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

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Running title: Bibliometric analysis of animal welfare science

Abstract

We undertook a bibliometric analysis 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 (i.e. emotions, moods) and fish welfare the most recent topics. Almost all core authors of Original Research articles study farm animals, though in the last 10 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 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 that bibliometric analysis is a useful addition to other approaches to investigate the trends and concepts of animal welfare.

Keywords: animal welfare, bibliometrics, citation analysis, 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 (e.g. 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 wefare science (Mason & Mendl 1993; Barnard & Hurst 1996; Fraser et al 1997). More recently, Mellor (2016) proposes 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

70 temporal influences on animal welfare science, it is valuable to identify past and emergent
71 trends in research activity and to use these to assist in identifying future directions and
72 challenges.

73 Bibliometrics is a rapidly expanding branch of science which aims to analyse and represent,
74 amongst other things, quantitative aspects of published scientific outputs in order to reveal
75 how disciplines are conceptually and socially structured (de Bellis 2009). Bibliometrics can
76 therefore assist in evaluating the contributions of individual scientists, groups, countries or
77 journals to the advancement of knowledge. Rodriguez-Ledesma et al (2015) used
78 bibliometrics to chart the emergence of different themes within the Science Citation Index
79 subject heading of Agriculture, Dairy and Animal Science. Within this one subject heading,
80 animal welfare emerged as a major theme, starting with an early emphasis on nutrition and
81 developing as a strong (though relatively isolated) theme within this subject heading, and
82 more recently encompassing studies of stress, aggression and environmental enrichment.
83 However, papers on animal welfare appear under many other Science Citation Index subject
84 headings. Indeed, at least 10 papers on the topic of animal welfare have appeared under
85 nearly 100 different headings, most commonly “Veterinary Science” but also under diverse
86 headings such as “Philosophy”, “International Relations” and “Neuroscience”.

87 The aim of our study was to bring this diverse literature together and present a bibliometric
88 analysis of the field of animal welfare science as a whole. We present metrics that chart the
89 development of the field, and of the individuals, organisations and countries that have had
90 most impact to date, as well as an analysis of emerging trends. To identify possibly divergent
91 trends in opinions and views, and in data-driven research, we have separately analysed
92 review and original research articles. Additionally, the identification of poorly-connected
93 nodes and trends in low-cited articles can generate hypotheses about barriers to exchange of
94 ideas and information. The use of bibliometrics to highlight areas that are well or poorly

connected may also be of interest to policy makers intent to improving the overall quality of animal welfare science. Our approach complements other histories (Albright 1998; Broom 2011, 2014), general reviews (e.g. Broom 1991; Fraser et al 1997; Dawkins 2006; Veissier & Mara 2014; Hemsworth et al 2015) and related commentaries supported by metrics and surveys (e.g. 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.

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 (1965) report 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 (e.g. 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 15614 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 3000 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 6 articles out of 3000 (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 the 10/4/2018. Our reason for including "animal welfare"

144 (and variations) in the search term was to extract publications that the authors have self-
145 identified as relevant to animal welfare. Hereafter, outputs generated using this search terms
146 are referred to as AW publications.

147 Three different types of analysis were conducted using different subsets of the original AW
148 publication database. These were (i) a brief historical overview of basic metric data from
149 1968 to 2017, (ii) a broad analysis of citations and keywords from 1988 to 2017 and (iii) an
150 in-depth bibliometric analyses of (separately) Review, Original Research and Low-cited
151 articles using datasets that had been subjected to a detailed visual search by both authors to
152 remove or re-categorise papers that had been misclassified by automated search strategies.

153 Analysis of publication metrics was undertaken using the WoS analysis tool (Clarivate
154 Analytics, Philadelphia, USA) and more detailed bibliometric analysis undertaken using
155 VOSviewer (van Eck & Waltman 2009, 2014). VOSviewer generates distance-based
156 visualisations of bibliometric networks. In the visualisations provided by VOSviewer, the
157 size of the nodes or colour in density overlays represents the frequency of the item (e.g the
158 number of citations, documents or occurences of a term). The distance between two nodes or
159 items in the visualisations indicates the relatedness of the nodes, so that closely related nodes
160 are positioned close together, and weakly related nodes are located far away from each other
161 (van Eck et al 2010). In some of the visualisation, closely related nodes are grouped into
162 clusters (indicated by different colours) which help in providing an "overview" picture of the
163 structure of the network. VOSviewer assigns nodes to clusters based on a modified
164 modularity-based clutering technique (Waltman et al 2010; Waltman & van Eck 2013). It is
165 common with bibliometric analysis to examine different thresholds before chosing thresholds
166 that provide meaningful visualisations. Since we were interested in the key influences on
167 animal welfare science, some of which may have been individual items, it was necessary to
168 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 (e.g. significant effect, year, decrease, fact).

(i) Brief historical overview of AW publication metrics (Initial Dataset = 19498 articles)

The number of publications, number of citations, H index and mean number of citations per publication was obtained using the WoS analysis tool. The above indices were presented for ten 5-year periods, spanning 1968-2017 inclusive to reveal changes in time.

(ii) Broad analysis of citations and keywords from the period 1988-2017 (Dataset 1a = 15068 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=17284). This selection resulted in the removal of non-citable items such as editorial letters, corrections and book reviews. We also exluded 2216 articles from Dataset 1 which were not on animal welfare (see explanation in the next section), and from the remaining Dataset 1a (n=15068), we identified the countries and source titles that have been most represented in the literature to date. A co-occurrence

193 network of the most common keywords (author keywords and KeyWord Plus®) of Dataset
194 1a was created using VOSviewer. At a broad scale, species names were common keywords,
195 potentially masking finer within-species co-occurrence networks. Therefore, we additionally
196 created separate datasets for five common species by filtering based on whether the species
197 name appeared in the abstract to create the following datasets: cattle (or cow), Dataset 1b
198 (n=2093); pig, Dataset 1c (n=2071); laying hens (filter used was"lay AND hen", Dataset 1d
199 (n=1275); dog, Dataset 1e (n=868); fish, Dataset 1f (n=1193). VOSviewer visualisations of
200 the most common keywords in each of these Datasets were created.

201 (iii) Bibliometric analysis of Review, Original Research and Low-cited articles

202 The titles and abstracts of all items within Dataset 1 were examined by hand by the two
203 authors to confirm that each article was classified correctly and to exclude articles not on
204 animal welfare. The above filtering by hand resulted in 2216 articles being excluded and
205 placed in Dataset 2. Common reasons for excluding articles were that they were on the
206 environment, human community well-being, on animals but dealt with human health and
207 well-being or that they were completely unrelated (e.g. using acronym of COW for a study on
208 human health). We next removed items with 3 or fewer citations, and placed these within
209 Dataset 3 (n=6291). This was because we were interested in significant trends in animal
210 welfare, and because bibliometric analysis depends upon a certain amount of data to be
211 statistically reliable. We then excluded very recent publications from Dataset 3 that might
212 receive few citations purely because of recency, so that the new subset (Dataset 3a, n=3656)
213 contained publications from the 1988-2015 period only which we used for further analysis of
214 Low-cited articles. We categorised the remaining 8777 items as Review articles (Dataset 4,
215 n=1759) which provided a review, synthesis or opinion on an animal welfare topic, and
216 included papers discussing ethical issues, and as Original Research articles (Dataset 5,
217 n=7018) which had to contain new data (experimental, observational, quantitative opinion)

on an animal welfare topic. Additional subsets of the last 10 years (2018-2017) of Review articles (Dataset 4a, n=915) and Original Research articles (Dataset 5a, n=4184) 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 as supplementary material.

Several networks were constructed in VOSviewer and visualisations presented in the results section. 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 6 articles and 300 citations for Dataset 4, or 3 articles and 120 citations for Dataset 4a) and Original Research articles (threshold 20 articles and 500 citations for Dataset 5 and 10 articles and 300 citations for Dataset 5a). 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.. 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

(i) Brief historical overview of AW publication metrics in the last 50 years (Initial Dataset)

242 92% of the original 19498 items obtained by our search were in English and 5.2% in German.
243 The number of AW publications has increased substantially from 15 in the period 1968-1972
244 to 7573 in the period 2013-2017; an annual growth of 13.3% (Figure 1a). Figure 1a suggest
245 significant growth in the last 30 years, and the number of publications in the period 1988-
246 1993 (406) to 2013-2017 (7573) has increased at a rate of 15.8% annually. Another measure
247 of the activity of the research field, citations, also indicates a rapid rise since the 1980's,
248 though the drop in citations for the period 2013-2017 is likely to be a result of the recency of
249 these publications (Figure 1a).

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

256 (ii) Broad analysis of citations and keywords from the period 1988-2017 (Dataset 1a)

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

262 A co-occurrence network of the most frequent keywords indicated that stress and behaviour
263 were common keywords and closely linked to many other keywords (Figure 3). On the whole
264 the visualisation indicated the broad concept of animal welfare, covering aspects such as
265 production (e.g. meat quality), husbandry (e.g. environmental enrichment, stocking density),

266 health (e.g. lameness, risk factors), management (e.g. transport, castration) and broader
267 considerations and issues such as ethics, conservation and sustainability. The broad
268 diagrammatic canvas (Figure 3) shows how research on different species may be related, but
269 is not sufficiently fine-scale to establish which animal welfare topics have received most
270 attention within each species.

