Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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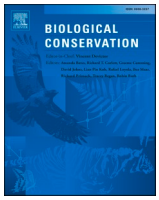

Policy analysis

Using internet search data to understand information seeking behavior for health and conservation topics during the COVID-19 pandemic☆

Varsha Vijay [a,b,*], Christopher R. Field [c], Florian Gollnow [a,d], Kelly K. Jones [a,e]

[a] National Socio-Environmental Synthesis Center, University of Maryland, Annapolis, MD 21401, USA
[b] National Institute for Mathematical and Biological Synthesis, University of Tennessee, Knoxville, TN 37996, USA
[c] Department of Natural Resources Science, University of Rhode Island, Kingston, RI 02881, USA
[d] Department of Earth and Environment, Boston University, 685 Commonwealth Avenue, Boston, MA 02215, USA
[e] National Institute on Minority Health and Health Disparities, National Institutes of Health, Bethesda, MD 20892, USA

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ABSTRACT

Emerging zoonotic diseases, such as COVID-19, exist at the intersection of human health and the environment. Public interest and support are required to maximize the effectiveness of policies to combat the current pandemic and prevent future outbreaks of zoonoses. Here, we use internet search data from the United States to investigate changes in public information seeking about topics at the intersection of health and the environment during the COVID-19 pandemic. Using breakpoint detection methods, we identify sharp increases in interest for 'wildlife trade', 'bats', and 'pangolins' in the early stages of the pandemic (on Jan. 12, Jan. 19, and Jan. 26, 2020, respectively). Network analyses also revealed increasing connectivity between terms related to human health and the environment, as well as the emergence of novel search terms pointing to a greater interest in wildlife trade and consumption. During the pandemic, the network connectivity between coronavirus keywords and conservation keywords increased, which we measured using the number of unique connections (edge connectivity, k′ (G)) and the number of simple paths (Sp) between keywords. Both measures of network connectivity increased between 'coronavirus' and 'bats' or 'pangolins' ($\Delta k'(G) = 1$, $\Delta Sp = 37$), and between 'coronavirus' and 'conservation' ($\Delta k'(G) = 1$, $\Delta Sp = 160$). These findings suggest that policy and outreach efforts aimed at engaging public interest in intersectional approaches to pandemic prevention (eg: One Health, Planetary Health), may be able to take advantage of increases in public information seeking following catalyzing events during the pandemic. Further monitoring is needed to determine if these changes persist over time.

1. Introduction

Habitat loss, wildlife trade, and human population pressures are increasingly important drivers of emerging infectious diseases worldwide (Rabinowitz et al., 2013; Dobson et al., 2020), including recent increases in outbreaks of zoonoses (Jones et al., 2008; Allen et al., 2017). Because of the transdisciplinary nature (Kelly et al., 2017) of these health crises, broad public understanding of issues at the human-animal-environment interface is a critical, yet often overlooked, component of any global science and policy response (Page and Shapiro, 1983; Phillis et al., 2013), such as those based on One Health and Planetary Health frameworks (Berthe et al., 2018; Seltenrich, 2018). Analyses of public interest and information seeking at the intersection of human health and conservation can provide insights to maximize the societal impacts of conservation policies and interventions (Ladle et al., 2016), including those aimed at reducing disease transmission.

The current COVID-19 pandemic, caused by a novel coronavirus of zoonotic origin, created profound public information needs as a result of its catastrophic global health, social, and economic impacts. Early in the pandemic, information seeking by the public focused primarily on coronavirus and coronavirus symptoms (Bento et al., 2020). However, as searches expand to information on disease spillover and outbreak there is a potential for increased search interest on conservation topics related to the pandemic (e.g. threatened host species, wildlife trade), creating an opportunity to understand public information seeking behavior at the human-environment nexus. Understanding whether the

☆ **Article Impact:** Pandemic search behavior shows increased awareness of health-related environmental topics, despite decreased interest in species conservation.

* Corresponding author at: National Socio-Environmental Synthesis Center, University of Maryland, Annapolis, MD 21401, USA.
E-mail address: varshavijay101@gmail.com (V. Vijay).

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COVID-19 pandemic has changed interest in these topics or connections between these topics is essential to designing effective public engagement strategies for long term policy efforts aimed at pandemic prevention.

As information seeking has shifted to primarily online sources, data from these sources can provide real-time insights into public understanding of emerging issues (Durmuşoğlu, 2017). Here, we use these data to analyze changes in information seeking behavior by the US public across broad topic areas at the intersection of health and the environment, before and during the COVID-19 pandemic. We quantified information seeking behavior using search volume and related search query data from Google Trends (GT) (2020). GT data are derived from Google search engine data, the most widely used search engine in the United States (Comscore, 2021). Correlations between search engine usage and economic, social, and epidemiological metrics have led to the broad adoption of these data for forecasting and nowcasting in the fields of economics, business and public health (Choi and Varian, 2012; Nuti et al., 2014). More recently, these data have also been used to evaluate public perceptions about biodiversity, conservation, and climate change (Anderegg and Goldsmith, 2014; Nghiem et al., 2016; Troumbis, 2017b). As the pandemic continues into a second year, these data form an important source for understanding public information seeking behavior about both health and environmental topics, when traditional polling would be cost-prohibitive and lag further behind current events.

We focused our study on three search topics along the gradient of health and the environment (Fig. 1A). The first topic, coronavirus,

