Does scientific interest in the nature impacts of food align with consumer information-seeking behavior?

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Key Points:

- Scientific research attention on nature-related impacts of food does not align with consumer information-seeking behavior.
- Scientific research focuses most on emissions and climate change impacts of agri-food systems and overlooks biodiversity impacts.
- Public information-seeking about biodiversity impacts of agri-food systems increased significantly between 2009 and 2020.

Abstract

Global food supply has substantial impacts on nature including environmental degradation from chemicals, carbon emissions and biodiversity loss through agricultural land conversion. Over the past decade, public demand for information on sustainable consumption choices has increased. Meanwhile, development and expansion of the life cycle assessment literature has improved scientific evidence on supply-chain impacts on the environment. However, data gaps and biases lead to uncertainty and undermine development of effective impact mitigation actions or behavior-change policies. This study evaluates whether scientific research into the nature-related impacts of agri-food systems aligns with the needs of the public, as indicated by patterns of information seeking. We compare the relative volume of public Google queries to scientific articles related to agri-food systems and three major impacts: chemical pollution, greenhouse gas emissions or biodiversity loss. We discover that biodiversity is systematically overlooked in scientific studies on agri-food system impacts in favor of research on emissions. In contrast, the relative volumes of public queries on agri-food systems and biodiversity equal those for emissions impacts at global and Australian scales. Public interest in biodiversity impacts of agri-food systems increased significantly between 2009 and 2020, despite no significant change in the relative volume of biodiversity-focused scientific articles. Both public and scientific attention on chemical impacts declined significantly over this time period. We recommend strategic investment into the biodiversity impacts of agri-food systems to build a knowledge base that allows the public to learn about the impacts of their choices and be inspired to change to more sustainable behaviors.

Plain Language Summary

We conducted a review of how people use social media (Twitter) and a public search platform (Google) to find information on the nature-based impacts of their food consumption choices. We compared public information seeking behavior with scientific research attention on the environmental impacts of food, and found that scientific interest in the nature-related impacts of food does not align with consumer information-seeking behavior. Scientific research focuses most on emissions and climate change impacts of agri-food systems and overlooks biodiversity impacts. In contrast, public information-seeking about biodiversity impacts of agri-food systems

increased significantly between 2009 and 2020. Lack of data on the environmental impacts of agriculture and food may constrain consumer awareness and behavior-change interventions. Strategic investment into research on nature-related impacts of agri-food systems will improve the public's knowledge base.

1. Introduction

Food supply and consumption places substantial pressures on natural resources with associated impacts on ecosystems and climate change. These pressures stem from the choices made by farmers before and during production, to consumer choices at the end of the supply chain (Kastner, Rivas, Koch, & Nonhebel, 2012; Tilman, 1999; Tukker et al., 2011). For a long time, public interest in the impacts of food and agriculture focused predominantly on welfare and ethical issues (Grunert, Sonntag, Glanz-Chanos, & Forum, 2018) or human health (Cavaliere, De Marchi, & Banterle, 2017; Prieto-Castillo, Royo-Bordonada, & Moya-Geromini, 2015; Yearley, 2001). Over the past decade, public interest in sustainability, sustainable production, and sustainable consumption has increased (Clark, Springmann, Hill, & Tilman, 2019; Crist, Mora, & Engelman, 2017). Concurrently, development and expansion of life cycle assessment (LCA) research has rapidly increased information available on the chain of agricultural product supply and associated environmental impacts around the world (de Baan, Alkemade, & Koellner, 2013; Nemecek, Jungbluth, i Canals, & Schenck, 2016; Vermeir & Verbeke, 2006). Generating data and providing timely, accurate and relevant information on the environmental impacts of food is an important foundation for public engagement and enabling more sustainable consumption choices. Here we ask, do scientific evaluations of the nature-related impacts of food supply chains align with the information needs of the public?

More than a third of the global land area is used for agricultural production of crops and livestock (FAO, 2018). Although environmental impacts occur across the food supply chain from production to consumption, most of the impacts occur at the start during production (Lai et al., 2016; Poore & Nemecek, 2018). Such impacts include pollution stemming from use of chemicals such as pesticides, herbicides and fertilizers during agricultural production, loss of biodiversity and important habitats stemming from conversion of forests to cropping and animal production, and carbon emissions stemming from both livestock grazing (in particular beef) and land clearing (Butler, Vickery, & Norris, 2007; Donald, 2004; Lai et al., 2016). Huge and immediate changes are needed to promote environmentally sustainable practices and ensure sustainable management of ecosystems. Numerous impact mitigation strategies have been developed to improve the environmental sustainability of food production and consumption, including climate-smart agriculture, efficiency-focused technological measures on farms and waste reduction innovations (Garnett, 2011). However, uptake of many sustainability strategies by the agricultural sector has been slow (Mills et al., 2019).

Mitigation of environmental impacts at the agricultural production end of the food supply chain will be insufficient to meet global targets for emissions reduction – consumer behaviors also need to change (Popp, Lotze-Campen, & Bodirsky, 2010). In the United Kingdom alone, changing from the current average diet to a vegetarian or vegan diet could generate greenhouse gas savings of 22-26% (Kim et al., 2019). Public education and behavior change campaigns aim to enable such societal change in food consumption choices and strengthen support for policies that reduce consumption of environmentally unsustainable products (Guthrie, Mancino, & Lin, 2015; Osbaldiston & Schott, 2011). Such changes may have the additional benefit of "nudging the marketplace," encouraging food producers and suppliers to improve products and make them more widely available, creating a virtuous circle in which making sustainable food choices is increasingly easy and normative, becoming the typical behavior for consumers (Andrews, Netemeyer, & Burton, 2009). Early adopters of new food consumption practices can influence the choices of others, through direct encouragement and modelling new behavioral norms (Dearing, 2008; Rogers, 1962). In one study of consumers with relatively high levels of knowledge and motivation—a group termed "the nutrition elite"— food purchase choices were influenced by nutrition information (Andrews et al., 2009). It is therefore possible that consumers with high levels of knowledge on the environmental sustainability of food could lead in transformative change of food purchasing and consumption practices to more sustainable options.