271 These potential differences in research focus were explored in more detail by
272 visualisationsons of keywords for five common species (Figure 4). Examination of the
273 visualisations shown in Figure 4, and in particular comparison between them can reveal
274 active areas of research and gaps. For example, research on cattle appeared to focus on dairy
275 and diseases of welfare importance such as mastitis and lameness, as well as milk yield.
276 However, there was little reference to housing or environmental enrichment for cattle (Figure
277 4a), even though housing and environmental enrichment topics were more common in the
278 visualisations for other species (Figures 4b-4e). A similar process of examination and
279 comparsion of the visualisations revealed that research on pigs was more closely aligned with
280 research on performance, meat quality and housing, including environmental enrichment, but
281 with little emphasis on cognition and emotion (Figure 4b). Research on laying hens appeared
282 to focus on housing system, feather pecking and a strong behavioural component comprising
283 both applied (design) and fundamental (motivation, aggression) studies (Figure 4c). Research
284 on dogs focussed on behaviour and welfare in particular with relation to kennels and housing,
285 as well as issues to do with their role as companion animals (e.g. attachment, aggression) and
286 some links to work on emotion and affective state (Figure 4d). Figure 3 supports this view
287 with animal emotion terms closely linked to rats, mice, dogs and zoo animals, but emotion
288 was not prominent in the pig and cattle visualisations, perhaps suggesting a gap in the
289 application of emotion research for some farm animal species. Interestingly, inherited
290 disorders did not appear as a common research topic in the dog visualisation (Figure 4d),

291 even though issues such as bone strength, legs and dystocia appear for hens, pigs and cattle.
292 Welfare research on fish is on a variety of different species, and appears most closely focused
293 on stunning, slaughter and pain, though also encompass production aspects such as stocking
294 density and growth (Figure 4e).

295 (iii) Bibliometric analysis of Review, Original Research and Low-cited articles

296 *Review articles (Dataset 4)*

297 Review articles (n=1759) comprised 8% of AW publications, were cited on average 34 times
298 each (articles cited <3 times excluded) with an average publication year of 2007. The
299 majority of review articles however were cited less than 10 times, although the recency of
300 these publications appeared to partly account for their lower number of citations (Figure 5a).

301 A citation analysis of Review articles indicated that 60 articles had been cited at least 150
302 times. Thirty-five of these articles were linked and the remaining 25 reviews were not clearly
303 interlinked with these clusters or with each other. VOSviewer grouped the linked review
304 articles into 5 clusters (Figure 6). The content of each cluster can be roughly typified as: 1)
305 stress and fear responses which included human-animal interaction and environmental
306 enrichment (blue), 2) emotion (green), 3) environmental enrichment which included
307 motivation, underlying welfare concepts and stereotypic behaviour (yellow), 4) welfare
308 assessment including stereotypic behaviour as an indicator of welfare (purple) and 5) fish
309 welfare (red). A complete list of all 60 review articles that were cited at least 150 times can
310 be seen in the Supplementary materials (Dataset 6). The three most highly cited reviews that
311 were not linked reviewed feedback mechanisms and food preferences in ruminants (Provenza
312 1995), undesirable effects of high production efficiency in farm animals (Rauw et al 1998),
313 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 7a). 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 Sandoe, 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 10 years (Figure 7b, e.g. 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 7b (e.g. 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 topic by authors who are not strongly integrated into the central animal welfare network (e.g. 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=7018) 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 10 times, and there was some indication that recency of publication accounted for the limited number of citations of some articles (Figure 5b).

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; 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 9a). Almost all of these authors mainly study farm animals. Tuyttens has an interesting position in Figure 9a, with close links to co-authors (Vanhonacker) but also with others in Spain and Latin america. The last 10 years has similarly focussed largely on farm animals (Figure 9b), though other topics such as consumer and stakeholder influences (e.g. Vanhonacker, Verbeke) and researchers in countries with a more recent tradition of animal welfare research (e.g. 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 9b 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 10 years (M Bateson, Gygax, Paul).

There was considerable overlap in the authors of 6 or more highly cited review articles (Figure 7a) and authors of 20 or more highly cited research articles (Figure 9a). Authors who appear in both of these datasets include Barnett, Baumans, Boissy, Broom, Fraser, Grandin,

362 Hemsworth, Keeling, von Keyserlingk, Jones, Manteca, Manteuffel, Mason, Mendl, Nicol,
363 Rushen, Veissier and Weary.

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

372 *Low-cited articles (Dataset 3a)*

373 Mean publication year of Low-cited articles from 1988-2015 was 2008, compared to 2007 for
374 articles with 4 or more citations. Co-occurrence network of all keywords indicated that, in
375 common with more highly cited articles, stress and behaviour were common keywords and
376 closely linked to other keywords (Figure 11) and that farm animals were commonly included
377 in keywords. On the whole there was little indication that the topics of Low-cited articles
378 differed from those of more highly cited articles. Citations analysis indicated that
379 publications originating from some countries (e.g. Brazil, Spain, Mexico, China) may not yet
380 be extensively cited because they have only recently begun publishing research on animal
381 welfare (Figure 12). More Low-cited articles originate from Germany than from other
382 countries (Figure 12), suggesting that publications in German are less frequently cited than
383 publications in English. This was supported by the finding that 15% of Low-cited articles
384 were in German, compared to 5.2% of all AW publications and that 76% of low cited articles
385 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 differerent searches and approaches (Borsi & Schubert 2011; Rodriguez-Ledesma et al 2014; Walker et al 2014; 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, and attract researchers and funding. However, this trend may also have some negative implications for the scientists, the public and policymakers. 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 will perhaps require researchers to adopt strategies to deal with these emerging challenges (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

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

426 Applied Animal Behaviour Science and Animal Welfare and animal-specific journals were
427 again found to dominate publications in animal welfare (Walker et al 2014). Our findings
428 show that PLOS One has emerged as a top-ten publisher of animal welfare articles, which did
429 not appear in the top 81 journal publishing animal welfare in the period 1993-2012 (Walker
430 et al 2014), though it is important to note that PLOS One started in 2006. In fact, in the last 5
431 years (i.e. 2013-2017, which is the period after the study of Walker et al 2014), PLOS One
432 has published 264 papers on animal welfare, compared to 410 articles in Applied Animal
433 Behaviour Science and 244 in Animal Welfare. It would appear that animal welfare scientists
434 have embraced Open Access publishing, though it is important to note that authors that are
435 unable to pay for this may not disseminate their findings as widely as authors able to afford

436 open publishing. However some journals such as Animal Welfare have mechanisms, such as
437 self-archiving and open access in developing countries, to overcome such challenges.

438 Review articles comprised 8% of AW publications and were on average cited more times
439 than Original Research articles (34 and 19 times respectively), which is not unusual in the
440 literature (e.g. Seglen 1997, Ioannidis 2006). However, little is known about the relative
441 proportion and citations of reviews and original research articles in the sciences. As presented
442 in the introduction, the concept of animal welfare can mean different things to different
443 people, animal scientists included (Fraser 2008), and we initially suspected that a need to put
444 forward and reinforce opposing views might contribute to a large proportion of review
445 articles. However, comparison with other fields suggests that animal welfare science may not
446 differ greatly from other animal science fields in this respect. The raw classifications of
447 document types for "animal welfare" in the ISI Science-Expanded index are articles 74.9%,
448 proceedings, 10.8%, reviews, 7.1%, editorials, 5.4% and news items 3.1%. In contrast, for
449 "animal science" the classifications are articles 76.9%, proceedings, 10.1%, reviews 9.3%,
450 meeting abstracts 2.7%, editorials 2.4% and news items 0.9% (documents can be classified as
451 more than one type so totals may add up to more than 100%). Although we are aware from
452 our examination of every document in the Initial Dataset that these raw classifications are not
453 very accurate, the similarity in patterning between these two fields does not confirm our
454 initial suspicion, with the exception that animal welfare appears to be a relatively popular
455 topic for editorials and news items. Furthermore, it is possible that our search terms were
456 more likely to identify review articles than original research articles, because we expect that
457 all reviews on animal welfare will include the term "welfare", whereas original articles may
458 not (for example, a publication on feather pecking in laying hens may not include the word
459 "welfare" per se). This latter point also does not support our initial suspicion that there would
460 be more review papers in animal welfare than in other fields.

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

478 There was considerable overlap in the core authors of Review and Original Research articles,
479 suggesting that many reviews within the field of animal welfare science are informed by
480 direct empirical experience. Identifying core researchers within a discipline may be useful in
481 obtaining highly knowledgeable viewpoints, or for identiying suitable individuals for
482 leadership and advisory roles (Boyack et al 2013). However, creating "lists" of core
483 researchers for policy purposes may not be as useful as it first appears within animal welfare
484 for two reasons. First, animal welfare has an ethical component, so that even when scientists
485 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 Shot & 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 underrepresented in our analysis for this reason. It is worth stressing that this consideration also applies more broadly, with research on some topics (e.g 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 10 years has similarly focussed largely on farm animals, though there is evidence of more "satellite" authors now working independently on specialised aspects of welfare, such

511 as welfare of wildlife and equine welfare. Interestingly, the last 10 years has also shown
512 tightly networked and interlinked work on cognition and emotion, perhaps indicating
513 considerable activity in this highly specialised area.

514 Network analysis of organisations revealed the main publishers of Original Research articles,
515 with the University of Bristol being cited more times than other organisations. In general the
516 four clusters identified were linked by geographical location, which were roughly around the
517 UK, USA, Scandinavia and the Netherlands. Some exceptions to the geography-based
518 composition of the clusters were found which may have been related to the movement of key
519 researchers, many of which studied in the UK. Within Europe, some framework programs
520 explicitly aim to encourage institutions from member states underprepresented in the research
521 area to become involved in research. Kirchner et al (2017) found that large research consortia
522 such as Welfare Quality (2013) do indeed provide communication platforms and assist in
523 establishing AW research in emerging institutes, though on the whole widespread
524 collaboration involving emerging institutes was rather low. Alternatively, particularly on a
525 global scale, it may be that animal welfare science addresses local issues (e.g. farming
526 conditions or species farmed) and this would limit the extent to which research is cited by
527 researchers in other geographical areas.

