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**Abstract:**

Animal welfare science is a young and thriving field. Over the last two decades, the output of scientific publications on welfare has increased by c. 10-15% annually (tripling as a proportion of all science papers logged by ISI's Web of Science), with just under half the c. 8500 total



being published in the last 4 years. These papers span an incredible 500+ journals, but around three quarters have been in 80 animal science, veterinary, ethology, conservation and specialized welfare publications, and nearly 25% are published in just two: *Animal Welfare* and *Applied Animal Behaviour Science*. Farmed animals – especially mammals – have attracted by far the most research. This broadly reflects the vastness of their populations and the degree of public concern they elicit; poultry, however, are under-studied, and farmed fish ever more so: fish have only recently attracted welfare research, and are by far the least studied of all agricultural species, perhaps because of ongoing doubts about their sentience. We predict this farm animal focus will continue in the future, but embracing more farmed fish, reptiles and invertebrates, and placing its findings within broader international contexts such as environmental and food security concerns. Laboratory animals have been consistently well studied, with a shift in recent years away from primates and towards rodents. Pets, the second largest animal sector after farmed animals, have in contrast been little studied considering their huge populations (cats being especially overlooked): we anticipate research on them increasing in the future. Captive wild animals, especially mammals, have attracted a consistent level of welfare research over the last two decades. Given the many thousands of diverse species kept by zoos, this must, and we predict will, increase. Future challenges and opportunities including refining the use of preference tests, stereotypic behaviour, corticosteroid outputs and putative indicators of positive affect, to enable more valid conclusions about welfare; investigating the evolution and functions of affective states; and last but not least, identifying which taxonomic groups and stages of development are actually sentient and so worthy of welfare concern.

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## **Animal Welfare Science: Recent Publication Trends and Future Research Priorities**

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Animal welfare science is a young and thriving field. Over the last two decades, the output of scientific publications on welfare has increased by c. 10-15% annually (tripling as a proportion of all science papers logged by ISI's Web of Science), with just under half the c. 8500 total being published in the last 4 years. These papers span an incredible 500+ journals, but around three quarters have been in 80 animal science, veterinary, ethology, conservation and specialized welfare publications, and nearly 25% are published in just two: *Animal Welfare* and *Applied Animal Behavior Science*. Farmed animals – especially mammals – have attracted by far the most research. This broadly reflects the vastness of their populations and the degree of public concern they elicit; poultry, however, are under-studied, and farmed fish ever more so: fish have only recently attracted welfare research, and are by far the least studied of all agricultural species, perhaps because of ongoing doubts about their sentience. We predict this farm animal focus will continue in the future, but embracing more farmed fish, reptiles and invertebrates, and placing its findings within broader international contexts such as environmental and food security concerns. Laboratory animals have been consistently well studied, with a shift in recent years away from primates and towards rodents. Pets, the second largest animal sector after farmed animals, have in contrast been little studied considering their huge populations (cats being especially overlooked): we anticipate research on them increasing in the future. Captive wild animals, especially mammals, have attracted a consistent level of welfare research over the last two decades. Given the many thousands of diverse species kept by zoos, this must, and we predict will, increase. Future challenges and opportunities including refining the use of preference tests, stereotypic behavior, corticosteroid outputs and putative indicators of positive affect, to enable more valid conclusions about well-being; investigating the evolution and functions of affective states; and last but not least, identifying which taxonomic groups and stages of development are actually sentient and so worthy of welfare concern.

At least in the developed world, concern about the welfare of animals kept by humans is widespread. At its heart are beliefs that animals have feelings that matter: beliefs that have recently spawned campaigns, guidelines and legislation. The European Union's Treaty of Lisbon, for example, decrees that: "...the Union and Member States shall, since animals are sentient beings, pay full regard to [their] welfare requirements..." (Council of the European Union, 2008); a National Academy of Sciences report argues that "*all vertebrates should be considered capable of feeling pain*", "*awareness [being] what distinguishes pain from nociception*" (National Research Council, 2009); and an impressive lobby is petitioning for a United Nations 'Universal Declaration on Animal Welfare' stating that animals are sentient and consequently that legislation should ensure their welfare (<http://www.wspa.ca/wspaswork/udaw/>, accessed Oct. 1<sup>st</sup> 2013). Such acknowledgments of sentience would seem a prerequisite for concern about animals' well-being (after all, organisms regarded as insentient, like plants, do not attract the same consideration), yet these explicit expressions of a philosophy around animal treatment lag behind decades of research, legislation and guidelines aimed at real-world, practical welfare improvements. Until the 1970s, the pressure for such legislation and guidelines typically came from journalists and campaigners. The discipline of animal welfare science – the field whose mandate is finding objective ways to improve the quality of life for animals in our care (Fraser, 2008) -- began following publication of the influential book *Animal Machines* (Harrison, 1964), the British government commissioning a group of scientists to determine animals' requirements in captivity (Brambell, 1965). Today, one aim of welfare science is to develop indicators of affective (emotional) states, often gleaned from studies of suffering humans, and validated for animals by subjecting them to situations known *a priori* to be aversive (e.g., Mason & Mendl, 1993; Walker, Duggan, Roulston, Van Slack, & Mason, 2012). Welfare scientists then use these to assess how animals feel about the different treatments that we expose them to. Validating some indicators for

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use in practical audits by farm inspectors is another important research area (e.g., Blokhuis, Miele, Veissier, & Jones, 2013). These research topics are thus the focus of our review. But first, what have they achieved to date?

One early example of legislation informed by welfare science was the Convention for the Protection of Animals kept for Farming Purposes, which outlined general principles for ensuring farm animal welfare (Council of Europe, 1976). Worldwide, many legislative and practical changes aimed at improving welfare have subsequently been made. In some, though not all, welfare science played a role. Battery cages for hens, for instance, have been banned in Europe (Council of the European Union, 1999), with California following suit (Government of California, 2008). The World Organization for Animal Health (OIE) has produced Codes on animal health and welfare aimed at promoting safe international trade between World Trade Organization members (OIE, 2013). Although not enforced, Member States are encouraged to adopt these standards so that welfare issues do not present international trade barriers (e.g., Kahn & Varas, 2013). In Canada, Codes of Practice provide industry-specific requirements and recommendations to promote better farm animal welfare; these are all informed by published welfare research (National Farm Animal Care Council, 2013). Similarly, in the United States the National Academies has commissioned working groups to review scientific literature on how to assess and alleviate laboratory animals' suffering, and care for them humanely (National Research Council, 2008, 2009, 2011). Furthermore, many commercial organizations now value animal welfare (e.g., Millman, Mench, & Malleau, 2010; Broom 2013). One fast food giant, for example, plans to phase out the use of gestation crates for sows in their supply chain (McDonald's, 2012). Certain grocers now offer products from "welfare friendly" systems, with some (e.g., Whole Foods Market, Inc., 2013) stocking nothing else. Charles River Laboratories, a billion-dollar biotechnology and research support corporation, has a Humane Care Initiative for establishing humane practices for laboratory animal care (Charles River, 2013). Finally, several zoos (e.g., Detroit Zoo, Brookfield and San Francisco) now hire specialized staff dedicated to welfare. Public pressure rather than scientific insights drove at least some of these decisions, but data from welfare science help ensure both that practices known or perceived to be poor are replaced by ones that are genuinely better for animals, and that welfare can be audited in ways that are valid as well as practicable.

