COVID-19 has led to a global increase in web searches for bats: a risk for conservation ?

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Abstract SARS-CoV-2, the virus that caused COVID-19 pandemic, is genomically similar to a SARS-like beta-coronavirus found in Chinese rhinolophids. This evolutionary relationship impressed global media, which emphasized bats as key actors in the spillover during the pandemic outbreak. In this study we highlight qualitative and quantitative changes about bats in the media coverage, and Internet search volumes that occurred since the beginning of COVID-19 pandemic in 2020.

We analyzed Google and Wikipedia searches for bats and coronaviruses across 20 countries in 8 languages, as well as television broadcasts in the US, some of which have a global coverage, between January 2016 and December 2020. The amount of television news about bats on US newscasts boomed in January 2020, and news associated with the term "bat" shifted to COVID-19 related topics. A nearly identical pattern was also observed on 2020 Google searches, at the global scale. The daily time series of television coverage, and Internet search volumes about bats and coronavirus in the US, showed a very high correlation in the first semester of 2020, in line with the existence of a media bubble. Time series analysis revealed that both the GoogleTrends index and visits to Wikipedia pages about bats boomed in early 2020, despite such time of the year was usually characterized by low search volumes.

The media coverage emphasized, correctly or not, the role of bats in COVID-19 pandemic and amplified public interest towards them worldwide, yet the public image of these mammals, in many cases threatened and important ecosystem service providers, was seriously compromised. We therefore recommend policymakers to quickly enforce communication campaigns about bats, which would help counteract the surge in bat persecution and leverage interest towards positive human-bat interactions.

Warning

This is a ***preprint***, not a peer-reviewed study. If you do not know what a preprint is, we encourage you to read more about this type of documents (https://en.wikipedia.org/wiki/Preprint), before evaluating and citing the study. The first version of the preprint was archived in April 2020. This update broadened the analysis of online searches, providing a comprehensive overview of Internet searches about bats throughout 2020. Previous versions of the preprint can be downloaded from EcoEvoRXiv at the menu "Download previous versions".

Introduction

COVID-19, the global pandemic outbreak caused by the SARS-CoV-2 coronavirus, was first detected in the city of Wuhan (China) in December 2019, and subsequently spread globally between January and March 2020. By 07th December 2020, SARS-CoV-2 is estimated to have infected 66,243,918 people, killing 1,528,984 [1].

Genetic comparisons showed that SARS-CoV-2 is most similar to RaTG13 and RmYN02, two Sarbecoviruses found in bats from China, respectively in *Rhinolophus affinis* [2] and *Rhinolophus malayanus* [3]. Although these viruses are very similar to SARS-CoV-2 (RmYN02 shares 93.3% nucleotide identity with SARS-CoV-2 and RaTG13 96.1%)[3] their spike protein – the external part of the virus that allows attachment to the host cells – could not bind efficiently to human cells, so they are not infectious to humans [2][3]. Sarbecoviruses found in the Malayan pangolin (*Manis javanica*)[4] are very similar to SARS-CoV-2 in the receptor-binding domain, yet they differ more from SARS-CoV-2 when the entire viral genome is examined (78.9-85.2%)[3]. The discovery of viruses similar to SARS-CoV-2 in bats and pangolins suggests that there is a wide and overlooked diversity of Sarbecoviruses in wildlife, some of which possibly involved directly in the emergence of SARS-CoV-2.

Given COVID-19 pandemic's dramatic evolution and impacts, both digital and social media relentlessly covered nearly every aspect of it [5], including the potential role of bats in the spillover event. Both the press and the TV jumbled up evidence about bats as reservoirs of many viruses and their role in zoonotic spillovers, often overstating available evidence or neglecting the complex interplay of these dynamics with broader environmental issues (e.g. https://www.washingtontimes.com/news/2020/mar/30/china-researchers-isolated-bat-coronaviruses-near-/). On the social

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media, the situation was even more critical, with the circulation of fake documents and news, which contributed to massive spread of misinformation (see: ttps://www.bbc.com/news/blogs-trending-51271037).