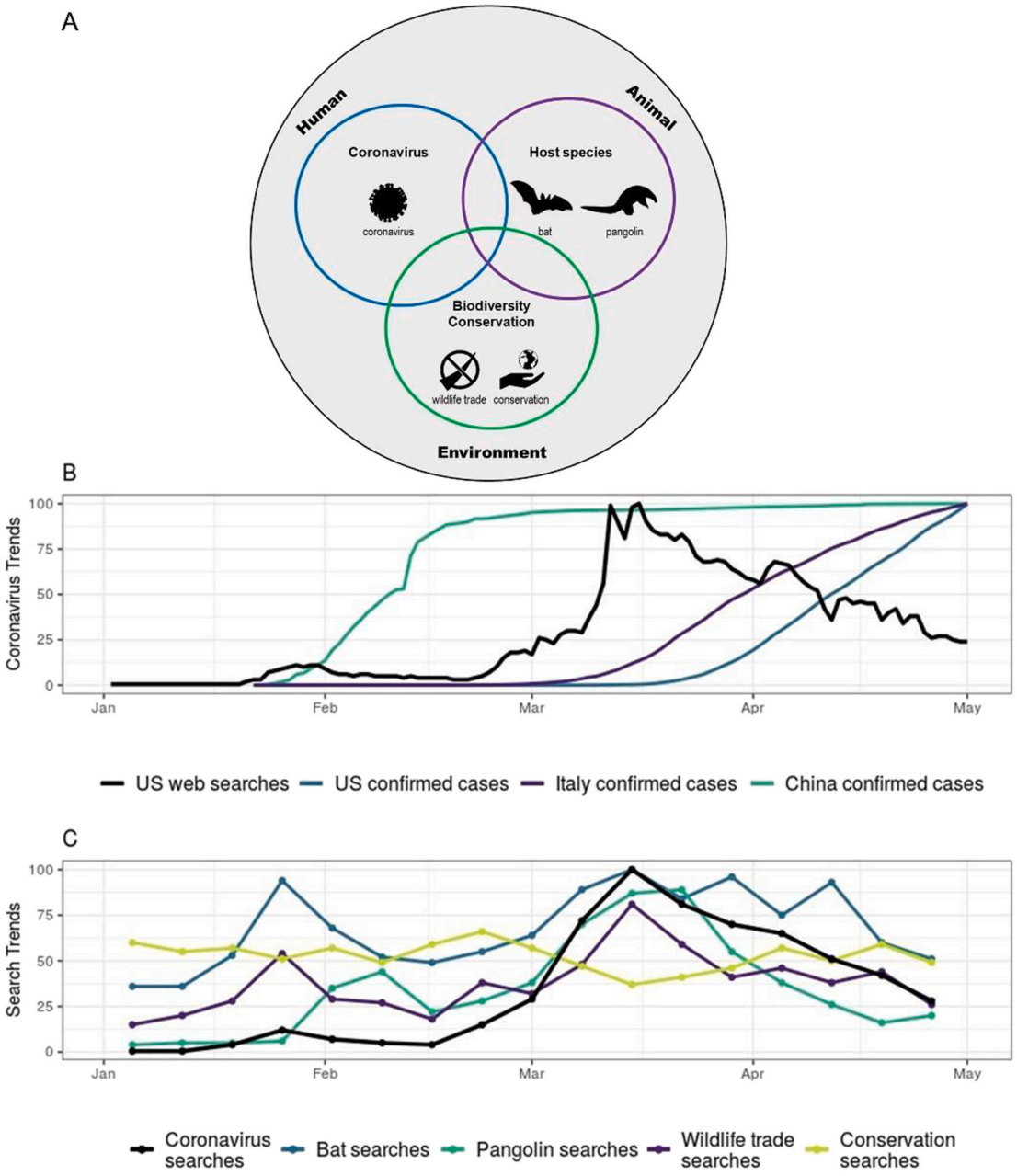

Fig. 1. Conceptual diagram of search topics and COVID-19 case data and web searches during the pandemic period (January 1, 2020–May 1, 2020). A) Conceptual diagram of search topics and their associations with the One Health framework. Species symbols from phylopic.org, conservation symbol by Tim Reiter from the Noun Project, and wildlife trade symbol by C.F. B) Comparison between daily 'coronavirus' web search trends (GT) for the United States to daily coronavirus case data for the United States, Italy, and China with trends normalized based on data collected during the pandemic. C) Comparison between weekly search trends (GT) for 'coronavirus', 'bats', 'pangolins', 'wildlife trade' and 'conservation' with trends normalized based on the full study period 2016–2020.

captures information seeking about the pandemic itself. The second topic, host species, focuses on the terms 'bats' and 'pangolins' (orders Chiroptera and Pholidota, respectively). These common names refer to taxonomic groups which include species that are both presumed hosts of the coronavirus (Lam et al., 2020; Zhou et al., 2020) and targets of conservation efforts (Challender et al., 2014; Frick et al., 2020). The third topic, biodiversity conservation, addressed broader, policy-relevant concepts through searches for 'wildlife trade' and 'conservation'. Using a novel combination of time series and network analyses, we investigated (i) associations between coronavirus information seeking and disease prevalence in the U.S., Italy, and China, (ii) changes in search interest for health-related environmental topics during the pandemic, and (iii) changes in search behavior as measured through search networks of related terms, especially changes in the connectivity between health and environmental topics. Analyzing both time series of search interest and networks of search terms before and during the pandemic allowed us to quantify not only changes in the volume of interest in a topic but also changes in knowledge structure through conceptual links between search terms (Carley, 1997; Popping, 2003).

2. Methods

To examine public information seeking in the United States related to the COVID-19 pandemic and connected environmental topics, we extracted weekly national Google Trends (GT) data for selected English language keywords to determine interest in the disease and conservation. We evaluated the period January 1, 2016 to May 1, 2020, a period for which the GT methodology remained consistent. GT normalizes search volume for each keyword, with 100 corresponding to the peak in relative search volume during the study period. This means that GT can serve as an overall metric of relative interest, but not a measure of absolute search volume. We assigned low search volume estimates, originally assigned the value <1, to 0.5 for all GT time series. We chose not to analyze GT data at a finer spatial scale (state level) because of difficulties in monitoring low volume search topics (SI: State Level Findings).

We use multiple search keywords to capture interest in each topic (Table S1). Potentially confounding meaning, use, and context of words can make it difficult to capture the intended topic in GT. We selected terms which are most narrowly related to our topic, to reduce chances of incorrect attribution. To capture interest in coronavirus we aggregated data for 'coronavirus', 'corona virus', and 'covid'. We identified related conservation topics as those that represent areas of conservation concern related to disease transmission. We used the keywords 'bat(s)' and 'pangolin(s)' to assess presumed hosts of coronavirus, which are also taxa that face increased extinction risks related to habitat loss and human consumption. To evaluate interest in consumption and trade in wild animals, we aggregated searches for 'wildlife trade' and 'bushmeat'. This is the second biggest threat to species after habitat loss. Finally, to understand changes in interest in conservation, we used the keyword 'conservation'. We selected terms which are not prone to confusion with unrelated terms or which could be refined by search category. For example, we identified searches for bats which exclude sports equipment and separate searches for biodiversity conservation from searches for conservation of energy.