Knowledge—of both environmental issues and how to take action—is a critical ingredient of promoting uptake of sustainable behaviors (Carmi, Arnon, & Orion, 2015; Dean, Lindsay, Fielding, & Smith, 2016; Kaiser & Fuhrer, 2003; Vicente-Molina, Fernández-Sáinz, & Izagirre-Olaizola, 2013). Accurate, comprehensive knowledge of environmental impacts is needed not only to help the public make informed choices, but also to guide investments in impact mitigation interventions and inform global and national sustainability policies. While the scientific literature in the field of food LCA increased more than ten-fold during the last 15 years, LCA studies vary hugely in the indicators that they select to measure, with the predominant focus being on indicators of energy-related impacts that are typically global in scale (Nemecek et al., 2016; Roy et al., 2009). This focus could undermine development of associated impact mitigation actions or policies addressing other types of site-dependent impacts (Notarnicola et al., 2017). One area that has been less well examined is the impacts of land use on nature and biodiversity. For example, unsustainable agricultural practices and resource depletion coupled with conversion of enormous amounts of land have led to agriculture jeopardizing more than 62% of all threatened species with extinction (Holden, White, Lange, & Oldfield, 2018; Maxwell, Fuller, Brooks, & Watson, 2016). Such changes in biodiversity may have important repercussions for human health and well-being (Díaz, Fargione, Chapin, & Tilman, 2006). In addition to undermining environmental impact mitigation efforts, lack of information on diverse types of impacts may bias the knowledge base, constraining public awareness and capacity to adopt new behaviors (Curran et al., 2016; Negra et al., 2020). Although many models to quantify land-use impacts on biodiversity have been proposed in the scientific literature (see Curran et al., 2016 for a review of such models), there has been no coordinated effort to track whether biodiversity is routinely incorporated into LCA studies of agri-food supply chains.

The aim of this study was to determine whether the scientific literature examining nature impacts of food aligns with the information needs and interests of the public. Public interest in nature-related impacts and sustainable behavior can range from reducing global emissions (e.g. choosing "low-carbon food" by switching from meat and dairy to plant-based alternatives), to reducing chemicals in farming and food production (e.g. "organic" food and farming) to mitigating impacts on the land and its biodiversity (e.g. buying "wildlife-friendly" food such as "crane-friendly" rice) (Khai & Yabe, 2015; Selfa, Jussaume, & Winter, 2008; Ujiie, 2014; Vlaeminck, Jiang, & Vranken, 2014). We identified short-term and long-term patterns in public information-seeking for different environmental impacts of agri-food systems by evaluating two different sources of information: web-based information (i.e. the internet) and social media posts. The internet and social media play increasingly important roles for scientific communication and popular science, and search patterns can provide important insights across many research areas including disease spread, unemployment, mental health, private consumption and public interest (Simionescu, Streimikiene, & Strielkowski, 2020; Vosen & Schmidt, 2011; Wilde & Pope, 2013; Willard & Nguyen, 2013; Yang, Huang, Peng, & Tsai, 2010). We focused on the three major types of nature-related impacts of agricultural production on terrestrial ecosystems – chemicals and associated pollution and land degradation, and carbon emissions and associated climate change, and loss of biodiversity through land clearing and habitat destruction (Tilman, 1999). We compared the magnitude and trends in public information-seeking over time with the magnitude and trends in scientific literature for each type of environmental impact at two scales – global and a national case study. Our objective was to evaluate whether scientific information about the environmental impacts of food is building a knowledge base that aligns with the interests of the public. Using the results, we make recommendations for investment in supply chain assessments and information communication that will meet the public's needs and contribute to the body of knowledge required for informing behavior change.

2 Materials and Methods

We were interested in change over time at different scales, so we evaluated trends at a global scale and then at a national scale for Australia. Australia presents an interesting case study as it has one of the highest biodiversity extinction rates and one of the highest land-clearing rates in the world, with agriculture the main driver of habitat clearing and associated species declines (Kearney et al., 2019; Woinarski, Burbidge, & Harrison, 2015). Furthermore, Australia has one of the highest per capita emissions of carbon dioxide in the world. Its 0.3% of the world's population releases 1.3% of the world's greenhouse gas emissions from human activity (World Resources Institute, 2015), and agriculture is the fourth largest source of greenhouse gas emissions (Bourne, Stock, Steffen, Stock, & Brailsford, 2018). This suggests that behavior change to more sustainable choices by a relatively small number of people could have very high benefits for the environment at both national and global scales.

We first investigated public information-seeking for the environmental impacts of agri-food systems since 2009 by comparing relative differences in *Google* query volumes for different terms at a global scale then at a national scale for Australia. We chose 2009 as the start date for the review as this was the time of the global food price crisis where interest in sustainable food production increased dramatically and agri-food system assessments such as LCAs began to rapidly increase (McLaren, 2010; Mogensen et al., 2009; Poore & Nemecek, 2018). We then took advantage of a social media dataset from Twitter users in Australia to zoom in at a fine scale on public and scientific interest in sustainable agriculture and food in Australia from 2016 to 2018. Finally, we compared trends in public interest to trends in published peer-reviewed scientific articles on each topic related to agriculture and food sustainability.