This has sparked concern among conservationists because misinformation could result in increased bat persecution by humans [6][7][8][9]. Worldwide, bats are often persecuted by people due to conflicts with colonies in buildings, negative beliefs or superstitions and, locally, crop raiding by frugivorous species [10]. Besides, in the last few years, the media increasingly covered the topic of bat-borne zoonoses, raising public concern [11]. This increase followed that of scientific publications about this topic in late 1990s [12], and is deemed to have caused bat killing to prevent bat zoonoses [13], a practice which can in fact increase disease transmission to humans since bats are handled during culling operations, or their killing might favour the arrival of further individuals bearing higher levels of active infection, or more susceptible to the latter [14][15][16].

The global importance of the COVID-19 pandemic outbreak, and its associated "infodemic" [5], poses an unprecedented risk of global escalation in bat persecution. It is therefore important to assess: (*i*) whether, and if so, to what extent, COVID-19 increased media coverage of bats; (*ii*) whether such coverage implied a change in how bats are framed; and, in case, (*iii*) if the public responded to these changes. To answer these questions, we: (*i*) explored temporal changes in the frequency at which television companies in the US covered bats, (*ii*) explored qualitative changes in the bat news presented by television broadcasting companies in the US, and in global Google searches on bats and (*iii*) assessed temporal changes in the volume of Google and Wikipedia searches about bats across 20 countries.

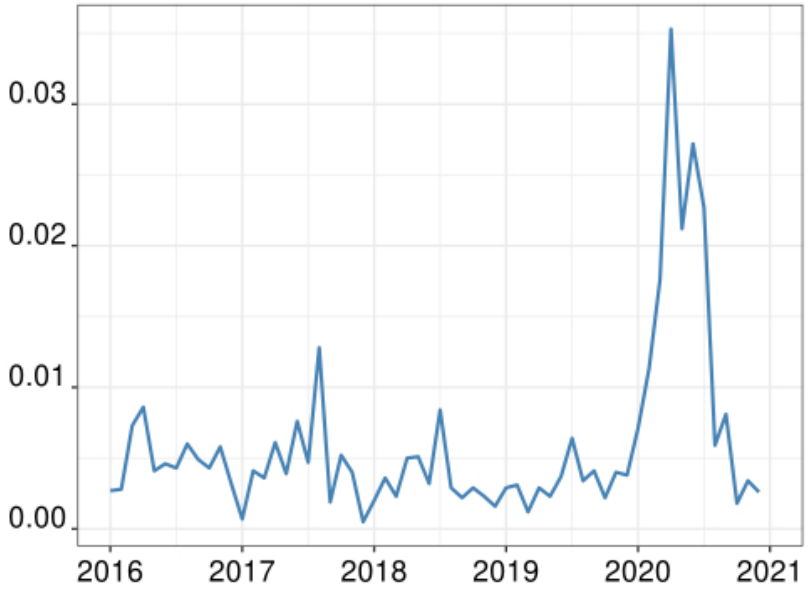

Figure 1: Volume of news, on major television broadcasts in the US, that talked about bats, extracted from GDEL Television Explorer (further details can be found here https://blog.gdeltproject.org/gdelt-2-0-television-api-debuts/)

Methods

Data collection: traditional media

In this study we distinguished between traditional media, characterized by a top-down information flow, from media companies to news consumers, and the "new" media, like social media, characterized by a crowdsourced propagation of news. This classification is widely adopted in the social sciences, as the two media systems coexist and interact, but have minor overlap [17].

To quantify temporal changes in the extent to which traditional media covered bats, before and after the beginning of the COVID-19 pandemic, we accessed the Internet Television News Archive. The archive contains a complete collection of daily news from the nine largest US television broadcasters. We focused on this country since it is the only one for which a comprehensive archive of television news is available. Besides, television broadcasting companies included some with a global audience of

several hundred million people, such as CNN and FoxNews (https://cnnpressroom.blogs.cnn.com/2020/02/19/cnn-digital-breaks-all-records-largest-digital-audience-in-history-in-january-2020/).