528 One possible reason for articles to be Low-cited could be if they were on very specialised
529 topics. However, our co-word analysis of keywords offered little indication that Low-cited
530 articles were on different topics than more highly cited articles. Instead, citation analysis of
531 country indicated that many Low-cited articles were originating from Germany and 15%
532 were written in German. It is important to stress that this result may have been an artefact of
533 our search strategy. Although we included all languages in our search, because our terms
534 were in English, they would have biased the sample and possibly excluded many non-English
535 publications. The pre-eminence of English within the scientific literature has been well-

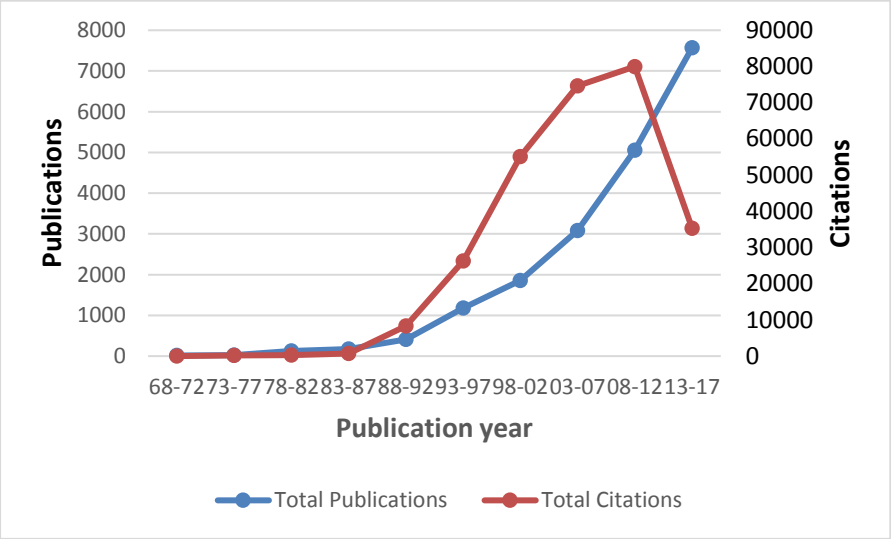
536 documented, and pros and cons to this de-facto state considered (e.g. van Leeuwen et al 2001;
537 Hamel 2007). It is possible that many worthwhile results and opinions on animal welfare may
538 be being missed by other researchers due to language barriers (Meneghini & Packer, 2007).
539 This is supported by the finding that 5299 (84%) Low-cited articles were in English,
540 compared to 92% of all AW publications. Our findings of Low-cited articles at first glance
541 indicate that countries such as Brazil, China, Mexico and Spain are only beginning to publish
542 in animal welfare, and this may be the case. However, the above observed higher proportion
543 of non-English compared to English Low-cited articles raises the possibility that the apparent
544 "emergence" of these countries may also be a result of the language barrier, and that perhaps
545 it is due to these countries only recently beginning to publish in English.

546 Finally, although bibliometric analysis has become established as a valuable method for
547 evaluating scientific production (Ellegaard & Wallin 2015), it should be remembered that
548 animal welfare in particular has a broader appeal beyond scientists and policymakers. The
549 reviews that have been most highly cited by other scientific publications as reported by ISI
550 Web of Science in our bibliometric analysis have been cited far more widely within the so-
551 called "grey literature" by Google Scholar (Provenza 1995, 516 vs 896 citations in Google
552 Scholar; Dawkins 1990, 470 vs 881 in Google Scholar; Barton 2002, 872 vs 1430 in Google
553 Scholar). This is similarly apparent for original research articles (Kestin et al 1992, 266 vs
554 443 in Google Scholar; Kruip & Den Daas 1997, 258 vs 364 in Google Scholar; Whay et al
555 2003, 262 vs 389 in Google Scholar). Thus there is likely to be considerable literature,
556 patents and government and other stakeholder reports which influence the discipline yet
557 would not appear in Scientific Journal databases. Much of this literature is written by animal
558 welfare scientists, and can even be in a scientific article format (e.g.
559 https://www.awselva.org.uk/journals).

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 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.

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).

(1a)



(1b)

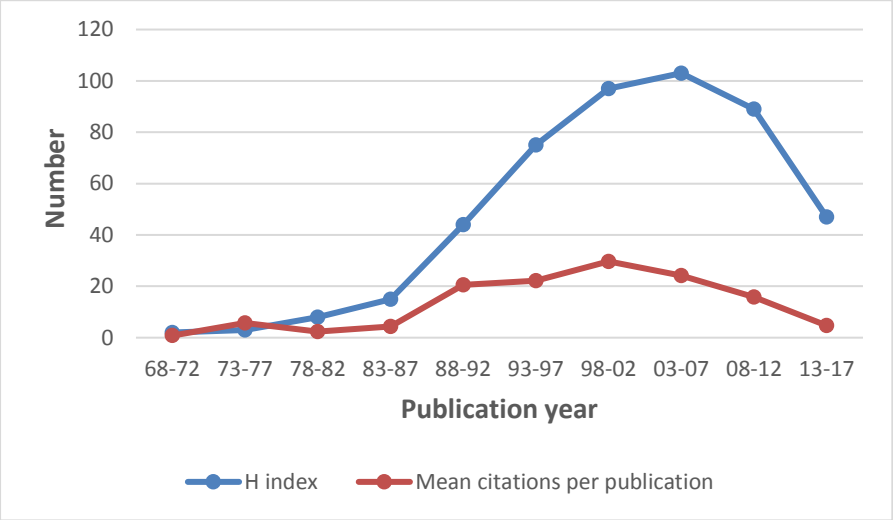
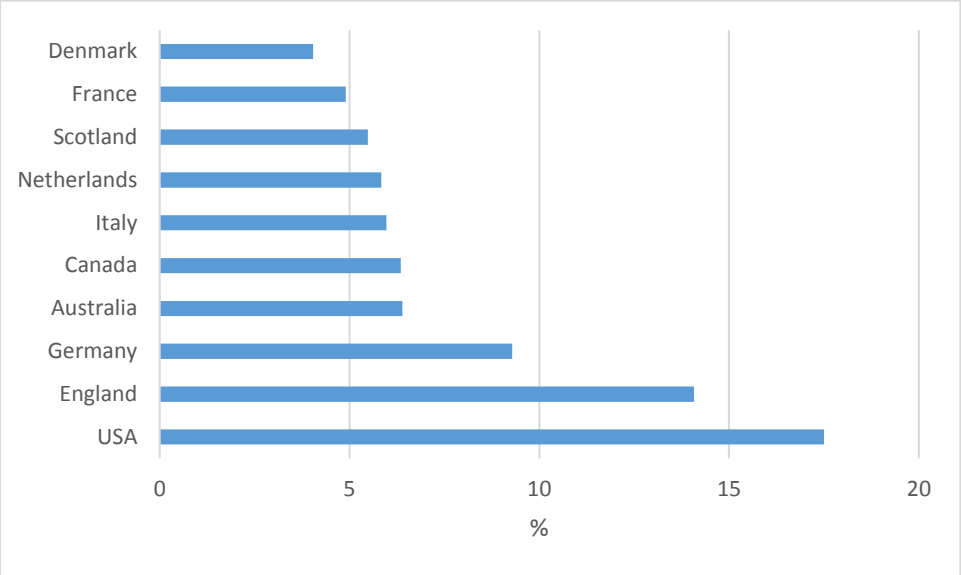


Figure 2: Percentage of AW publications from 1988-2017 (Dataset 1a) indexed by (a) country of origin and (b) source title (*Web of Science Core Collection)*. The 10 results from each field that have contributed most are presented.

(a)



(b)

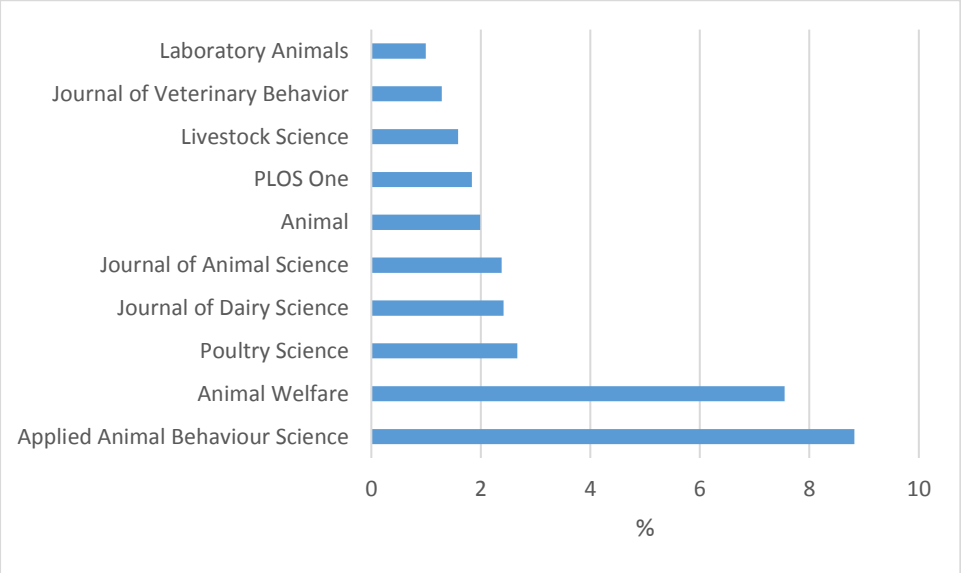


Figure 3: VOSviewer density visualisation of a keyword co-occurrence network of AW publications from 1988-2017 (Dataset 1a). Yellow areas indicated a larger number of publications that have the corresponding term and terms that co-occur frequently are located close to each other in the visualisation.

