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A bibliometric analysis of past and emergent trends in animal welfare science

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Abstract

A bibliometric analysis was undertaken to chart the development of animal welfare (AW) science as a whole, and of the individuals, organisations and countries that have had most academic impact to date. Publication data were collected from the Web of Science for the year range 1968–2017 and by-hand pre-processing of the data was undertaken to identify reviews and original research articles on AW. VOSviewer was used to create bibliometric networks. There has been a 13.3% annual growth in AW publications in the last 50 years with Animal Welfare *and* Applied Animal Behaviour Science *the most frequent publishers of AW publications. Farm animals continue to dominate the subject of AW research and comparison of network visualisations for five key species suggested possible gaps in the research, such as relatively little emphasis on emotion research for some farm animals and little research on inherited disorders in dogs. However, keyword analysis indicated a recent broadening of AW findings to include other international contexts, such as conservation and sustainability. Highly cited review articles were grouped into five clusters with affective state (ie emotions, moods) and fish welfare the most recent topics. Almost all core authors of original research articles study farm animals, though in the last ten years other topics, such as consumer attitudes and wildlife, have emerged as highly cited areas of original research articles. Network analysis of organisations revealed the University of Bristol, UK as the main publisher of original research articles. Citation analysis indicated that many low-cited articles were originating from Germany and were published in German journals, suggesting that many worthwhile results and opinions on AW may be being missed by other researchers due to a language barrier. Several limitations of bibliometric analysis to generate an overview of AW science were identified, including the challenge of how to search and extract all the relevant publications in this discipline. In conclusion, animal welfare science is still in an exponential phase of growth which will bring opportunities, such as for the publication of new journals, but also challenges. The insights generated by this study suggest bibliometric analysis to be a useful addition to other approaches investigating the trends and concepts of animal welfare.*

Keywords: *animal welfare, animal well-being, bibliometrics, citation analysis, publications, scientometrics*

Introduction

There is a desire within many scientific fields to obtain an overview of the literature but, for diffuse subject areas such as animal welfare science where content is widely scattered, traditional review articles can present only part of an overall picture, and bibliometric analysis can be a useful complement (Ellegaard & Wallin 2015). Additionally, areas of research activity within disciplines can change with time and can vary between different geographical areas or where there are different social, political or economic drivers. This is particularly true for animal welfare science which is influenced by people's views about, simply stated, what constitutes a good life for animals. Fraser (2008) suggests that people's views can be roughly grouped into three main areas of concern: for the basic health and functioning of animals; for their mental state; and for their ability to live a natural life. Perspectives on animal welfare around the world also vary (Caporale *et al* 2005; Masiga & Munyua 2005; Rahman *et al* 2005), perhaps reflecting regional variations in people's views. Although there have been attempts to reach a consensus on the scientific concept of animal welfare (eg Broom 1991; Fraser *et al* 1997), the above variation in views about animal welfare is at least partly responsible for fuelling considerable discussion on the research direction of the field of animal welfare science (Mason & Mendl 1993; Barnard & Hurst 1996; Fraser *et al* 1997). More recently, Mellor (2016) proposed that our understanding of animal welfare, and its definition, will change over time as ideas evolve so that current definitions and concepts will need to be revised or replaced.

The fluid concept of animal welfare and its propensity to be influenced by people's views raises the intriguing question of

how research into animal welfare has changed over time, and the possible reasons for any past and emergent trends. Animal welfare science is a young field that has grown considerably at a rate proportionally greater than many other scientific disciplines (Borsi & Schubert 2011; Walker *et al* 2014). Given the social, geographical and temporal influences on animal welfare science, it is valuable to identify past and emergent trends in research activity and to use these to assist in identifying future directions and challenges.

Bibliometrics is a rapidly expanding branch of science which aims to analyse and represent, amongst other things, quantitative aspects of published scientific outputs in order to reveal how disciplines are conceptually and socially structured (de Bellis 2009). Bibliometrics can therefore assist in evaluating the contributions of individual scientists, groups, countries or journals to the advancement of knowledge. Rodriguez-Ledesma *et al* (2015) used bibliometrics to chart the emergence of different themes within the Science Citation Index subject heading of Agriculture, Dairy and Animal Science. Within this one subject heading, animal welfare emerged as a major theme, starting with an early emphasis on nutrition and developing as a strong (though relatively isolated) theme within this subject heading, and more recently encompassing studies of stress, aggression and environmental enrichment. However, papers on animal welfare appear under many other Science Citation Index subject headings. Indeed, at least ten papers on the topic of animal welfare have appeared under nearly 100 different headings, most commonly 'Veterinary Science' but also under diverse headings such as 'Philosophy', 'International Relations' and 'Neuroscience'.

The aim of our study was to bring this diverse literature together and present a bibliometric analysis of the field of animal welfare science as a whole. We present metrics that chart the development of the field, and of the individuals, organisations and countries that have had most impact to date, as well as an analysis of emerging trends. To identify possibly divergent trends in opinions and views, and in data-driven research, we have separately analysed review and original research articles. Citation analysis was used to examine trends over time in numbers of publications, and to explore interactions between different groups of researchers and subfields. Content analysis based upon keywords was used to examine changing trends in the field and to identify emerging areas of scientific interest. Citation network analysis was used to reveal areas of inter-dependence and cross-reference or high linkage to key theoretical or empirical texts, shown by highly connected nodes. Additionally, the identification of poorly connected nodes and trends in low-cited articles can generate hypotheses about barriers to exchange of ideas and information. Such barriers may be language-based, geographical or arise from an inward focus on small or specialist areas of animal welfare. The use of bibliometrics to highlight areas that are well or poorly connected may also be of interest to policy-makers intent on improving the overall quality of animal welfare science. Our approach complements other histories (Albright 1998; Broom 2011, 2014), general reviews (eg Broom 1991; Fraser *et al* 1997; Dawkins 2006; Veissier & Miele 2014; Hemsworth *et al* 2015) and related commentaries supported by metrics and surveys (eg Borsi & Schubert 2011; de Azevedo *et al* 2007; Lawrence 2008; Goulart *et al* 2009; Walker *et al* 2014; Rodriguez-Ledesma *et al* 2015; Kirchner *et al* 2017) about the development and underpinning concepts of animal welfare science.

Materials and methods

Selection of search terms for generating datasets

Publication data were collected from the Web of Science, core collection-science citation index expanded (SCI-EXPANDED). All languages and all document types were selected. Year range was from 1968–2017; there were few publications on animal welfare before this date, or indeed in the early 1970s, so 1968 was chosen as it was just a few years after the publication of Ruth Harrison's book, *Animal Machines* (Harrison 1964) and the Brambell Report (1965) which followed in response. The Brambell Report set out the original Five Freedoms of movement for intensively kept livestock and is often credited as the beginning of animal welfare science (eg Albright 1998).

Initial search of the topic (using the TS field tag, which searches for topic terms within the title, abstract, keywords and Keywords Plus®) using terms 'animal welfare', 'animal well-being' or 'animal wellbeing' found 10,349 publications. Examination of a sample of 100 randomly selected publications from this list indicated that all were related to animal welfare, but raised concern that this search may have excluded too many relevant publications. A broader search, using terms 'welfare OR wellbeing OR well-being' combined with 'animals OR animal' yielded 15,614 publications. Examination of a sample of 100 randomly selected publications from this latter search result indicated that 96% of publications were related to animal welfare. The remaining 4% of articles were on human health/welfare, but mentioned animals (such as animal trials in human medicine).

Of concern was the possibility that authors may refer to species names and not include the terms 'animal' or 'animals'. To investigate this possibility, we used 'pigs' as a trial subject term. There were 3,000 publications on 'pig or pigs or piglet or *Sus scrofa*' and 'welfare' (and variations). However, there were an additional 754 publications on animal welfare (and variations) that included the terms 'pig' (and variations) but not the terms 'animal' or 'animals'. A random sample of 100 of these publications from both these search results indicated that the majority of publications were indeed on 'pig welfare'. This suggested that perhaps as much as 25% of articles on the welfare of farm animals do not include the terms 'animal' or 'animals'. The use of Latin terms did not appear to be particularly important: only six articles out of 3,000 (0.2%) included *Sus scrofa* but not pig (or pigs or piglet). Two of these articles were animal welfare reviews and the other four were not on animal welfare. It was therefore decided to include species names for some key farm, laboratory and companion animals but not Latin terms in future searches.

After this initial exploration, the most effective search strategy was one that combined the terms 'welfare' (and variations), 'cattle', 'pig', 'chicken', 'duck', 'fish', 'fur', 'horse', 'rabbit', 'dog', 'cat', 'sheep', 'rat' and 'mouse' (and variations which included plurals). This list was taken from the *Welfare of various animals* section of Broom and Fraser (2015) with the addition of 'rats' and 'mice'. Therefore, the final search terms were: TS = ('animal welfare' OR 'animal wellbeing' OR 'animal well-being') OR TS = ('welfare' OR 'wellbeing' OR 'well-being') AND TS = ('cattle' OR 'cow' OR 'calves' OR 'pig' OR 'piglet' OR 'chicken' OR 'chick' OR 'hen' OR 'duck' OR 'fish' OR 'fur production' OR 'horse' OR 'rabbit' OR 'dog' OR 'cat' OR 'sheep' OR 'goat' OR 'mice' OR 'mouse' OR 'rat'), enacted on 10/4/2018. Our reason for including 'animal welfare' (and variations) in the search term was to extract publications that the authors have self-identified as relevant to animal welfare. Hereafter, outputs generated using this search terms are referred to as AW publications.

Three different types of analysis were conducted using different subsets of the original AW publication database. These were: (i) a brief historical overview of basic metric data from 1968 to 2017; (ii) a broad analysis of citations and keywords from 1988 to 2017; and (iii) an in-depth bibliometric analyses of (separately) review, original research and low-cited articles using datasets that had been subjected to a detailed visual search by both authors to remove or re-categorise papers that had been misclassified by automated search strategies.

Analysis of publication metrics was undertaken using the WoS analysis tool (Clarivate Analytics, Philadelphia, USA) and more detailed bibliometric analysis undertaken using VOSviewer (van Eck & Waltman 2009, 2014). VOSviewer generates distance-based visualisations of bibliometric networks. In the visualisations provided by VOSviewer, the size of the nodes or colour in density overlays represents the frequency of the item (eg the number of citations, documents or occurences of a term). The distance between two nodes or items in the visualisations indicates the relatedness of the nodes, so that closely related nodes are positioned close together, and weakly related nodes are located far away from each other (van Eck *et al* 2010). In some of the visualisations, closely related nodes are grouped into clusters (indicated by different colours) which help in providing an 'overview' picture of the structure of the network. VOSviewer assigns nodes to clusters based on a modified modularity based clustering technique (Waltman *et al* 2010; Waltman & van Eck 2013). It is common with bibliometric analysis to examine different thresholds before choosing thresholds that provide meaningful visualisations. Since we were interested in the key influences on animal welfare science, some of which may have been individual items, it was necessary to select thresholds that balanced the needs to provide overview visualisations of the large networks as well as identifying influential items. To achieve this, we generally adjusted thresholds in order to create visualisations that included between 30 and 100 of the most common items. For larger networks, we accepted VOSviewer's default option to only show the items with the top 60% relevance scores. Relevance scores are a numerical value indicating how often an item occurs with a limited number of other items (high score), or whether it occurs with other items in a random pattern (van Eck & Waltman 2014). In addition, some minor cleaning of visualisations of keywords was undertaken to remove 'welfare' and 'well-being' terms, since these were in the searches and terms meaningless in the context of identifying key topics (eg significant effect, year, decrease, fact).