For each month, between January 2016 and the 8th of December 2020, we extracted the GDELT Television Explorer relative index, for the "bats" query The index shows the relative coverage that is attained by a certain keyword on televisions (further details are available on https://blog.gdeltproject.org/gdelt-2-0-television-api-debuts/), in our case the extent to which all the major US television broadcasting companies covered bats in the period of time considered.

Moreover, since archive news are indexed with multiple keywords, we also extracted the other keywords characterizing news indexed with the keyword "bats". This approach summarized news on bats, enabling us to detect qualitative changes in how television broadcasts had changed their framing of these mammals. Data were extracted with the package 'newsflash' (https://github.com/hrbrmstr/newsflash) within the "R" software environment [18].

Data collection: Google and Wikipedia

Information-searching behavior on the Internet can be a barometer to evaluate whether a certain topic is salient to laypeople [19]. Internet penetration has in fact increased over the last 15 years [20] and nowadays people search online for information about scientific [21], environmental [22][23][24][25] or health-related topics [26]. To quantify whether, and if so to what extent, people reacted to the media coverage on bats that followed COVID-19, we analyzed bat searches in Google, the leading search engine accounting for ca. 87% of the global volume of Internet searches.

Google automatically classifies related searches, i.e. those searches made altogether with a certain query, into various topics. To measure whether people changed the type of their Internet searches about bats, we extracted the most common topics characterizing related searches about bats on Google between 2016 and 2020.

Moreover, to detect changes in the volume of Internet searches about bats, we downloaded the weekly value of the Google Trends index for the query "bats", between January 2016 and 08 December 2020. The Google Trends index (https://support.google.com/trends/?hl=entopic=6248052) is a relative metric obtained by: (i) dividing the total number of searches for a certain query over the total number of Google searches in the same time span, (ii) normalizing each value of this relative index, for the maximum point of the time-series, and multiplying it by 100. The GoogleTrends index showed the overall volume of searches about bats on Google, and their evolution through time, adjusting for temporal changes in the overall volume of Google searches.

We downloaded Google data from 20 countries: Argentina, Australia, Austria, Brazil, Canada, Chile, Colombia, France, Germany, Ireland, Italy, Japan, Mexico, New Zealand, Portugal, Republic of Korea, Spain, the UK, Uruguay, and the US. We did not consider China, where Google is outcompeted by Baidu. Google data were downloaded with the 'gtrendsR' package [27] of the statistical software R [18].

To complement our analysis of Internet search volumes, we also downloaded visits to Wikipedia pages about bats between 2016 and 2020. Wikipedia is the largest online encyclopedia and visits to its pages cannot be extracted at the country level, but only across different languages. We downloaded data from those languages that were spoken in the 20 countries considered for Google: English, Spanish, French, Portuguese, German, Italian, Japanese, Korean. Daily visits were downloaded from PageViews (https://pageviews.toolforge.org/), and aggregated on a weekly basis to reduce noise. Moreover, to account for temporal changes in the overall Wikipedia usage, we analyzed the numbers of visits to Wikipedia pages about bats per million of visits to Wikipedia. For each country and language, the query "bats" was translated accordingly (Table 1).

Data analysis

We adopted wordclouds to depict qualitative changes in keywords associated with news about bats, as well as qualitative changes in the topic of related searches about bats on Google. Wordclouds were computed for each year between 2016 and 2020. Google topics and news keywords had already been ranked by Google and GDELT according to, respectively, their average GoogleTrends and their GDELT indexes. In our wordclouds we assigned a size to each word that was proportional to these index, to make popular related searches and keywords more evident.

We used the Pearson correlation coefficient to measure the covariation of daily television news, Google searches and visits to Wikipedia, about coronaviruses and bats, between January and September 2020, a timespan of 9 months for which daily values of the GoogleTrends index could be extracted. For this analysis, we considered time series from the US, the only country for which television data

were available. In case of a media bubble about bats and COVID-19, we expected time-series to be positively correlated, as a result of a rapid flow of information between traditional and digital media.