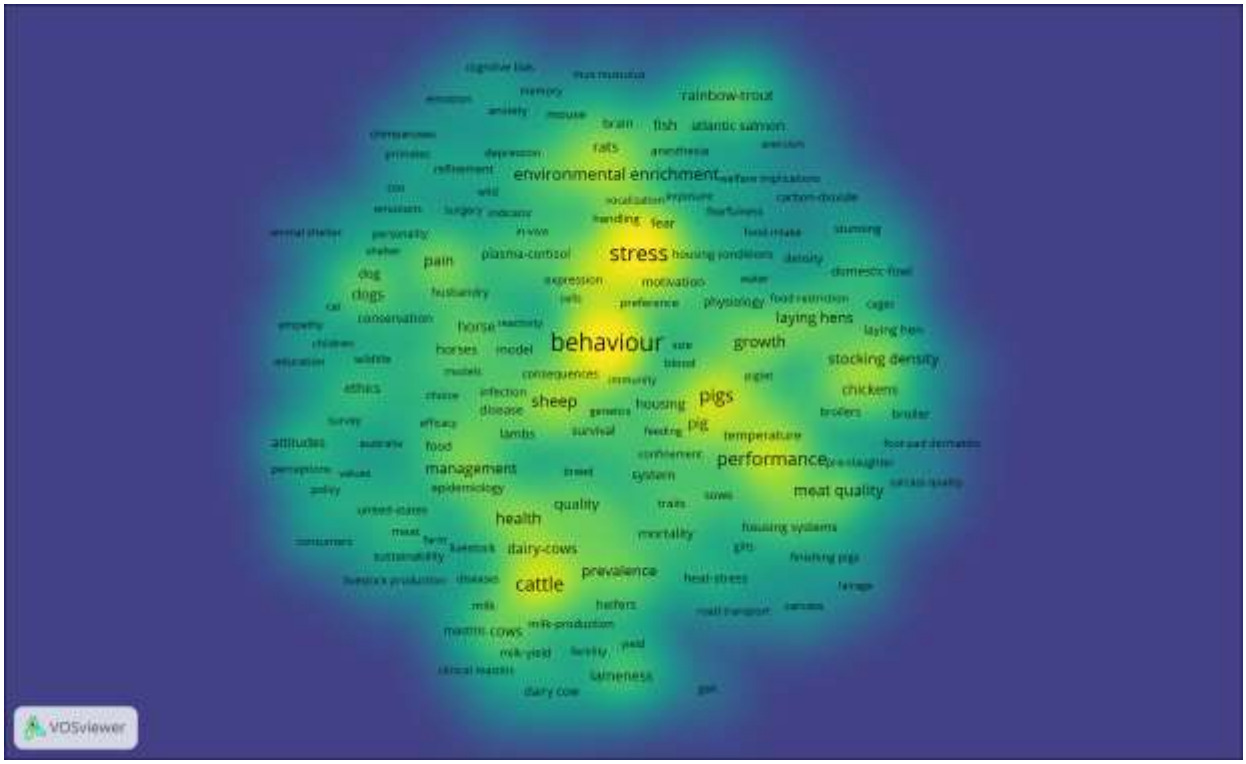
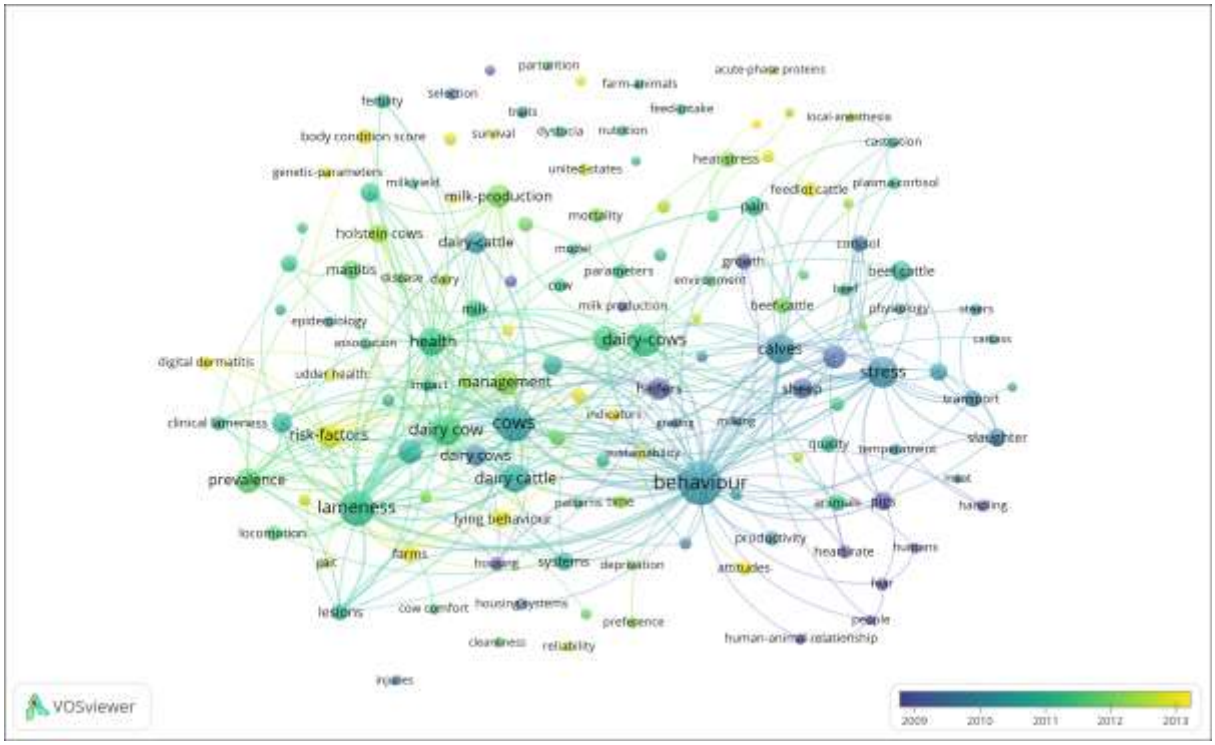
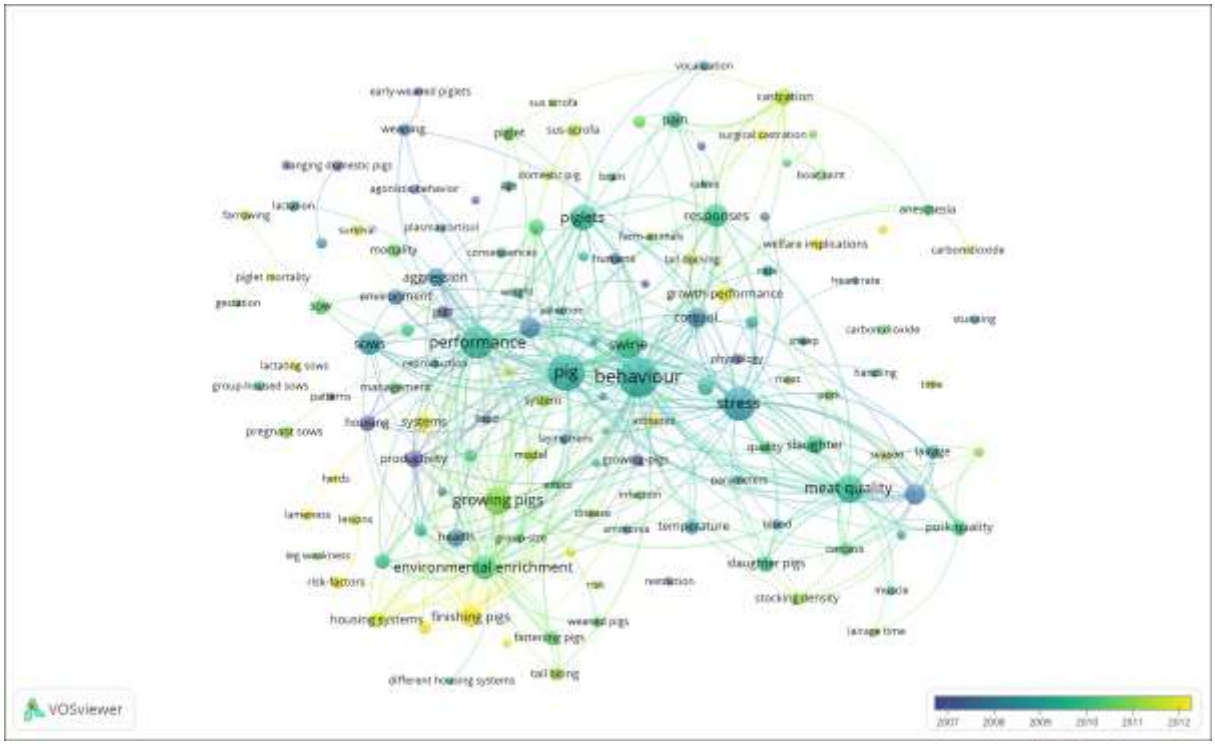


Figure 4: VOSviewer visualisation of a keyword co-occurrence network of AW publications from 1988-2017 on (a) cattle (Dataset 1b), (b) pig (Dataset 1c), (c) laying hen (Dataset 1d), d) dog (Dataset 1e) or e) fish (Dataset 1f). Size of node is related to frequency of occurrence of the term and terms that co-occur frequently are located close to each other in the visualisation.

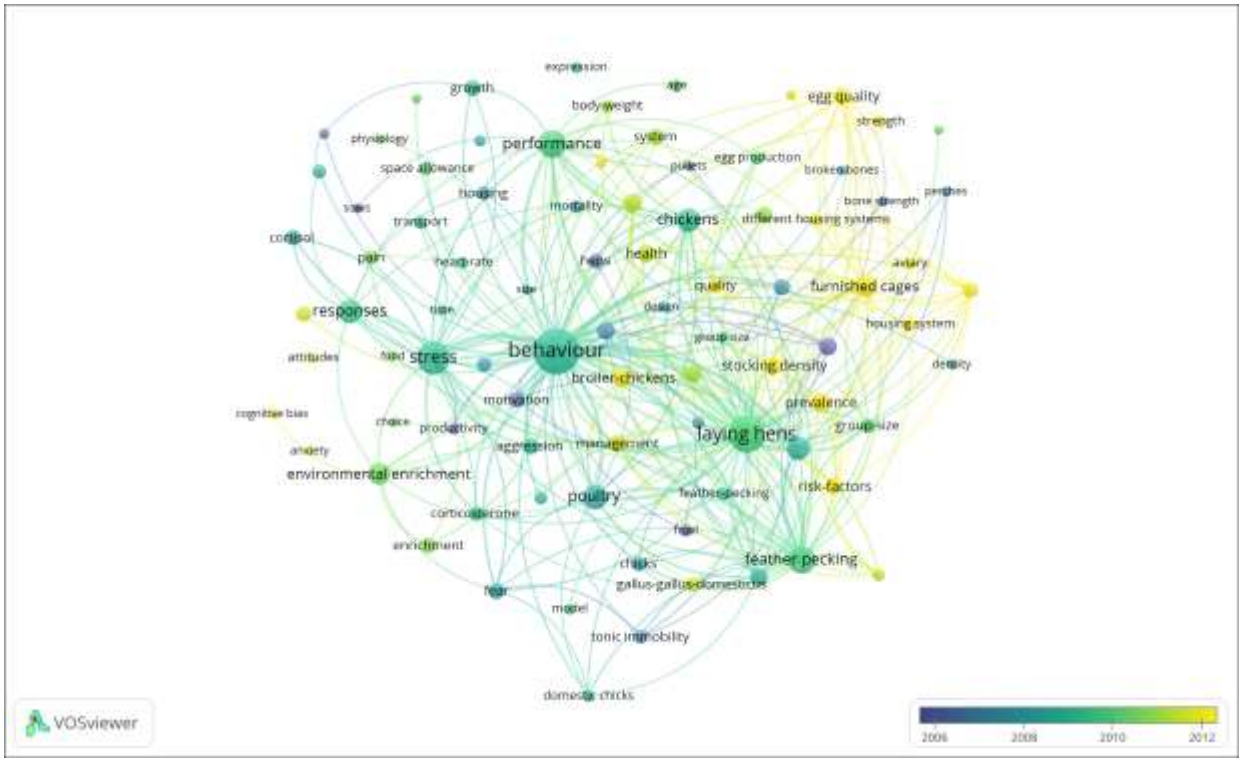
(a)