Having provided context, here we review the state of animal welfare science, addressing questions provided by this special issue's editors (Miller & Hill, 2014). We mined the Web of Science database (<http://thomsonreuters.com/web-of-science/>) for relevant publications from the past 20 years, analyzed recent papers, books and presentations, and consulted with colleagues to answer the following. First we asked, which peer reviewed journals are publishing on the topic? How have publication rates changed over the last two decades? And what factors might underlie any emergent trends? Furthermore, which sub-topics have garnered the most interest from this academic community? Have these sub-topics changed over this 20-year time period, and what factors account for this? To end, we discuss welfare science's future research priorities.

## **Recent Research Patterns**

### **Key Journals, Publication Rates Over the Past 20 Years, and Potential Explanations For a Rising Research Output**

Using the search term "animal AND humane OR welfare OR well-being", we searched the online Thomson Reuters Web of Science<sup>SM</sup> "Science Citation Index expanded" database (search date: 5<sup>th</sup> Sept. 2013), restricting this search to the last 20 full years (1993-2012), and to original research articles and reviews written in English. To minimize false hits, the search was also restricted to the following Web of Science subject categories: agriculture, dairy and animal science; behavioral sciences; biodiversity conservation; fisheries; neurosciences; psychology - biological; veterinary sciences; and zoology. This yielded 8,462 papers spread over more than 500 journals. To identify and highlight the key journals, those with fewer than 20 relevant records (thus averaging under one animal welfare publication per year) were excluded. Table 1 shows the

remaining 81, ranked by relevant publication count, and with the Thomson Reuters 5-year impact factor for each also reported. Together these published 6,525 papers, thus 77% of the 20-year grand total.

As this table reveals, two journals, *Applied Animal Behavior Science* and *Animal Welfare*, dominate, together publishing 23% of all the papers found by our search (and 29% of the papers in Table 1). Perhaps this is not surprising: the former specializes in behavioral research on captive animals, much of which (36% of its 2,746 papers over the last 20 years) is fuelled by interests in animal well-being; the latter specializes in animal welfare research (99.5% of its 919 published papers were caught by our search terms); and neither restricts submissions by region or sector, allowing them to publish papers from all over the world on a variety of species and systems. In contrast, most of the other relevant journals are sector- (poultry, dairy, veterinary, laboratory, zoo, etc.) or region- (Canadian, British, Australian, etc.) specific, and thus much narrower in scope. Another finding of note is the marked lack of psychology journals publishing on animal welfare, suggesting that the fields of psychology and animal welfare have yet to significantly overlap. However papers on animal welfare are regularly being published in fundamental ethology journals (*Animal Behavior*, *Behavior Processes*), as well as in *Physiology & Behavior* and many animal science and veterinary publications, suggesting reasonable integration into and acceptance by these other disciplines.

To observe trends over time, all 8,462 relevant papers were broken down annually by year. Because journals have been proliferating and scientific output in general has increased, we also searched Web of Science for the total number of publications (again, articles and reviews in English only) for each of these years, so that we could express the annual number of welfare-related papers as a proportion of the total number of scientific publications logged by this database. As Figure 1a illustrates, the number of animal welfare related publications has increased by around 10-15% a year annually from 1993-2012, with just under half published in just the last four years (although even in recent years absolute numbers are relatively low; several hundred *p.a.*, in contrast to, say, the tens of thousands of neuroscience papers published annually) (Table 1). Furthermore, the proportion of animal welfare related publications relative to the total number of publications in all science disciplines has increased (see Figure 1b), more than tripling from 1993 to 2012. This rise is remarkable, and likely reflects both growing societal concerns for the humane treatment of animals, and an increase in the scientific respectability of animal welfare research, including recognition of the interesting fundamental questions it raises (an issue we return to in our 'Future Priorities' section). Together, these factors have inspired a growing number of researchers and graduate students to study animal welfare issues, and helped ensure a growing availability of funding. To highlight just some of the recent financial support for animal welfare research, at least in Europe: in 2005 the UK's Biotechnology and Biological Sciences Research Council committed £8M over five years to this field (BBSRC, 2013); the UK's National Centre for the Replacement, Refinement, and Reduction of Animals in Research has awarded over £35M in funding since its inception in 2004, much to laboratory animal welfare research (NC3Rs, 2013); and lastly, the European Commission awards c.14€M annually to animal welfare research (European Commission, 2012).

### **Publication Sub-Topics Over the Past 20 Years: Which Animal Sectors, Potential Welfare Problems, and Animal Welfare Indicators Have Featured Most Heavily, and Why?**

**Animal sectors.** We used two main approaches for identifying animal sectors that have attracted welfare research. One was to identify journals from Table 1 that are clearly sector-specific (e.g., *Journal of Dairy Science*; *Aquaculture*; *Lab Animals*) and sum by sector the welfare papers that they have published (Table 2). Our second main approach was to focus solely on *Animal Behavior Science* and *Animal Welfare*, because relevant publications were so disproportionately represented by these journals, extracting the titles of all the papers they published on animal welfare in two five-year periods (1993-1997 and 2008-2012, i.e., 10 years encompassing the beginning and end of the two decades of interest). From these, we used VocabGrabber™ ([www.visualthesaurus.com/vocabgrabber](http://www.visualthesaurus.com/vocabgrabber)) to count repeated terms (Table 3). All common

Table 1  
*Counts of animal welfare related publications per journal over the past 20 years*

Journal Title	Count	5-Year Impact Factor
Applied Animal Behaviour Science	997	2.06
Animal Welfare	914	1.68
Poultry Science	228	2.07
Livestock Science	222	1.49
Journal of Animal Science	189	2.64
Journal of Dairy Science	162	3.01
Laboratory Animals	152	1.52
Animal	127	1.76
British Poultry Science	125	1.37
Physiology Behavior	125	3.34
Aquaculture	105	2.62
Veterinary Record	105	1.64
Italian Journal Of Animal Science	103	0.38
Revue Scientifique et Technique Office International Des Epizooties	103	1.13
Worlds Poultry Science Journal	100	1.68
Zoo Biology	94	1.11
Acta Agriculturae Scandinavica Section A Animal Science	92	0.56
Anthrozoos	84	1.42
Preventive Veterinary Medicine	82	2.57
Journal of Applied Animal Welfare Science	78	1.1
Journal of Veterinary Medical Education	77	0.56
Journal of The American Association For Laboratory Animal Science	74	1.2
Veterinary Journal	71	2.66
Journal of The American Veterinary Medical Association	70	1.95
Animal Science	68	0.95
Small Ruminant Research	68	1.55
Journal of Veterinary Behavior Clinical Applications And Research	65	1.58
In Practice	61	0.32
Acta Veterinaria Scandinavica	59	1.53
Animal Behaviour	59	3.41
ILAR Journal	58	2.26
Society Animals	58	0.78
New Zealand Veterinary Journal	53	1.35
Australian Veterinary Journal	52	1.06
Lab Animal	52	0.5
Equine Veterinary Journal	51	2.19
Cattle Practice	50	0.19
Journal of Applied Poultry Research	48	1.38
Veterinary Parasitology	45	2.61
Pain	42	6.13
Behavioural Processes	40	1.63