Brief historical overview of AW publication metrics (initial dataset = 19,498 articles)

The number of publications, number of citations, H index and mean number of citations per publications of AW publications was obtained using the WoS analysis tool. The above indices were presented for ten five-year periods, spanning 1968–2017 inclusive to reveal changes in time.

Broad analysis of citations and keywords from the period 1988–2017 (dataset 1[a] = 15,068 articles)

Full citation records began to appear in the 1980s, permitting more complete analysis of AW publications for the last 30 years (1988–2017). Citable items only were selected from this period, as is common practice in bibliometric analysis, by selecting items categorised as 'article' or 'review' by WoS (dataset 1; n = 17,284). This selection resulted in the removal of non-citable items such as editorial letters, corrections and book reviews. We also excluded 2,216 articles from dataset 1 which were not on animal welfare (see explanation in following section), and from the remaining dataset 1[a] (n = 15,068), we identified the countries and source titles that have been most represented in the literature to date. A co-occurrence network of the most common keywords (author keywords and KeyWord Plus®) of dataset 1(a) was created using VOSviewer. On a broad scale, species names were common keywords, potentially masking finer within-species co-occurrence networks. Therefore, we additionally created separate datasets for five common species by filtering based on whether the species name appeared in the abstract to create the following datasets: cattle (or cow), dataset 1(b) (n = 2,093); pig, dataset 1(c) (n = 2,071); laying hens (filter used was 'lay AND hen'), dataset 1(d) (n = 1,275); dog, dataset 1(e) (n = 868); fish, dataset 1(f) (n = 1,193). VOSviewer visualisations of the most common keywords in each of these datasets were created.

Bibliometric analysis of review, original research and low-cited articles

The titles and abstracts of all items within dataset 1 were examined by hand by the two authors to confirm that each article was classified correctly and to exclude articles not on animal welfare. The above filtering by hand resulted in 2,216 articles being excluded and placed in dataset 2. Common reasons for excluding articles were that they were on the environment, human community well-being, on animals but

dealt with human health and well-being or that they were completely unrelated (eg using acronym of COW for a study on human health). We next removed items with three or fewer citations, and placed these within dataset 3 (n = 6,291). This was because we were interested in significant trends in animal welfare, and because bibliometric analysis depends upon a certain amount of data to be statistically reliable. We then excluded very recent publications from dataset 3 that might receive few citations purely because of recency, so that the new subset (dataset 3[a]; n = 3,656) contained publications from the 1988–2015 period only which we used for further analysis of low-cited articles. We categorised the remaining 8,777 items as review articles (dataset 4; n = 1,759) which provided a review, synthesis or opinion on an animal welfare topic, and included papers discussing ethical issues, and as original research articles (dataset 5; n = 7,018) which had to contain new data (experimental, observational, quantitative opinion) on an animal welfare topic. Additional subsets of the last ten years (2008–2017) of review articles (dataset 4[a]; n = 915) and original research articles (dataset 5[a]; n = 4,184) was used to further analyse recent influences on animal welfare science. Our classification of reviews and original research articles differed substantially from that generated automatically by the Science Citation Index. Tab-delimited text files of the above datasets are available from the author.

Several networks were constructed in VOSviewer and visualisations are presented in *Results*. Citation networks were created to show highly cited review (150 or more citations) and original research articles (100 times or more citations). In order to investigate the impact of core authors in animal welfare, citation analysis was again used to create a network of the authors of review articles (threshold six articles and 300 citations for dataset 4, or 3 articles and 120 citations for dataset 4[a]) and original research articles (threshold 20 articles and 500 citations for dataset 5 and ten articles and 300 citations for dataset 5[a]). The full counting method in VOSviewer was used which gives each author of a document equal weight in the visualisations, irrespective of how many authors there or their position in the author list. As mentioned earlier, these thresholds were selected to provide visualisations which balance the needs to generate an overview of the large networks as well as to identify influential items. Trials indicated that slight changes to thresholds mentioned above, for example ± 2 articles and ± 100 citations, produced almost identical visualisations.

Additionally, a network of organisations that have published at least 50 original research articles was generated. A co-occurrence network of all keywords (author keywords and KeyWord Plus®), and the countries and journals that have published the most low-cited articles was generated using VOSviewer.

Results

Brief historical overview of AW publication metrics in the last 50 years (initial dataset)

Ninety-two percent of the original 19,498 items obtained by our search were in English and 5.2% in German. The number of AW publications has increased substantially from 15 in the period 1968–1972 to 7,573 in the period 2013–2017; an annual growth of 13.3% (Figure 1[a]). Figure 1(a) suggests significant growth in the last 30 years, and the number of publications in the period 1988–1993 (406) to 2013–2017 (7,573) has increased at a rate of 15.8% annually. Another measure of the activity of the research field, citations, also indicates a rapid rise since the 1980s, though the drop in citations for the period 2013–2017 is likely to be a result of the recency of these publications (Figure 1[a]).

The impact of AW publications similarly increased in the 1980s (Figure 1[b]). The H index — the number of papers in our sample that have at least the same number of citations — has levelled off at around 80 publications since 1998, though the recent drop in H-index is likely to be related to these articles being published recently. The average number of citations per article follows a similar trend, levelling off at around 20 since the late 1980s, though, again, is lower in recent years (Figure 1[b]).

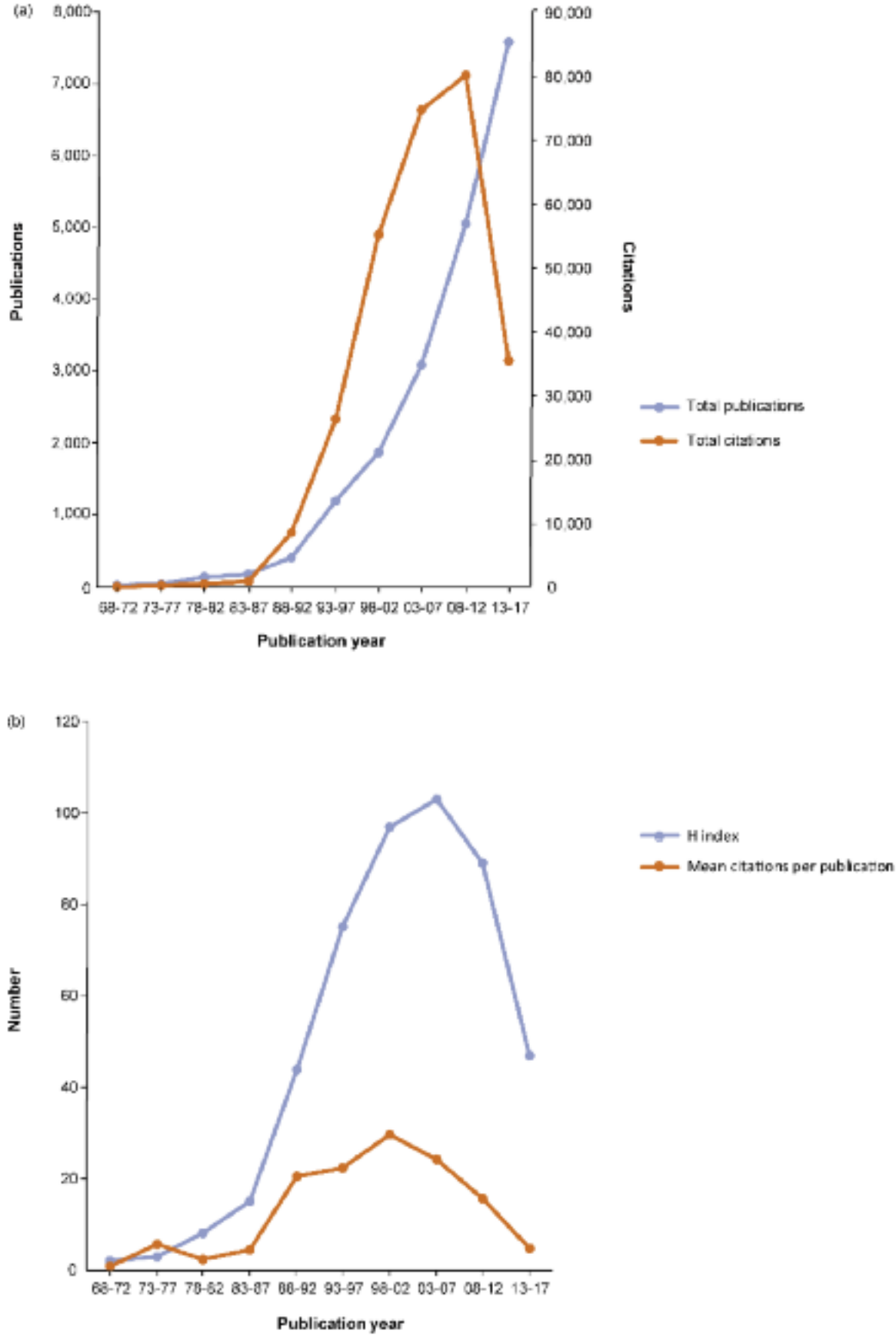
Broad analysis of citations and keywords from the period 1988–2017 (dataset 1[a])

The USA, UK and Germany have contributed the most AW publications in the last 30 years (Figure 2[a]), though 35 countries/regions have provided 100 or more AW publications during this time-period. *Applied Animal Behaviour Science* and *Animal Welfare* were the most frequent publishers of AW publications (Figure 2[b]), though there were 31 source titles that had published more than 100 AW publications in this time.

A co-occurrence network of the most frequent keywords indicated that stress and behaviour were common keywords and closely linked to many other keywords (Figure 3). On the whole, the visualisation indicated the broad concept of animal welfare, covering aspects such as production (eg meat quality), husbandry (eg environmental enrichment, stocking density), health (eg lameness, risk factors), management (eg transport, castration) and broader considerations and issues, such as ethics, conservation and sustainability. The broad diagrammatic canvas (Figure 3) shows how research on different species may be related, but is not sufficiently fine-scale to establish which animal welfare topics have received most attention within each species.