We compared short-term daily GT data, between January 21 (when COVID-19 case data were first made available) and May 1, for coronavirus searches against COVID-19 case data obtained from Johns Hopkins (Dong et al., 2020). We use daily case data for COVID-19 in three countries US, Italy and China, in order to understand how US search interest for conservation responded to highly publicized trends in disease incidence. Italy and China were selected as examples to explore how international disease trends, in Europe and Asia respectively, may affect information seeking in the US. This higher temporal resolution analysis allows us to evaluate patterns of covariation between these data. Case data were also normalized from 0 to 100 to increase comparability with search data.

Interest in biodiversity conservation may not be fully captured by our selected keywords 'conservation' and 'wildlife trade'. We used Google autocomplete to try to determine additional terms for inclusion in our analysis but were unable to identify terms which unambiguously referred to the concepts we were attempting to measure (e.g.: poaching as a cooking term and as a term to describe illegal hunting). Using search category refinement for some of these lesser-used terms resulted in lower search levels than could be detected. Despite the potential for underestimating search volume, our approach of minimizing errors of commission is key for quantifying changes in search behavior in network analyses.

To evaluate the presence of statistically significant breakpoints in search interest for topics, we applied an additive decomposition model (Verbesselt et al., 2010a) that iteratively fits a piecewise linear trend and a seasonal "dummy" model followed by breakpoint detection. These methods identify the points at which changes to time series occur, taking into account the baseline degree of stochasticity and autocorrelation (Verbesselt et al., 2010b, a). The ordinary least squares (OLS) residuals-based MOving SUM (MOSUM) test is used to test the occurrence of one or more breakpoints. If the test indicates significant change ($P < 0.05$), breakpoints are estimated using Bayesian Information Criterion (BIC) and a 95% confidence interval is calculated around the date of each breakpoint.

We fit seasonal "dummy" models for interest in 'bats' and 'conservation' to detect changes in interest independent from seasonal variation. We find that the range of seasonal amplitude is <30% ('bats') and <20% ('conservation') of the range of GT values for each topic respectively. In contrast, we observed no seasonality in interest for 'pangolins' or 'wildlife trade' and fit no seasonal model for these trends.

We impose a minimum segment length between breaks of approximately three months of weekly data to emphasize the detection of longer-term changes, while being robust against changes detected as a result of high variability between successive samples. Where multiple breakpoints are detected within the minimum segment length, only the most significant is reported. For detected shifts in search interest during the pandemic period, we calculate the magnitude of change as the difference in the linear trend component before and after the breakpoint.

For keywords with detected breakpoints during the pandemic, we calculate the magnitude of change as the difference in the linear trend component before and after the breakpoint. We identified local post-breakpoint maxima for breakpoints associated with increases in interest.

To evaluate changes in users' search behavior, we analyzed the network of each search term and their related search queries, at the US national level. We compared a baseline network, covering the years 2016–2019 to a pandemic network covering the period from January 1 to May 1, 2020. Changes in network structure between the baseline and pandemic periods can be understood to represent changes in how users connect key concepts (Paranyushkin, 2011). So called 'related search queries' describe the most common and rapidly growing search terms that people also search for when they search for our search keywords. We estimate these search queries for each study year at the US national level. One example is the search "what is coronavirus" during the baseline period by users searching for the coronavirus topic (see Table S1 for component search keywords). We reconciled word conjugations for keywords and excluded rare single word searches because they would have no connections to any other term in the network, making it impossible to contextualize and analyze it in the framework used in this study.

The networks built from these searches represent our most complete estimate of user searches before and during the pandemic, though low frequency queries may not be included. Each word in our related search queries may be thought of as nodes in a network of frequent search engine queries by users during a given time period. We used natural language processing to compose an undirected network based on the relationships between words in each search query (Silge and Robinson, 2016; Csardi and Nepusz, 2006). We decomposed each search query into

bigrams (node pairs) using a Markov chain model to identify consecutive two-word combinations (Table S2). Though the bigrams were associated with particular search keywords, we analyze bigrams across all keywords because of the overlap in the content of those searches (ex: users searching for both bats and pangolins also searched for the bigram 'coronavirus bat'). We filtered bigrams containing "stop words", common words in the English language, and numerical objects.

We used common network metrics to characterize and compare the derived networks. Node centrality is a simple measure of the importance of search network terms, particularly those that directly connect to a large number of other terms. This represents the structure of user information seeking. Change in the degree of a specific search term indicates the change of search term importance within the larger search network, reflecting differences in search behavior. Additionally,