Journal Title	Count	5-Year Impact Factor
Table 1 (continued)		
Journal Title	Count	5-Year Impact Factor
Canadian Journal of Animal Science	39	0.96
Asian Australasian Journal of Animal Sciences	38	0.65
Epilepsy Behavior	38	2.11
Research in Veterinary Science	38	1.72
American Journal of Primatology	37	2.42
Canadian Veterinary Journal Revue Veterinaire Canadienne	37	1.09
Psychoneuroendocrinology	37	5.93
Theriogenology	36	2.52
Psychiatry and Clinical Neurosciences	35	2.15
Appetite	32	3.24
Brain Injury	32	2.06
Tropical Animal Health and Production	31	1.16
Wildlife Society Bulletin	30	1.95
Irish Veterinary Journal	29	0.3
Journal of Developmental and Behavioral Pediatrics	29	2.58
Veterinary Research Communications	29	0.99
Animal Science Journal	28	0.95
Animal Reproduction Science	27	1.94
Aquaculture Research	27	1.45
Conservation Biology	27	5.46
Reproduction in Domestic Animals	27	1.82
Sleep	27	6.18
Acta Veterinaria Brno	26	0.56
Journal of Fish Biology	26	1.84
Annals of Animal Science	24	0.32
Archiv für Geflügelkunde	24	0.42
Journal of Animal and Veterinary Advances	24	0.36
Scandinavian Journal of Laboratory Animal Science	24	0.45
Wildlife Research	24	1.51
Annals of the New York Academy of Sciences	23	3.52
Archiv für Tierzucht Archives of Animal Breeding	23	0.49
Behavioural Brain Research	23	3.67
Comparative Medicine	23	1.34
Veterinary Microbiology	22	3.25
Neuropsychological Rehabilitation	21	2.16
American Journal of Veterinary Research	20	1.61
Aquacultural Engineering	20	1.67
Biological Conservation	20	4.24
Fish Physiology and Biochemistry	20	1.78
Veterinary Clinics of North America Food Animal Practice	20	2.04

*Note.* Entries are ranked by number of counts. Journals with fewer than 20 publications (i.e., less than one per year on average) are not included. (Counts for journals that changed name in the course of the past 20 years are merged).

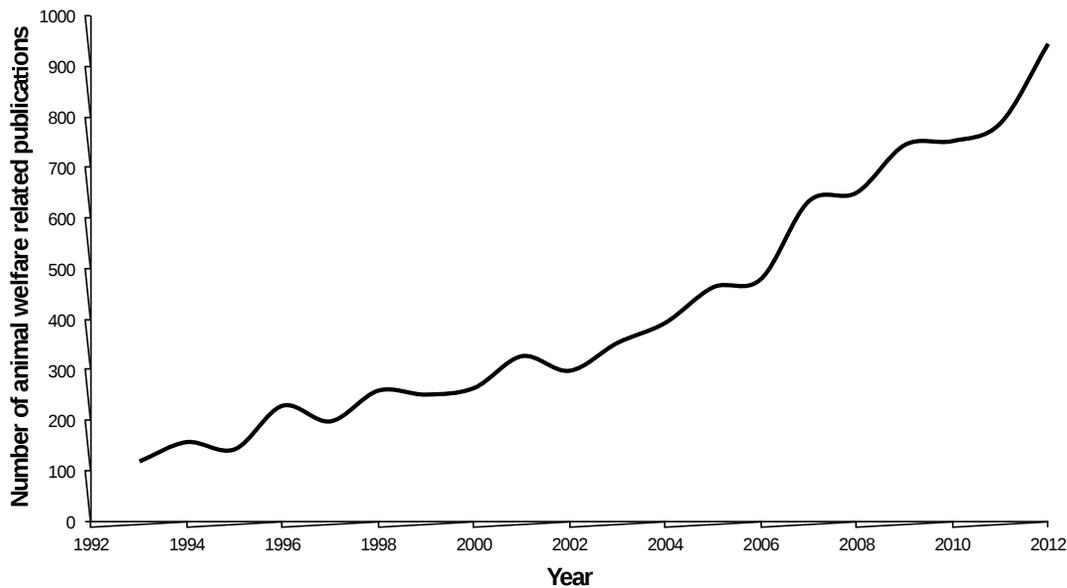


Figure 1a. The absolute number of animal welfare papers published each year. The number of publications from 2010-2012 ( $n = 2,483$ ) comprises approximately one third of the total number of publications over the past 20 years.

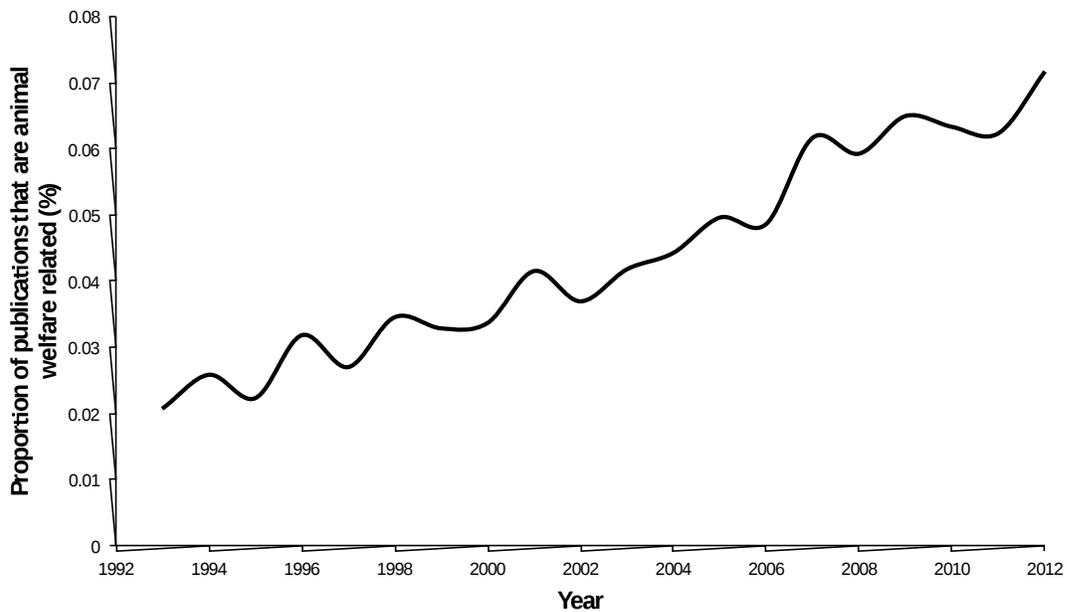


Figure 1b. The proportion of animal welfare related publications each year relative to the total number of publications in all disciplines.