Then we adopted Bayesian generalized additive models (GAM) to identify temporal changes in Internet search volumes, before and after 2019. Changes in the number of visits to Wikipedia pages about bats, per million of visits to Wikipedia, were modelled through a first-order random walk smoother with a Gamma distribution of the error and penalized complexity prior [28]. Temporal changes in the GoogleTrends index were modeled with a B-spline with 128 knots and a Gamma distribution of the error, using the various weeks of the time series as a predictor [29]. The number of knots was selected through information criteria and leave-one-out cross-validation [28]. As values of the GoogleTrends index from different countries could not be aggregated, we included a random-intercept term for each country. The reproducible software code, our datasets and the country-specific analyses are available on the OSF website (https://osf.io/wxh6a/).

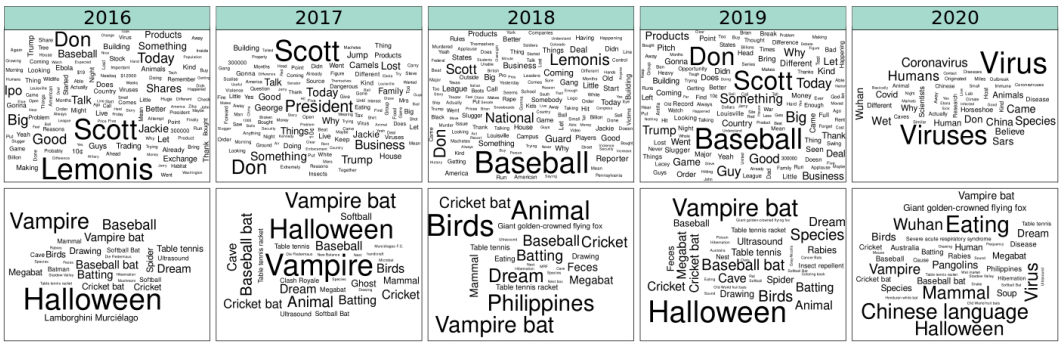

Figure 2: Word clouds representing keywords associated with news about "bats" on US television broadcasts (top row), and representing topics of Google searches related to bats in 20 different countries (bottom row).

Results

News coverage about bats on US televisions was low until the end of December 2019. Then, from January 2020, in parallel with the first cases of SARS-CoV2, it peaked and remained high across the first semester of 2020 (Fig. 1).

The analysis of indexed keywords shows a clear change in how US televisions framed bats, before and after December 2019. Until 2019, most news about "bats" focused on a wide range of topics, also marginally including health-related ones like "Ebola", "virus", "MERS", or "HIV". However, these became dominant in 2020, when most news about bats were indexed with keywords like "virus", "SARS", "coronavirus" or "humans" (Supplementary Information). A similar change was observed in Google searches around the world. Until 2019 searches related to bats covered also topics unrelated to Chiroptera, like Halloween or baseball (due to "baseball bat") or limited to bat biology. On the other hand, since 2020 there was a clear shift in Google searches about bats, which largely focused on the role of Chiroptera in disease transmission and the COVID-19 pandemic (Fig. 2, see also Supplementary Information).

Daily television coverage and Google search volumes in the US, as well as visits to English Wikipedia pages on coronavirus and bats co-varied between January and September 2020. Their correlation was even higher between late February and late May. Only television programs that focused specifically on bats, had a lower correlation, peaking later, in early summer 2020 (Fig. 3, 4). Please note that these programs were documentaries or in-depth reports about bats and viruses, that were different from news about COVID-19 which also mentioned bats.

Bayesian smoothing shows that both Wikipedia searches and the GoogleTrends index boomed in early 2020, despite this time of the year used to be characterized by low volumes of Internet searches about bats in the years preceding the pandemic (Fig. 5).

Discussion

This study constitutes the first effort to link systematic changes in media coverage about bats to shifts in public interest towards them following the beginning of COVID-19 pandemic. Our findings are highly suggestive that, in early 2020, a media bubble formed around bats and their role in the spillover of SARS-CoV2, following the "infodemic" that surrounded COVID-19. This media bubble in turn affected public interest towards these mammals, boosting Internet searches.