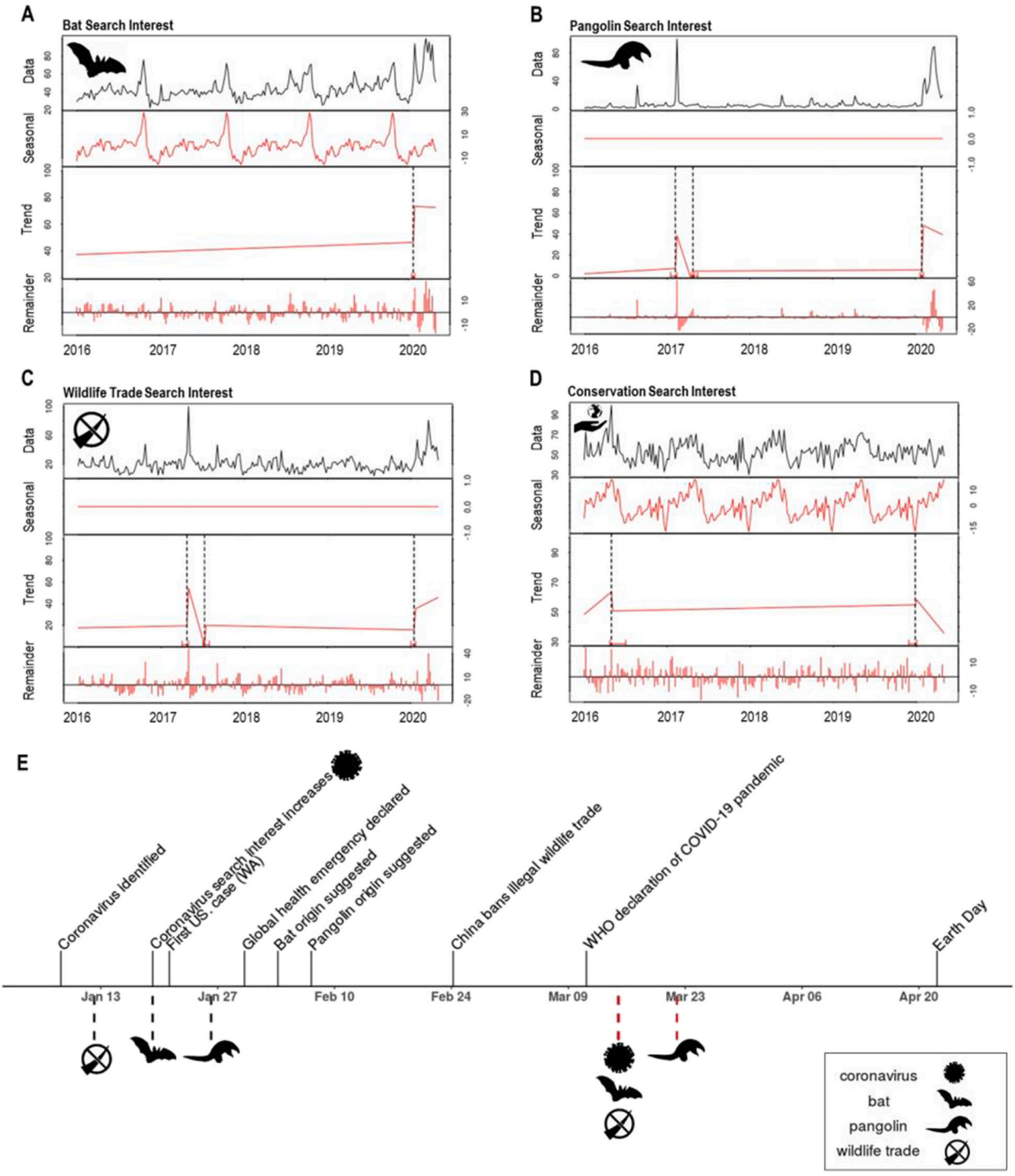

Fig. 2. Time series decomposition for health-related environmental search keywords for host species and biodiversity conservation. A–D) Significant breakpoints ($P < 0.05$) in the linear trend component shown with black dashed lines (95% CI indicated with red brackets around breakpoints). E) Current events related to the pandemic and interest increase for coronavirus (GT > 1, above dateline). Significant breakpoints (black dashed lines) and post-breakpoint maxima (red dashed lines) for keywords with interest increases during the pandemic (below dateline). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

changes in network connectivity across the pandemic describe changes in user-determined connections between search topics before and during the pandemic. We quantify node centrality using node degree, defined as the number of direct connections to a given node. We then normalize these values to the highest value node in the network. We determine differences in network connectivity between time periods using both edge connectivity, defined as the minimum number of connections (edges) that need to be removed to isolate search keywords, and simple path analysis, defined as the total number of connections between keywords including intermediate nodes, between topic areas. Though local metrics of network connectivity are the focus of our analyses, we also explore changes in network community structure during the pandemic (SI: Network Community Analysis).

3. Results

Search interest in coronavirus began to increase in late January 2020 (Jan. 19, GT = 4), two to three weeks after the novel coronavirus was identified. Early increases in interest occurred when confirmed cases were reported in the US (March 1, 75 cases) and in 64 other countries, driving widespread awareness of the magnitude of the pandemic. Interest increased rapidly from early March (GT = 17) to reach maximum values on March 16 (GT = 100), after China approached maximum recorded cases and when Italy and the US had recorded relatively few cases (Fig. 1B). A cross correlation analysis between the US case incidence rate and web searches for coronavirus reveals that the two trends are most correlated at a 16-day time lag ($r = 0.85$) with search interest preceding higher case rates. Search interest lagged behind case rates in China, with searches most correlated at a 12-day time lag ($r = 0.62$). A lower time lag was present with case rates in Italy, where search interest also preceded higher case rates (max correlation at 5-day time lag, $r = 0.93$). Despite decreases in search volume by May 1, 2020, interest in coronavirus remained high compared to pre-pandemic levels (GT = 24).

We found statistically significant increases in search interest for hosts species ('bats', 'pangolins') and conservation topics ('wildlife trade') during the pandemic, though the same period was associated with decreased interest in 'conservation' (Fig. 1C). We found significant increases in interest during the COVID-19 pandemic, determined using the linear trend component of the time series, for 'bats' (Fig. 2A; breakpoint (CI) = Jan. 19 (Jan. 12, Jan. 26), magnitude = 27.1), 'pangolins' (Fig. 2B; Jan. 26 (Jan. 19, Feb. 2), 42.1) and 'wildlife trade' (Fig. 2C; Jan. 12 (Dec. 29, Jan. 19), 19.6). However, the largest magnitude breakpoint for 'wildlife trade' was detected around Earth Day 2019 (April 23 (April 2, April 30), 34.8), suggesting that the most important recent shift may not have occurred during the pandemic. We detected a small recent shift in interest for 'conservation' near the pandemic period (Fig. 2D; Dec. 22 (Nov. 24, Dec. 29), 3.3), but this was followed by a sharp decline in the linear trend for conservation until the end of the study period, after accounting for the expected seasonal increase around Earth Day. Additional breakpoints in interest for 'wildlife trade' and 'pangolins' were observed in 2017, though the events related to these spikes are difficult to determine as they may not always reflect events found in the news (e.g. SI: Pangolin Love).

We found a consistent association between interest in coronavirus and related topics, indicated by strong temporal congruence in topic breakpoints and post-breakpoint maxima (Fig. 2E). Current events associated with each of the search keywords did not appear to be related to breakpoints, but their occurrence before interest peaks likely served to sustain and increase interest (see: timeline events in Fig. 2E). On average, interest in each topic peaked approximately two months after its initial interest shift, indicating a narrow temporal window of rapid increase in interest.