English words were first removed (e.g., the, an, as); the terms ‘animal’ and ‘welfare’ were omitted because all analyses were about subcategories of animal welfare; different versions of the same word (e.g., derivatives) were automatically combined (e.g., stereotypy, stereotypies, stereotypic), and similar terms and synonyms were also combined into larger topics (see Table 3 for a list of different terms that were each combined into

one representative word), although systems were kept separate from animals (e.g., ‘dairy’ and ‘beef’ were kept separate from ‘cows’). For clarity, the resultant table and figure (Figure 2) only include the top 85 terms from both searches. In order to compare the relative research effort on each of these topics in the two periods, 1993-1997 and 2008-2012, we then regressed counts against each other (Figure 2). From this, we could identify topics that became more prevalent (i.e., lying markedly above the regression line), topics that remained essentially stable (i.e., lying close to the regression line), and topics that became less prevalent (i.e., lying markedly below the regression line).

Supplementing these analyses of research effort, we also conducted two additional searches to assess research impact (as assessed traditionally via impact on other academics; obviously in this field impact could also be assessed via changes effected in the treatment of animals). We looked to see which of the 8,462 papers found in our Web of Science search for 1993-2012 have been most highly cited since publication, focusing on the twenty that have been cited 150 times or more. We also searched for coverage of animal welfare issues in the leading multi-disciplinary journals *Science* and *Nature*, a search that revealed just seven original research papers but 36 opinion pieces and news items. For reasons of space we do not present these results as tables of data; instead we just report the most relevant findings at appropriate points in the text.

Table 2  
*The publication effort attracted by different sectors of managed vertebrates*

Species/sector group <i>Sub-group</i>	Count of animal welfare papers in sector- or system-specific journals <sup>a</sup>	Count of relevant species names in animal welfare papers published in AW <sup>b</sup> & AABS <sup>c</sup>	Total
Farmed mammals & birds	1863	526	2389
<i>Poultry</i>	501	79	580
<i>Cattle, Small ruminants</i>	280	229	509
Fish	198	31	229
Laboratory rodents, primates* & lagomorphs	401.5	111.5	513
Wild animals*	213.5	156.5	370
Companion animals	135	92	227
<i>Horses</i>	51	37	88

<sup>a</sup> All relevant papers 1993-2012 (from Table 1)

<sup>b</sup> All welfare papers in AW (*Animal Welfare*) 1993-1997 and 2008-2012

<sup>c</sup> All welfare papers in AABS (*Applied Animal Behavior Science*) 1993-1997 and 2008-2012

Note. \* Primate papers span wild and laboratory categories, and so their counts were split evenly between these.

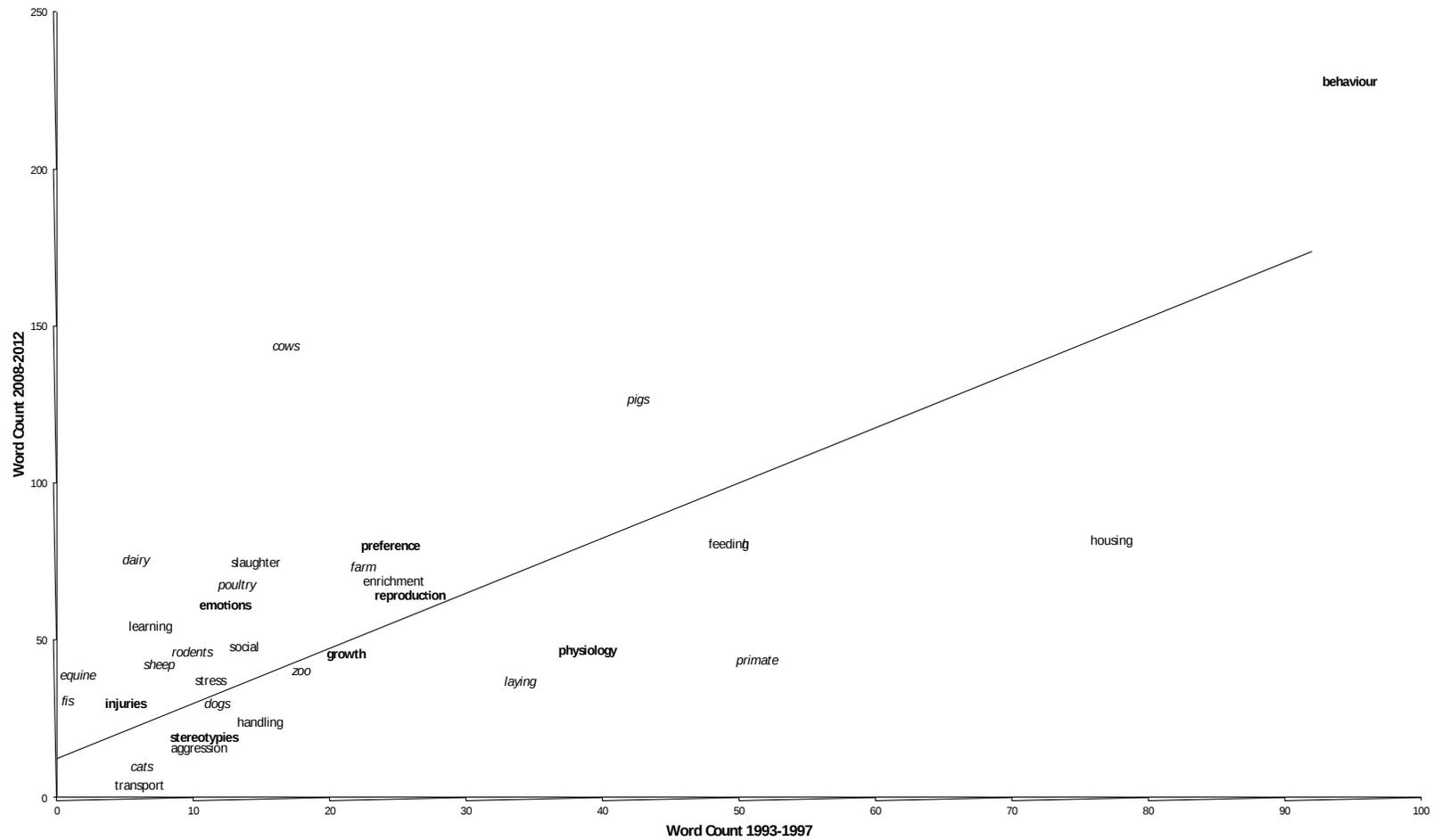


Figure 2. Counts of each word/topic appearing in *Applied Animal Behavior Science* and *Animal Welfare* article titles from 1993-1997 regressed against counts of the same word/topic in those journals from 2008-2012. Values above the line represent topics that have increased in relative frequency, while topics below the line have decreased in relative frequency. Labels highlight some topics that have changed in research effort most noticeably, as well as a few topics whose frequency has remained stable over the past 20 years. Italicized terms are species and sectors/systems; terms in bold broadly represent techniques or indicators used in welfare assessment; while terms in plain text encompass treatments and aspects of husbandry under investigation.

Table 3

*Counts of words in the journals Animal Welfare and Applied Animal Behavior Science relating to animal welfare.* Italicized terms are species and sectors/systems; terms in bold broadly represent techniques or indicators used in welfare assessment; while terms in plain text encompass treatments and aspects of husbandry under investigation.

