Animal Conservation

ZSL

Animal Conservation. Print ISSN 1367-9430

Trending extinctions: online interest in recently extinct animals

S. Canavan[1], D.M. Doyle[2], A. Kane[3], G. Nolan[3] & K. Healy[1]

1 School of Natural Sciences, Ollscoil na Gaillimhe—University of Galway, Galway, Ireland
2 School of Law and Criminology, Maynooth University, Maynooth, Ireland
3 School of Biology and Environmental Science, University College Dublin, Dublin, Ireland

Keywords
conservation culturomics; online engagement; Kunming-Montreal global biodiversity framework; conservation awareness; IUCN red list; Twitter; Wikipedia.

Correspondence
Susan Canavan, School of Natural Sciences, Ollscoil na Gaillimhe—University of Galway, Galway, Ireland.
Email: sucanavan@gmail.com

Editor: Iain Gordon
Associate Editor: Ana Nuno

Received 11 January 2024; accepted 24 September 2024

doi:10.1111/acv.12997

Abstract

Half of all species are predicted to face extinction by the end of the century. Despite this, awareness of certain species' extinctions remains surprisingly muted, highlighting the need to improve and quantify public awareness. We explore the connection between biodiversity loss and public awareness by quantifying the changes in online interest on Twitter (now known as X) and Wikipedia both before and after the extinctions of eight species and following their reclassification in the IUCN Red List. Our findings reveal that extinction announcements generally spike online interest for most species, albeit briefly on Twitter (i.e. tweets and retweets about species), while Wikipedia (i.e. article pageviews of species) exhibits a more prolonged interest. IUCN reports were generally not associated with increased interest. Coordinated media coverage, especially when aligned with broader environmental narratives and key events, enhanced the impact of extinction announcements. On Twitter, spatially we observed a shift from local to global interest of users following extinction. We also found a small subset of influential users on Twitter, including content creators and media organisations, who disproportionately shaped conservation discussions. Environmentally oriented individuals and organisations also play a significant role, collectively comprising a third of the top retweeted users. Overall, these results highlight the need for conservation bodies, such as the IUCN, to engage more directly both with media organisations and content creators in order to drive public interest for conservation efforts, especially for less charismatic species. The tragedy of species extinction necessitates such efforts to ensure sustained and meaningful public awareness. Our findings also show that while social media outlets can generate global interest quickly, which may drive public discussions regarding ongoing extinctions and potential future de-extinctions, this is likely to be short-lived, underscoring the importance of alternative platforms such as Wikipedia, which can foster longer-term engagement.

Introduction

Biodiversity loss is a pressing global issue, with over 42 100 species documented as threatened (IUCN, 2022). In response to this threat, raising public awareness about biodiversity has emerged as a crucial conservation objective, as emphasised by the Kunming–Montreal Global Biodiversity Framework of the Convention on Biological Diversity (CBD), which calls for making the best available data and knowledge accessible to all to foster effective biodiversity management and awareness in target 21 (Joly, 2023). Public interest in species not only shapes funding and direction for conservation and de-extinction efforts but is also crucial for garnering support and resources necessary to prevent extinction or, when unavoidable, to gather vital genetic material for future initiatives (Valdez *et al*., 2019; Mooney *et al*., 2020).

One approach to gauge public interest in particular species and conservation topics is through assessing web salience—the prominence and attention a particular topic receives—with various web-based indicators (Correia *et al*., 2017; Ladle *et al*., 2019; Fernández-Bellon & Kane, 2020). Several studies have utilised online platforms, leveraging engagement metrics from news outlets and social media platforms, as a valuable measure of public interest in conservation culturomics related to specific topics, as well as specific species (Ballouard, Brischoux, & Bonnet, 2011; McCallum & Bury, 2013; Okoli *et al*., 2014). For example, Roll *et al*. (2016) used Wikipedia's daily page views to show that

certain reptile attributes increase online interest, while Van Huynh (2023) found that the severity of a species' status on the International Union for Conservation of Nature (IUCN) Red List significantly predicts increased Google searches. However, despite the extensive use of social media, there has been little exploration of how web salience towards a species changes through the transition of it becoming extinct.