2.1. Search Term Selection Process

We established search terms that related to agriculture and food and paired them with terms that related to nature impacts, specifically biodiversity, environmental degradation from chemicals, and carbon emissions (climate change). To capture the nuances of how internet users search for information on different impacts, we first identified a wide pool of search terms related to the three broad categories of impacts of food and agriculture on nature: biodiversity, chemicals, and carbon emissions. We based this pool on a combination of terms and phrases used in media previous reviews on sustainable agriculture to derive a comprehensive set of relevant search terms that could sufficiently capture information search behavior by the public (Clucas, Parker, & Feldpausch-Parker, 2018; Kok, de Olde, de Boer, & Ripoll-Bosch, 2020; Lin, Philpott, & Jha, 2015; Orsini, Kahane, Nono-Womdim, & Gianquinto, 2013; Pullin & Stewart, 2006; Velten, Leventon, Jager, & Newig, 2015; Wilde & Pope, 2013).

We narrowed the list by testing each of the terms in the broad pool in the publicly available Google Trends in order to estimate the popularity of each term and discover any related terms. Google Trends provides the option of searching by entities and topics instead of terms. We used search terms instead of Google entities or topics due to the better clarity of what data was being returned and because there were no topics directly related to some impact combinations (e.g. biodiversity and food). We narrowed the pool of terms down to the five most relevant for each impact (Supporting Information, Table S1). Search strategies and terms were modified if necessary, according to the requirements of each dataset (see below).

2.2. Public Interest in Food Impacts

2.2.1. Google Trends Dataset

We used Google Trends analysis to evaluate long-term (from 1 January 2009 to 1 January 2020) web searching behavior by global and Australian internet users on agri-food systems and their environmental impacts. Google Trends is a freely accessible search engine that provides access to a largely unfiltered sample of Google search requests and returns web searching behavior for a search term in a specific region of the world over a defined period. While no search engine can represent the queries of all internet users, a vast majority of online searchers use Google, and a number of researchers have demonstrated its usefulness as a tool for understanding the public's attitudes and behaviors (Ficetola, 2013; Proulx, Massicotte, & Pépino, 2014; Stephens-Davidowitz, 2014; Willard & Nguyen, 2013; Yang et al., 2010). Google is currently the most-used search engine on the World Wide Web; more than 5 billion queries are submitted every day.

Google Trends provides a time series index of the relative volume of search queries conducted through Google. The query index is based on query share: the total query volume for the search term in question within a geographic region divided by the total number of queries in that region during the time period being examined. Web searching behavior is reported as a random unbiased sample of the relative popularity of a given search term or topic on a standardized scale of 0 to 100, where 100 represents the highest query volume for a considered time period and geographic region (Choi & Varian, 2012). Web searching data from the public are anonymized, categorized (determining the topic for each search query) and aggregated according to broad matches; for example queries such as "used cars" are counted in the calculation of the query index for "cars".

We first adjusted our search term sets to account for the unique requirements of Google Trends for search term analysis. Google Trends does not include misspellings, spelling variations, synonyms, plural, or singular versions of terms in results. Because different terms might be used to indicate the same topic, we therefore created "search term sets" for each of the selected terms, allowing multiple terms to represent each broad term (see Table S2). For example, to identify public interest in carbon emissions on farms, we searched for "farm emissions + farms emissions + farming emissions". Results included searches including the words emissions and either farm, farms or farming.

In the Google Trends interface (https://www.google.com/trends/), if one searches for three related searches (e.g. "food emissions," "agricultural emissions," "food carbon footprint") the results are rescaled proportional to the largest value returned for those search terms within the specified region and time range. This means that that results for different regions or time ranges are not initially comparable because the scale will be different for every query. For this reason, we scaled all searches to an independent benchmark search term, "sustainable farming", which consistently showed the largest values across the entire time range of interest (Ficetola, 2013). All queries were conducted without the enclosing quotes. Quotes are used throughout this document to indicate the exact wording of the search terms.

Because Google Trends results are based on random-samples from the raw Google search volume cache rather than absolute values, results made at different times for a single search term in the same time-period will be different. To account for variability in results taken through this random sampling approach, we collected five samples for each search term set and time range, then took the average of those five samples at each time stamp (a month in a year) as the input data for the analysis. Any search term set that had a median value of 0 was removed from the analysis, thereby excluding terms that are rarely used by the public.

2.2.2. Tweets Dataset

We analyzed Twitter data to provide an understanding of the relative frequency of concerns for biodiversity, chemicals or climate change related to agri-food systems. The dataset used for this component of our study was extracted from the Australian Twittersphere, which is managed by the QUT Digital Observatory. The Australian Twittersphere is a longitudinal, curated collection of public tweets from approximately 530,000 Twitter accounts that were identified as 'Australian' in 2016. Approximately 800,000 tweets from 100,000 unique active users are captured on a daily basis, and the total collection consists of more than 1.8 billion tweets. There are some gaps in the collection prior to June 2016, and between April 2017 and March 2018. To work around this limitation, two comparable time periods from the Australian Twittersphere were selected and compared: June to December 2016 (for simplicity, this is referred to as 2016 hereafter) and June to December 2018 (referred to as 2018 hereafter). Each tweet in the Australian Twittersphere contains all metadata including (but not limited to) the tweet text, hashtags, the associated timestamp (i.e., the time at which the tweet was published), and the user ID of the user who published the tweet.

Each time period was searched for tweets that matched combinations of a first set of terms related to food or agriculture (Term 1) and a second set of terms related to impacts on biodiversity, chemicals or emissions (Term 2). The hashtags that represent each term are listed in Table S1. Tweets needed to contain at least one hashtag (or hashtags for those that must appear together, e.g., #susty AND #farming) from Term 1 and one hashtag from Term 2 in order to be counted.