Word	Count	Combined terms (if any), excluding derivatives that were also counted <sup>a</sup>
<b>behavior</b>	320	
<i>pigs</i>	168	gilt, pork, sow, piglet, boar
<i>cows</i>	159	calf, bovine, cattle, bull, veal, steer, heifer
housing	157	cage, enclosuer, pen, stall, shelter, kennel, crate
feeding	128	food, forage, foraging, diet, nutrition, meal
<i>preference</i>	101	motivation, rewarding, avoidance, aversion, demand, approach, choice
<b>primate</b>	93	ape, gorilla, chimpansee, orangutan, bonobo, monkey, macaque, mangabey, marmoset, rhesus, tamarin, baboon, capuchin, lemur
<b>farm</b>	91	agriculture
enrichment	89	furnished, toys, platform, ball, complexity
<i>reproduction</i>	87	pregnant, prenatal, parturition, gestation, lactation, nursing, suckling, maternal, breeding, farrowing, calving
slaughter	87	abattoir, stunning, killing, shooting, cull
<i>physiology</i>	81	neurobiological, neuroendocrine, neurophysiology, immune, plasma, pharmacological, leukocyte, haematological, hormones, cortisol, lymphocyte, heart, eosinophil, biochemical, prolactin, thyroxine, endocrine, adrenal, adrenocortical
<b>dairy</b>	80	milk
<b>poultry</b>	79	fowl, turkey, quail, chicken, chick, hen, leghorn, duck
<i>emotion</i>	73	affect, empathy, needs, pleasure
<b>laying</b>	69	
<i>growth</i>	65	fattening, weight, development
<b>zoo</b>	60	wolf, wombat, zebra, seal, dolphin, rhinoceros, lion, koala, kangaroo, leopard, capybara, elephant, cheetah, bear, peccary, badger, wallaby, wapiti, impala, whale, giraffe
social	59	
learning	58	conditioning, reinforcement, training, operant, cognition, habituation, instrumental, cognitive
weaning	53	
<b>rodent</b>	52	rat, mouse, vole, hamster, mole, gerbil
<b>sheep</b>	52	ewe, lamb
captive	47	
<i>stress</i>	45	
<i>production</i>	44	performance
<b>dog</b>	40	puppy, greyhound, canine, bulldog
<b>fur</b>	39	fox, mink, vixen, marten
<b>equine</b>	37	horse, pony, mare, mule, donkey, foal
<b>laboratory</b>	35	
handling	34	restraint, tether, holding
<b>fish</b>	31	catfish, fishery, cod, cichlid, goldfish, trout, salmon, aquaculture

Table 3 (continued)

Word	Count	Combined terms (if any), excluding derivatives that were also counted <sup>a</sup>
<i>injuries</i>	31	lesion, harm, bruising, wound
space	29	density
<i>aggression</i>	27	
<b>broiler</b>	27	
<i>stereotypies</i>	26	pacing, self-directed, regurgitation
flooring	25	slat, mat
substrate	25	straw, peat, bedding, soil
<i>biting</i>	23	
<b>birds</b>	22	parrot, ostrich, finch, pigeon, starling, penguin, owl, seabird, gull, goldfinch, partridge
environment	22	
gas	22	dioxide, monoxide, argon, nitrogen
ethics	21	
nest	21	
<i>fear</i>	20	
<i>pain</i>	20	nociception
activity	19	
management	19	
<b>goats</b>	18	kid
lying	18	rest
rearing	18	
genetics	16	
<b>cat</b>	15	
<b>wildlife</b>	15	
<b>beef</b>	14	
<b>rabbit</b>	13	
castration	12	
control	12	
economics	12	
<i>health</i>	12	
<i>lameness</i>	12	
locomotion	12	movement, running
<i>play</i>	12	
transport	12	
deer	11	stag
<i>pecking</i>	11	
<i>coping</i>	10	
<i>temperament</i>	10	personality
<i>survival</i>	10	
<b>conservation</b>	8	reintroduction
<i>pathology</i>	8	disease, morbidity

Table 3 (continued)

Word	Count	Combined Terms (if any), excluding derivatives that were also counted <sup>a</sup>
Anaesthesia	7	
<b>crustacean</b>	7	decapod, crab, lobster
surgery	7	
<i>vocalization</i>	7	bark
<b>bats</b>	6	
humane	6	
temperature	6	
hunger	5	
confinement	4	
docking	4	
<b>reptile</b>	4	lizard, skink, python
<b>hedgehog</b>	3	
deprivation	2	

<sup>a</sup> (e.g., “behavior” for “behaviour”; “stereotypic” for “stereotypies” etc.)

In the last 20 years, agricultural homeotherms have clearly dominated the welfare literature, as shown by counts in Table 3 (note the prominence of ‘pigs’ and ‘cows’). Farm animal papers were also often amongst the most highly cited welfare papers, and generated two of the seven welfare papers published by *Nature* and *Science* (Dawkins et al., 2004, Keeling et al., 2004). This intense research effort and high degree of impact is unsurprising given that it was intensive agricultural practices that triggered the first welfare research, and that the populations of these animals are vast: in 2011, the Food and Agriculture Organization of the United Nations estimated that there were approximately 960 million pigs, 1.4 billion cattle, and 22 billion poultry worldwide (FAO, 2013). One thing that stands out however, is an incongruity between the population sizes of different farm animal groups and the amount of research they attract. Even though there are over 20 times more poultry on the planet than pigs (and even though poultry encompass more than one species), welfare research on them is outweighed by research on pig welfare. They also attract only a little more welfare research than cows, sheep and goats (see Table 2); while in our two focal journals, as Table 3 reveals, cattle are substantially better represented than poultry, a discrepancy that has become particularly marked in more recent years (see Figure 2). This relative paucity of work on poultry has previously been commented on by experts in this field (Millman et al., 2010). On a more optimistic note, however, the enormous global importance of poultry to humans has meant that some poultry welfare research is academically impactful: of the two farm animal welfare research papers accepted by *Nature* and *Science* in the last 20 years, both were on poultry. As for what is driving the recent explosion in research on cows, especially dairy animals, possibilities include that welfare issues in dairy cattle been only recently been acknowledged (unlike pigs and poultry, which have attracted public disquiet for decades), and that the dairy industry is particularly supportive of welfare research.

The lack of work on heterotherms is even more discordant: fish and other animals farmed in aquaculture systems are produced on such an huge scale that they are measured in terms of millions of tonnes rather than numbers of individuals (e.g., FAO, 2012), and yet they attract around 10% of the research effort devoted to farmed mammals and birds (see Table 3). However, fish are now attracting some welfare research, whereas 20 years ago they were not even considered (see Figure 2). The European Food Safety Authority (EFSA, 2009) thus recently published the views that “*the concept of welfare is the same for all the animals, i.e., mammals, birds and fish*” and “*there is some evidence for the neural components of sentience in some species of fish,*” while also mourning the lack of more concrete information or rigorous protocols for assessing fish well-being. Perhaps because good studies are still rare, our set of 20 animal welfare studies in the last two

decades that had been cited 150+ times included four fish welfare papers (more than on any other single group). As aquaculture becomes an ever-larger industry, and as we learn more about the sentience of “cold-blooded” species, this research interest will surely continue to increase, a topic we revisit in ‘Future Priorities’.