(b)

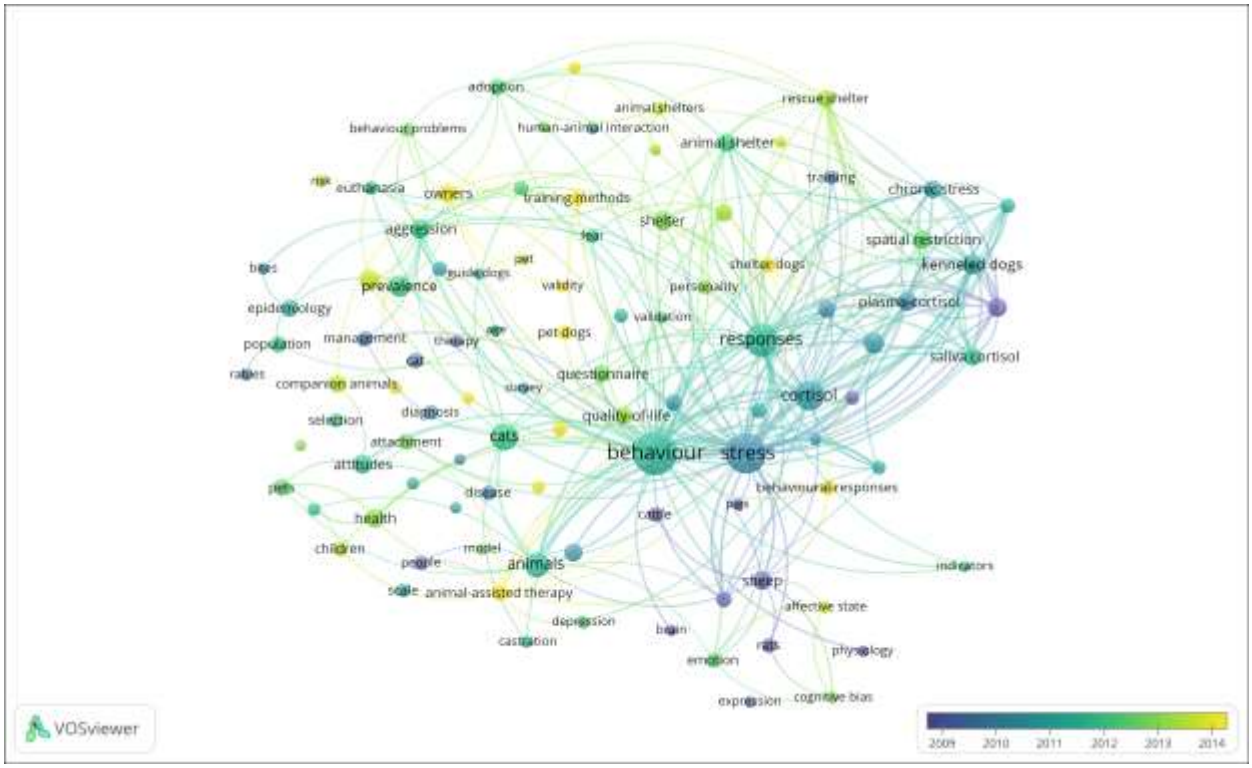


628 (c)



629

630 (d)



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(e)

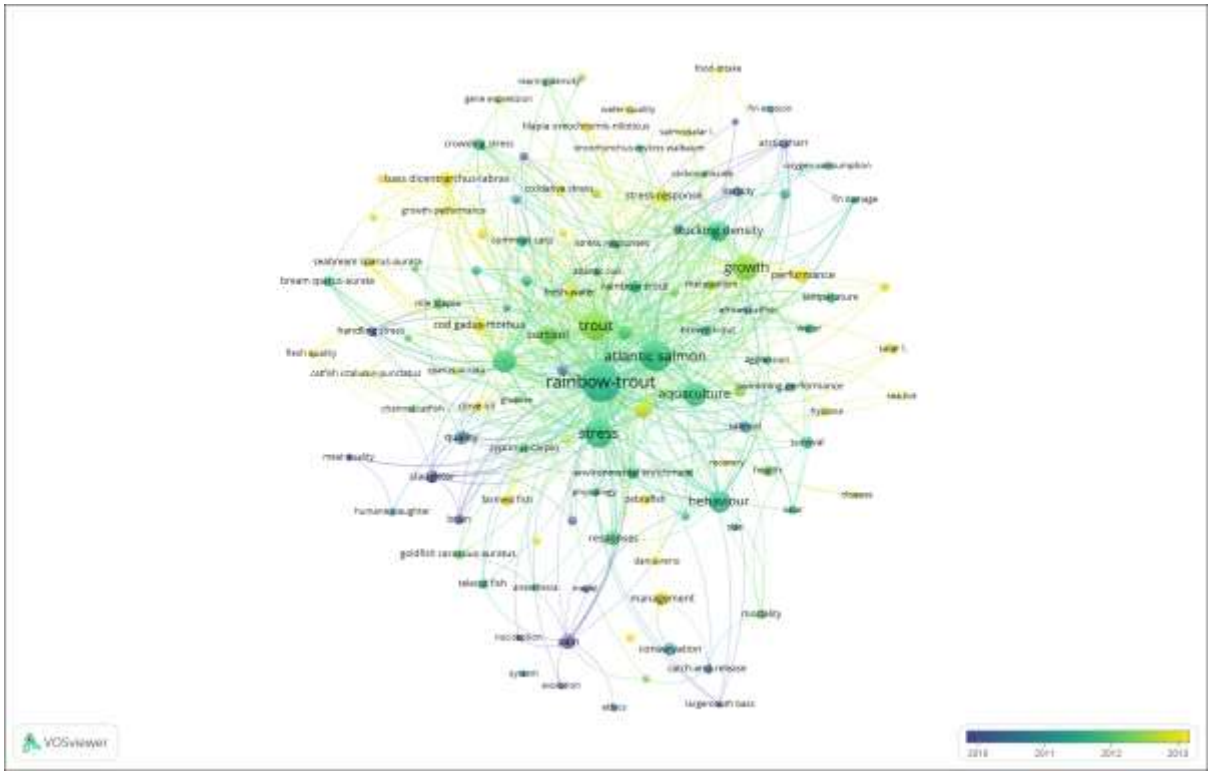
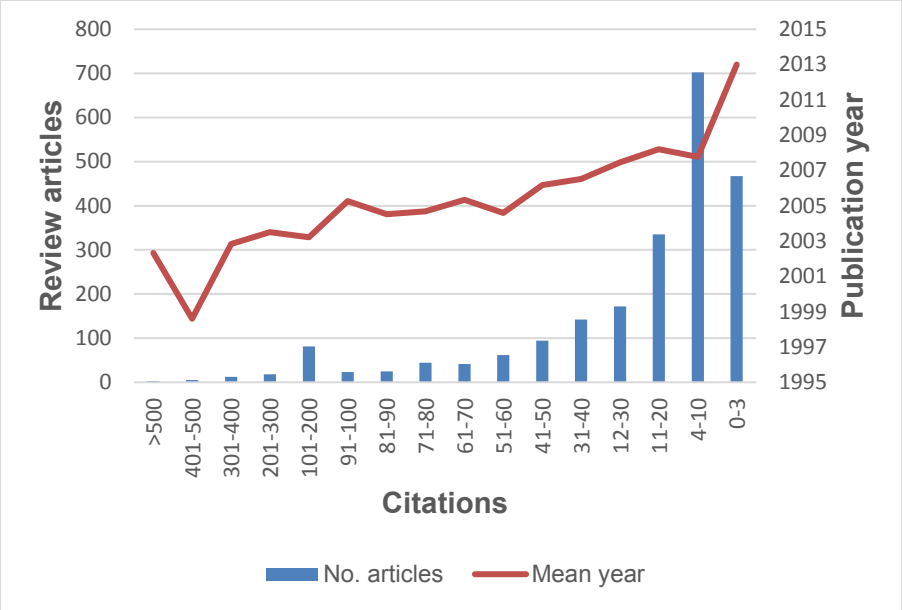

stocking density
growth
performance
trout
salmo
atlantic salmon
rainbow-trout
aquaculture
stress
behaviour
welfare
management
mortality
VOSviewer

Figure 5. Frequency of article citations and mean publication year of (a) Review articles (Dataset 4) and (b) Original Research articles (Dataset 5).