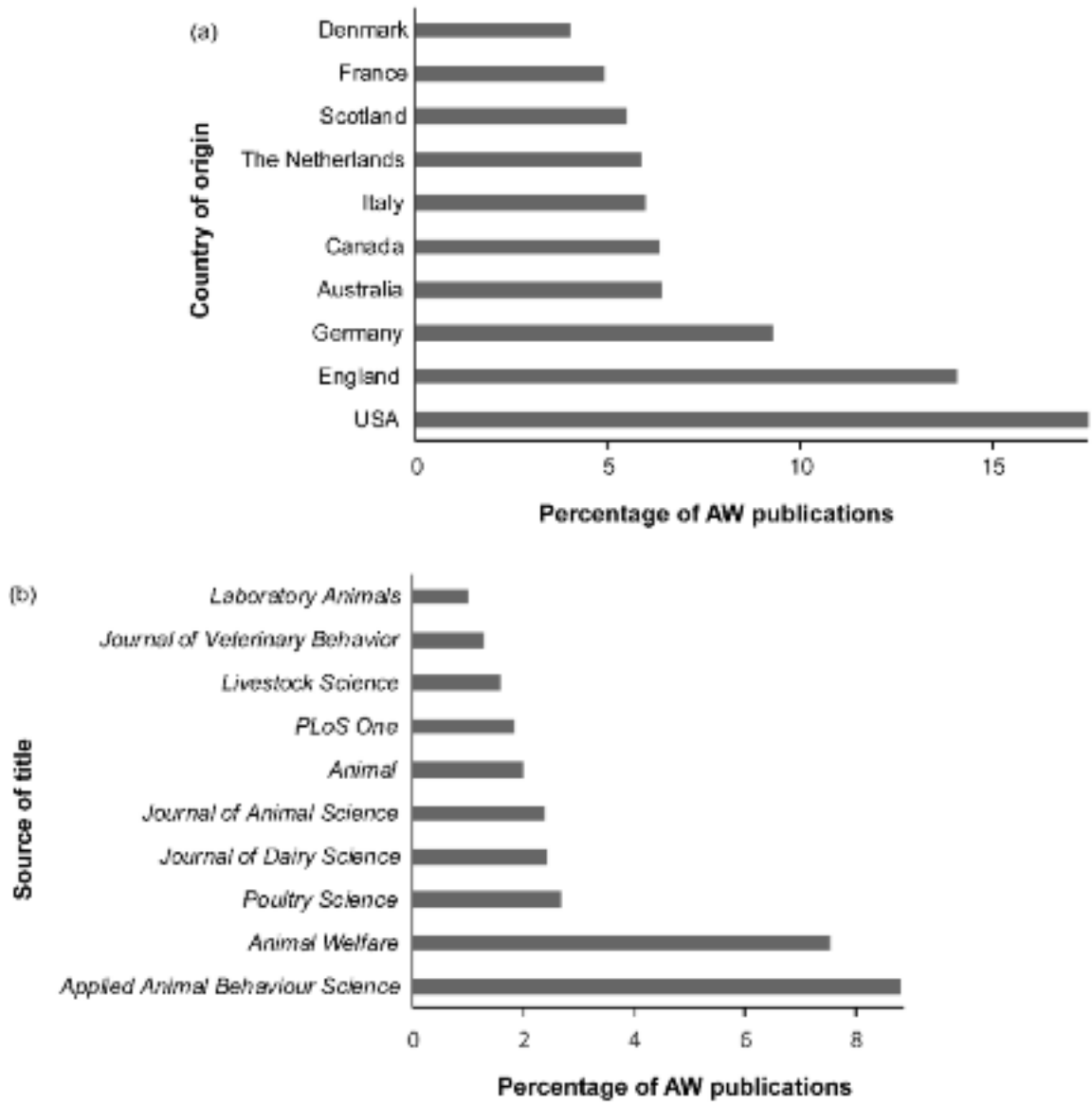
These potential differences in research focus were explored in more detail by visualisations of keywords for five common species (Figure 4) and comparison between them can reveal active areas of research and gaps. For example, research on cattle appeared to focus on dairy and diseases of welfare

Figure 1



(a) Number of publications and the number of times that these publications have been cited and (b) H index and mean citations per publication of animal welfare publications in the last 50 years (initial dataset).

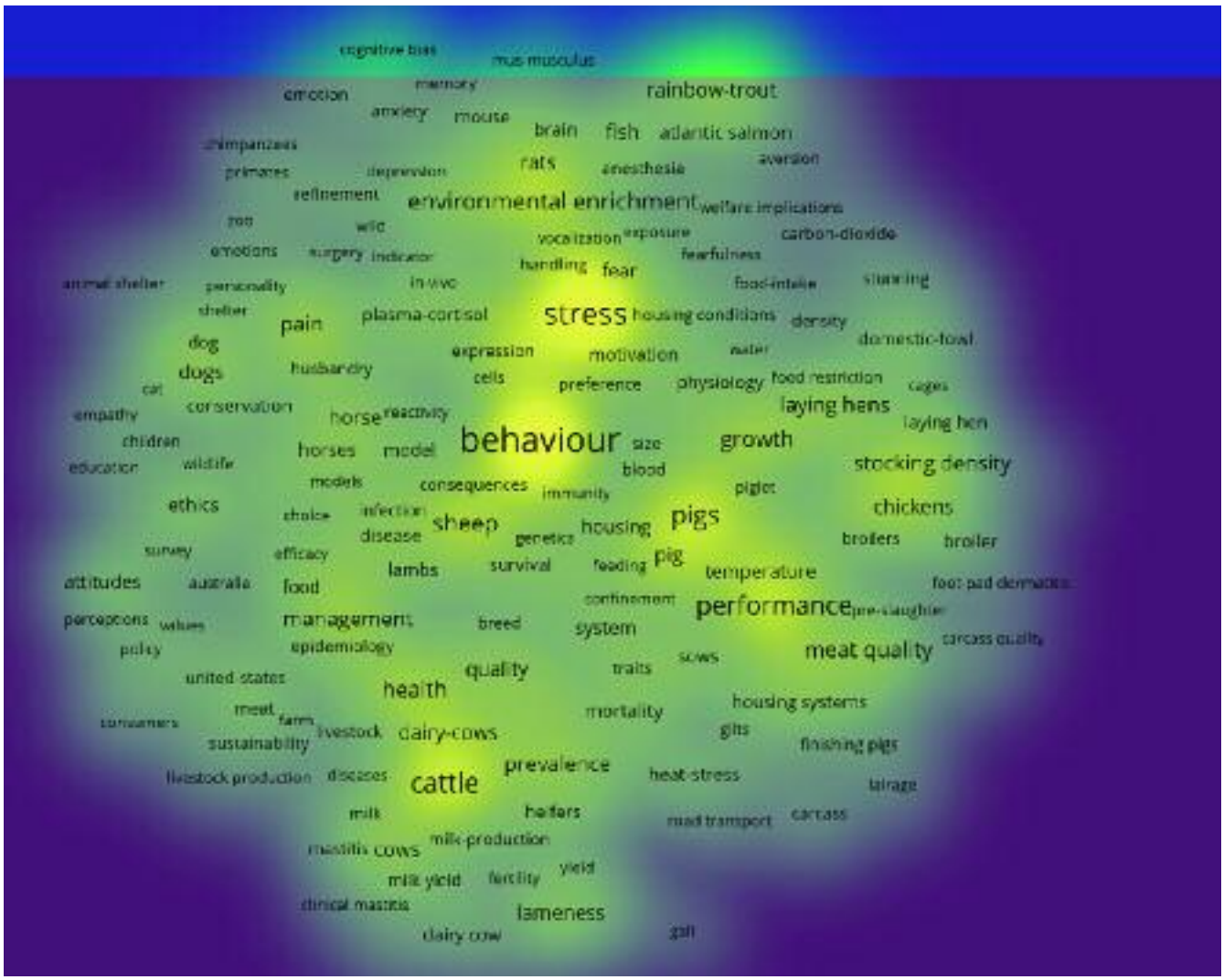
Figure 2



Percentage of AW publications from 1988–2017 (dataset 1[a]) indexed by (a) country of origin and (b) source of title (Web of Science Core Collection). The ten results from each field that have contributed most are presented.

importance, such as mastitis and lameness, as well as milk yield. However, there was little reference to housing or environmental enrichment for cattle (Figure 4[a]), even though housing and environmental enrichment topics were more common in the visualisations for other species (Figures 4[b]-4[e]). A similar process of examination and comparsion of the visualisations revealed that research on pigs was more closely aligned with research on performance, meat quality and housing, including environmental enrichment, but with little emphasis on cognition and emotion (Figure 4[b]). Research on laying hens appeared to focus on housing system, feather-pecking and a strong behavioural component comprising both applied (design) and fundamental (motivation, aggression) studies (Figure 4[c]). Research on dogs focused on behaviour and welfare, in particular with relation to kennels and housing, as well as issues to do with their role as companion animals (eg attachment, aggression) and some links to work on emotion and affective state (Figure 4[d]). Figure 3 supports this view with animal emotion terms closely linked to rats, mice, dogs and zoo animals, but emotion was not prominent in the pig and cattle visualisations, perhaps suggesting a gap in the application of emotion research for some farm animal species. Interestingly, inherited disorders did not appear as a common research topic in the dog visualisation (Figure 4[d]), even though issues such as bone strength, legs and dystocia appear for hens, pigs and cattle. Welfare research on fish is on a variety of different species, and appears most closely focused on stunning, slaughter and pain, though also encompass production aspects, such as stocking density and growth (Figure 4[e]).

Figure 3



VOSviewer density visualisation of a keyword co-occurrence network of AW publications from 1988–2017 (dataset 1[a]). Yellow areas indicate a larger number of publications that have the corresponding term and terms that co-occur frequently are located close to each other in the visualisation.

Bibliometric analysis of review, original research and low-cited articles

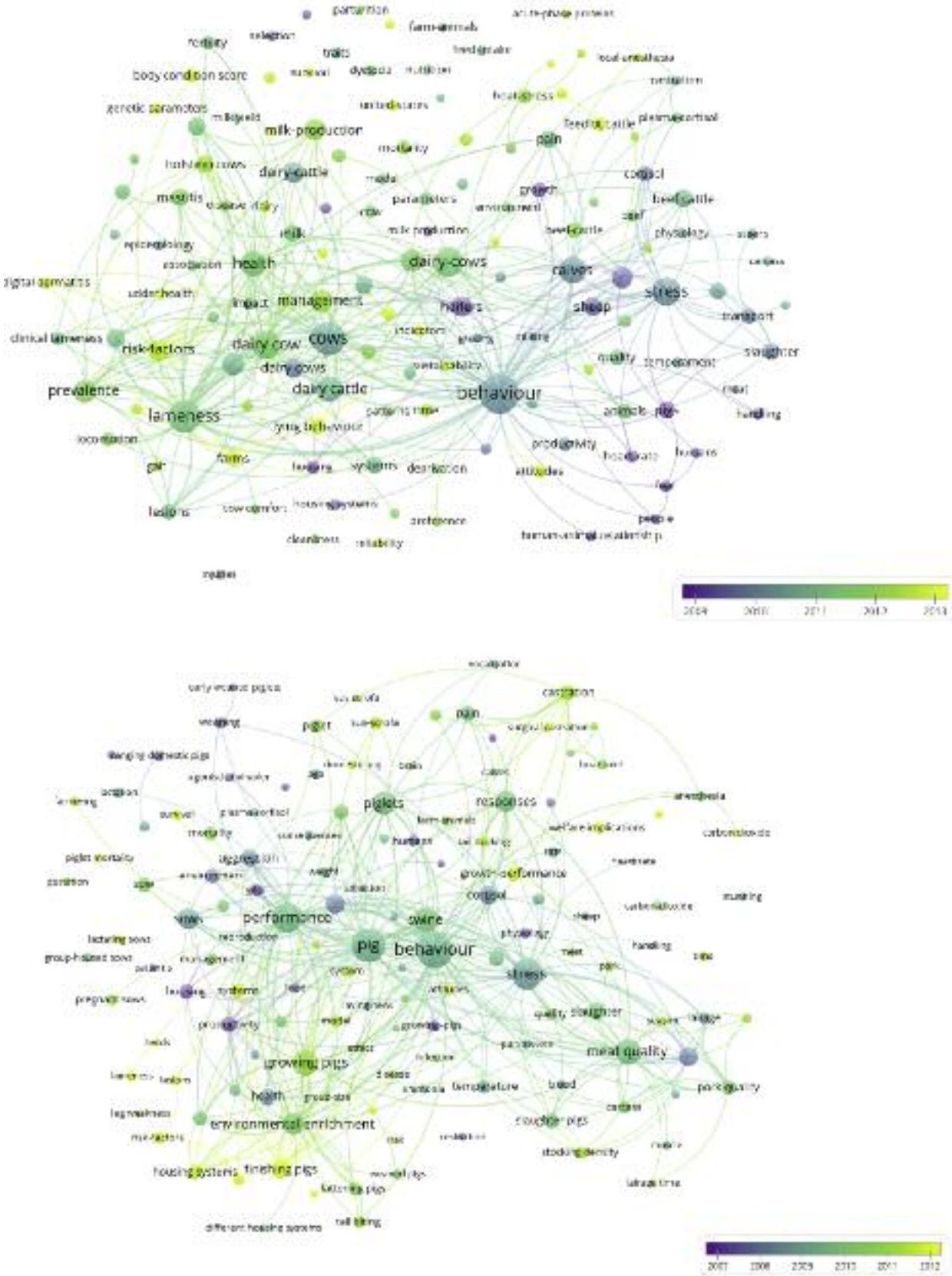
Review articles (dataset 4)

Review articles (n = 1,759) comprised 8% of AW publications and were cited, on average, 34 times each (articles cited < 3 times excluded) with an average publication year of 2007. The majority of review articles, however, were cited less than ten times, although the recentness of these publications appeared to partly account for their lower number of citations (Figure 5[a]).