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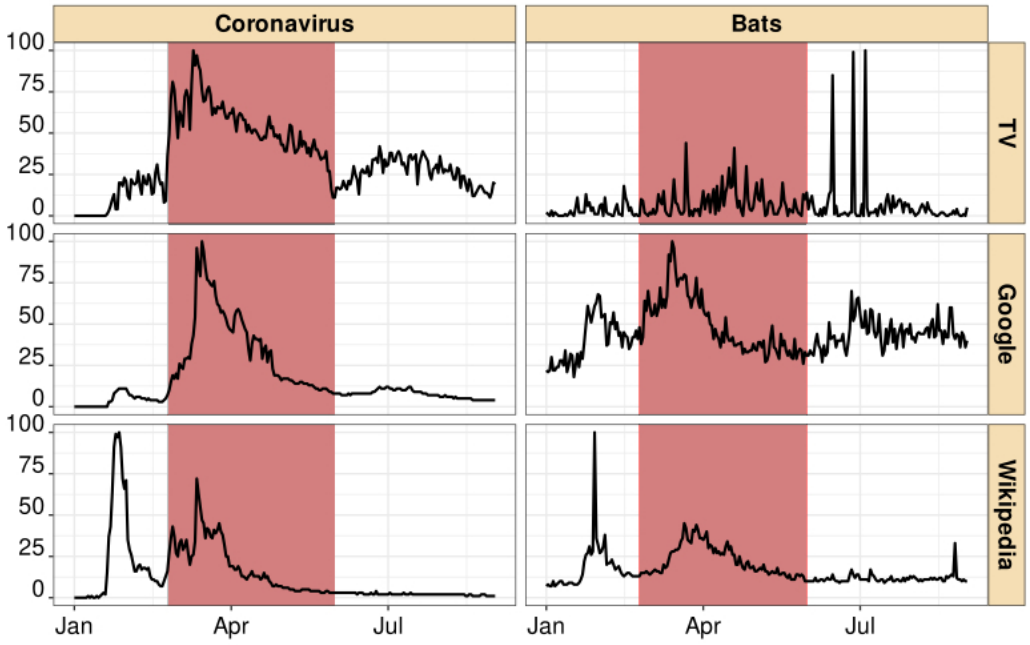

Figure 3: Daily time-series of television news, the GoogleTrends index, and Wikipedia searches about bats and coronavirus in the US. Data were extracted between January and September 2020, the maximum timespan for which daily GoogleTrends data could be obtained. The highlighted rectangular area represents the period between late February and early June 2020, when correlation between time series was maximized.

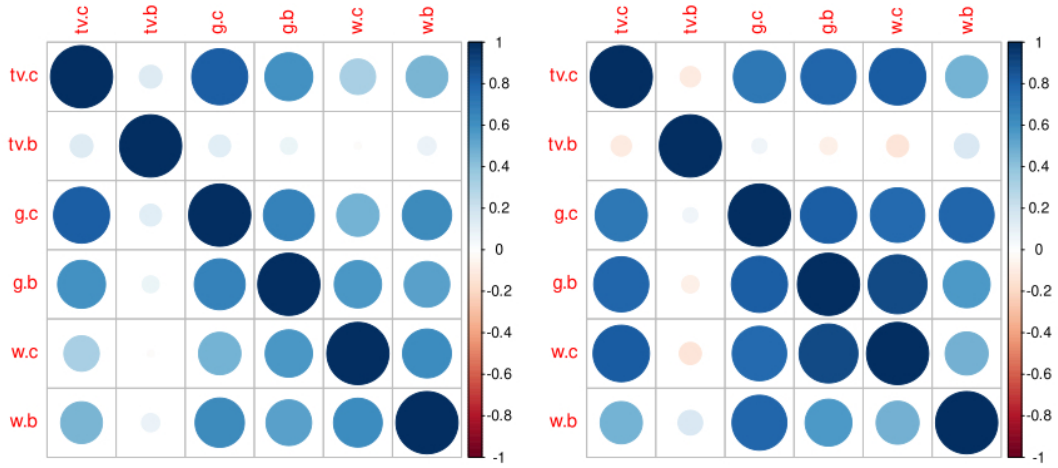

Figure 4: Correlation between daily time-series of television news, the GoogleTrends index, and Wikipedia searches about bats and coronavirus in the US: January-September 2020 (left) and late February – early June 2020 (right). Legend: tv.c = television news about coronavirus, tv.b = television news about bats, g.c. = GoogleTrends index about coronavirus, g.b. = GoogleTrends index about bats, w.c. = Wikipedia visits to the page about coronavirus, w.b = Wikipedia visits to the page about bats.