(a)



(b)

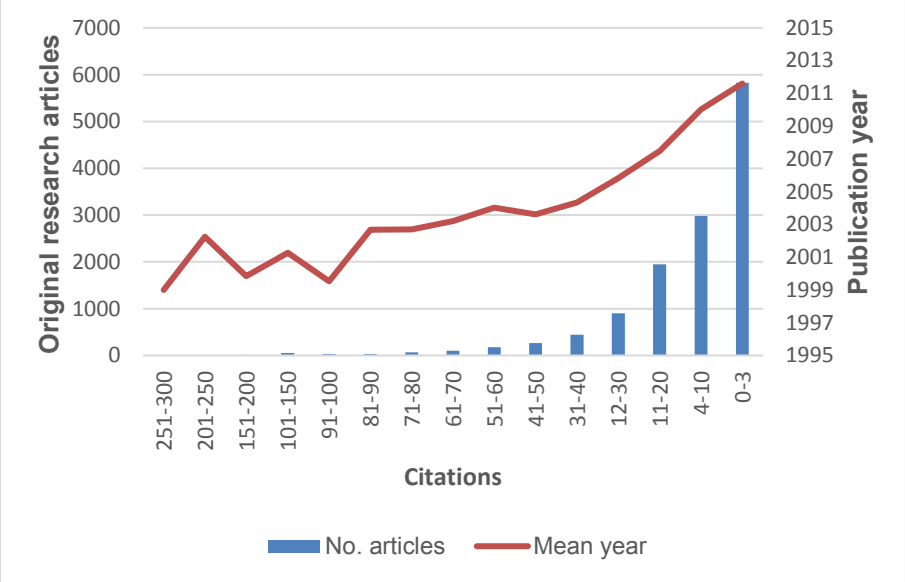
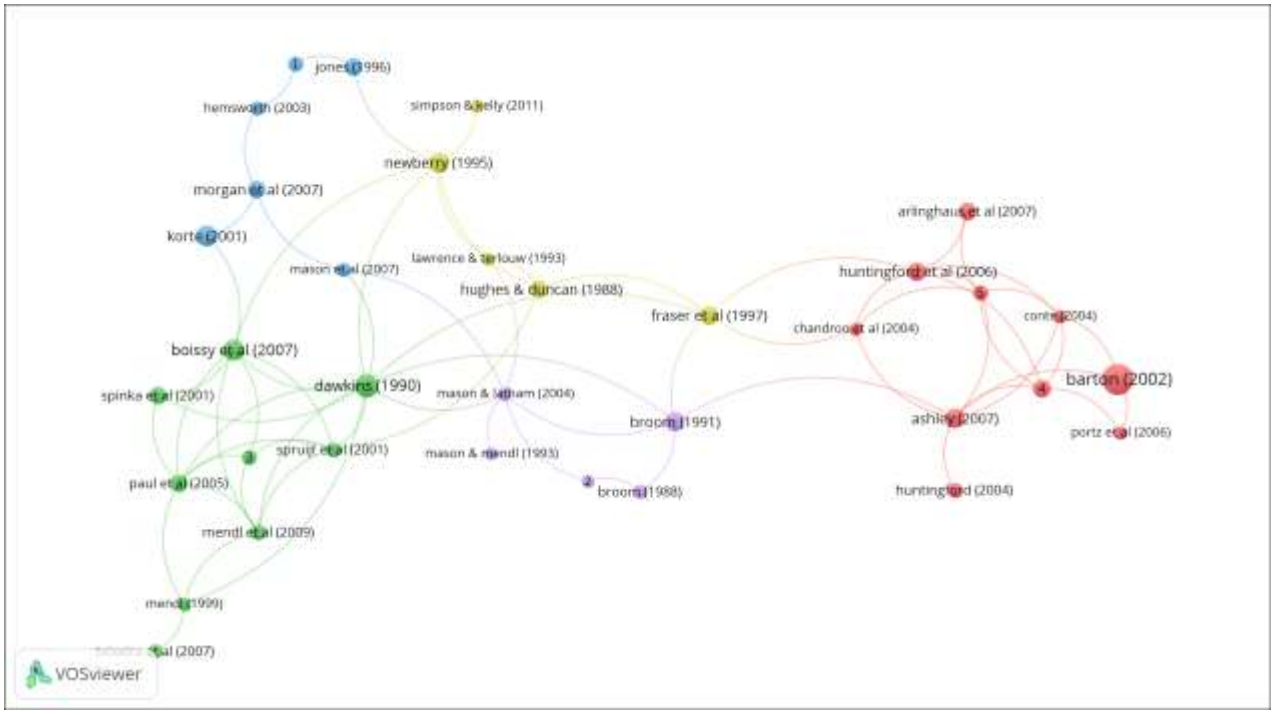


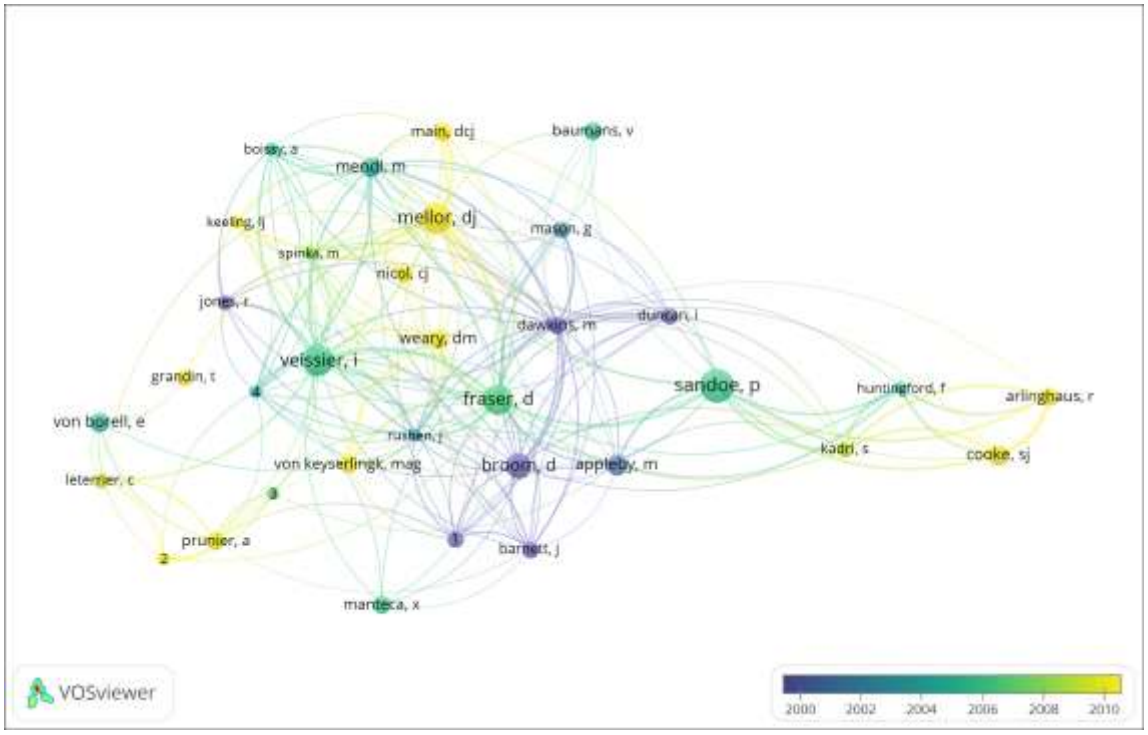
Figure 6: VOSviewer visualisation of a publication citation network of linked Review articles that have been cited at least 150 times (Dataset 4). Size of nodes indicated the number of citations and nearness of nodes indicates authors that are closely linked (i.e. authors that have been co-cited more times). Colours indicate the clusters generated by VOSviewer.



Key. 1, Waiblinger et al. (2006); 2, Wielebnnoski et al. (2002); 3, Mendl et al. (2010); 4, Ellis et al. (2002); 5, Rose (2002).

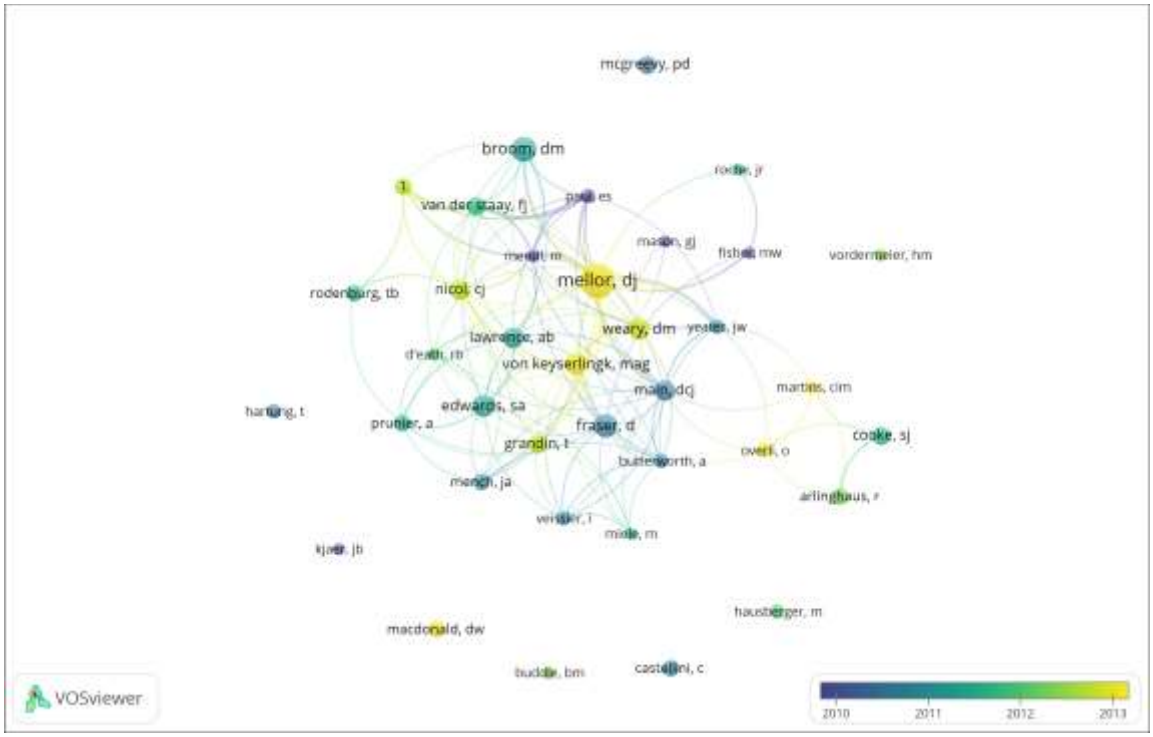
Figure 7: VOSviewer visualisation of a network of core authors of Review articles from (a) 1988-2017 (Dataset 4) and (b) from 2008-2017 (Datasest 4a). Size of nodes indicates the number of citations and nearness of nodes indicates authors that are closely linked by VOSviewer (i.e. authors that have been co-cited more times).