A citation analysis of review articles indicated that 60 articles had been cited at least 150 times. Thirty-five of these articles were linked and the remaining 25 reviews were not clearly interlinked with these clusters or with each other. VOSviewer grouped the linked review articles into five clusters (Figure 6). The content of each cluster can be roughly typified as: i) stress and fear responses which included human-animal interaction and environmental enrichment (blue); ii) emotion (green); iii) environmental enrichment which included motivation, underlying welfare concepts and stereotypic behaviour (yellow); iv) welfare assessment including stereotypic behaviour as an indicator of welfare (purple); and v) fish welfare (red). A complete list of all 60 review articles that were cited at least 150 times can be obtained from the author (dataset 6). The three most highly cited reviews that were not linked reviewed feedback mechanisms and food preferences in ruminants (Provenza 1995), undesirable effects of high production efficiency in farm animals (Rauw *et al* 1998) and euthanasia (Beaver *et al* 2001).

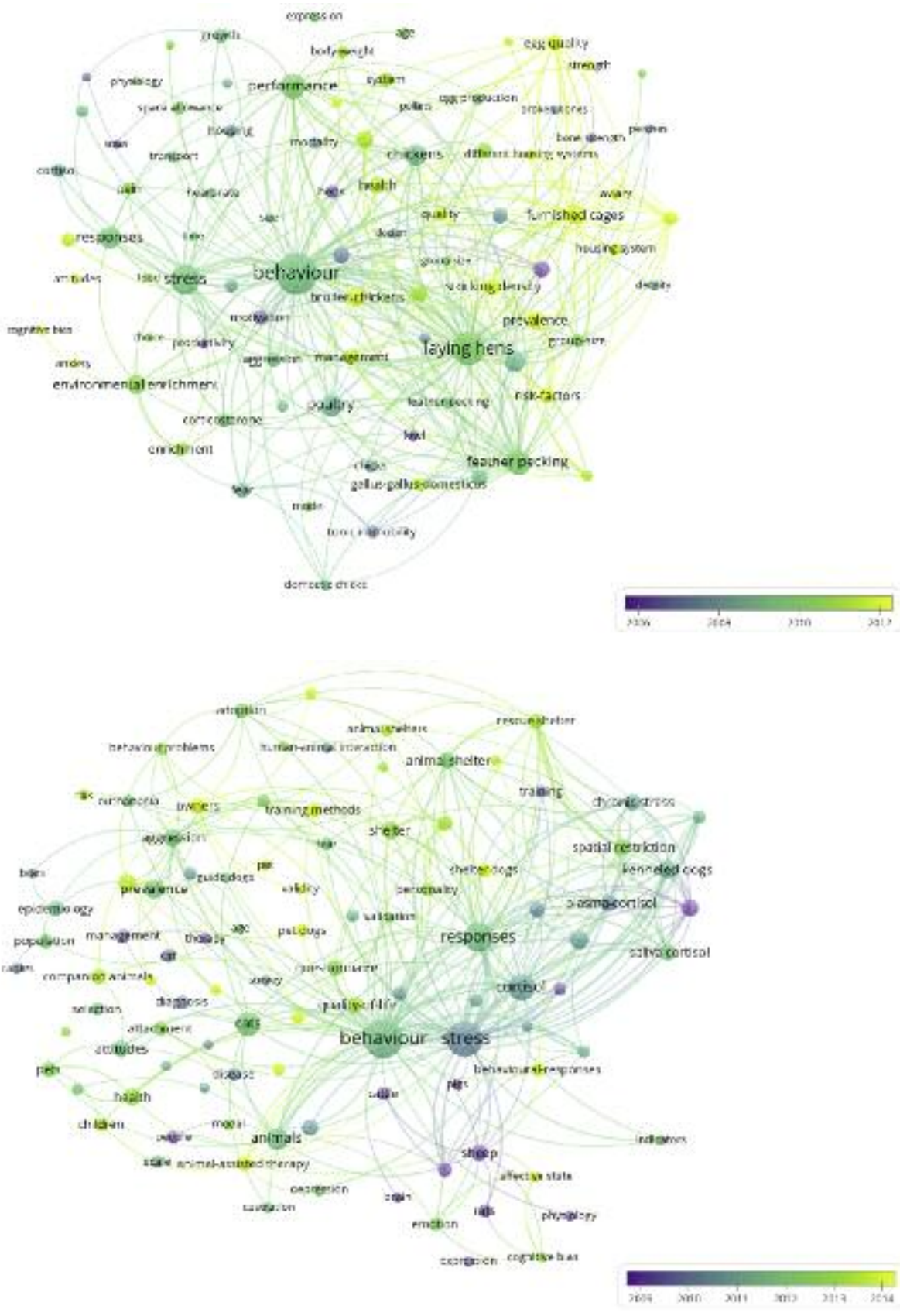
A citation analysis of authors that have both published review articles in animal welfare and been cited extensively provided a network of 34 core authors (Figure 7[a]).

Figure 4



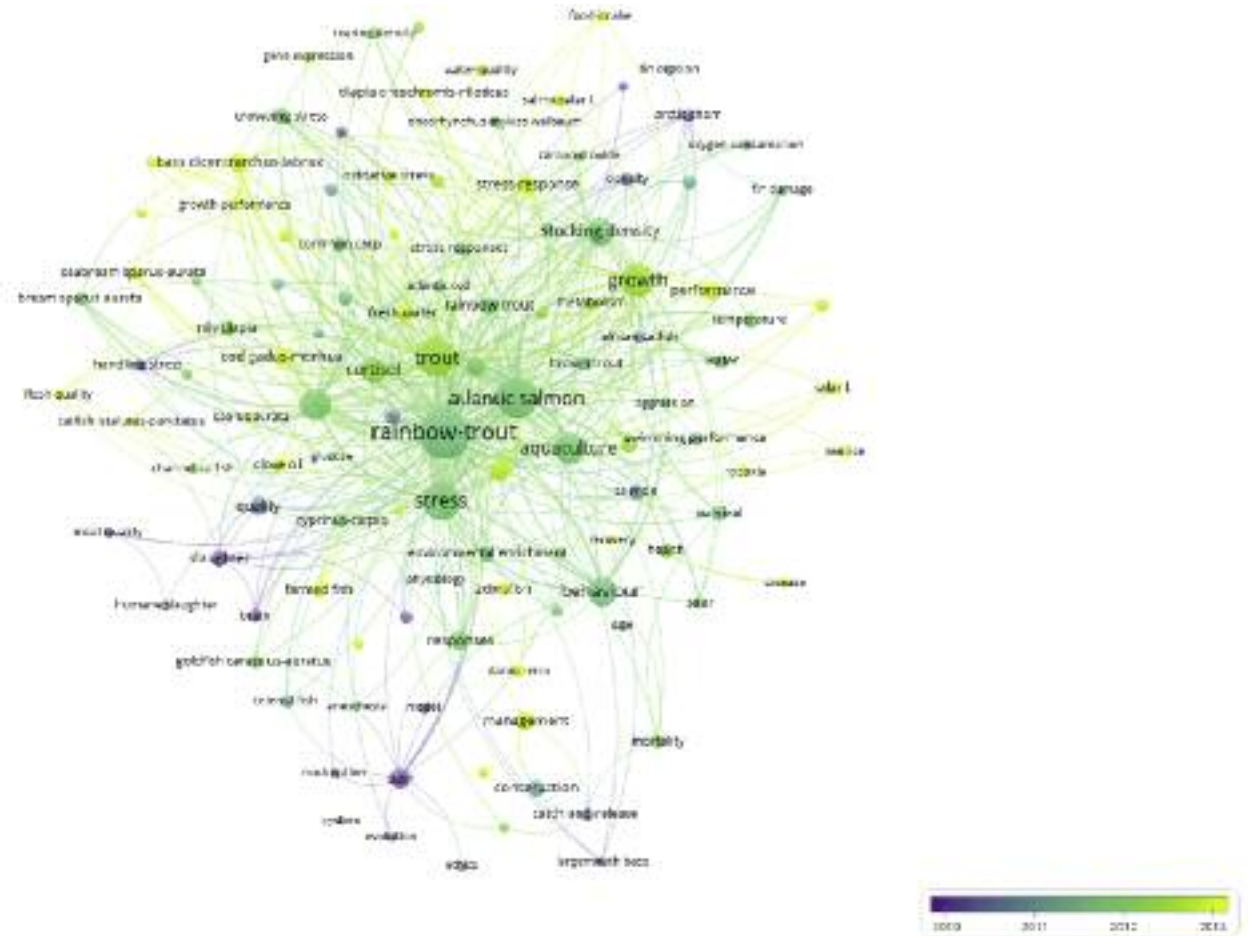
VOSviewer visualisation of a keyword co-occurrence network of AW publications from 1988–2017 on (a) cattle (dataset 1[b]) (top) and (b) pigs (dataset 1[c]) (bottom). Size of node is related to frequency of occurrence of the term and terms that co-occur frequently are located close to each other in the visualisation.

Figure 4 (cont)



VOSviewer visualisation of a keyword co-occurrence network of AW publications from 1988–2017 on (c) laying hens (dataset 1[d]) (top) and (d) dogs (dataset 1[e]) (bottom). Size of node is related to frequency of occurrence of the term and terms that co-occur frequently are located close to each other in the visualisation.

Figure 4 (cont)



VOSviewer visualisation of a keyword co-occurrence network of AW publications from 1988–2017 on (e) fish (dataset 1[f]). Size of node is related to frequency of occurrence of the term and terms that co-occur frequently are located close to each other in the visualisation.