Laboratory animals are the second most well-studied group (see Table 2). It is conservatively estimated that 127 million animals (mostly rodents) were used in scientific research worldwide in 2005 (Knight, 2008), and so this level of research focus may seem fitting. Figure 2 also shows that work on rodents has slightly increased with time. This contrasts with a decline in those on primate welfare, which could reflect the phasing out of primates in biomedical research and a shift to rodent models (e.g., National Institute of Health, 2013): a pattern that now needs confirming with a detailed search of specialized laboratory animal journals. Finally, our searches in *Nature* and *Science* further showed that in the last 20 years, the welfare and protection of animals used in research and education received considerable coverage here in terms of letters and news pieces: of 36 such items on welfare issues, 25 were on laboratory animals. This suggests that laboratory animal welfare issues are close to the hearts of research biologists, although sadly these content of these commentaries reveal that such topics often elicit more fear and suspicion than support.

In terms of population sizes, pets greatly outnumber animals used as research subjects. It has been estimated that there are 500 million dogs on the planet, for example (Coren, 2012), and furthermore, that cats outnumber dogs 3:1 (Bradshaw, 2013). Pets are also the second largest category of animals in Europe after farm animals, with around 120 million dogs and cats and possibly 35 million birds (European Commission, 2012). Despite this, as yet they have attracted relatively little welfare research (see Table 2). While research on dogs has remained stable, cat research, disturbingly, seems to have gone down over the same period: issues we return to in ‘Future Priorities’ below.

Wild animals, in practice largely zoo mammals, perhaps seem over-studied for their small captive population sizes: it was estimated that in 2011 there were only 7 million individuals in zoos worldwide (Frynta, Šimková, Lišková, & Landová, 2013). Despite this, these wild animals seem better-studied than pets (see Table 3); they attracted two of the seven welfare research papers to make it into *Nature* and *Science* (Clubb & Mason, 2003; Clubb, Rowcliffe, Lee, Mar, Moss, & Mason, 2008); and their involvement in welfare research seems to have stayed stable over time (see Figure 2). However, wild animals are by far the most speciose sector managed by humans, and so, given the vast number and diversity of taxa kept in zoos (perhaps as many as 10,000 species [Mason, 2010]); certainly nearly 4,000 even excluding fish [Conde et al., 2011]), it could be argued that actually, far *more* research than this is needed, a topic we revisit in ‘Future Priorities’. Furthermore, at least in our two focal journals, studies of wild mammals seem to dominate to the exclusion of other wild taxa (see e.g., the ‘zoo’, ‘birds’, ‘primates’ and ‘reptiles’ lines of Table 3). The possibility of such a bias needs to be checked with a more detailed search of specialist journals (especially *Zoo Biology*), but if confirmed, it should surely be corrected in the future.

**Husbandry issues and welfare indicators.** Our labeling of husbandry issues under investigation, and indicators used to assess them (see Table 3 & Figure 2), is inevitably rather approximate, since we are inferring this usage from the presence of words in titles. With that note of caution, however, some “broad brushstroke” patterns are evident. Feeding and housing are the most prominent welfare issues under investigation (though less so in more recent years). This likely relates primarily to agricultural animals, as feeding and housing have historically been welfare issues central to the economic success of animal production. Studies addressing transport seem to have decreased in frequency, again perhaps because there is now less need for more data on their welfare consequences (see e.g., Schwartzkopf-Genswein, Faucitano, Dadgar, Shand, Gonzalez, & Crowe, 2012 on transportation). The research effort devoted to environmental enrichment and learning appears to have increased, in contrast. This likely reflects the fact that these are now known to be effective strategies for improving captive animals’ welfare (e.g., Baumans & Van Loo, 2013; Chua, Coenen, van Delen, & Weary, 2002; Pomerantz & Terkel, 2009). Environmental enrichment, for example, has become mainstream in labs

(Hutchinson, Avery, & Vandewoude, 2005) and zoos (Hoy, Murray, & Tribe, 2010), and is now even extending to agricultural animals (e.g., mink: Buob, Meagher, Dawson, Palme, Haley, & Mason, 2013; Hansen, Malmkvist, Palme, & Damgaard, 2007). Research on the welfare implications of killing methods has also increased, perhaps reflecting an increased recognition of the importance of suffering associated with slaughter initiated by Temple Grandin and others (e.g., Grandin, 2012).

The term ‘behavior’ was the most common word in article titles, and this has only increased in recent years (Figure 2). To be more specific, mentions of some form of preference have increased over time (see Table 3 for the words covered by the term ‘preference’), suggesting that measuring animals’ choices, and their motivations to approach or avoid particular treatments, has become an increasingly popular approach. Stereotypies are another key behavioral indicator, whose use seems to have been relatively stable over the past 20 years. Other indicators used by welfare researchers have somewhat changed in use over the past 20 years. The use of physiological indicators in general has declined, suggesting a general acceptance that behavior alone can assess welfare, and perhaps concerns with the validity of some traditional physiological indicators (see below). There has also been a notable increase in assessments of animal emotions (see Figure 2), a topic that may have been regarded as unscientific or frivolous in earlier years but which is now attracting superb scholarship (e.g., Harding et al., 2004; Mendl et al., 2009; Paul et al., 2005).

### **Future Priorities for Animal Welfare Research**

In order to identify future priorities, we took a number of approaches. We looked at the top 25 downloads for 2013 from all the veterinary and animal science journals produced by Elsevier (the publisher of *Applied Animal Behavior Science*), to find out which welfare-relevant papers have been read often in the last year (see <http://csemails.elsevier.com/201309/top25/VeterinaryAnimalScience.htm> and Table 4). We looked at recent conferences, where researchers may present ideas that are not yet published, reading all the abstracts for two – the 2013 UFAW meeting in Barcelona and 2013 International Ethological Conference in Newcastle – and those for the plenaries at 2013’s International Society for Applied Ethology (ISAE) meeting; we also looked at topics selected for special focus at the forthcoming 2014 ISAE meeting. We read the relevant chapters of several recent welfare books (Fraser, 2008; three in the new Springer-Verlag animal well-being series; and Appleby et al.’s “*Animal Welfare*” [2011]). We also googled the phrase “future of animal welfare research”. Finally, we sought feedback from Guelph’s Animal Behavior and Welfare Group (<http://www.uoguelph.ca/abw/>): the largest welfare program in Canada and one of the largest in the world. The four themes we identified are discussed below.