(a)



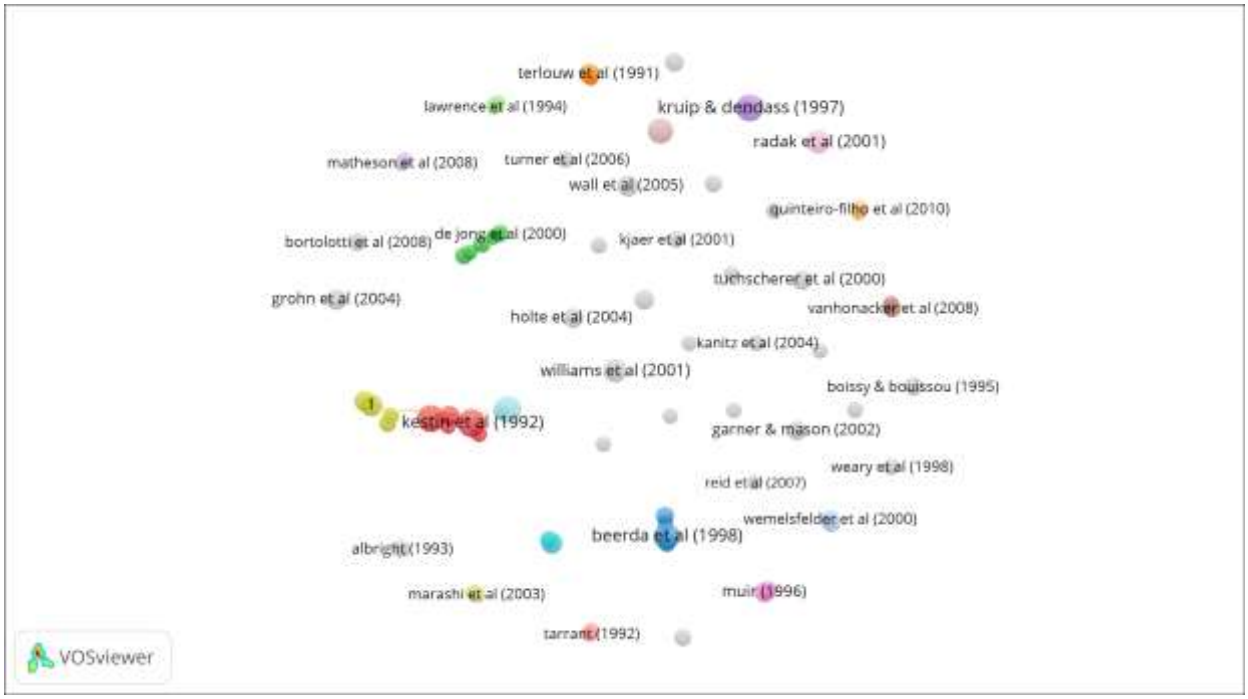
Key: 1, Hemsworth, P; 2, Mormede, P; 3, Guemene, D; 4, Maunteuffel, G.

(b)



Key: 1, Nordquist, RE.

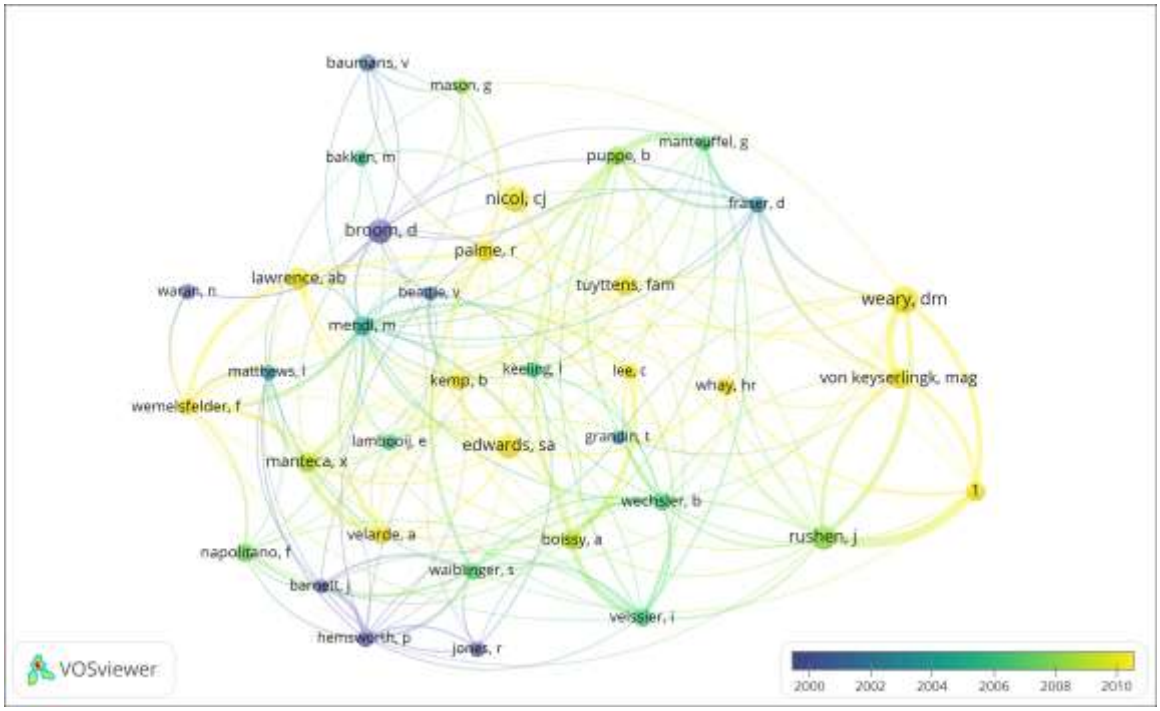
Figure 8: VOSviewer visualisation of a publication citation network of Original Research articles that have been cited at least 100 times (Dataset 5). Size of nodes indicated the number of citations and nearness of nodes indicates authors that are closely linked (i.e. authors that have been co-cited more times). Colours indicate the clusters generated by VOSviewer.



Key: 1, Sneddon et al 2003.

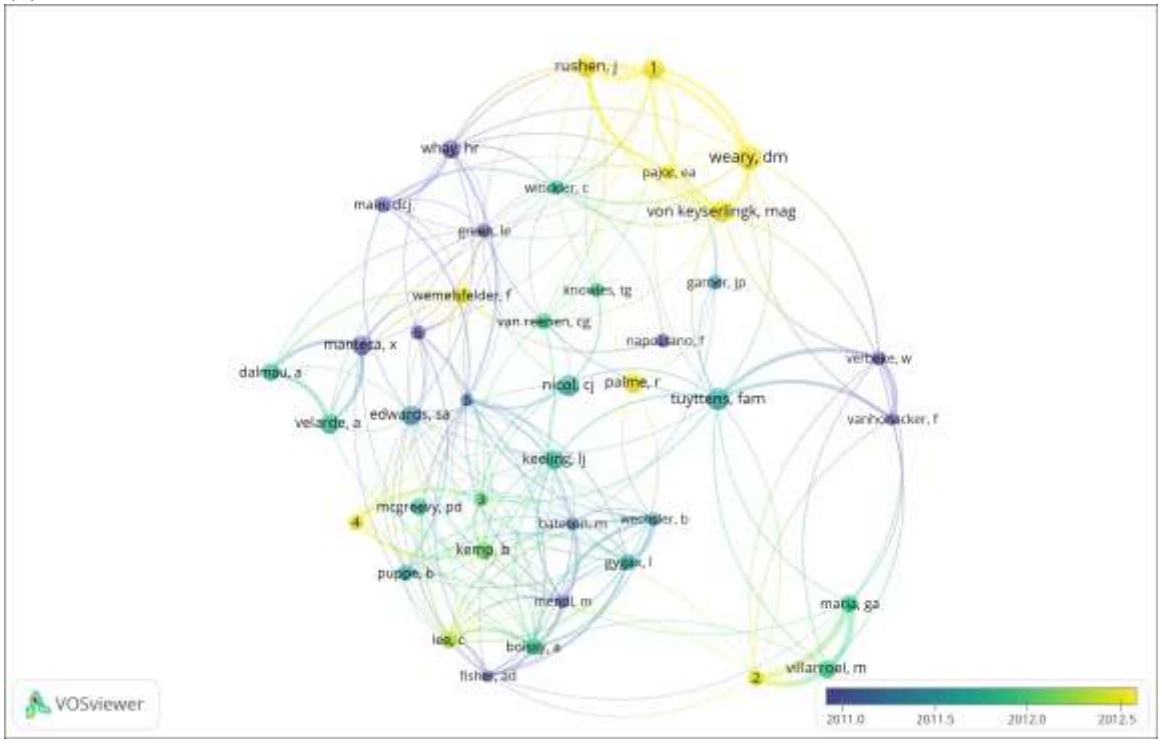
Figure 9: VOSviewer visualisation of a network of core authors of Original Research articles from (a) 1988-2017 (Dataset 5) and (b) 2008-2017 (Dataset 5a). Size of nodes indicates the number of citations and nearness of nodes indicates authors that are closely linked (i.e. authors that have been co-cited more times).