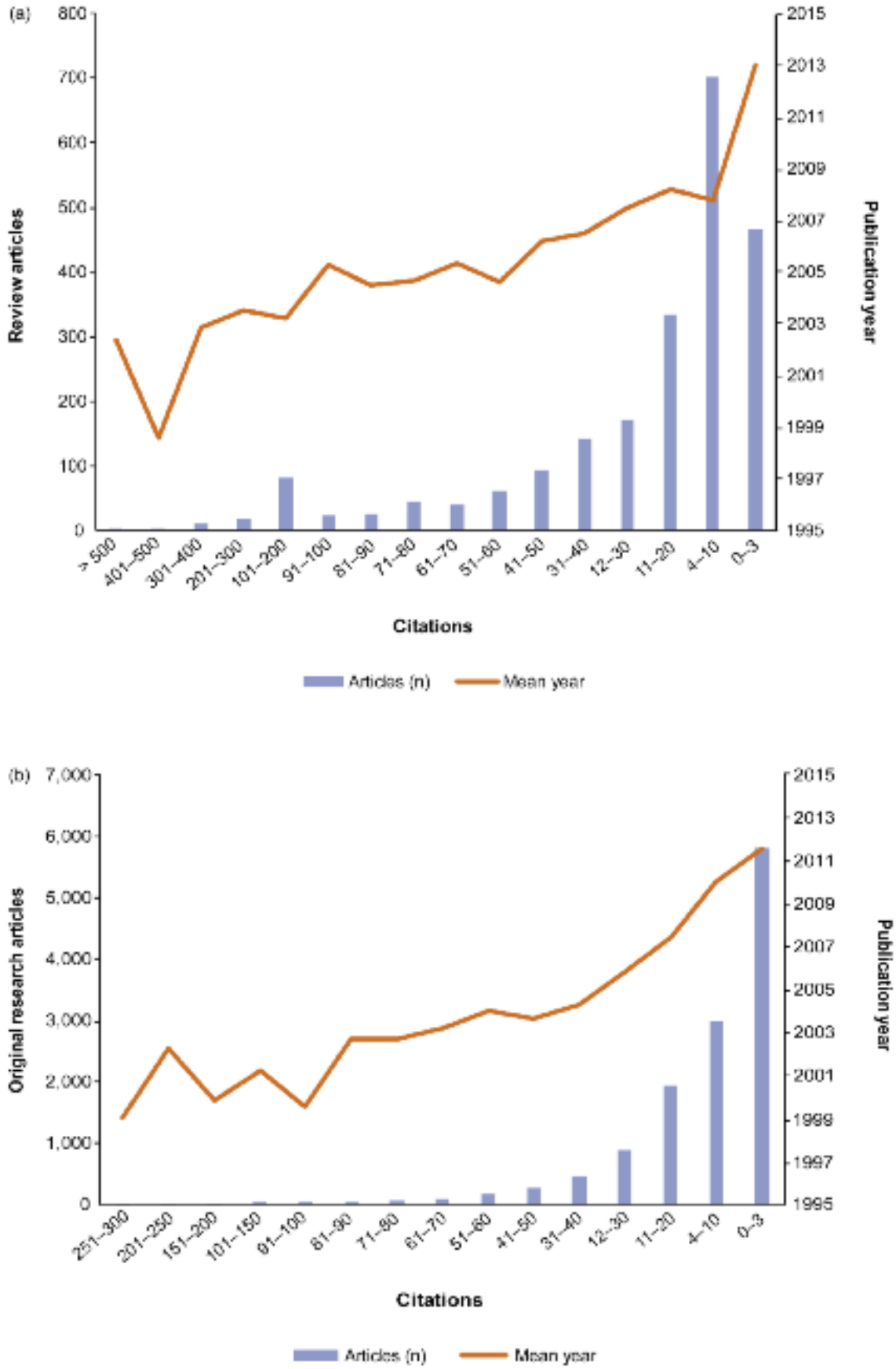
Authors predominantly covering aspects of farm animal welfare are closely linked as are authors of reviews of fish welfare. It is papers on ethics, primarily by Sandøe, that provide the main bridge between farm and fish welfare. Overlaying the mean year of publication on authors of highly cited review articles reveals trends in timing of their peak publication impact. Veissier has been highly cited for contributions to reviews of both mechanisms of stress and of animal emotion. Broom and Fraser have been highly cited for their reviews on the concept and measurement of animal welfare. Many of the core authors of review articles of the last 30 years have also been cited extensively in the last ten years (Figure 7[b]) (eg Broom, Fraser, Mellor), showing longevity of influence in this field. High citations for authors who write about specific topics within the overall networked field of animal welfare are also apparent from Figure 7(b) (eg farm animal welfare: Lawrence; education and on-farm assessment: Main; emotion: Paul and van der Staay). Alongside this, there appears to be a growing trend for independent reviews of animal welfare topics by authors who are not strongly integrated into the central animal welfare network (eg organic systems and meat quality in chickens and rabbits: Castellini; welfare of wild animals: MacDonald; horse welfare: Hausberger; dog and horse welfare: McGreevy).

Original research articles (Dataset 5)

Original research articles (n = 7,018) comprised 76% of AW publications and were, on average, cited fewer times (19) than review articles, and had an average publication year of 2007. As with review articles, the majority of original research articles were cited less than ten times, and there was some indication that recentness of publication accounted for the limited number of citations of some articles (Figure 5[b]).

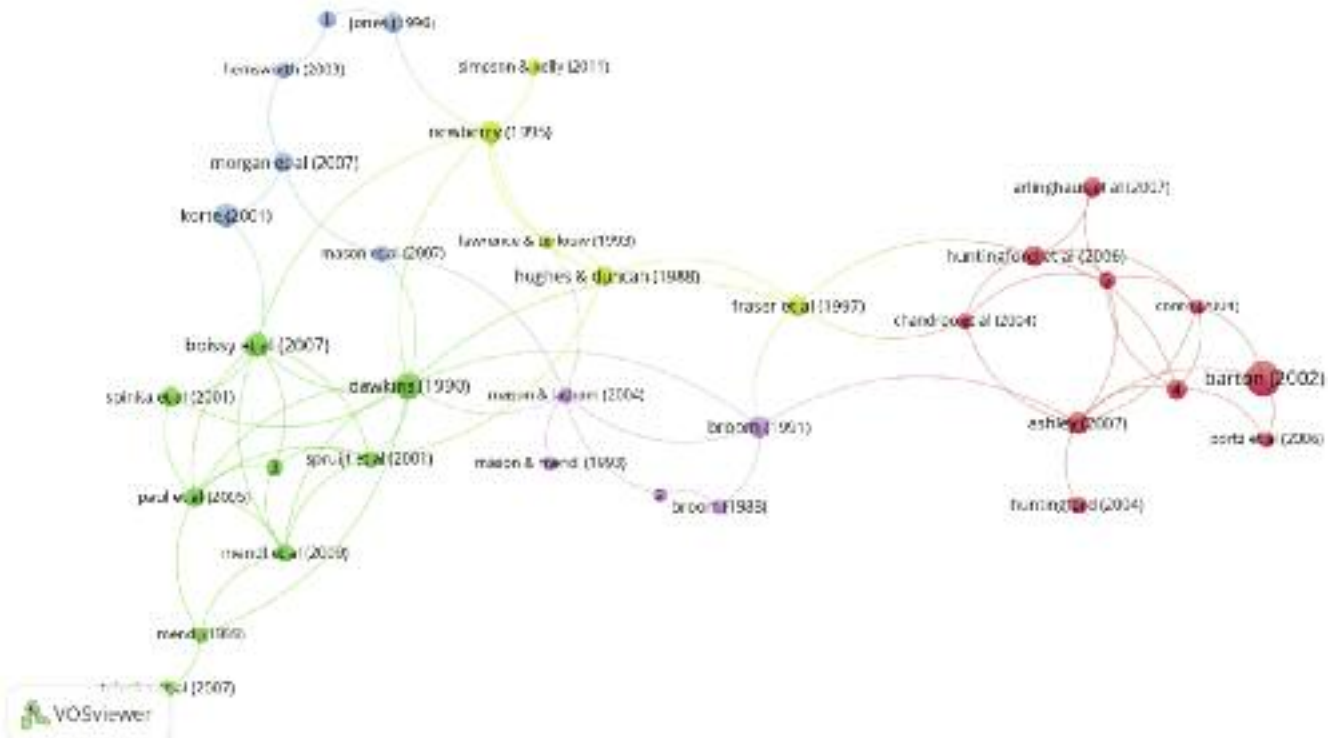
A citation analysis indicated that few of the 71 original research articles that have been cited 100 times or more were linked (Figure 8), indicating that they are rarely citing each other. The exceptions were four small clusters, one comprising articles on lameness in broiler chickens and cattle (including Kestin *et al* 1992; Weeks *et al* 2000;

Figure 5



Frequency of article citations and mean publication year of (a) review articles (dataset 4) and (b) original research articles (dataset 5).

Figure 6



VOSviewer visualisation of a publication citation network of linked review articles that have been cited at least 150 times (dataset 4). Size of nodes indicate the number of citations and nearness of nodes indicates authors that are closely linked (ie authors that have been co-cited more times). Colours indicate the clusters generated by VOSviewer. Key: (1) Waiblinger *et al* (2006); (2) Wielebnoski *et al* (2002); (3) Mendl *et al* (2010); (4) Ellis *et al* (2002); (5) Rose (2002).

O'Callaghan *et al* 2003; Dawkins *et al* 2004; Knowles *et al* 2008), pig welfare (including Pearce & Paterson 1993; Beattie *et al* 2000; Moinard *et al* 2003; van de Weerd *et al* 2003), stress in dogs (including Beerda *et al* 1996, 1998, 1999a,b) and fish welfare (including Sneddon *et al* 2002, 2003; Turnbull *et al* 2005; North *et al* 2006).

VOSviewer included 37 authors in the visualisation of the core authors of original research articles (Figure 9[a]). Almost all of these authors mainly study farm animals. Tuyttens has an interesting position in Figure 9(a), with close links to co-authors (Vanhonacker) but also with others in Spain and Latin America. The last ten years has similarly focused largely on farm animals (Figure 9[b]), though other topics, such as consumer and stakeholder influences (eg Vanhonacker, Verbeke), and researchers in countries with a more recent tradition of animal welfare research (eg Maria, Miranda-de La Lama and Villarroel) have also been highly cited. There is also evidence of some 'satellite' authors working on specialised areas, such as the welfare of wildlife (M Bateson) and equine welfare (McGreevy). Figure 9(b) also shows a highly connected network of researchers working on animal emotion and cognition, derived from tightening links between some core researchers from the last 30 years — Boissy, Keeling, Mendl, Nicol and Wechsler — and being joined by other researchers in the last ten years (M Bateson, Gygax, Paul).