2.3. Scientific Interest in Food Impacts

We evaluated global scientific interest in agriculture and food sustainability using the quantity and subject matter of peer-reviewed scientific articles indexed in Web of Science since 2008. We again compared agriculture and food impacts by searching for scientific articles on each of six topics: biodiversity and agriculture, chemicals and agriculture, carbon emissions and agriculture, biodiversity and food supply, chemicals and food supply, and carbon emissions and food supply. Each topic search consisted of a different set of search terms (see Supporting Information, Table S3), published from 2009 to 2020. We aggregated the resulting data to create a dataset that contained the number of published scientific articles on each topic per year. This dataset included any paper published in English. To explore the case study of Australia, we subset the dataset from the global literature search and quantified the annual number of articles published in Australia for each of the nature-based impact topics.

2.4. Statistical Analysis

We used generalized linear models (GLM) to evaluate trends in public and scientific attention to different environmental impacts of agri-food systems over time (Young, Torrone, Urata, & Aral, 2018; Zuur, Ieno, Walker, Saveliev, & Smith, 2009). A quasi-binomial GLM was used to model the proportion of attention on each impact each year as proportional odds, as data were over-dispersed (Zuur et al., 2009).

The response variable for trends in Google search behavior was the Google Trends output for each search term set related to each broad impact (biodiversity, chemicals or emissions) relative to the benchmark term "sustainable farming" (a value between 0 and 100, rescaled to a value between and including 0 and 1). The response variable for trends in scientific attention was the annual proportion of all sustainable food production papers that were related to the broad impact (a value between and including 0 and 1). We added search term sets as a fixed effect to evaluate the effect of choice of search term on our measures of attention.

We ran these models for the global data then for the data subset of Australia. Time-series analysis may be affected by autocorrelation, which may cause overestimation of significance. However, performing auto-regressive models using generalized least squares yielded essentially the same conclusions (Zuur et al., 2009), so results are shown for only the generalized linear models. Generalized linear models were constructed in R version 3.5.3 (R Core Team 2019), and inspection of diagnostic plots indicated that all models met statistical assumptions (Zuur et al., 2009).

3. Results

3.1. Long-term attention on environmental impacts of agri-food systems

In the decade between 2009 and 2020, the average amount of public attention on the nature-related impacts of food and agriculture was similar for biodiversity- and emissions-related impacts, and higher than chemicals-related impacts (Fig. 1b,d). These patterns were consistent both at a global (means of 0.092 ± 0.003 and 0.096 ± 0.002 for biodiversity and emissions compared with 0.051 ± 0.002 for chemicals) and an Australian scale (means of 0.040 ± 0.002 and 0.049 ± 0.002 for biodiversity and emissions compared with 0.029 ± 0.003 for chemicals) (Fig. 1b,d).

In the same time period, the relative volume of scientific research into the environmental impacts of agri-food systems was on average higher for both emissions and chemicals compared with biodiversity. Biodiversity-focused studies comprised less than 10% of all scientific articles on agri-food systems impacts compared with emissions-focused studies that made up 45% of scientific articles. Biodiversity received consistently lower scientific attention at both a global scale (means of 0.371 ± 0.040 and 0.146 ± 0.007 for emissions and chemicals compared with 0.030 ± 0.005 for biodiversity) and an Australian scale (means of 0.376 ± 0.050 and 0.127 ± 0.018 for emissions and chemicals compared with 0.086 ± 0.015 for biodiversity; Fig. 1a,c).