(a)



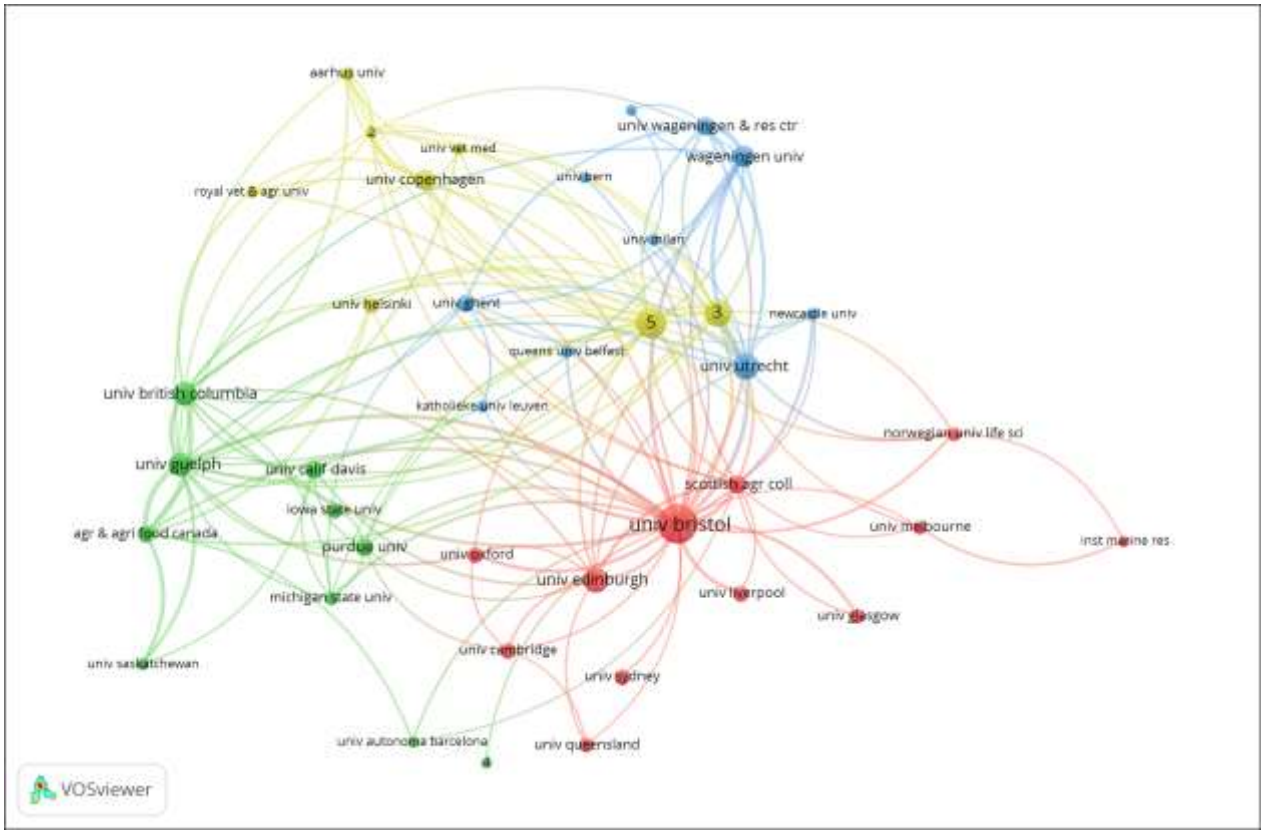
Key: 1, de Passile, AM.

(b)



Key: 1, de Passille, 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 indicates the number of citations and nearness of nodes indicates organisations that are closely linked (i.e. organisations that have been co-cited more times). Colours indicate the clusters generated by VOSviewer.



Key: 1 (blue node next to Univ Wageningen & Res Ctr), Univ Padua; 2, Danish Inst Agr Sci; 3, INRA; 4, Massey Univ; 5, Swedish Univ Agr Sci.

Figure 11: VOSviewer visualisation of a network of the most common keywords in Low-cited articles (Dataset 3a). Yellow areas indicated 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.

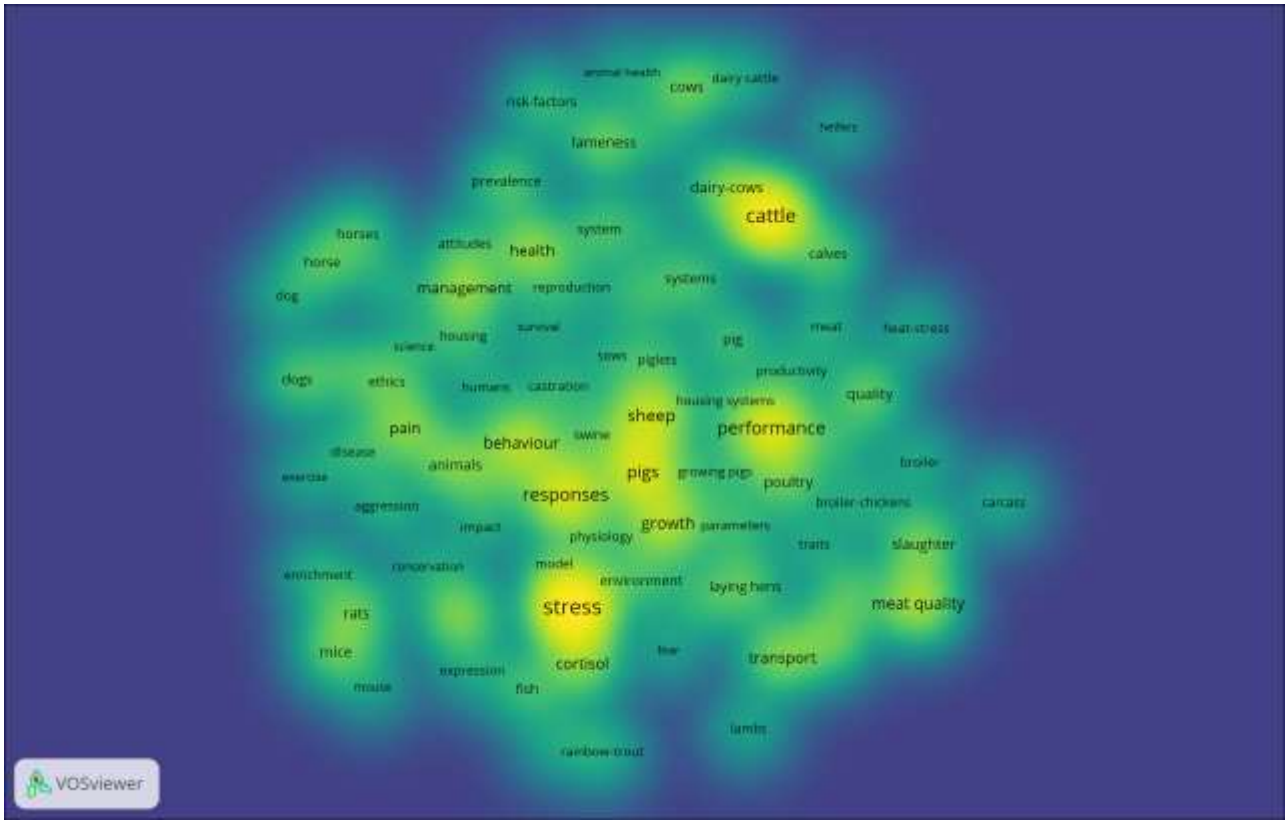
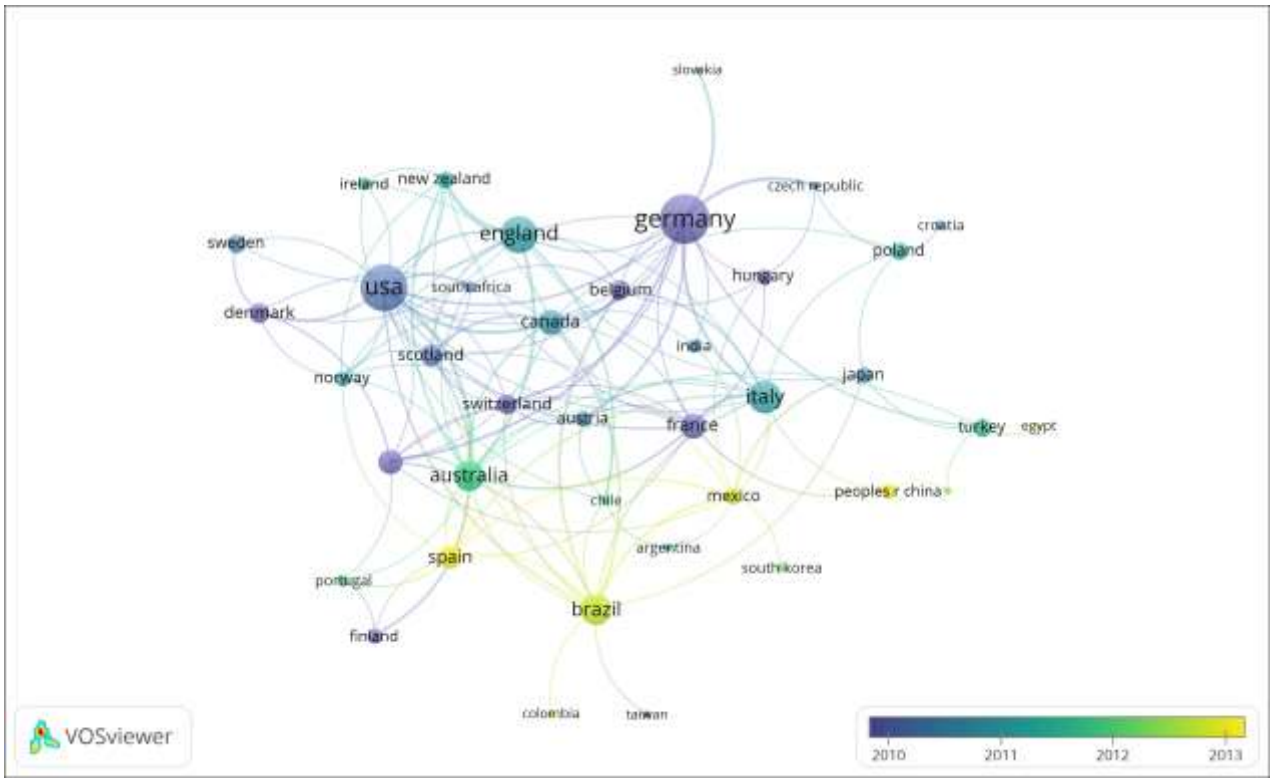


Figure 12: VOSviewer visualisation of countries that have the most Low-cited articles (Dataset 3a). Size of nodes indicated the number of citations and nearness of nodes indicates countries that are closely linked (i.e. countries that have been co-cited more times).



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