Currently, we are witnessing a new era in which species are going extinct within the relatively short timeframe of social media's existence. This includes some notable examples, such as the endling 'Lonesome George', which has represented the last surviving individual of Pinta giant tortoise (*Chelonoidis abingdonii*) in the public eye for several decades (Jorgensen, 2017; Adams, McCorristine, & Searle, 2023). However, while species with endlings may be expected to garner more public awareness before extinction, many endangered species—such as the recently extinct tropical land snail (*Partula faba*)—are likely to have relatively low and local salience among the public before they go extinct. This lower salience may be attributed to factors such as their small size, inconspicuous nature or limited geographic distribution. For instance, molluscs, despite being the group most affected by extinction according to the 2007 IUCN Red List, often receive less attention compared to mammals and birds (Régnier, Fontaine, & Bouchet, 2009). Understanding how the public reacts to the extinctions of species from different regions, taxonomic groups, and those facing distinct ecological pressures (see Table 1), will help inform conservation strategies by highlighting the need for targeted engagement with influential online communities and media. This can ensure sustained awareness, especially for less charismatic species, and support more effective mobilisation of public interest across online platforms.

Using examples of well-documented recent extinctions, we investigate changes in web salience, following the (1) announcement of a species extinction and (2) if applicable, the release of the IUCN Red List report changing the species status to extinct. To do this, we quantify and test changes in online interest of each species on Twitter (now known as X but referred to as Twitter given that this was the name of the network for our study period) and Wikipedia (pageviews of species' articles) before and after their extinction. Specifically for Twitter, we explore spatio-temporal variation and analyse the discourse surrounding the species and the factors contributing to their online virality. Lastly, we examine the influence of users driving engagement on Twitter by identifying the most influential users.

Materials and methods

Species selection

Our initial search to make a list of species used 'The Recently Extinct Plants and Animals Database' developed by Holmes (2023). This database contains information on 11 267 recently extinct (126 ka–present), missing and rediscovered species and subspecies as of January 2023. We specifically chose species that were recorded as extinct between 2011 and 2019 (see Table 1). This approach was adopted to ensure that they had received sufficient online attention before and after extinction for analysis taking into consideration the age of the social media platforms. We define the date of extinction to be the moment when the last known individual of a species dies, typically in cases where it is in captivity. For species extinct in the wild, the date was determined by an official declaration of extinction made by a government body. Using this database, we found seven species that met our criteria. These were the Pinta giant tortoise (*C. abingdonii*), Christmas Island Forest skink (*Emoia nativitatis*), Alagoas foliage-gleaner (*Philydor novaesi*), tropical land snail (*P. faba*), apex tree snail (*Achatinella apexfulva*), Rabbs' fringe-limbed treefrog (*Ecnomiohyla rabborum*) and western black rhino (*Diceros bicornis longipes*). Each of these species originates from different regions and taxonomic groups (Table 1). An additional species, Bramble Cay melomys (*Melomys rubicola*), which met these criteria was also found through a Google web search using the search terms 'recently', 'extinct' and 'species'. In the case of *M. rubicola*, there were two extinction dates due to discrepancies between the regional state announcement and the national declaration made by the Australian government, but we considered the first date.

We also examined the influence of species reclassification to an extinct status by the IUCN Red List of Threatened Species. It is the most reliable and comprehensive resource detailing the conservation status of plant and animal species (Rodrigues *et al.*, 2006) and is the basis for much global conservation action, including increases in scientific knowledge, public awareness and requests for conservation funding (Betts *et al.*, 2020). Five of our eight species examined have been relisted as extinct, with the remaining three yet to be declared.

Collecting data

We selected X (formerly known as Twitter) and Wikipedia as our primary online platforms for measuring interest in these species for two main reasons: accessibility and popularity. As it was Twitter at the time, we will refer to it as such throughout the paper. Wikipedia offers an open and free API, while at the time, we could leverage Twitter's previous research API. Additionally, these platforms are widely used, ensuring a broad representation of online interest. Twitter has been one of the most popular sources of real-time data on trends in public opinion and is commonly used to monitor awareness of various topics, while Wikipedia remains the largest online encyclopaedia and a primary go-to resource for general internet users seeking information (Roberge, 2014; Fernández-Bellon & Kane, 2020).

