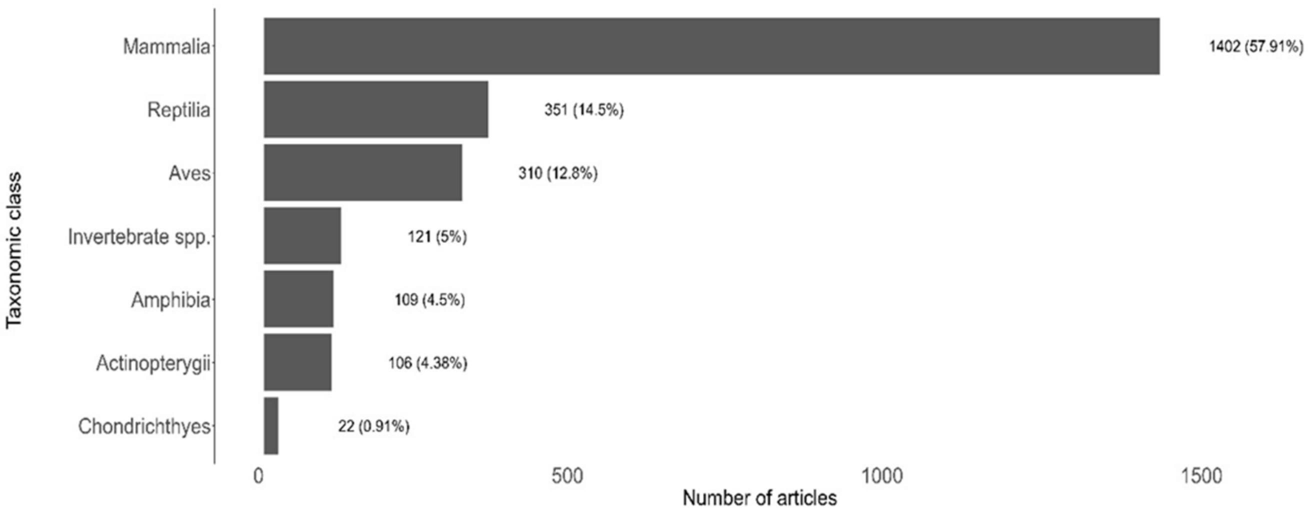

Figure 5. Number of studies identified in by taxonomic Class.

spp. (-0.06), although the strength of this trend varied between Class (Actinopterygii=0.17; Mammalia=0.78; Reptilia=0.74; Amphibia=0.43; Aves=0.71; Chondrichthyes=0.56). Interestingly, Figure 6b shows that, while mammals remain by far the most studied order overall, this dominance has weakened over time, with later years having a more even spread of taxonomic orders. Finally, we found an average publication lag of 3.6 ± 3.3 years (between when data for a study was collected and when the study was published).

Review findings

This systematic map identified 1,070 unique studies measuring the effects of management interventions on the conservation and welfare of captive animals in zoos. It also demonstrates that, perhaps contrary to expectations (e.g. Melfi 2009), there is at least some published evidence for the vast majority (90%) of our identified interventions known to be used in zoos. However, many of these studied interventions have very little evidence, with many interventions being based on a single study, have not been trialled equally between taxa (see also Melfi 2009) and there are clear thematic differences in both intervention type and outcomes measured. Overall, the map gives a clear overview not only of which intervention types have not been studied at all, but also which interventions have been relatively poorly studied. Thus, it highlights potentially important knowledge gaps to be addressed in the future. There are also, however, many interventions with substantial evidence in our map; 11 level 2 interventions have >50 studies, e.g. food enrichment and/or presentation (177 studies), enclosure space size, access, or complexity (149 studies) and artificial reproduction (102 studies). These would be appropriate targets for further evidence synthesis efforts to determine how effective such interventions are in ex-situ environments.

We also found very clear spatial patterns in the global distribution of evidence in our map, with institutions in two countries (the USA and the UK) producing over half of all evidence presented in the map. There may be several reasons for this, the first being that most zoos that are professional members of regional or global associations with a conservation and welfare remit are found in Europe and North America (Conde et al. 2011; Martin et al. 2014b; WAZA 2023), and these associations actively promote research and publication of findings related to their work. A relationship between institutions with greater funding resources (mostly located in the regions we identify) and research outputs has been previously identified (Loh et al. 2018). This dominance of English-speaking countries is also likely due to our excluding non-English sources from the map; an issue that often applies to syntheses of studies testing interventions (Christie et al. 2021b) (see limitations section below).