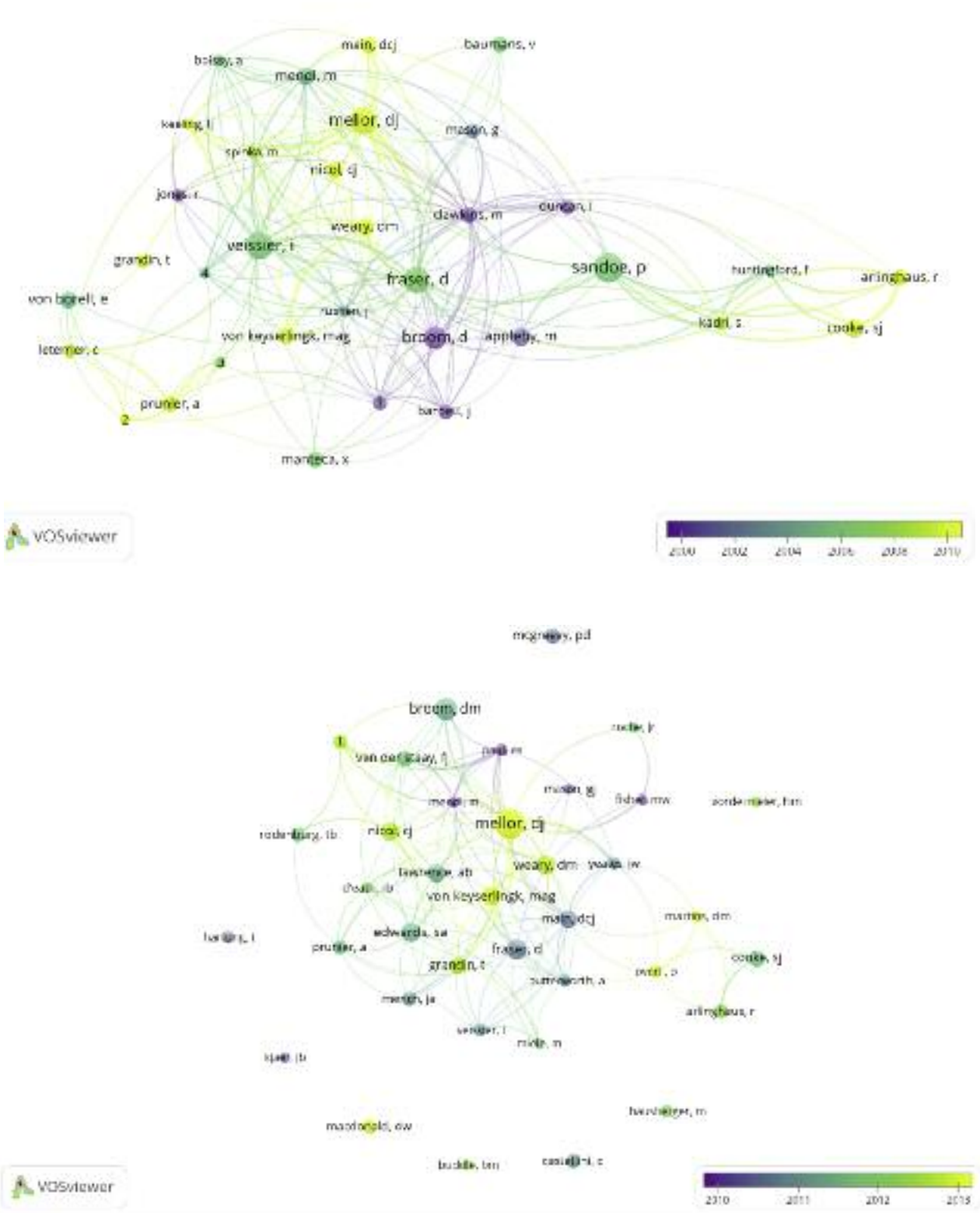
There was considerable overlap in the authors of six or more highly cited review articles (Figure 7[a]) and authors of 20 or more highly cited research articles (Figure 9[a]). Authors who appear in both of these datasets include Barnett, Baumans, Boissy, Broom, Fraser, Grandin, Hemsworth, Keeling, von Keyserlingk, Jones, Manteca, Manteuffel, Mason, Mendl, Nicol, Rushen, Veissier and Weary.

A citation analysis of organisations publishing original research articles indicated strong geographical links both within the UK and between the UK and Australia; within and between institutes in the USA and Canada, between institutions in Sweden, Denmark, France and Finland, and within The Netherlands and between The Netherlands, Belgium and Italy (Figure 10). Although, on the whole, organisations were clustered by geographical location, there were some interesting associations that are likely to result from the movement of key researchers, many of whom, now based in Sweden, Australia or Canada, for example, studied animal welfare at a post-graduate level within the UK.

Low-cited articles (dataset 3[a])

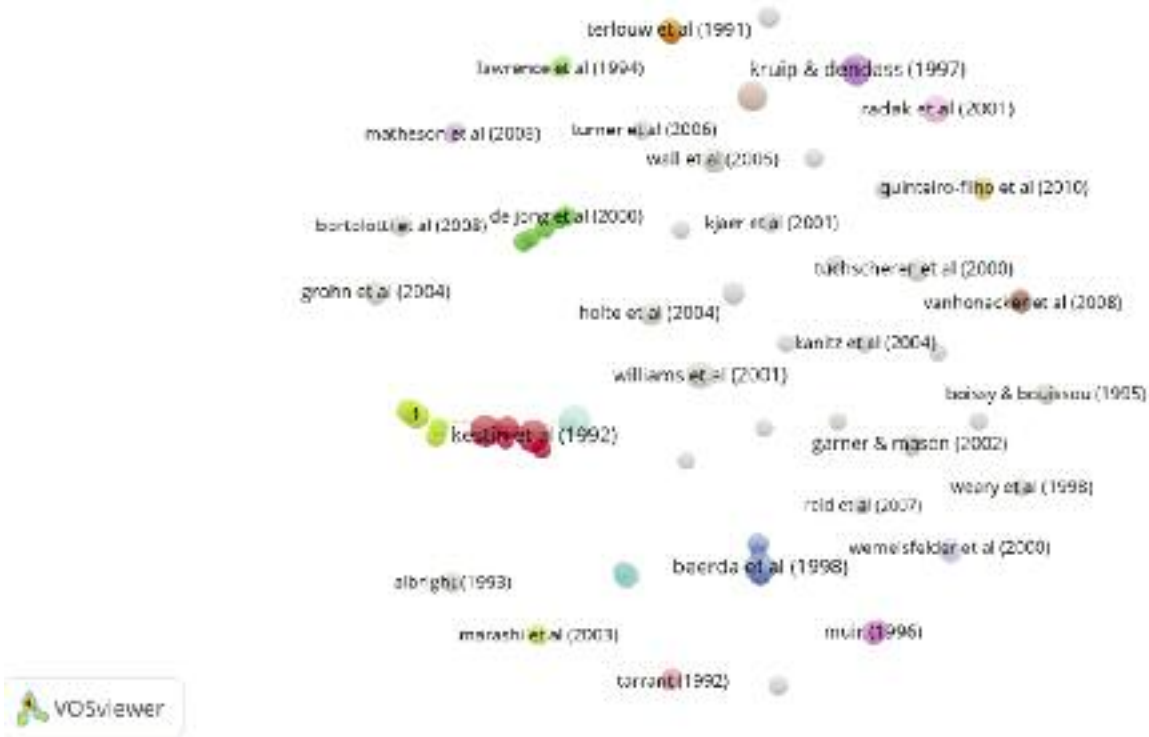
Mean publication year of low-cited articles from 1988–2015 was 2008, compared to 2007 for articles with four or more citations. Co-occurrence network of all keywords indicated that, in common with more highly cited articles, stress and behaviour were common keywords and closely linked to other keywords (Figure 11) and that farm animals were

Figure 7



VOSviewer visualisation of a network of core authors of review articles from (a) 1988–2017 (dataset 4) (top) and (b) from 2008–2017 (dataset 4[a]) (bottom). Size of nodes indicates the number of citations and nearness of nodes indicates authors that are closely linked by VOSviewer (ie authors that have been co-cited more times). Key: (a) (1) Hemsworth, P; (2) Mormede, P; (3) Guemene, D; (4) Manteuffel, G; (b) (1) Nordquist, RE.

Figure 8



VOSviewer visualisation of a publication citation network of original research articles that have been cited at least 100 times (dataset 5). Size of nodes indicate the number of citations and nearness of nodes indicates authors that are closely linked (ie authors that have been co-cited more times). Colours indicate the clusters generated by VOSviewer. Key: (1) Sneddon *et al* (2003).

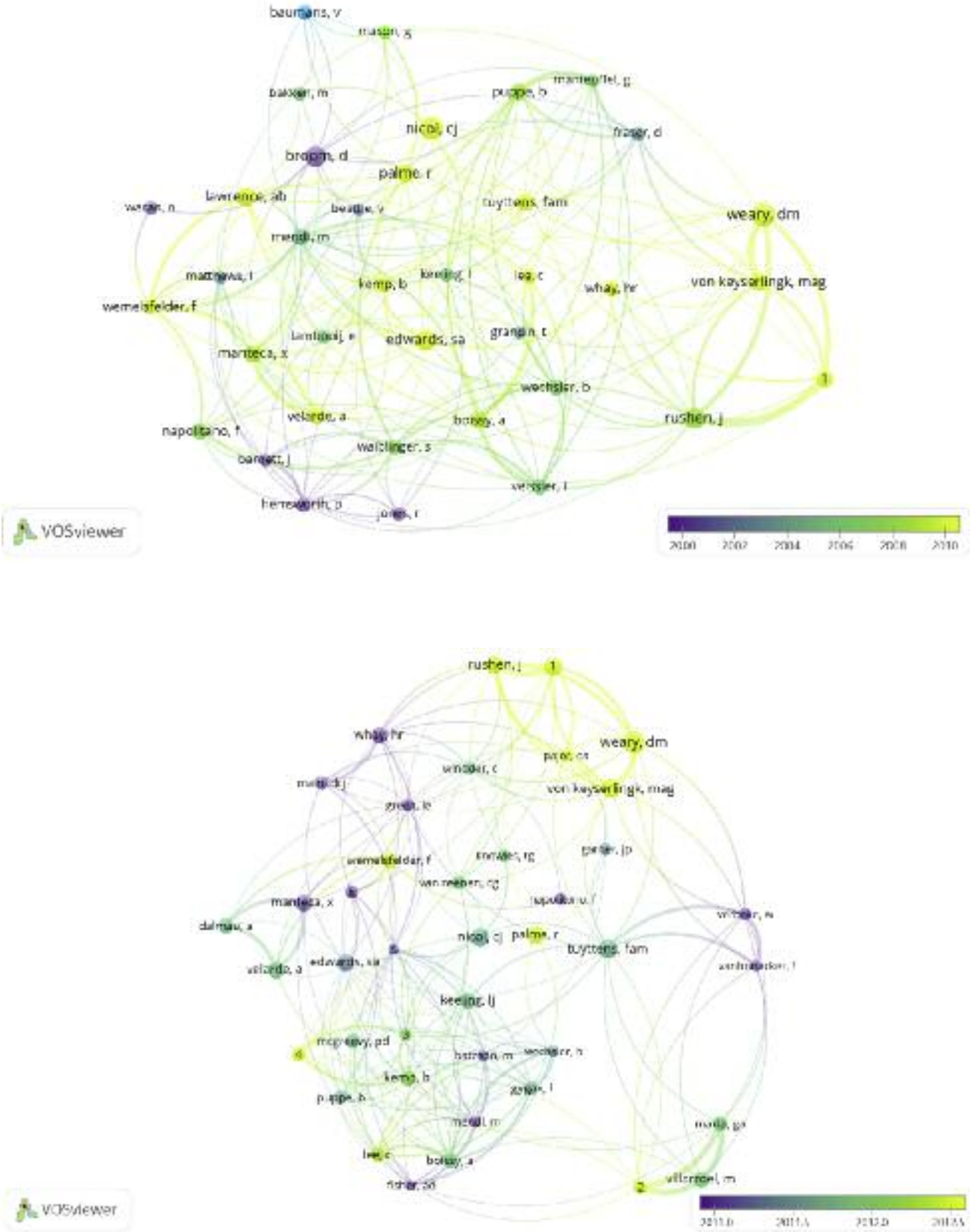
commonly included in keywords. On the whole, there was little indication that the topics of low-cited articles differed from those of more highly cited articles. Citations' analysis indicated that publications originating from certain countries (eg Brazil, Spain, Mexico, China) may not yet be extensively cited because they have only recently begun publishing research on animal welfare (Figure 12). More low-cited articles originate from Germany than from other countries (Figure 12), suggesting that publications in German are less frequently cited than publications in English. This was supported by the finding that 15% of low-cited articles were in German, compared to 5.2% of all AW publications and that 76% of low-cited articles were in English, 1.8% in Portuguese and 1% in Italian.