To retrieve Twitter data, we collected all tweets and retweets that contained both the full scientific name of each species and their respective vernacular names. Vernacular names were sourced from the Global Biodiversity Information Facility (GBIF) as it provides a source of names in different languages. We used the R package *academictwitteR* (Barrie & Ho, 2021) and its 'get_all_tweets' function to

Table 1 Characteristics of species. The scientific and vernacular name, group classification, extinction status, IUCN conservation status, whether the death occurred in captivity, native range and the major driver leading to extinction for each species

Scientific name	Vernacular name/s	Group	Extinct	IUCN status	Death in captivity	Native	Major drivers
Chelonoidis abingdonii	Abingdon Island Tortoise; Pinta Giant Tortoise; Abingdon Island Tortoise; Abingdon Island Tortoise	Reptile	2012	EX	Yes	Ecuador	*Overexploitation:* Excessive hunting by whalers and sailors for their meat
Emoia nativitatis	Christmas Island Forest Skink; Christmas Island Whiptail-skink	Reptile	2014	EX	Yes	Christmas Island, Indian Ocean	*Habitat destruction*: Habitat disruption from phosphate mining and the introduction of non-native species
Melomys rubicola	Bramble Cay Mosaic-tailed Rat; Bramble Cay Melomys	Mammal	2016	EX	No	Australia	*Climate change*: The vulnerability of its low-lying vegetated coral cay habitat to severe weather and rising sea levels was identified as the primary cause of extinction
Philydor novaesi	Alagoas Foliage-gleaner; Alagoas-Blattspäher; Alagoasblattspäher; Alagoasløvgransker; Alagoasløvkæmmer; Anabate d'Alagoas; Novaes' bladspeu'der; Spigolafoglie di Alagoas; Ticotico de Alagoas; Alagoaslövletare; Alaguavinis filidoras; Alaogasi liánjáró; Hrnčiřík alagoaský; Latvusorneero; Limpa-folha-do-nordeste; Liściowiec leśny; Lístiar muricijský; Plegafulles d'Alagoas; アラゴアスマユカマドドリ; 亞拉哥亞斯拾葉雀; 诺氏拾叶雀	Bird	2019	EX	No	Brazil	*Habitat destruction*: Clearance of Atlantic Forest areas in Alagoas and Pernambuco, leaving only a few suitable habitats
Partula faba	Captain Cook's Bean Snail; Polynesian Tree Snail; Areho[a]	Mollusc	2016	EW	Yes	Society Islands	*Invasive species*: Introduction of a predatory snail (*Euglandina rosea*)
Achatinella apexfulva	Oahu Treesnail	Mollusc	2019	CR	Yes	Hawaiian Islands, USA	*Invasive species*: Introduction of a predatory snail (*Euglandina rosea*), rats (*Rattus spp.*) and Jackson's chameleon (*Trioceros jacksonii*)
Ecnomiohyla rabborum	Rabb's fringe-limbed treefrog	Amphibian	2016	CR	Yes	Panama	*Invasive species*: An epidemic of *Batrachochytrium dendrobatidis*, a fungal pathogen responsible for chytridiomycosis in amphibians
Diceros bicornis longipes	West African black rhinoceros	Mammal	2011	EX	No	Sub-Saharan Africa	*Overexploitation*: Illegal wildlife trade, especially poaching for its horn

[a]Term excluded in search.

retrieve all tweets and retweets between 1 January 2007, and 1 January 2023. These dates are 4 years before and after the oldest and newest extinction dates of our species, respectively. Access was obtained through Twitter's Application Programming Interface (API) for academic research and using the R package *academictwitteR* to download tweets. This pull only included publicly available tweets. The data retrieval took place before the termination of free access following the Twitter takeover by Elon Musk (Novoa *et al*., 2022).

We gathered daily data on Wikipedia pageviews for each species' article in English using the R package

wikipediatrend (Meissner and R Core Team, 2020). This was done using the function 'wp_trend' for the same period queried on the Twitter pull.

Temporal dynamics

To test for changes in online interest over time associated with the events of (1) the announcement of species extinction and the (2) release of the IUCN Red List report changing species status to extinct, we performed both causal impact analysis and anomaly detection. Causal impact analysis is used to estimate the causal effect of an intervention on time-series data. This model predicts the counterfactual response that would have occurred had no intervention taken place (in this case, extinction), allowing for an analysis of longer-term changes in trends (Brodersen *et al*., 2015). To identify shorter term spikes in interest for each species on both platforms, we used anomaly detection. Anomaly detection uses an algorithm called Seasonal Hybrid ESD (S-H-ESD) to detect patterns that significantly differ from the majority of the data in time-series data. We set 'max_anoms' to 0.001, representing the maximum percentage of anomalies to be detected relative to the data within a 1-year period. This approach allowed us to identify tweets that went viral, or days in which there were surges in interest in species on Wikipedia. We then visualised the results in plots that showed interest over time for Twitter (Fig. 1) and Wikipedia (Fig. 2), highlighting significant spikes (i.e. detected anomalies) in engagement and the periods surrounding the extinction and IUCN listing events.