### **Farm Animal Welfare Research**

Thanks to research and public pressure, “*much has changed about farm animal welfare since the publication of ‘Animal Machines’ ... pigs, veal calves, geese, broiler chickens and other food animals are, at least some parts of the world, treated very differently from how they were in 1964*” (Dawkins 2013, p. 1). Farm animals will, however, continue to dominate as the subjects of welfare research. One reason for this is that some of their welfare problems have not yet been resolved, even for animals in the most well-studied sectors in Europe and North America. How to avoid de-beaking hens without them harming each other via feather-pecking, eliminate needs to castrate piglets, reduce health problems like lameness (still common in broilers and dairy cattle) and kill farmed fish humanely, are just a few of the problems that remain outstanding (European Commission, 2012). A second reason is that numerically, farm animals will continue to represent by far the vastest animal populations kept by humans. For example, between 2000 and 2050, global farmed cattle, goat and sheep populations are projected to rise from 3.2 billion to 5.3 billion (Rosengrant et al., 2009 as cited by Thornton, 2010), with pig (e.g., Lay & Marchant-Forde, 2009), poultry and fish populations on the rise too (e.g., Cluff & Jones, 2013): increases driven by the ever-growing human population (set to reach c. 9 billion by 2050: FAO Experts Forum, 2009; Thornton, 2010), along with increasing demands for animal

protein in the developing world and countries with newly-burgeoning economies (e.g., China, India) (Lay & Marchant-Forde, 2009, Thornton, 2010, Cluff & Jones, 2013). The third reason is that in parallel, and as we reviewed in our introduction, an increasing number of countries are instigating animal welfare regulations and guidelines; some guidelines (e.g., those from the OiE) also specifically aim to harmonize practices and standards globally. This in turn is likely to increase the number of countries in which animal welfare research is conducted, because local data are often more relevant, and also received more openly, than are findings from other regions.

Table 4  
*Rankings and descriptive data for the welfare-related papers found in Elsevier's "Most popular articles in 2013 in Veterinary/Animal Science - Top 25 list"*

Ranking	Title of Article	Author(s)	Year of Publication
1	Sources of Stress in Captivity	Morgan & Tromberg	2006
2	How Does the Zoo Environment Affect the Behavior of Captive Primates?	Hosey	2006
3	Animal-Visitor Interactions in the Modern Zoo: Conflicts and Interventions	Fernandez et al.	2006
4	Why and How Should We Use Environmental Enrichment to Tackle Stereotypic Behaviour?	Mason et al.	2006
5	Breed Differences in Canine Aggression	Duffy et al.	2008
7	Sensory Stimulation as Environmental Enrichment for Captive Animals: A Review	Wells	2009
8	Genetically Modified Farm Animals and Fish in Agriculture: A Review	Forabosco et al.	2013
9	The Potential of the Human-Animal Relationship as Environmental Enrichment for the Welfare of Zoo-Housed Animals	Claxton	2011
15	Inherited Defects in Pedigree Dogs. Part 1: Disorders Related to Breed Standards	Asher et al.	2009
17	Fear Responses to Noises in Domestic Dogs: Prevalence, Risk Factors and Co-occurrence with other Fear Related Behaviour	Blackwell et al.	2013
18	A Review of Environmental Enrichment for Kennelled Dogs, <i>Canis familiaris</i>	Wells	2004

The farm animal welfare research of the future will not, however, just be “more of the same”: it will change in its nature too. The growing internationalism will drive one type of change: welfare studies will be needed on agricultural breeds and even species that to date have been overlooked (e.g., Lenhart, 2011, Nielsen & Zhao, 2012). More diverse species will also be studied as concerns for animal sentience (an issue returned to below) embrace a broader range of taxonomic groups, such as the many species of fish, reptile and invertebrate farmed on enormous scales in Asia (FAO, 2012; reviewed by Mason, Burn, Dallaire, Kroshko, Kinkaid & Jeschke, 2013). A third way in which farm animal welfare research will change is via an increasing focus on auditing schemes for inspectors, and also on automated techniques, for use in the on-farm welfare assessments needed by commercial assurance schemes and legislators. Developing methods that are practical yet also valid is an ongoing research challenge (e.g., Blokhuis, Miele, Veissier & Jones, 2013; Lay & Marchant-Forde, 2009), while at the same time, “*new technology is providing opportunities for monitoring the health and well-being of farm animals that could improve their welfare in an unprecedented way*” (Dawkins, 2012a, in a call for contributions on this topic to a special edition of the journal *Animals*). Finally, the farm animal welfare research of the future will have to explicitly integrate its findings with those relevant to other pressing societal and environmental issues, such as biodiversity, global warming, land use and food security (e.g., Broom, Galindo, & Murgueitio, 2013; Dawkins, 2012b; FAWC, 2009; Garnett et al., 2013; Thornton, 2010).

## Research to Assess and Improve the Welfare of Wild and Pet Animals

A variety of evidence suggests that increasing research effort will be devoted to the welfare of pets and wild animals in the future. These topics attracted the greatest number of downloads from Elsevier in 2013: of the 12 top-downloaded Elsevier-published papers that discussed animal welfare, all except one focused on zoo animals or dogs (see Table 4). Focusing on pets first, concern over cat and dog welfare was expressed in a recent report on the state of animal welfare in the European Union (European Commission, 2012), which noted the lack of Europe-wide consistent protection for them. Issues for dogs here and elsewhere in the developed world include welfare problems arising from inbreeding, inherited disease and the selection for extreme morphologies; poor or negligent management and care of breeding dogs; and inadequacies in the way they are bought and sold (Bateson, 2010). Issues for dogs in the developing world include disease and starvation in feral animals, and the methods used to kill them (OiE, 2009). Issues for cats have attracted far less attention, which is of great concern in itself; and the same is true for other pets (e.g., pet birds, rodents and rabbits).

2012-2013 saw the publication of four books on the management, behavior and welfare of zoo animals (Hosey, Melfi & Pankhurst, 2013; Kleiman, Thompson & Baer, 2012; Maple & Perdue, 2013; Rees, 2013): an extraordinary achievement that predicts a dynamic future for zoo animal welfare research. As already mentioned, the huge number of species held in zoos represents one of the greatest challenges for this sector: currently, there are simply not enough researchers to investigate and come up with evidence-based recommendations for the husbandry of each (even for controversial species such as cetaceans, which have attracted lots of public attention but still negligible welfare research). Consequently, a lack of basic knowledge about zoo animals was highlighted as the core problem by a recent working group: *“The EU directive on zoos ... contains some animal welfare elements but no detailed requirements. Many Member States seem not to make much effort to provide guidance to operators. In addition, official inspectors often have little experience and training on the specific needs of wild animals in captivity. Usually, zoo personnel do not seem to have a sound knowledge of keeping such animals. The absence of EU research in defining the particular animal welfare needs of wild animals in captivity has also been pointed out as problematic”* (European Commission, 2012, p. 19). It should be emphasized, however, that the diversity of species held in zoos also represents an incredible research opportunity, since understanding why some species thrive in captivity while others struggle there has the potential to reveal some fundamental principles about animal welfare: principles that could not easily be investigated in other ways (e.g., whether captive birds need to fly, or intelligent animals need learning opportunities, in order to have good welfare) (Mason, 2010, Mason Burn, Dallaire, Kroshko, Kinkaid & Jeschke, 2013). Investigating zoo animal welfare is thus an exciting as well as much-needed avenue for future research. Future studies of wild animals’ welfare will not be restricted to captivity, however: a growing “Compassionate Conservation” movement is likely identifying, studying and attempting to alleviate the many diverse welfare problems that humans cause to free-living wild animals (see e.g., <http://www.compassionateconservation.org/>; also Fraser & McRae, 2011; Harrop, 2011; Mathews, 2010).