Comparing the search behavior between the pandemic and baseline network, we found an increase in connectivity between health and environmental topics, including the emergence of novel search terms that bridged these two topic areas (Figs. 3, 4). On the other hand, connections between searches related to the host species and biodiversity conservation topics decreased (Fig. 4). Among search keywords in the baseline network, searches for 'bats' were most central, followed by 'conservation' and 'pangolins' (Normalized node degree (*Dn*) for bats = 1.00; *Dn* for conservation = 0.52; *Dn* for pangolins = 0.50; Fig. 3A), when measured by the number of connections to a given node – i.e. node degree. 'Coronavirus' was most central to the pandemic network and had the largest increase from baseline levels ($\Delta Dn = 0.79$). During the pandemic, the centrality of 'bats' ($\Delta Dn = -0.38$) and 'conservation' ($\Delta Dn = -0.22$) decreased, while connections to pangolins were nearly constant ($\Delta Dn = 0.02$). For some keywords with significant increases in search volume during the pandemic, the degree of centrality decreased or remained constant. This pattern suggests that during the pandemic people searched less broadly on certain topics as interest in specific issues grew (e.g. – bats as hosts for COVID-19; see also node strength: Fig. S2).

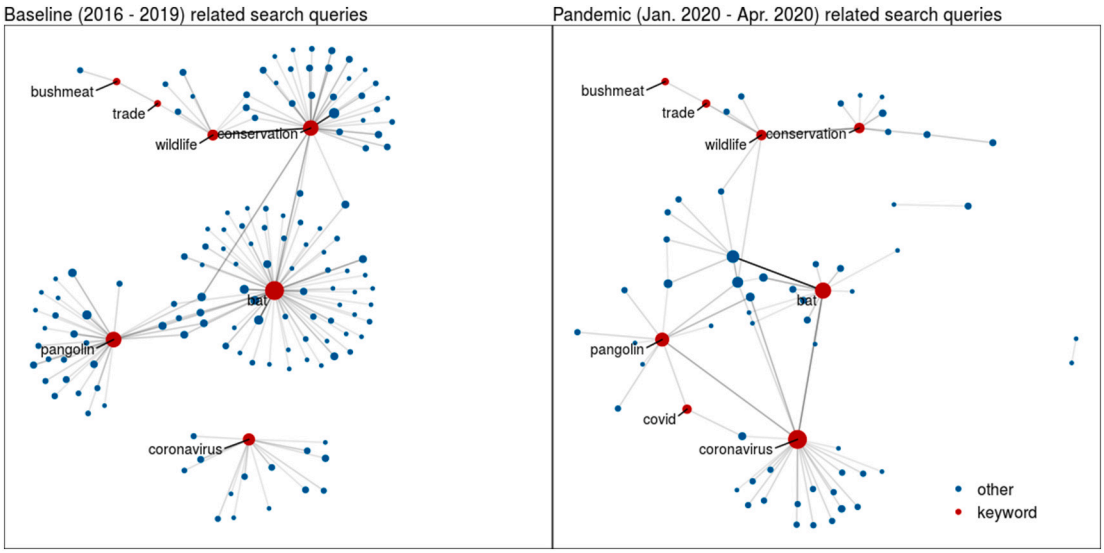

Fig. 3. Search networks of top and rising queries related to search keywords. Baseline search query network (Jan 2016–Dec. 2019; left) and pandemic search query network (Jan-April 2020; right). Nodes sized by search term frequency and edges by bigram frequency. For ease of interpretation, we maintained node locations and reconciled word conjugations for search keywords. Interactive combined network found at https://shiny.sesync.org/apps/interactivenetwork/.