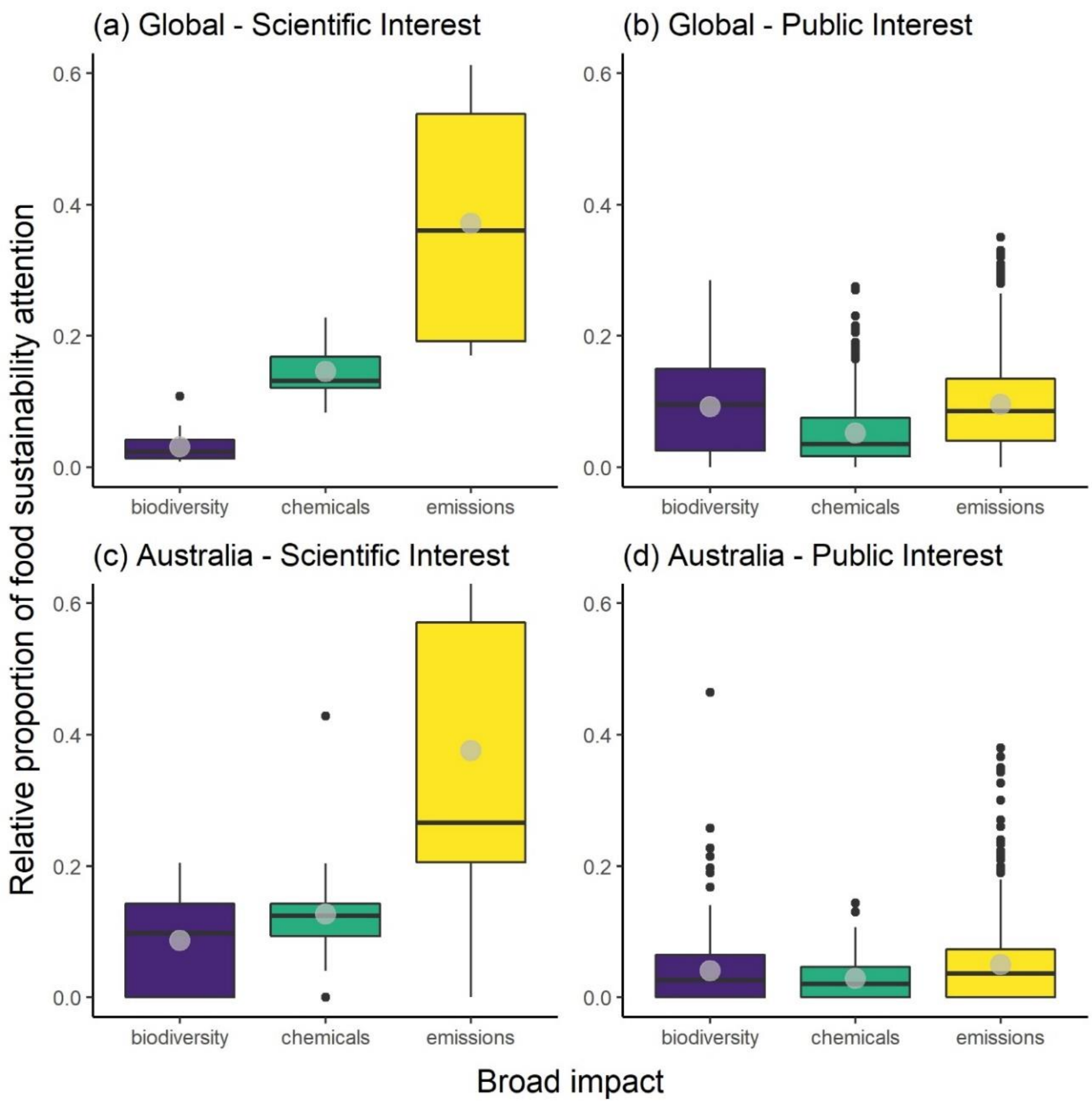

Figure 1. Relative volumes of global (a,b) and Australian (c,d) attention by the public and the scientific community to different environmental impacts of agri-food systems on biodiversity, chemical pollution and degradation, and carbon emissions from 2009 to 2020, comparing (a,c) scientific attention and (b,d) public attention .Boxplots indicate median (black line), mean (grey filled circle) and 25th and 75th percentiles of data (extent of boxes). Public attention was measured as the proportion of all food and farming sustainability searches in *Google* focused on one of the three broad impacts. Scientific attention was measured as the proportion of all food sustainability or life cycle assessment studies each year from either (a) global research or (c) Australian research focused on each of the three broad impacts.

3.2. Long-term trends in public and scientific attention

Public and scientific attention changed significantly over time for some nature-related impacts of agri-food systems. At a global scale, public web-searching for information on biodiversity- and emissions-related impacts increased significantly (Fig. 2, 3a). In contrast, there was no significant trend in the relative volume of biodiversity-related scientific articles over time, and the relative volume of emissions-related articles declined (Fig. 2, 3a, Table S5). During this time, the relative volume of global public web-searching for information on chemicals-related impacts decreased significantly (Fig. 2, 3a, Table S4), as did the relative volume of scientific articles (Table S5).

In Australia, public web-searching for information on biodiversity impacts showed the greatest increase over time whilst queries for information on emissions impacts decreased (Fig. 2, 3b). In contrast, the relative volume of scientific articles increased significantly over this time period (Fig. 3b) whilst there was no significant change in scientific articles on biodiversity impacts (Table S5). There was no significant trend over time in interest for chemicals-related impacts by either the Australian public or the Australian scientific community (Fig. 2d, Table S4).