For each platform, we calculated aggregated daily counts of the number of tweets and retweets (Twitter) or pageviews (Wikipedia) for each species (Table 2). For Twitter, we added null days, days with zero tweets or retweets, and combined the number of tweets and retweets per day. We tested the platforms and species separately. To perform causal impact analysis, we used the R package *CausalImpact* (Brodersen *et al*., 2015), which constructs a Bayesian structural time-series model using a diffusion–regression state-space model. We chose to limit the time frame to 1 year prior and 1 year after extinction, and the same time frame for the release of IUCN extinction reports. This time frame was chosen to minimise the effect of external factors such as general changes in social media usage. To detect anomalies, we used the 'AnomalyDetectionTs' function from the R package *AnomalyDetection* (Vallis *et al*., 2019). We used the aggregated daily counts of tweets and retweets, as well as Wikipedia pageviews, for each species. We set the period as 365 days to capture yearly patterns and only included positive anomalies. Additionally, we set maximum number of anomalies that S-H-ESD will detect as a proportion of the data as 0.001 (equivalent to 0.1%) to focus on only the most prominent anomalies. The results of the causal impact analysis were then summarised by species, including absolute average and cumulative effects, relative effects in percentage and Bayesian *P*-values (Table 3).

Spatial dynamics

To determine the geographic locations of Twitter users engaging with the studied species, we used the 'lookup_users' function from the *rtweet* package, which allowed us to extract Twitter user's data including the location specified in the user's profile, if the user provided one (Kearney, Heiss,

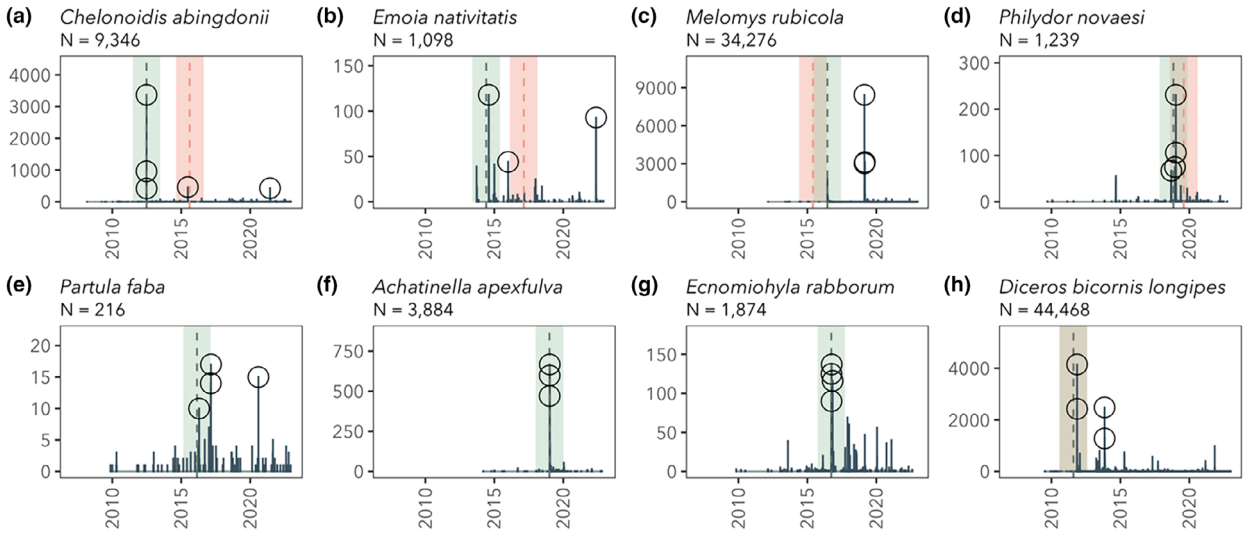

Figure 1 Twitter interest. Anomaly detection plots for daily Twitter activity (tweets and retweets) related to each species (panels a–h), showing posts that contain either the scientific or vernacular names. Black circles indicate days where there was a significant spike in activity. Green dashed vertical lines represent the extinction date with a lighter green shade indicating the year before and after the event. Red dashed lines indicate the date that IUCN listed the species as extinct (with a lighter red shade indicating the year before and after the event, if applicable). The total number (*N*) of tweets and retweets over the given period is annotated at the top of each plot.