Discussion

Animal welfare science seems to be increasing at an exponential rate. Although the publication of the Five Freedoms was around 50 years ago, it is in the last 30 years, in particular, that animal welfare science appears to have reached its maximum growth of 15.8% per annum. Slightly different searches and approaches (Borsi & Schubert 2011; Walker *et al* 2014; Rodriguez-Ledesma *et al* 2015; Kirchner *et al* 2017) have also found substantial growth in animal welfare science, suggesting it is a robust finding. In comparison, scientific output across all disciplines has been estimated to have grown by around 3% annually in the last 30 years (Bornmann & Mutz 2015). Growth in animal welfare science matches the exponential growth in the most rapidly expanding areas of biological sciences (Pautasso 2012). Pautasso (2012) suggests that exponential growth cannot be sustained in the long term, but the numbers of publications and resources in animal welfare science are still relatively low and new countries are getting involved, so after a very slow first 20 years, we predict exponential growth will continue for the foreseeable future. Such growth in animal welfare science is likely to fuel the launch of new scientific journals, particularly online journals, with a lower carbon footprint, and attract researchers and funding. However, this trend may also have some negative implications for the scientists, the public and policy-makers. For example, the inability of researchers to keep abreast of all developments in their field, referred to as information overload, is likely to increase and and will perhaps require researchers to adopt strategies to deal with these emerging challenges (eg Landhuis 2016).

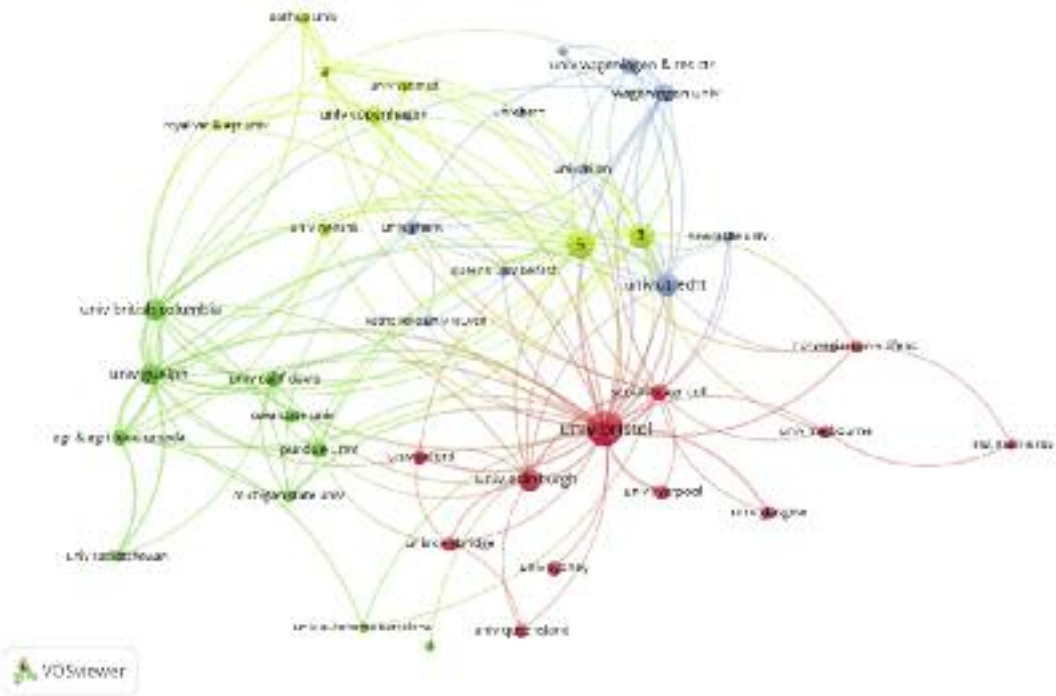
Turning to the more detailed part of our study, behaviour, physiology and farm animals were common keywords in AW publications, as has been reported previously (Walker *et al* 2014). Network analysis and the visualisation of closely related nodes allows us to confirm some of the opinions raised by Walker *et al* (2014), for example, that farm animals are closely linked to production terms such as performance and reproduction. Careful examination of the network analysis visualisations for each species revealed popular topics and gaps in research for each species. Our

Figure 9



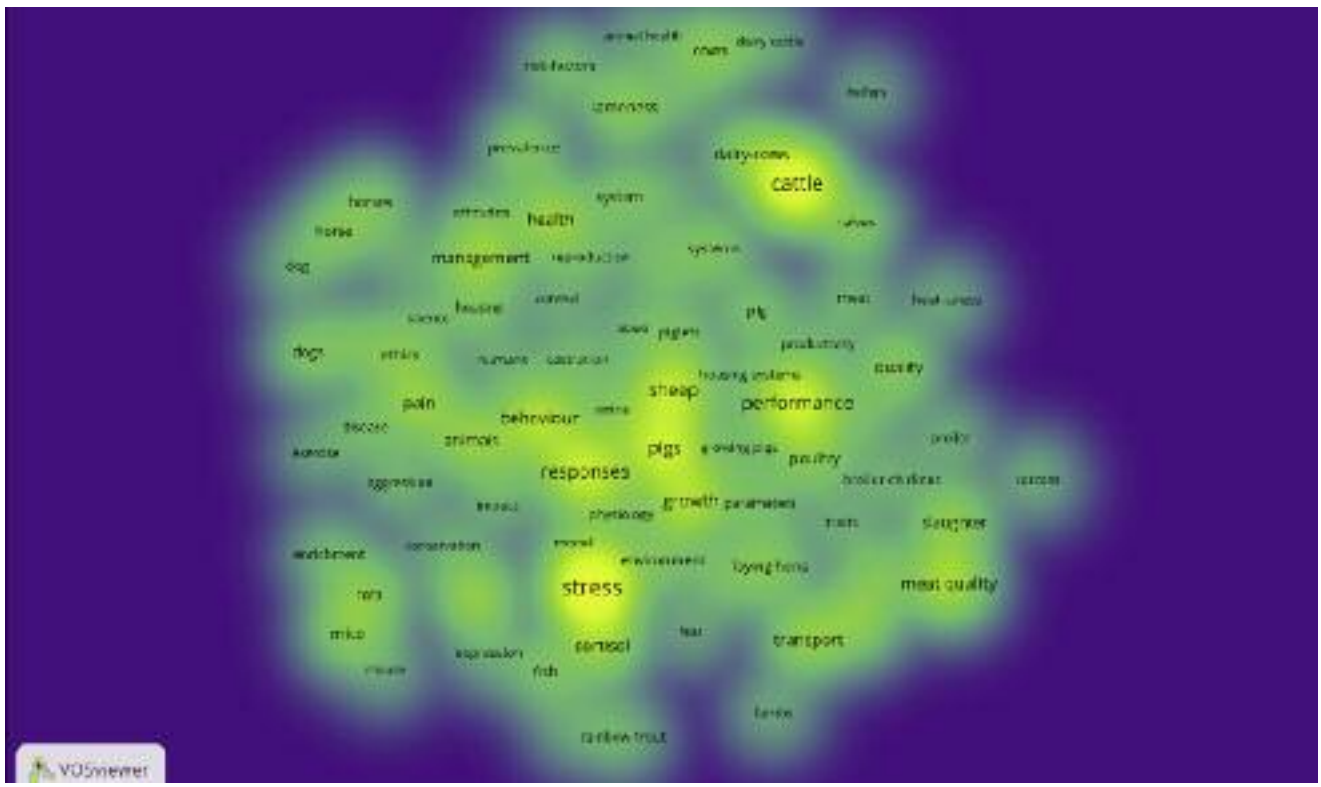
VOSviewer visualisation of a network of core authors of original research articles from (a) 1988–2017 (dataset 5) (top) and (b) from 2008–2017 (dataset 5[a]) (bottom). Size of nodes indicates the number of citations and nearness of nodes indicates authors that are closely linked (ie authors that have been co-cited more times). Key: (a) (1) de Passillé, AM; (b) (1) de Passillé, AM; (2) Miranda-de-la-Lama, GC; (3) Rodenburg, TB; (4) Bolhuis, JE; (5) Paul, ES; (6) Lawrence, AB.

Figure 10



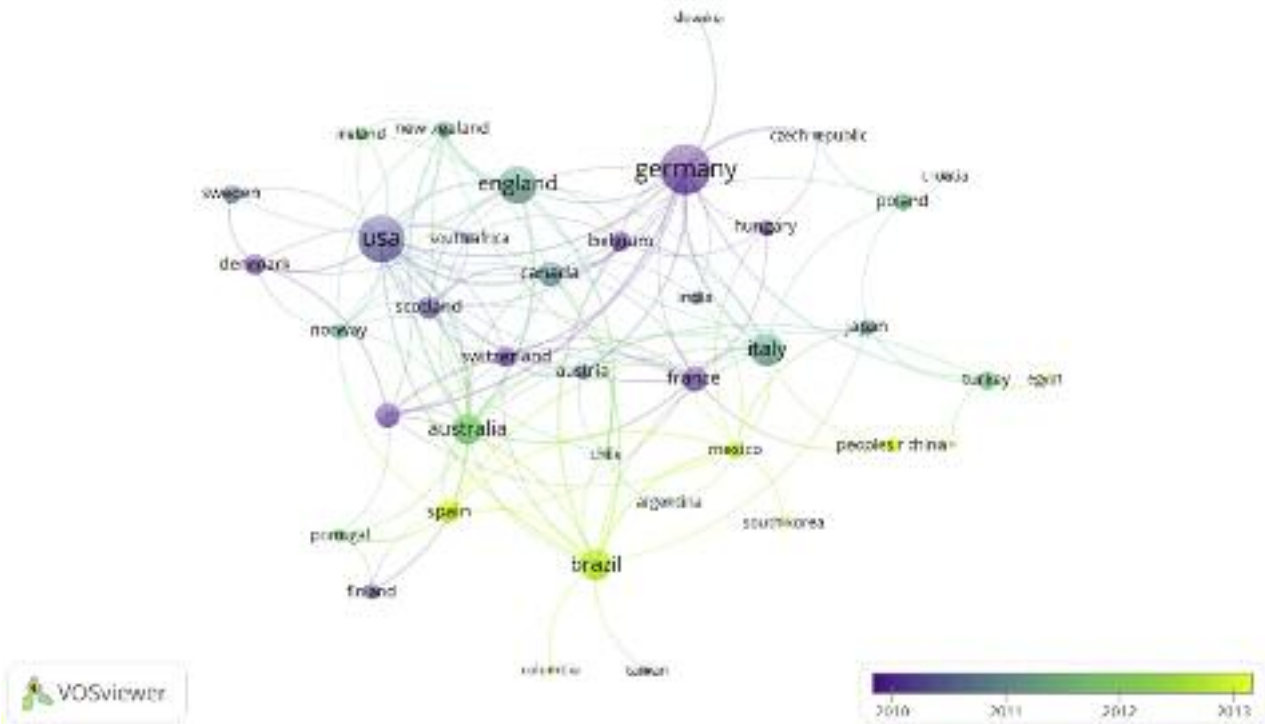
VOSviewer visualisation of organisations that have published 50 or more original research articles (dataset 5). Size of nodes indicate the number of citations and nearness of nodes indicates organisations that are closely linked (ie organisations that have been co-cited more times). Colours indicate the clusters generated by VOSviewer. Key: (1) Blue node next to University of Wageningen & Research Centre, University of Padua; (2) Danish Institute of Agricultural Science; (3) INRA; (4) Massey University; (5) Swedish University of Agricultural Science.