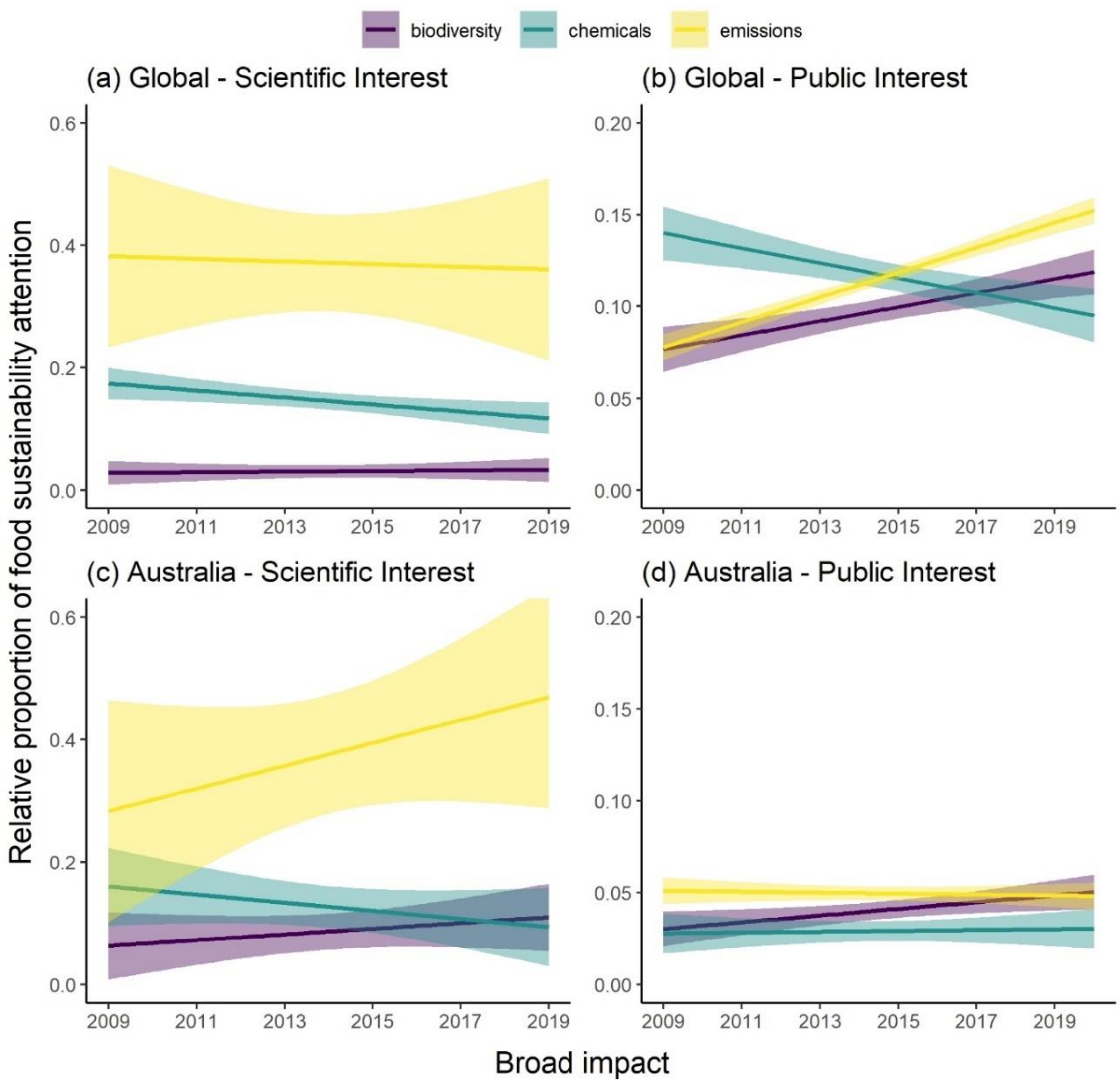

Figure 2. Global (a,b) and Australian (c,d) interest in different environmental impacts of food and agriculture for biodiversity, chemical pollution and degradation, and carbon emissions, comparing (a-c) scientific interest (measured as the proportion of all food sustainability or life cycle assessment studies each year focused on each of the three broad impacts) and (b-d) public interest (measured as the proportion of all food and farming sustainability searches in Google focused on one of the three impacts).

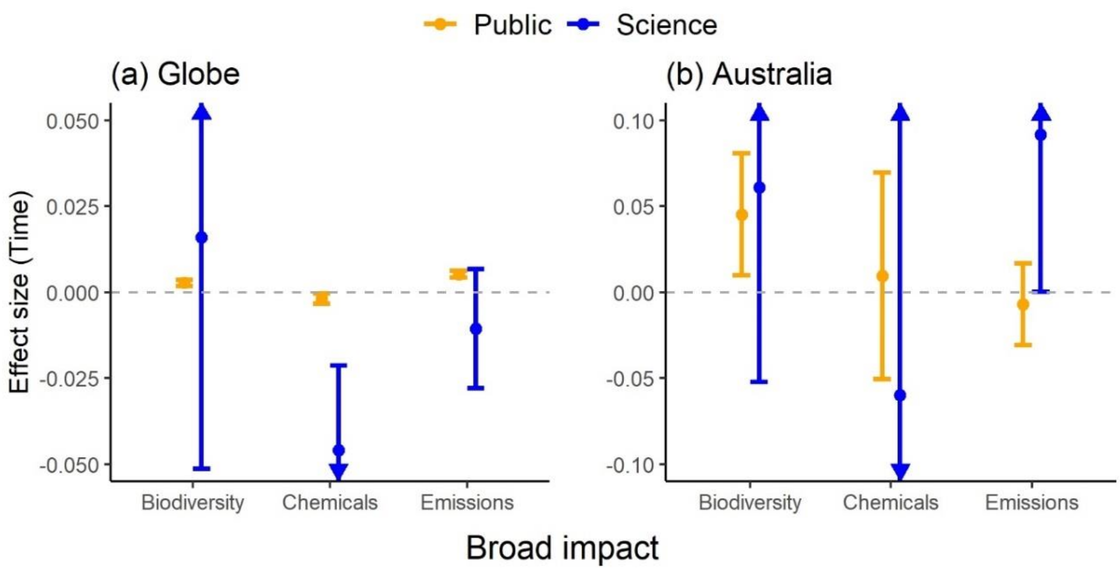

Figure 3. The effect size (average trend over time ± 95% confidence interval) from generalized linear models relating the level of public or scientific attention to time (a) at a global scale and (b) in Australia (see Tables S4 and S5). Compares public (blue) and scientific (orange) interest in food and agriculture topics related to biodiversity, chemicals or climate change. Arrows indicate that the 95% confidence interval extended beyond the limits of the y axis, and have been truncated for visualization purposes.

3.3. Short-term social media trends

In addition to changes in public web-searching behavior over time, we found changes in social media attention to environmental impacts of agri-food systems (Table 1). Like the rise in Australian Google search queries, the relative percentage of food sustainability tweets in the Australian Twittersphere related to biodiversity increased by 6% (from 28% of all tweets in 2016 to 34% in 2018).

Correspondingly, the relative proportion of Australian food sustainability tweets related to emissions declined during this two-year period from 51% of all tweets to 44% (Table 1). Tweets on agriculture or food and chemicals and climate change consistently made up 21% of all evaluated tweets on sustainability between 2016 and 2018.

Table 1. The total and relative number of tweets by the Australian public during 2016 and 2018 on each of three broad nature-based impacts of food and agriculture.