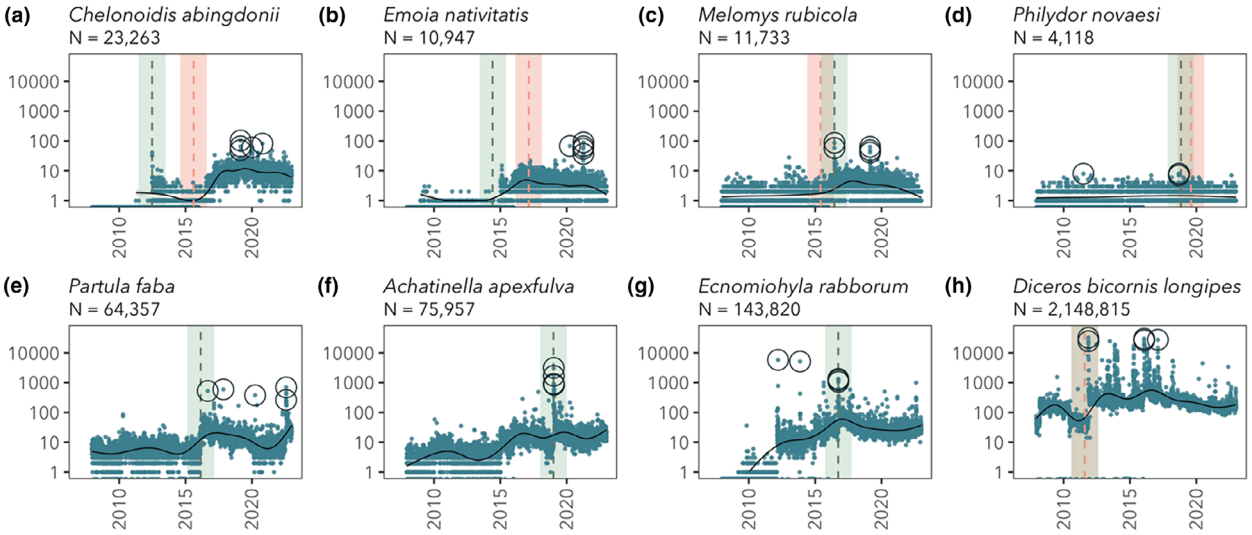

Figure 2 Wikipedia pageviews. Anomaly detection plots for the daily Wikipedia pageviews (blue solid dots) of each species article, with each panel (a–h) representing a different species over time (years). Black open circles indicate days where there was a significant spike in pageviews as determined by anomaly detection. Green dashed vertical lines represent the extinction date with a lighter green shade indicating the year before and after the event. Red dashed lines indicate the date that IUCN listed the species as extinct (with a lighter red shade indicating the year before and after the event (if applicable). The total number (*N*) of pageviews over the given period is annotated at the top of each plot.

Table 2 Counts of Wikipedia pageviews (green), tweets and retweets (blue) associated with each species from 1 January 2007 to 1 January 2023. Darker shaded colours indicate more counts relative to other species within the column.

Taxa	Wikipedia pageviews	Retweets	Tweets
Diceros bicornis longipes	2 148 815	23 061	21 407
Ecnomiohyla rabborum	143 820	1533	341
Achatinella apexfulva	75 957	3451	433
Partula faba	64 357	143	73
Chelonoidis abingdonii	23 263	4949	4397
Melomys rubicola	11 733	28 188	6088
Emoia nativitatis	10 947	811	287
Philydor novaesi	4118	1089	150