Large American newscasts increasingly covered bats, since the beginning of the COVID-19 pandemic in January 2020. Moreover, they also changed how bats were framed, focusing on health-related issues and their potential role in the COVID-19 pandemic. Indeed, before 2020, most television news about "bats" in the US did not even talk about Chiroptera, because referred to other meanings of the word "bat", like "baseball bat". This change in media coverage was synchronous with a change in the topic of related searches about bats on Google, at the global scale: across 20 countries we observed that searches related to bats shifted from a wide range of disconnected topics to health-related ones (Fig. 2).

Changes in media depiction and Internet searches about bats were also quantitatively synchronized at least in the US. The fact that the amount of television coverage, Google and Wikipedia searches had a very similar variation in time, being highly correlated in the second trimester of 2020, supports the idea that bats were affected by the COVID-19 "infodemic" and that a media bubble formed around them and their role in the SARS CoV-2 spillover in the first semester of 2020. Traditional media, in

the early stages of COVID-19 pandemic, mentioned bats as reservoirs for many diseases, including SARS-CoV-2, or blamed bat consumption in China as the main cause for the spillover. Following this information campaign, people probably searched the topic on the Internet, generating volumes of Internet searches that were temporally correlated with the above-mentioned television news and which further inflated the appealing of bat-related news for traditional media.

Specific news about bats were relatively scarce, compared to the news about COVID-19 (Supplementary Information). The former peaked between June, when the CNN broadcast specific programs about bats and the spillover of SARS-CoV-2 (https://cnnpressroom.blogs.cnn.com/2020/06/09/cnn-to-air-special-on-the-connection-between-bats-and-covid-19/); and in July, when Chinese scientists published a detailed reply to the accusation of having fabricated SARS-CoV-2 in their laboratories in Wuhan, from which it was suspected to have leaked (https://www.sciencemag.org/news/2020/07/trump-owes-us-apology-chinese-scientist-center-covid-19-origin-theories-speaks-out). However, considered the huge amount of news about COVID-19 in the second trimester of 2020, and the resulting sensitivity of people about this topic, even marginally mentioning bats within the coronavirus coverage in spring 2020, probably sufficed to synchronize Internet searches about such topics in the same period.

It is therefore not surprising that our time-series analysis found a massive increase in Internet searches about bats in early 2020. We showed a threefold increase in the GoogleTrends index about "bats" in early 2020 over the same period in previous years, and a similar increase in weekly visits to Wikipedia pages on bats compared to the average seasonal pattern. Both the GoogleTrends index and our Wikipedia visits accounted for the total volume of searches on Google and Wikipedia, these results were thus not influenced by any increase in Internet searches caused by COVID-19.