Regardless of the reason, this pattern may be a cause for concern. Zoos located outside these geographical evidence clusters (and especially those in the tropics) are likely to (and should) have an increasingly important role to play in future global conservation efforts (Martin et al. 2014b). Zoos in the global south keep species not found elsewhere, and these species are often threatened or likely to become threatened in future scenarios, given that tropical species are exposed to elevated extinction risk (Vamosi and Vamosi 2008). Numbers of such species may also increase if international wildlife export barriers intensify (Bowkett 2014; Biega et al. 2017), and tropical zoos are also often well-situated to take a leadership role in integrated ex-situ/in-situ conservation strategies (Conde et al. 2011). As such, encouraging the testing of interventions in institutions outside of the main clusters identified in our map, and seeking means to incorporate non-English sources into future versions of our database, are important recommendations for improving knowledge on management interventions specific to these areas, as well as the unique species they keep.

The finding that nearly half (44.5%) of studies in our map were completed in non-zoo institutions (most notably in universities and research centres) is notable and builds on previous research showing that 'non-traditional' institutions have an important role to play in supporting ex-situ conservation efforts (Biega et al. 2017). It also highlights the importance of fostering successful collaborations between zoos and research institutions (Schultz et al. 2022). It should be noted that there are likely to be taxonomic biases in the contributions made by non-zoo institutions. For example, many of the research efforts by non-zoo institutions took place at primate laboratories and thus, focused on examining primate husbandry interventions.

Conversely, the finding that standalone aquariums are apparently producing proportionally little research on the