Broad Impact	Specific Nature-Based Impact	Number of Tweets 2016	Number of Tweets 2018	Relative Proportion of Tweets 2016	Relative Proportion of Tweets 2018
Biodiversity	Biodiversity + Agriculture	25	24		
	Biodiversity + Food	2	5		
	Total biodiversity	**27**	**29**	**0.284**	**0.345**
Emissions	Carbon emissions + Agriculture	41	29		
	Carbon emissions + Food	7	8		
	Total emissions	**48**	**37**	**0.505**	**0.441**
Chemicals	Chemicals + Agriculture	14	12		
	Chemicals + Food	**6**	**6**		
	Total chemicals	**20**	**18**	**0.211**	**0.214**

4. Discussion

Over the past decade, public interest in environmental sustainability has increased, with consumers increasingly demanding information on impacts of their food consumption choices on the environment, human health, and animal welfare. Scientific evidence for the impacts of alternative agricultural production methods and supply chain interventions is necessary to provide a platform to enable change – in consumer behavior, in farmer choices, in land management interventions and in agri-environmental policies (Walsh, Dicks, & Sutherland, 2015). This study finds that biodiversity is systematically under-represented in the scientific evidence base on environmental impacts of agri-food systems, and that this bias is not aligned with the needs of the public for information. Public information-seeking about biodiversity impacts of agri-food systems increased significantly between 2009 and 2020, whilst global scientific research attention on biodiversity impacts did not increase concurrently. By 2019, public information-seeking on this topic represented 13% of food sustainability searches, which was double the relative representation of biodiversity in the scientific literature. Scientific research into the environmental impacts of agri-food systems remains focused on greenhouse gas emissions despite public interest in biodiversity impacts equaling that for emissions at both global and Australian scales (Fig. 1). Biases and gaps in research into the environmental impacts of agri-food systems constrain consumer awareness and engagement with environmental sustainability and limit the scope and potential impacts of behavior-change interventions.

Certain information sources, such as social media, have been shown to be associated with greater awareness of and interest in environmental topics including water management and sustainable business management (Dean, Fielding, & Newton, 2016; Pearson, Tindle, Ferguson, Ryan, & Litchfield, 2016). Social media and Google query trends in our study indicate that the public is becoming more interested and engaged in issues related to biodiversity and agri-food systems. As this need for information grows, scientific evidence is required to inform public queries about environmental impacts, as greater public awareness of issues could influence more sustainable behavior choices. The current data bias towards emissions-focused scientific research on the impacts of agri-food systems means that the public receives a biased representation of the range of environmental issues associated with these systems. One reason for this bias is that biodiversity indicators for the environmental impacts of land use are relatively poorly developed in comparison to other indicators for chemicals, water use and emissions (Curran et al., 2016; Souza, Teixeira, & Ostermann, 2015). Indeed, previous studies have identified several shortcomings in the ability of biodiversity indicators to accurately reflect environmental impacts at a fine enough scale to inform supply chain assessments such as LCA (Curran et al., 2011).

Biodiversity is a complex concept, including multiple hierarchical levels (genes, species, communities, and ecosystems) and different attributes, such as structure, composition, and function (Noss, 1990). Designing an indicator to meaningfully capture agricultural impacts on biodiversity is challenging, and made even more difficult by the paucity of biodiversity data available to decision-makers (Tulloch et al., 2018). Most biodiversity indicators for monitoring human impacts operate at global or national scales (Hill et al., 2016; Vačkář, ten Brink, Loh, Baillie, & Reyers, 2012). However, to understand whether biodiversity has been affected by agri-food systems that often have locally and globally distributed supply chains, we need both local and global information on species distributions and abundances, and how they change over space and time (de Baan, Alkemade, et al., 2013; Feeley & Silman, 2011; Whittaker et al., 2005; Winter et al., 2016). In LCA, researchers usually try to quantify the biodiversity value of a selected agricultural system using these data and compare it to the value of a reference land use type (e.g., natural land) (Milà i Canals et al., 2007). Biodiversity loss is assessed across the entire system simultaneously, either in relative terms (e.g., what percentage of species were lost from the agricultural area) or in absolute terms (e.g., how many species were lost). However, biodiversity impacts of agriculture are usually much more complex than simply the loss (or gain) of species (Dudley & Alexander, 2017; Tulloch, Mortelliti, Kay, Florance, & Lindenmayer, 2016). Ecosystems can become degraded but not lost, species' populations can decline but not disappear, and the composition and distribution of ecological communities (groups of species) can change, all without species richness changing (Kay et al., 2018) – without these nuances we are likely underestimating the impacts of agriculture (Hill et al., 2016). Numerous approaches have been suggested to improve indicators, but there is still no globally accepted method for assessing agri-food system impacts on biodiversity (de Baan et al., 2015; de Baan, Mutel, Curran, Hellweg, & Koellner, 2013; Milà i Canals et al., 2007; Schenck, 2001). This requires urgent addressing through targeted investment into indicator development, followed by more balanced environmental impact assessments (e.g. LCAs) of agri-food systems that evaluate multiple impacts including biodiversity.