Figure 11



VOSviewer visualisation of a network of the most common keywords in low-cited articles (dataset 3[a]). Yellow areas indicate a larger number of publications that have the corresponding term and terms that co-occur frequently are located close to each other in the visualisation.

Figure 12



VOSviewer visualisation of countries that have the most low-cited articles (Dataset 3[a]). Size of nodes indicates the number of citations and nearness of nodes indicates countries that are closely linked (ie countries that have been co-cited more times).

analysis indicated that perhaps housing and environmental enrichment of cattle, cognition and emotion in farm animals in general, inherited disorders in dogs and general knowledge about the welfare of a wide range of fish species were under-represented in the literature. Additionally, the occurrence of conservation and sustainability as common keywords indicates the broadening of animal welfare in recent years to include other international contexts, as anticipated by Walker *et al* (2014). Although our search terms included 'animal welfare' (and variations), it is possible that we could have underestimated the number of publications on wild and zoo animals, due to the greater number of species, if these papers only preceeded the term 'welfare' with the species name. Our exploratory searches, however, indicated that the instances when this would have occurred for species of zoo and wild animals, without 'animal welfare' appearing in the publication were infrequent. Nonetheless, future bibliometric analyses in the fields of zoo or wild animal welfare should consider alternative search strategies which are better able to deal with the large number of species in these research areas.

Applied Animal Behaviour Science and *Animal Welfare* and animal-specific journals were again found to dominate publications in animal welfare (Walker *et al* 2014). Our findings show that *PLoS One* has emerged as a top-ten publisher of animal welfare articles, which did not appear in the top 81 journals publishing animal welfare in the period 1993–2012 (Walker *et al* 2014), although it is important to note that *PLoS One* started in 2006. In fact, in the last 5 years (ie 2013–2017 which is the period after the study of Walker *et al* 2014), *PLoS One* has published 264 papers on animal welfare, compared to 410 articles in *Applied Animal Behaviour Science* and 244 in *Animal Welfare*. It would appear that animal welfare scientists have embraced Open Access publishing, though it is important to note that authors that are unable to pay for this may not disseminate their findings as widely as authors able to afford open publishing. However, some journals, such as *Animal Welfare*, have mechanisms, such as self-archiving and open access in developing countries, to overcome such challenges.

Review articles comprised 8% of AW publications and were, on average, cited more times than original research articles (34 and 19 times, respectively), which is not unusual in the literature (eg Seglen 1997; Ioannidis 2006). However, little is known about the relative proportion and citations of reviews and original research articles in the sciences. As presented in the *Introduction*, the concept of animal welfare can mean different things to different people, animal scientists included (Fraser 2008), and we initially suspected that a need to put forward and reinforce opposing views might contribute to a large proportion of review articles. However, comparison with other fields suggests that animal welfare science may not differ greatly from other animal science fields in this respect. The raw classifications of document types for 'animal welfare' in the ISI Science-Expanded index are articles 74.9%, proceedings 10.8%, reviews 7.1%, editorials 5.4% and news items

3.1%. In contrast, for 'animal science' the classifications are articles 76.9%, proceedings 10.1%, reviews 9.3%, meeting abstracts 2.7%, editorials 2.4% and news items 0.9% (documents can be classified as more than one type so totals may add up to more than 100%). Although we are aware from our examination of every document in the initial dataset that these raw classifications are not very accurate, the similarity in patterning between these two fields does not confirm our initial suspicion, with the exception that animal welfare appears to be a relatively popular topic for editorials and news items. Furthermore, it is possible that our search terms were more likely to identify review articles than original research articles, because we expect that all reviews on animal welfare will include the term 'welfare', whereas original articles may not (for example, a publication on feather-pecking in laying hens may not include the word 'welfare' *per se*). This latter point also does not support our initial suspicion that there would be more review papers in animal welfare than in other fields.

Highly cited review articles were grouped into five clusters with stress, human-animal interactions, environmental enrichment, ethics, motivation, stereotypies and welfare assessment being key concepts in three of the clusters, and these have been key areas of animal welfare research for some time. The possibility that animals may possess affective states (ie emotions, moods) is a key question for many people in deciding how animals should be treated, and a fourth cluster shows a possible development of this concept from earlier views on understanding the animal's experiences (Dawkins 1990), to later views on cognitive bias as a tool for examining animal emotion (Mendl *et al* 2009). Interestingly, the fifth cluster of review articles includes recent reviews on fish welfare, including the most highly cited review in our datasets (Barton 2002). Fish welfare was largely under studied prior to 2012 (Walker *et al* 2014), and the finding that fish was a common theme in review articles, and to a lesser extent in original research articles, shows that fish welfare has become a popular topic in recent years. Our analysis indicates that research on fish welfare is closely linked to stunning, slaughter, pain and stocking density. It was also interesting to note that the relatively recent interest in fish welfare was closely linked with Sandøe, a bioethicist, and perhaps illustrates how attention to new welfare areas can be driven by ethical concern for the animals in question.

There was considerable overlap in the core authors of review and original research articles, suggesting that many reviews within the field of animal welfare science are informed by direct empirical experience. Identifying core researchers within a discipline may be useful in obtaining highly knowledgeable viewpoints, or for identifying suitable individuals for leadership and advisory roles (Boyack *et al* 2013). However, creating 'lists' of core researchers for policy purposes may not be as useful as it first appears within animal welfare for two reasons. First, animal welfare has an ethical component, so that even when scientists agree on results they can disagree on the overall effect on the animal's welfare or on the balance of competing claims (Fraser 2008), and some individuals may find it difficult to dissociate interpretation of the science with this ethical component. Second, there is also the possibility that interpretation of the literature for policy purposes may be influenced by the main source of funding of the indivduals (van der Schot & Phillips 2013). It is important to stress that there may be other approaches to identify 'core' researchers which may yield different lists of scientists, though in our study small alternations to the thresholds of the number of publications and citations had little effect on our list. Additionally, the identification of 'core' researchers may have been limited by our search terms which required papers to include the term 'welfare'. There are some authors who do not always use the term 'welfare' in articles that in our opinion are on animal welfare. Two such authors are Mills and Würbel, though there are without doubt others who would be under-represented in our analysis for this reason. It is worth stressing that this consideration also applies more broadly, with research on some topics (eg feather-pecking, stereotypies) perhaps also not including the word 'welfare' as frequently as research on other topics, resulting in the omission of some articles. Authors who change their name over the course of their career could also be missing or under-represented in our list of core researchers.

Few of the most highly cited original research articles were linked, suggesting that highly cited articles may be on very specialist, and new, themes. The exception was four small clusters, two of which were on farm animals (broiler chickens and pigs). The other two small clusters of highly cited original research articles were on dogs and fish, perhaps indicating significant advancement in these areas through multiple highly cited articles. VOSviewer created a visualisation of 37 core authors of original research articles (at least 20 publications and cited over 500 times), who almost all have a research focus on farm animals. The last ten years has similarly focused largely on farm animals, though there is evidence of more 'satellite' authors now working independently on specialised aspects of welfare, such as welfare of wildlife and equines. Interestingly, the last ten years has also shown tightly networked and interlinked work on cognition and emotion, perhaps indicating considerable activity in this highly specialised area.

Network analysis of organisations revealed the main publishers of original research articles, with the University of Bristol, UK being cited more times than other organisations. In general, the four clusters identified were linked by geographical location, which were roughly around the UK, USA, Scandinavia and The Netherlands. Some exceptions to the geography-based composition of the clusters were found which may have been related to the movement of key researchers, many of which studied in the UK. Within Europe, some framework programmes explicitly aim to encourage institutions from member states under-represented in the research area to become involved in research. Kirchner *et al* (2017) found that large research consortia, such as Blokhuis *et al* (2013), do indeed provide communication platforms and assist in establishing AW

research in emerging institutes, though, on the whole, widespread collaboration involving emerging institutes was rather low. Alternatively, particularly on a global scale, it may be that animal welfare science addresses local issues (eg farming conditions or species farmed) and this would limit the extent to which research is cited by researchers in other geographical areas.

One possible reason for articles to be low-cited could be if they were on very specialised topics. However, our co-word analysis of keywords offered little indication that low-cited articles were on different topics than more highly cited articles. Instead, citation analysis of country indicated that many low-cited articles were originating from Germany and 15% were written in German. It is important to stress that this result may have been an artefact of our search strategy. Although we included all languages in our search, because our terms were in English, they would have biased the sample and possibly excluded many non-English publications. The pre-eminence of English within the scientific literature has been well-documented, and pros and cons to this *de facto* state considered (eg van Leeuwen *et al* 2001; Hamel 2007). It is possible that many worthwhile results and opinions on animal welfare may be being missed by other researchers due to language barriers (Meneghini & Packer 2007). This is supported by the finding that 5,299 (84%) low-cited articles were in English, compared to 92% of all AW publications. Our findings of low-cited articles at first glance indicate that countries such as Brazil, China, Mexico and Spain are only beginning to publish in animal welfare, and this may be the case. However, the above observed higher proportion of non-English compared to English low-cited articles, raises the possibility that the apparent 'emergence' of these countries may also be a result of the language barrier, and that perhaps it is due to these countries only recently beginning to publish in English.

Finally, although bibliometric analysis has become established as a valuable method for evaluating scientific production (Ellegaard & Wallin 2015), it should be remembered that animal welfare, in particular, has a broader appeal beyond scientists and policy-makers. The reviews that have been most highly cited by other scientific publications, as reported by ISI Web of Science in our bibliometric analysis, have been cited far more widely within the so-called 'grey literature' by Google Scholar (Provenza 1995: 516 vs 896 citations in Google Scholar; Dawkins 1990: 470 vs 881 in Google Scholar; Barton 2002: 872 vs 1,430 in Google Scholar). This is similarly apparent for original research articles (Kestin *et al* 1992: 266 vs 443 in Google Scholar; Kruip & Den Daas 1997: 258 vs 364 in Google Scholar; Whay *et al* 2003: 262 vs 389 in Google Scholar). Thus, there is likely to be considerable literature, patents and government and other stakeholder reports which influence the discipline yet would not appear in scientific journal databases. Much of this literature is written by animal welfare scientists, and can even be in a scientific article format (eg https://www.awselva.org.uk/journals).

Conclusion

Animal welfare science is still in an exponential phase of growth which will bring opportunities, such as for the publication of new journals, but also challenges. The literature is still dominated by topics relevant to farm animals, but new topics and new influential figures are emerging, some more connected than others. Although our intention was not to create a complete list of all research gaps, the process of comparing visualisation of different species appears to be useful in revealing possible gaps in research. Language and geography appear to be challenges for research activity and wider dissemination of results. The insights generated by this study would suggest that bibliometric analysis of animal welfare is a useful addition to other approaches to investigate the trends and concepts of animal welfare.

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