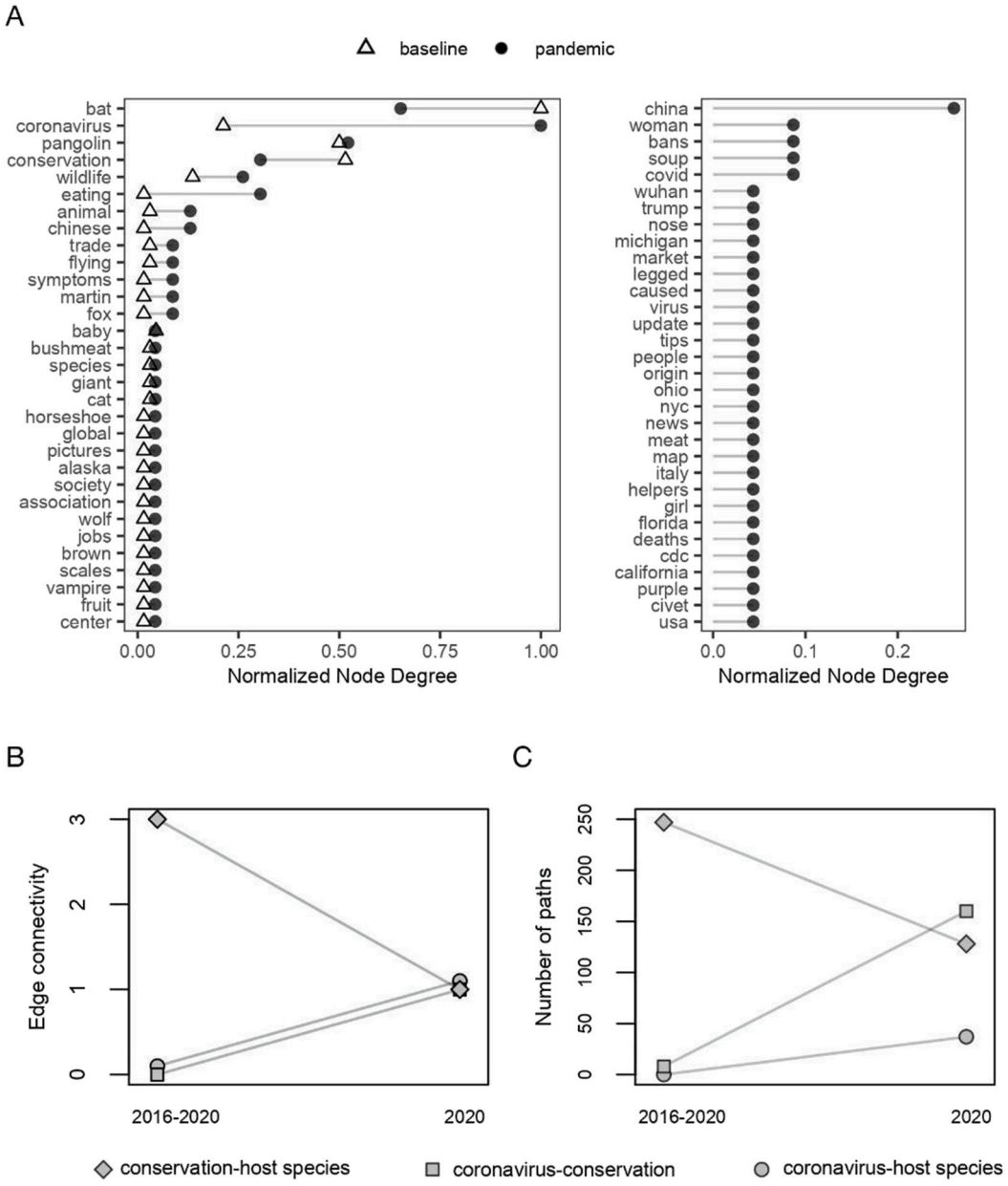

Fig. 4. Connectivity metrics for baseline and pandemic networks. A) Normalized node degree for baseline and pandemic network, organized in descending order. The right plot shows normalized node degree for novel nodes found only during the pandemic. B) Edge connectivity between biodiversity conservation ('conservation', 'wildlife trade', 'bushmeat') and host species ('bats', 'pangolins'; shown with diamonds), between coronavirus ('coronavirus', 'covid') and biodiversity conservation (squares), and between coronavirus and host species (circles) for baseline and pandemic networks. C) Paths between biodiversity conservation and host species (diamonds), between coronavirus and biodiversity conservation (squares), and between coronavirus and host species (circles) for baseline and pandemic networks.

During the pandemic period, we found increased interest in human-wildlife interactions and disease spillover, including changes to the degree of conserved nodes and the emergence of novel nodes. For example, the largest increase in centrality for a term outside of the keywords, was for 'eating' (Fig. 4A, $\Delta\, Dn = 0.28$), and there were novel searches for 'soup', 'Wuhan market', 'meat', and 'bans'. Novel nodes in the pandemic network consist of both topics that specifically relate to the disease itself and those at the intersection of human health and conservation. A comparison of baseline and pandemic networks reveals 32 novel nodes that emerged during the pandemic period (Fig. 4A). Only one of these terms, "covid", refers exclusively to the current coronavirus. Another novel search term, "civet", may have emerged based on the presumed role of masked palm civets in the spread of SARS, a previous coronavirus, in the early 2000s (Shi and Hu, 2008). Of these novel nodes the most dominant, when measured by node degree, was 'China' (Dn = 0.25). During the pandemic, novel search terms also included geographic locations, reflecting interest in disease outbreak and case data in the United States and other nations.

There was no evidence for connections between keywords related to coronavirus and keywords related to conservation before the pandemic. During the pandemic, the network connectivity between coronavirus keywords and conservation keywords increased, which we measured using the number of unique connections (edge connectivity, k′ (G)) and the number of simple paths (*Sp*) between keywords. Both measures of network connectivity increased between 'coronavirus' and 'bats' or 'pangolins' (Fig. 4B, C, $\Delta k'$ (G) = 1, $\Delta Sp = 37$), and between 'coronavirus' and 'conservation' ($\Delta k'$ (G) = 1, $\Delta Sp = 160$). These increases during the pandemic period were the result of both stronger direct

connections and new connections between novel nodes. In contrast, the connections between conservation and host species, which were present in the pre-pandemic network (k' (G) = 3, Sp = 250), were reduced during the pandemic ($\Delta k'$ (G) = −2, ΔSp = −119)(comparison of global network metrics found in SI: Network Community Comparison).

4. Discussion

US search interest in coronavirus was not closely correlated to concurrent case numbers in either China, Italy or even the US (Fig. 1). Higher search interest for coronavirus lagged behind the highest case rates in China and preceded higher case rates in both the US and Italy. Thus, case rates alone may be insufficient to describe search interest in a complex global media environment. Instead, the peak of search interest for coronavirus in mid-March may indicate that interest is more linked to international policy actions like the World Health Organization (WHO) declaration of COVID-19 as a pandemic on March 11, 2020 (Fig. 2E). Despite the growing number of cases in the US following the WHO declaration, search interest for coronavirus declined following the mid-March peak. This suggests that during this latter part of our study period, there was greater public knowledge of the disease itself and searches shifted toward disease symptoms and prevention methods (Springer et al., 2020), though search interest in coronavirus remained much higher than pre-pandemic levels.

In addition, we observed significant and marked increases in interest for presumed coronavirus host species and wildlife trade (Fig. 2) and increased connections between health and environment topics (Fig. 4). The sharpest increases in interest for these topics occurred over short time scales, with peaks of interest aligning closely with interest in the disease, and in particular around the declaration of the pandemic. These patterns of early, rapid increase in interest have implications for the timing of outreach focused on health and the environment. Efforts to engage the public during this period may be most successful, as they are more likely to reach the largest, most engaged, audience. However, both the persistence of elevated interest levels and the presence of increased search network connectivity suggest a potential resilience in receptiveness that may benefit ongoing efforts. Increased public awareness of health-environment connections during the pandemic may also benefit conservation, even in light of reduced interest in species conservation efforts, by providing a mechanism for maintaining interest in health-related conservation topics. However, connections drawn between these topics may not always result in positive outcomes for conservation. To mitigate the possibility of perverse outcomes, we concur with suggestions that communication strategies avoid reinforcing misleading negative associations between wildlife and zoonoses (MacFarlane and Rocha, 2020), placing emphasis instead on nuanced messaging on the role of biodiversity loss in disease spillover and outbreak.