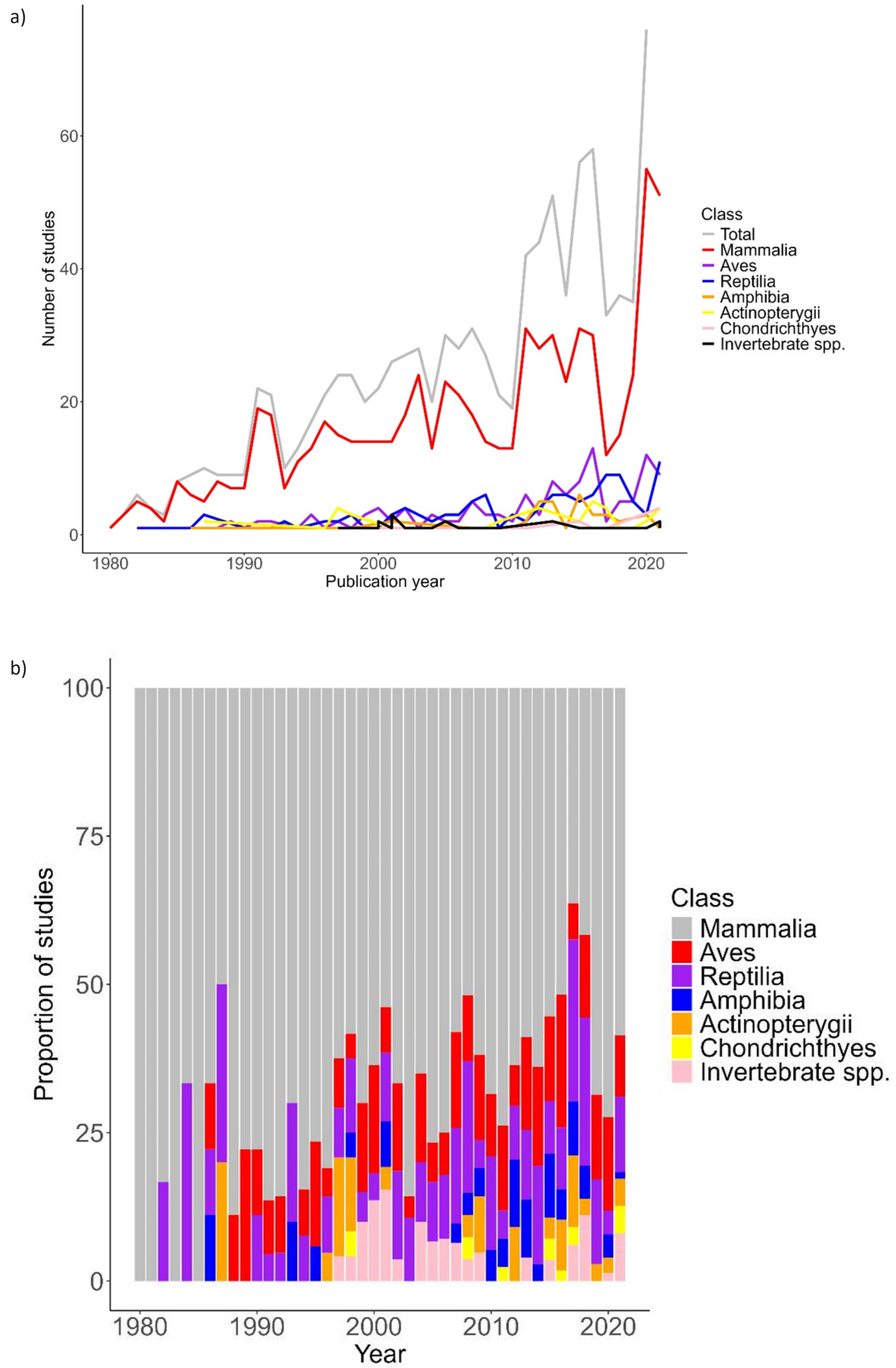

Figure 6. a) Line graph showing number of studies per year for each of our studied taxonomic groups (mammals, birds, reptiles, amphibians, ray-finned fish, cartilaginous fish, and invertebrates), as well as the number of studies published per year overall. b) Stacked bar graphs showing proportion of studies per year for each of our studied taxonomic groups (mammals, birds, reptiles, amphibians, ray-finned fish, cartilaginous fish, and invertebrates).

effectiveness of interventions (a result similar to Anzai et al. 2022) is also notable. Globally, aquariums support important numbers of threatened species, including numerous Critically Endangered and Extinct in the wild species (da Silva et al. 2019). However, our map does not include a strong evidence base to support management interventions in these institutions, despite the fact that we included relevant journals based on the advice of our expert advisory panel (which included two aquarium practitioners). This may be related to the acknowledged challenges of completing certain kinds of aquarium-based research, given the difficulties in observing intervention impacts on individuals in multi-species exhibits with large numbers of animals (Bishop et al. 2013).

Alternatively (or additionally), this finding could potentially be because studies testing interventions in aquariums are often published in the grey literature or in specialist journals from fields not identified at the protocol stage.

The dominance of mammals (and in particular primates and other large-bodied mammals) in our map is not unexpected – such patterns have long been noted in conservation research generally (e.g. Clark and May 2002) and in zoo management research specifically (Melfi 2009; Ward et al. 2018; Escribano et al. 2021). This is no doubt in part due to long-standing general research biases towards large-bodied, 'charismatic' mammalian species (Melfi 2009; Troudet et al. 2017). The fact that many mammalian species possess large body and brain sizes (e.g. Manger et al. 2013), and hence may require more complex management actions to successfully keep ex situ, could also be a driver for this bias. Disproportionate research into the welfare of large mammals in zoos may also relate to the fact that these species tend to attract the greatest attention from the public and media (along with associated pressures) (Binding et al. 2020). It could also be partially due to research into less-studied taxonomic groups being more likely to appear in grey literature or specialist journals which are harder to find – see limitations section below. Regardless, the comparatively small evidence base for non-mammalian taxa is concerning, given that most species held in zoos are not mammals (Conde et al. 2011; Rose et al. 2019; Brereton and Brereton 2020), and nor do mammals necessarily represent the most important conservation priorities. For example, amphibians are the most threatened taxonomic class globally (e.g., McCallum 2007) and an increasing number of amphibian species are now held in zoos (Dawson et al. 2015). However, without a strong foundation of evidence-based management actions, simply holding threatened amphibian species in zoos is not a guarantee of their effective conservation (Bowkett 2014).