This study uses trends in public information seeking as a surrogate for public interest in different agri-food system sustainability issues, to explore where investing in new knowledge might help influence public behavior change. Public interest in nature impacts of food production and consumption creates an opportunity to build an engaged and empowered community—a community that not only changes consumption behaviors, but also knows, values, and actively supports the changes in policy, practices and technology required to ensure sustainable agri-food system management (Dean, Lindsay, et al., 2016). Promoting adoption of environmentally sustainable food consumption behaviors is complex, and behavior change programs may need to target diverse factors that influence behavior (Michie, van Stralen, & West, 2011). Nonetheless, a critical component of increasing adoption of sustainable food choices is making these choices easier, by providing guidance and promoting availability of lower impact consumption options (Dean, Church, Loder, Fielding, & Wilson, 2018; Dean, Fielding, et al., 2016; Kaiser & Fuhrer, 2003). Importantly, while knowledge about the issue and solutions can enhance uptake of behaviors, knowledge may influence adoption of sustainability behaviors through a range of pathways. For example, topic knowledge may provide a foundation for further information seeking, allowing people to extend knowledge boundaries; conversely, individuals with poor topic knowledge may have difficulties processing information, or avoid opportunities to discuss related issues with others due to lack of confidence (Dean, Fielding, Jamalludin, Newton, & Ross, 2018; Paasche-Orlow & Wolf, 2007). Ensuring that provision of information and guidance aligns with what people value and want to know can strengthen engagement (Ficetola, 2013; Guthrie et al., 2015; Stephens-Davidowitz, 2014; Willard & Nguyen, 2013; Yang et al., 2010). For consumers to learn about environmental impacts and be inspired to adopt more sustainable behaviors, scientific research needs to be translated into communication materials that are readily accessed and understood by the public (e.g. online sites, news stories, food labelling systems). Models of information use indicate that individuals use different information depending on the situation (Schiffman & Kanuk, 2014). As such, it is likely that information provision can best strengthen engagement by targeting diverse types of information-seeking behavior, including purposeful information seeking (e.g. via online sites), opportunistic information seeking (e.g. via news stories), and situational decision making (e.g. point of sale information, food labelling systems).

This study has several limitations due to the global scope of the analysis and the nature of the available data on information-seeking behavior. First, the *Google* data on public queries for information on particular topics is likely to be biased as not all of the globe has access to the internet, and not all of the globe uses *Google* to search for web-based information. Additionally, online keyword queries in *Google* Trends within a country are sent from highly populated cities, which do not form a representative (that is, spatially extensive, random, and unbiased) sample of a region. Second, one cannot know the real motives behind each internet search recorded by *Google* Trends. For example, we do not know whether search-term queries returned for pesticides and food are entered by farmers searching for agricultural products, researchers studying the topic, or by web surfers looking for information on the relationship between pesticides and food products (Kang, Zhong, He, Rutherford, & Yang, 2013; Matsa, Mitchell, & Stocking, 2017; Nuti et al., 2014; Rice, 2006; Vosen & Schmidt, 2011). Third, temporal or spatial patterns are correlations only, and may not have been driven by specific behavior-change processes such as increased public interest in a topic. We addressed these limitations through several measures during the data collection and analysis process. We cross-validated search terms to ensure that they all related to the same process by exploring the related topics and keywords for each individual search term set and correlating search hits between like terms (e.g. pesticides and herbicides). We excluded search trends of irrelevant terms (e.g., "carbon" on its own was excluded from the *Google* Trends searches as it was associated mainly with carbon farming not food production). We also controlled for variability in search term use by using a list of associated search terms to estimate trends in public attention rather than focusing on a single term (Dugas et al., 2012). Another challenge of using *Google* queries to indicate public interest in a topic is that increasing use of the internet by diverse audiences for diverse objectives ranging from leisure to science is likely to have diluted usage of search terms over time, leading to perceived changes that are not reflected in real behavior (Ficetola, 2013). To address this, we evaluated all *Google* Trends results relative to a benchmark term, thus standardizing the data prior to analysis (Ficetola, 2013). Finally, we were able to validate the data from the Australian *Google* Trends analysis with social media data from the Australian Twittersphere, showing that trends elucidated from *Google* Trends correlated with those occurring over a shorter time frame on social media (Fig. 3, Table 1).

Detecting genuine temporal changes in public awareness of and engagement with any topic is challenging at very large scales. The internet plays an increasingly important role for scientific communication and popular science, therefore *Google* search patterns can be an excellent source of information on public interests (Wilde & Pope, 2013; Willard & Nguyen, 2013; Yang et al., 2010). Unlike many other behavioral data collection methods, *Google* data are unlikely to suffer from major social censoring – *Google* searchers are online and likely alone, both of which make it easier to express socially taboo thoughts (Kreuter, Presser, & Tourangeau, 2009). Individuals, indeed, note that they are unusually forthcoming with *Google* (Conti & Sobiesk, 2007). Furthermore, aggregating information from millions of searches, *Google* can meaningfully reveal behavioral patterns and socially sensitive attitudes (Cervellin, Comelli, & Lippi, 2017; Yang et al., 2010), and *Google* search data have been shown to consistently correlate strongly with demographics of those one might most expect to perform the searches (Stephens-Davidowitz, 2014). Because the information returned by *Google* Trends is disaggregated at the city level, integrating its results with other global or regional data could help elucidate drivers of information-searching behavior. Future studies could link *Google* Trends results to cities' geographic coordinates and investigate the relationships between web-searching trends and climate, land cover, land use, species and ecosystem conservation status, and socioeconomic data, or with the implementation of national or regional policies. For instance, a number of country governments, including Brazil (Ministry of Health of Brazil, 2014) and more recently Canada (Health Canada, 2019), have put forth dietary guidelines emphasizing predominantly plant-based foods. While this is a critical step toward aligning consumption patterns with biodiversity goals, public awareness and uptake of these guidelines is unclear.

This is the first study to examine global information-seeking behavior by the public to inform research agendas. Our findings highlight that knowledge gain on the biodiversity impacts of agri-food systems could have important benefits in terms of increasing public awareness of the impacts of their food choices on species and ecosystems. Enabling the public to learn about the impacts of their choices is the first step towards inspiring them to change to more sustainable behaviors, actions that will have flow-on effects to the environment and global health.

Acknowledgments, Samples, and Data

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