Both changes in node degree of conserved nodes and the emergence of novel nodes in the pandemic network point to increased interest in wildlife trade, particularly the role of wildlife consumption and wet markets as the potential origin of COVID-19 (Woo et al., 2006). Global interest in wildlife trade plays a strong role in enforcement and monitoring of global trade flows underlying the sale and consumption of wildlife (Dobson et al., 2020). This public engagement also plays a role in the ongoing debates about the consistency of revisions to China's Wildlife Protection Law and illegal wildlife trade bans with international treaties like CITES (the Convention on International Trade in Endangered Species) and CBD (Convention on Biological Diversity) (Chen and Yifan, 2020; Koh et al., 2021). The speculation behind the early spread of COVID-19 is reflected in the most frequent bigram within the pandemic search network: 'eating bat' (n = 20). Taken together, these could be seen as a desire by users to seek additional information on wildlife trade in ways that may not be captured by an analysis of only search volume data on the search keywords of 'bat' or 'wildlife trade'. Network analyses reveal that during the pandemic, public knowledge seeking extended to other issues in the public discourse, like 'wet markets', when early research on the origins of the disease led to greater focus on the role of these markets in zoonotic spillover (Aguirre et al., 2021). Effective and ethical conservation policies will need to incorporate local context and drivers of wildlife trade, to avoid unintended consequences (Eskew and Carlson, 2020; Roe et al., 2020).

5. Conclusions and policy implications

Our study of changes in public interest during the COVID-19 pandemic is a clear example of emerging awareness of health-environment connections during a major public health event. These findings are congruent with prior studies of public interest following catalyzing events, such as major hurricanes or the death of "Cecil" the lion (Howe et al., 2014; Buhrmester et al., 2018). Interest following these events has the potential to lead to changes in environmental or health behaviors. We find sufficient evidence to propose that the COVID-19 pandemic may be such a catalyzing event, providing an opportunity to raise awareness of conservation actions that reduce risks of future disease spread. However, the persistence of public interest in this intersection of health and conservation is uncertain and requires ongoing monitoring during and after the pandemic. Much like public interest in climate issues after natural disasters (Howe et al., 2014), interest may eventually fade in the absence of additional catalyzing events and outreach efforts.

Though we found that interest in several topics related to conservation increased, interest in the term 'conservation' decreased during the pandemic. This is similar to findings in Europe, where interest in terms describing nature increased during the COVID-19 pandemic, but interest in terms describing environmental policies did not (Rousseau and Deschacht, 2020). Interest in conservation during the pandemic may suffer from a reduction in media attention and an emphasis on short term improvements in pollution or benefits to wildlife from reduced human mobility, despite coincident negative impacts on invasive species control or management of threatened taxa (Manenti et al., 2020). A key finding of this work, that the largest increases in public interest occur over relatively short time frames, suggests that there is a small window to engage support for intersectional approaches to pandemic prevention (e.g. EcoHealth Alliance) which further conservation goals while highlighting human health benefits that are the focus of greater public interest.

New approaches for improving understanding of societal responses to long term environmental changes and disease emergence, such as calls for a permanent preparedness enterprise to prevent future pandemics (Zerhouni et al., 2020), will rely on continued engagement in efforts to simultaneously assess and manage human health and conservation goals. Despite the current limitations of search index data (Troumbis, 2017a; Arora et al., 2019), as we have shown, these approaches are useful real-time indicators of public interest. As internet coverage expands and new data sources become available, new methods of analyzing and synthesizing public health and environmental data will need to be developed (Jarić et al., 2020). Such analyses and tools can guide responses to future health and environmental crises, when it is critical to leverage the full capacity of publicly available data.

CRediT authorship contribution statement

V.V. designed the study, acquired data, conducted the analyses, and wrote the original draft. C.F. provided input on study design, and contributed to network analyses. F.G. and K.J. provided conceptual input, analysis feedback and domain specific knowledge on policy and public health. All authors edited the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

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Data and materials availability

Archived data and code are available at https://github.com/varshavijay101/COVID19healthconservation

References

Aguirre, A.A., Gore, M.L., Kammer-Kerwick, M., et al., 2021. Opportunities for transdisciplinary science to mitigate biosecurity risks from the intersectionality of illegal wildlife trade with emerging zoonotic pathogens. Front. Ecol. Evol. 9, 604929.

Allen, T., Murray, K.A., Zambrana-Torrelio, C., et al., 2017. Global hotspots and correlates of emerging zoonotic diseases. Nat. Commun. 8, 1–10.

Anderegg, W.R., Goldsmith, G.R., 2014. Public interest in climate change over the past decade and the effects of the 'climategate' media event. Environ. Res. Lett. 9, 054005.

Arora, V.S., McKee, M., Stuckler, D., 2019. Google Trends: opportunities and limitations in health and health policy research. Health Policy 123, 338–341.

Bento, A.I., Nguyen, T., Wing, C., et al., 2020. Evidence from internet search data shows information-seeking responses to news of local COVID-19 cases. PNAS 117, 11220–11222.

Berthe, F.C.J., Bouley, T., Karesh, W.B., et al., 2018. One Health: Operational Framework for Strengthening Human, Animal, and Environmental Public Health Systems at Their Interface. The World Bank.

Buhrmester, M.D., Burnham, D., Johnson, D.D.P., et al., 2018. How moments become movements: shared outrage, group cohesion, and the lion that went viral. Front. Ecol. Evol. 6.

Carley, K.M., 1997. Extracting team mental models through textual analysis. J. Organ. Behav. 18, 533–558.

Challender, D.W., Waterman, C., Baillie, J.E., 2014. Scaling up Pangolin Conservation. IUCN SSC, Pangolin Specialist Group Conservation Action Plan Zoological Society of London, London, UK (21pp).

Chen, W., Yifan, J., 2020. The Legal Proposals Shaping the Future of Wildlife in China. China Dialogue. Available at. https://www.chinadialogue.net/article/show/single/en/11940-The-legal-proposals-shaping-the-future-of-wildlife-in-China.

Choi, H., Varian, H., 2012. Predicting the present with Google Trends. Econ. Rec. 88, 2–9.

comScore. comScore Releases January 2021 U.S. Desktop Search Engine Rankings - comScore, Inc. [Accessed March 29,2021]; https://www.comscore.com/Insights/Rankings#tab_search_share/.