Our results show an encouraging positive relationship between number of studies published and year (a similar finding to that of Binding et al. 2020), indicating that calls for more evidence-based zoo research (Melfi 2009) may be being heeded. Indeed, the increasing output of publications that meet the criteria for this study is also matched by a recent increase in outputs of zoo research generally (Rose et al. 2019; Welden et al. 2020; Escribano et al. 2021). While still by far the most frequently studied order, the dominance of mammal-focused studies also appears to be diminishing over time. However, increased publication rates were not observed in all taxa, notably invertebrates. Additionally, we also highlight that studies in our map also suffer from severe publication delays, the 3.6 year average delay between data collection and final publication identified here being considerably longer than the 2.6 year average for general conservation literature (Christie et al. 2021a). This is surprising given that captive settings offer substantially easier access to animals and opportunities to control study design compared to free-ranging wildlife populations. One reason might be the lack of time for staff responsible for publication of such results.

Limitations of the map

The principal limitations of the map relate to gaps in the literature searched. The protocol focused on sources that could be reliably accessed and systematically searched, and while this allowed for a robust, repeatable methodology, some evidence will have inevitably been missed. As mentioned above, the exclusion of non-English sources, while not an uncommon practice in evidence synthesis (Christie et al. 2021b), is likely to have led to valuable information related to species conservation being overlooked (Amano et al. 2021; Anzai et al. 2022). Similarly, the exclusion of grey literature (which is often hard to access and challenging to review systematically) is also likely to have led to some evidence being missed (see Downey et al. 2022), especially as Spooner et al. (2023) highlight that much zoo research is not published in peer-reviewed journals. Finally, exclusion of sources published prior to 1980, although done for rational reasons (see methods) may have also led to some, likely limited, evidence being missed.

Conclusions

We provide the first systematic map of evidence for the effectiveness of husbandry and management interventions for the conservation and welfare of captive animals in zoos, aquariums and other facilities. However, we also highlight specific interventions for which little evidence has been found, as well as notable geographical, thematic, and taxonomic differences within the map.

There are several important recommendations and next steps to the work presented. Firstly, we reiterate previous calls (Melfi 2009) for zoo practitioners and researchers to publish research testing the effectiveness of interventions whenever possible. In those cases where interventions are being studied or implemented but do not have an existing evidence base, we encourage researchers to share and publish results, but also urge caution to ensure study goals align with natural history and are hypothesis-driven. We emphasize that the publication of results demonstrating that specific management interventions are ineffective are of high importance. While such negative results are disproportionately under-represented in the academic literature (Fanelli 2011), they are vital to learn from and to avoid wasting resources on interventions that are known not to work (see Michaels et al. 2014). JZAR's "Evidenced-based practice" article category is a useful outlet for short studies evaluating the effectiveness of management interventions in zoos. We also echo the call of Christie et al. (2021a) for greater co-operation between practitioners, scientists, funders, and publishers to expedite the production of evidence as a matter of urgency.

Secondly, while the map we present represents the most extensive summary of tests of the effectiveness of interventions conducted in zoos to date, it can be expanded on and improved. It is our intention that our map represents a "living document" that can be updated on a regular basis. This would include the incorporation of new studies as they are published, perhaps using emerging semi-automated technologies to filter studies meeting our criteria (van Dijk et al. 2023), and also expanding the coverage of existing evidence not included in the protocol (such as that found in journals not searched in this study). This particularly applies to the inclusion of non-English sources. While including these sources was beyond the logistical capacity of this study, we acknowledge that there is a particularly well-developed zoo literature base from Europe, particularly in German and French, that would be beneficial to scan and integrate into the evidence map. There is substantial scope in the near future to scan and collate such literature using trained Artificial Intelligence model facilitation, which despite requiring some level of human validation, would greatly reduce the time and costs associated.

Thirdly, while this map provides a broad overview of the distribution and abundance of studies of interventions between outcomes, species, countries, and years, it does not examine the effectiveness of the management interventions. This is a critical next step, to be completed as part of a detailed synopsis of evidence of the effectiveness of interventions used in zoos or as part of narrower systematic review and meta-analytical approaches.

Finally, a perennial challenge involved with utilising the evidence presented in our map (and perhaps more pertinently any future synopsis) is to ensure that zoo management practitioners utilise the presented evidence-base. Science-based recommendations

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are only effective if they are actually implemented (Lees and Wilcken 2009); hence translating knowledge of 'what works' in zoo care and conservation from published articles into active management is of paramount importance. To this end, we envisage this map as a first step towards combining scientific evidence of effectiveness with experiential evidence of implementation to create evidence-based guidance. This would ensure formalising the systematic integration of evidence into new and existing tools, such as records systems and best practice guidelines.

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