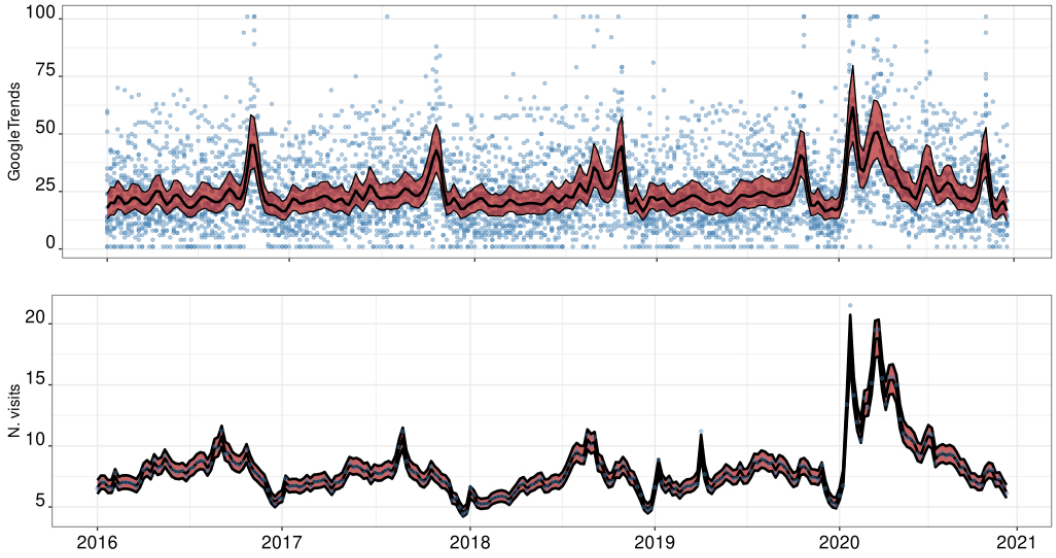

Figure 5: Temporal evolution of Google searches about bats, across 20 different countries, measured through the GoogleTrends index (upper panel), and of aggregated visits to Wikipedia pages about bats (lower panel). Wikipedia visits are expressed as weekly visits to pages about bats per 1 million visits to Wikipedia on the same week.

Public opinion could particularly be affected by mass media when the audience has little experience with a particular issue [30]. Individual search for orientation depends on the relevance of a topic and its level of uncertainty [31]. Taken together, our findings suggest that media coverage play a fundamental role in making people inquire about wildlife and emerging zoonoses [32]. In this case, the effect was to make bats viral, although these species are often not iconic and even repulsive to some people [11][33]. Bats play key roles in the ecosystems, e.g. as insect suppressors, seed dispersers and pollinators, thus providing essential services also in human-modified ecosystems [34][35]. Considering the role of the media in shaping human-wildlife attitudes [36], the importance of delivering evidence-based information on this topic too is fundamental. Raising public awareness correctly has also a remarkably important role both in disease management and in shaping attitudes towards wildlife and the environment. People's reactions to information by media may trigger persecution of some wildlife species, e.g. bats, in case news focus prolonged over their role as reservoirs for zoonoses without explaining the important role of these mammals in ecosystems functions [6][37][38].

Attempts to control wildlife diseases or to limit zoonosis transmissions have been long based on health/hygienic measures such as construction of barriers and vaccinations, as well as on practices directly targeting vectors or reservoir species such as culling programs [39]. The latter of course pose se-

rious problems when the spillover process is not clear, targeted species have a threatened conservation status, are poorly known with regards to their population size and parameters, or provide key ecosystem services, such as bats [10][34]. Also, following COVID-19, inappropriate/illegal persecution of bats was reported in some countries (e.g. Indonesia: https://www.scmp.com/video/asia/3075441/hundreds-bats-culled-indonesia-prevent-spread-coronavirus; Peru: https://phys.org/news/2020-03-peru-blamed-coronavirus.html; Egypt: https://www.arabnews.com/node/1661221/middle-east), raising great concern among bat conservationists [7][9][40]. Besides the fact that bat legal protection is restricted mostly to developed countries, persecution of bats usually occurs at very local scales (e.g. people evicting or deliberately killing bats roosting in buildings), and it is as such difficult to record and actually prevent [41]. Given the severity and the media resonance of the COVID-19 pandemic and the widespread misinformation circulating on bats, it is pivotal to create trustworthy sources of information, e.g. Wikipedia, based on solid and evidence-based statements, as well as to further investigate how such increase in public attention on bats translated into a change (positive, or more likely negative) in public attitude towards such mammals.

Although our conjoint analysis of television newscasts and Internet searches was confined to the US, we expect that what we recorded also occurred in other countries, for two reasons. First, CNN or Fox News have a global audience and are major actors in the global circulation of news, almost certainly influencing national televisions, at least in most English-speaking countries. Second, we observed a worldwide (20 countries) change in Google searches which matched the changes in the US news on bats.