Csardi, G., Nepusz, T., 2006. The igraph software package for complex network research. InterJournal, complex systems 1695, 1–9.

Dobson, A.P., Pimm, S.L., Hannah, L., et al., 2020. Ecology and economics for pandemic prevention. Science 369, 379–381.

Dong, E., Du, H., Gardner, L., 2020. An interactive web-based dashboard to track COVID-19 in real time. Lancet Infect. Dis. 20, 533–534.

Durmuşoğlu, Z.D.U., 2017. Using Google Trends data to assess public understanding on the environmental risks. Hum. Ecol. Risk Assess. Int. J. 23, 1968–1977.

Eskew, E.A., Carlson, C.J., 2020. Overselling wildlife trade bans will not bolster conservation or pandemic preparedness. Lancet 4, e215–e216.

Frick, W.F., Kingston, T., Flanders, J., 2020. A review of the major threats and challenges to global bat conservation. Ann. N. Y. Acad. Sci. 1469, 5–25.

Google Trends, 2020. Coronavirus Search Trends. https://trends.google.com/trends/story/US_cu_4Rjdh3ABAABMHM_en.

Howe, P.D., Boudet, H., Leiserowitz, A., Maibach, E.W., 2014. Mapping the shadow of experience of extreme weather events. Clim. Chang. 127, 381–389.

Jarić, I., Correia, R.A., Brook, B.W., et al., 2020. iEcology: harnessing large online resources to generate ecological insights. Trends Ecol. Evol. (Apr 10).

Jones, K.E., Patel, N.G., Levy, M.A., et al., 2008. Global trends in emerging infectious diseases. Nature 451, 990–993.

Kelly, T.R., Karesh, W.B., Johnson, C.K., et al., 2017. One Health proof of concept: bringing a transdisciplinary approach to surveillance for zoonotic viruses at the human-wild animal interface. Prev. Vet. Med. 137, 112–118.

Koh, L.P., Li, Y., Lee, J.S., 2021. The value of China's ban on wildlife trade and consumption. Nature Sustainability 4, 2–4.

Ladle, R.J., Correia, R.A., Do, Y., et al., 2016. Conservation Culturomics. Front. Ecol. Environ. 14, 269–275.

Lam, T.T.-Y., Jia, N., Zhang, Y.-W., et al., 2020. Identifying SARS-CoV-2-related coronaviruses in Malayan pangolins. Nature 583, 282–285.

MacFarlane, D., Rocha, R., 2020. Guidelines for communicating about bats to prevent persecution in the time of COVID-19. Biol. Conserv. 248, 108650.

Manenti, R., Mori, E., Di Canio, V., et al., 2020. The good, the bad and the ugly of COVID-19 lockdown effects on wildlife conservation: insights from the first European locked down country. Biol. Conserv. 249, 108728.

Nghiem, L.T.P., Papworth, S.K., Lim, F.K.S., Carrasco, L.R., 2016. Analysis of the capacity of Google Trends to measure interest in conservation topics and the role of online news. PLoS One 11, e0152802.

Nuti, S.V., Wayda, B., Ranasinghe, I., et al., 2014. The use of Google Trends in health care research: a systematic review. PLoS One 9, e109583.

Page, B.I., Shapiro, R.Y., 1983. Effects of public opinion on policy. Am. Polit. Sci. Rev. 175–190.

Paranyushkin, D., 2011. Identifying the pathways for meaning circulation using text network analysis. Nodus Labs 26.

Phillis, C.C., O'Regan, S.M., Green, S.J., et al., 2013. Multiple pathways to conservation success. Conserv. Lett. 6, 98–106.

Popping, R., 2003. Knowledge graphs and network text analysis. Soc. Sci. Inf. 42, 91–106.

Rabinowitz, P.M., Kock, R., Kachani, M., et al., 2013. Toward proof of concept of a one health approach to disease prediction and control. Emerg. Infect. Dis. 19.

Roe, D., Dickman, A., Kock, R., et al., 2020. Beyond banning wildlife trade: COVID-19, conservation and development. World Dev. 136, 105121.

Rousseau, S., Deschacht, N., 2020. Public awareness of nature and the environment during the COVID-19 crisis. Environ. Resour. Econ. 76, 1149–1159.

Seltenrich, N., 2018. Down to Earth: the emerging field of planetary health. Environ. Health Perspect. 126.

Shi, Z., Hu, Z., 2008. A review of studies on animal reservoirs of the SARS coronavirus. Virus Res. 133, 74–87.

Silge, J., Robinson, D., 2016. Tidytext: text mining and analysis using tidy data principles in R. J. Open Source Softw. 1, 37.

Springer, S., Menzel, L.M., Zieger, M., 2020. Google Trends reveals: focus of interest in the population is on treatment options rather than theories about COVID-19 animal origin. Brain Behav. Immun. 87, 134.

Troumbis, A.Y., 2017a. Declining Google Trends of public interest in biodiversity: semantics, statistics or traceability of changing priorities? Biodivers. Conserv. 26, 1495–1505.

Troumbis, A.Y., 2017b. Google Trends and cycles of public interest in biodiversity: the animal spirits effect. Biodivers. Conserv. 26, 3421–3443.

Verbesselt, J., Hyndman, R., Newnham, G., Culvenor, D., 2010a. Detecting trend and seasonal changes in satellite image time series. Remote Sens. Environ. 114, 106–115.

Verbesselt, J., Hyndman, R., Zeileis, A., Culvenor, D., 2010b. Phenological change detection while accounting for abrupt and gradual trends in satellite image time series. Remote Sens. Environ. 114, 2970–2980.

Woo, P.C., Lau, S.K., Yuen, K., 2006. Infectious diseases emerging from Chinese wet-markets: zoonotic origins of severe respiratory viral infections. Curr. Opin. Infect. Dis. 19, 401–407.

Zerhouni, W., Nabel, G.J., Zerhouni, E., 2020. Patents, economics, and pandemics. Science 368, 1035.

Zhou, P., Yang, X.-L., Wang, X.-G., et al., 2020. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature 579, 270–273.