## Improving the Validity of Animal Welfare Indicators

Several recent texts express dissatisfaction with the tools routinely used in current animal welfare research. Corticosteroids, for example, are commonly used as stress indicators, and yet the metabolic functions of these hormones mean that they increase in a variety of non-harmful scenarios, such as being active, for example engaged in play or sexual behavior (e.g., Fraser, 2008). Fraser (2008) astutely sums up the central problem thus:

We cannot [always] assume that different levels of activation of the stress response systems have any bearing on animal welfare.... if want to treat activation of the stress response systems as a welfare indicator, we need to be clear on how we believe it signals some difference in basic health and functioning, in affective states, or in the animals’ ability to live in the manner to which it is adapted.

Without such links, we cannot assume that changes in the activation of these systems are related to animal welfare. (p. 284)

For chronic husbandry issues like housing, Rushen, Passillé, Keyserlingk, & Weary (2008) even argue that these steroids mean so little as to have limited practical value in welfare assessment. The use of preference testing also needs refining to yield more valid information about welfare (Fraser, 2008; Fraser, & Nicol, 2011; Mason & Burn, 2011). Current problems with preference data include that animals' short-term preferences may be at odds with what is best for their long-term welfare (e.g., Fraser & Nicol, 2011); and that the very exposure to enrichments of interest during testing may, through experience, elevate motivations for those resources, making these approaches unreliable for answering research questions about inherent behavioral needs (Mason & Burn, 2011). For both these welfare indicators, our judgment is that there is a real future need here, not for more empirical research but for more scholarship and careful, logical thinking about how best to use endocrine changes and preference data more validly.

Links between stereotypic behavior and welfare also need to be better clarified (e.g., Fraser, 2008; Olsson, Wuerbel, & Mench 2011). That stereotypic behaviors indicate welfare-poor environments is a good, well-validated rule of thumb (Mason, 2006; Mason & Latham, 2004; Olsson, Wuerbel, & Mench 2011). However, at the individual level, interpreting the relative welfare of stereotypic versus non-stereotypic animals within these types of welfare-poor environment is more problematic (Mason & Latham, 2004). Non-stereotypic individuals may be too physically-incapacitated, depressed or scared to perform these behaviors; or they may be too cognitively normal, lacking the intense perseverative tendencies known to be a predisposing factor (e.g., Campbell, Dallaire, & Mason, 2013; Jones, Mason, & Pillay, 2011; Mason, 2006). Furthermore, non-stereotypic individuals may even lose out on some potential benefits of performing these behaviors (e.g., coping effects); and/or be more vulnerable to harm, if these activities involve abnormal interactions between conspecifics (e.g., feather-pecking) (Fraser, 2008; Mason, 2006; Meagher & Mason 2012; Olsson, Wuerbel, & Mench 2011). Our judgment here is that only empirical studies can resolve these problems. We particularly see two needs for future research. One is to investigate what non-stereotypers do in poor environments, and what this reveals about their welfare. The other is to investigate why stereotypic behavior becomes more resistant to enrichment with age. Does stereotypic behavior become a welfare-neutral 'habit' (Fraser, 2008)? Or more worryingly, does it instead become associated with forms of anhedonia that render enrichments less effective at improving welfare (Tilly, Dallaire, & Mason, 2010)?

A final type of indicator that needs more research, and will surely attract it in the future, relates to positive welfare. A growing desire to assess animal pleasure and contentment in objective, well-validated ways was strongly in evidence in, for example, two symposia at the 2013 International Ethological Symposium: one organized by Alan McElliott and Elodie Briefer on the measurement of positive emotions, and one organized by Patrick Bateson on play. One possible candidate could include cognitive or judgment bias: an innovative method of assessing how animals respond to ambiguous stimuli that is sensitive to positive as well as negative affective states (Mendl, Burman, Parker, & Paul, 2009; Paul, Harding, & Mendl, 2005).

### **Understanding Animals' Mental Experiences**

The final growing area anticipated by many (e.g., Keeling, Rushen, & Duncan, 2011; Lay & Marchant-Ford, 2009; Millman, Mench, & Malleau, 2010) is work on the mental experiences of animals and how they relate to welfare. Anyone studying animal welfare soon hits some very tough questions. For example, what does it mean for an animal to have a 'life worth living' (FAWC, 2009; Yeates, 2011): a life without negative experiences (if that is even possible), or one in which positive experiences outweigh negative ones? If the latter, how to weigh up these two types of experience? And is the term 'suffering' useful? Does it add any meaning, beyond identifying a negative affective state? If yes, can we operationalize it for use in welfare research (e.g., Weary in press)? The publications highlighted here are the type of novel, careful,

thought-provoking analysis we expect to see more of in the future, perhaps involving a greater degree of collaboration with professional philosophers. Other fascinating research questions now being asked about affective states are evolutionary in nature: what are the ultimate functions of emotions and moods (e.g., Keeling, Rushen, & Duncan, 2011)? For example, the 2013 International Ethological Conference featured an excellent symposium on “The Co-Evolution of Behavior and Emotional States”, organized by Tim Fawcett, Andy Higginson and Pete Trimmer, in which mathematical models based on state-dependent decision-making and signal detection theory were amongst the tools being used to try and tackle this issue.

But perhaps the trickiest question of all is, who has affective states anyway? Does it make sense to talk about the wellbeing of maggots, bacteria or geraniums? Can a blastocyst suffer, or have a life worth living? Or do these organisms instead have ‘life without experiences’ (cf. Yeates et al., 2011)? We opened this paper with some firm statements on animal sentience from legal and campaigning bodies, that typically are applied to all vertebrates plus *Octopus*. Anyone reading these might thus assume that conscious awareness had already been conclusively demonstrated for all vertebrates, and for some invertebrates as well. Indeed an international group of neuroscientists recently signed a Cambridge Declaration on Consciousness, arguing “*the weight of evidence indicates that humans are not unique in possessing the neurological substrates that generate consciousness. Non-human animals, including all mammals and birds, and many other creatures, including octopuses, also possess these neurological substrates*” (Low, 2012, p. 2). The truth is, however, that we are still a long way from identifying conclusive behavioral or neurological markers of sentience: it is not clear what these are in humans, let alone what they look like in species very different from ourselves (e.g., Dawkins, 2012b, Rose et al., 2012). As a consequence, several reports that urge that vertebrates, including fish, should be treated as if they are sentient are simultaneously careful to acknowledge that this case rest on some untested assumptions (EFSA, 2009, National Research Council, 2009). Likewise, experimental studies presenting new data consistent with conscious affective states, such as recent work on bees and crustacea, are careful to acknowledge that their findings represent necessary but far from sufficient evidence for definitive conclusions about sentience (Bateson et al., 2011, Magee & Elwood, 2013). We therefore agree with Millman et al. (2010) and others, that there is a pressing need for factual information about sentience. However, we are heartened by the current level of academic interest in this issue (it was, for instance, the focus of another excellent 2013 International Ethological Conference symposium, one organized by Robert Hubrecht). We hope that the next decade will see real progress in identifying sentient states, and thence revealing the stages of development and taxonomic groups that either do, or do not, have states of wellbeing that we should strive to protect.

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