The COVID-19 pandemic might be a turning point for human-bat interactions in the 21st century, which is bringing bats in the spotlight at an unprecedented extent, potentially representing both a challenge and an opportunity for bat conservation. A better understanding of media-public interactions on this topic is therefore fundamental for the future of bat populations worldwide, as well as for the correct media management of future pandemic zoonoses. From our analyses it was clear that Wikipedia visits and Google searches peaked on specific dates: understanding which type of news framing [42] caused such trends would be extremely important to tailor communication campaigns aimed at mitigating bat persecution. We also believe that our approach, based on Internet searches, albeit useful to detect rapid and pervasive shifts in public interest towards bats, cannot reveal long-term changes in human bats interactions. From Internet searches we found that society became more interested in Chiroptera in early 2020, than at any time in recent years. But any persecution of bats, or any action that will benefit them (e.g. the use of bat-boxes in urbanized environments) will certainly be carried out by a minority of people. Minoritarian behavior might get unnoticed on the Internet. Similar changes would be better detected by combining questionnaire based surveys, administered to representative samples of people in the various countries of the world, with the content analysis of social and traditional media, where persecution is likely being occasionally reported. The use of questionnaire-based surveys could also broaden data collection to countries with a low Internet access, that cannot be explored through the analysis of Internet search volumes, like in our study. We encourage this combination in future studies, to re-assess the direction of human-bat interactions after 2020, at the global scale.

Bats are often indicated as special reservoirs of zoonotic pathogens [43], having physiological traits that lead them to host many viruses. Bats were involved in the spillover of several zoonotic viruses, such as Ebola, Nipah, Hendra, and SARS-like coronaviruses [44]. However, in most cases, bats were a reservoir of these pathogens, whereas spillover to humans has been mediated by other wild or domestic species; but see Nipah virus for an example of direct spillover from bats to humans [45].

Although bats have physiological and ecological traits which make them good viral reservoirs [44], recent research has shown that the proportion of viruses which may infect humans varies minimally across reservoirs in birds and mammals and that the observed number of zoonoses at the order level increases along with their species richness [46]. A high proportion of emerging infectious diseases have been linked to wild animals; most spillover events are associated to environmental factors such as wildlife hunting, trade, consumption, forest loss and fragmentation, or human settlements encroaching on spaces formerly occupied by natural habitats [47].

While pathogen surveillance in regions where future spillover events are likely is crucial, messages regarding the rise of zoonoses should highlight the overwhelming role played by nature destruction and biodiversity loss within this context. On the other hand, communication should avoid portraying species such as bats as the "culprits" of zoonoses [6], which is also highly likely to result in the direct persecution of wildlife, in this way weakening the provision of essential ecosystem services and also increasing the risk of zoonoses due to the arrival of new individuals with possibly a higher levels of active infection [14][16]. A recent paper already presented guidance to effectively communicate about bats to prevent misinformation and persecution, identifying three key areas of psychological science: debunking misinformation, counteracting negative associations, and changing harmful social norms [6].

This study shows that online information searches about zoonoses are affected by their media coverage. However, while this point was already known for other zoonoses than COVID-19 (e.g. Zika)[26], our findings indicate that news spread in response to media coverage might not only involve pathogens but also their potential reservoir species. Furthermore, media coverage seems to determine which aspects of a zoonotic pandemic become viral and dominant in Internet searches. These points are of the uttermost importance for wildlife conservation, and they emphasize the importance of providing scientifically accurate information about zoonoses on both traditional and the social media, during delicate and potentially dangerous phenomena, like pandemics.

Table 1: Complete list of Google searches, and Wikipedia pages that were considered, across the various languages and countries

Language	Google query	Wikipedia pages
English	bats	https://en.wikipedia.org/wiki/Bat
Spanish	murciélagos	https://es.wikipedia.org/wiki/Chiroptera
Portuguese	morcegos	https://pt.wikipedia.org/wiki/Morcego
French	chauves-souris	https://fr.wikipedia.org/wiki/Chiroptera
German	Fledermaus	https://de.wikipedia.org/wiki/Fledertiere
Italian	pipistrelli	https://it.wikipedia.org/wiki/Chiroptera
Japanese	コウモリ	https://ja.wikipedia.org/wiki/ コウモリ
Korean	박쥐	https://kn.wikipedia.org/wiki/ 박쥐

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Supplementary Information

The data, altogether with the reproducible software code, are available on the Open Science Framework repository, at the following link: https://osf.io/wxh6a/

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