& Briatte, 2016). As this is a freeform value, it may not indicate a valid location so we used the R package *tidygeocoder* function 'geocode' to convert the user manually entered locations to addresses and then to latitude and longitude points, where possible. To assess the accuracy of the converted locations, we manually checked a subset of 300 converted locations, which constituted 0.92% of the dataset (N = 32 507). We found 94% of the locations were accurately classified. The remaining 6% were labelled as unknown and listed as 'NA'. These unknowns were not mapped in the final dataset. Among the classified addresses, 4.6% were found to be inaccurate. These inaccuracies arose from entries containing multiple regions (e.g. 'New York, Paris, London'; 4%) where only one region was classified, or entries with nonsensical descriptions (e.g. 'somewhere'; 9%). Despite these discrepancies, the overall accuracy level remained sufficiently high and inaccuracies typically originated from the description rather than the conversion process itself. We mapped the coordinates of tweets associated with user locations before and after extinction for each species (Fig. 3). We used the 'world' dataset from the maps package to define the global map boundaries and plotted with ggplot2. Additionally, to better visualise the geographical hotspots where many points overlap, we employed the 'geom_density_2d' function from the *ggplot2* package to perform a 2D kernel density estimation (Wickham *et al.*, 2023).

Textual analysis

To better understand the main topics and conversations related to each species happening online, we did textual analysis on the tweets and retweets. We first pre-processed the text data to clean using the packages *tidytext*, *textstem* and *textclean* (Silge & Robinson, 2016; Rinker, 2018a, b). Cleaning the text included removing characters and punctuation, converting all text to lowercase, applying lemmatisation to reduce words to their base root form and addressing contractions and kerning. Additionally, we removed common stop words in multiple languages (English, Spanish, French, Portuguese and German) to emphasise meaningful content in the analysis. We translated the top tweets (Fig. 4) and retweets (Fig. S1) into English using Microsoft Copilot and then generated bi-gram networks using the function 'bigram' from the package *saotd* package (Munson *et al.*, 2019). For example, analysing pairs of consecutive words from the translated tweets and retweets, such as 'climate change' or

Table 3 Causal impact results of online interest testing before and after the date of extinction I and the date of the IUCN report's (I) release classifying the species as extinct, where applicable. Interest is measured as the cumulative daily tweets and retweets, as well as Wikipedia page views per species. The table provides absolute average and cumulative effects, relative effects in percentage, and Bayesian *P*-values, to examine the impact on online interest

	Date	Absolute average effect	Absolute cumulative effect	Relative effect (%)	*P*
Twitter—tweets and retweets					
Ecnomiohyla rabborum	E	2.4 (0.21) [2, 2.8]	862.7 (77.38) [719, 1017.1]	−925% (39 734%) [−14 172%, 16 108%]	**0.00267**
Emoia nativitatis	E	1.1 (0.42) [0.19, 1.8]	410.0 (155.34) [68.44, 654.8]	−231% (5164%) [−3454%, 2890%]	**0.02752**
	I	0.38 (0.1) [0.18, 0.59]	139.10 (37.3) [65.87, 215.11]	7953% (241 199%) [−8168%, 5873%]	**0.001**
Melomys rubicola	E	21 (0.012) [21, 21]	7600 (4.476) [7591, 7609]	216 118% (1 449 165%) [−1 148 274%, 1 835 836%]	**0.001**
	I	−0.13 (0.27) [−0.65, 0.4]	−49.13 (98.29) [−239.64, 146.4]	−96% (181%) [−145%, −54%]	0.30439
Philydor novaesi	E	0.42 (0.89) [−1.8, 2]	154.99 (325.22) [−644.9, 723]	197% (1664%) [−696%, 778%]	0.31532
	I	−0.69 (2.5) [−5.6, 4.3]	−250.96 (904.8) [−2036.5, 1581.6]	−70% (400%) [−343%, 180%]	0.39355
Partula faba	E	0.062 (0.045) [−0.025, 0.15]	22.669 (16.314) 22.669 (16.314)	512% (10 151%) [−2078%, 3003%]	**0.084**
Chelonoidis abingdonii	E	15 (0.038) [14, 15]	5309 (13.887) [5283, 5338]	31 526% (669 988%) [−221 725%, 2e+05%]	**0.00102**
	I	−4.5 (4.7) [−14, 4.9]	−1632.3 (1719.9) [−4943, 1789.6]	−110% (307%) [−205%, 9%]	0.17312
Achatinella apexfulva	E	9.8 (0.13) [9.5, 10]	3576.6 (48.04) [3479.4, 3674]	55 073% (2 278 364%) [−118 025%, 126 295%]	**0.00124**
Diceros bicornis longipes	E	29 (0.019) [29, 29]	10 591 (7.032) [10 577, 10 606]	125 741% (1 269 886%) [−847 734%, 1 066 842%]	**0.001**
	I	"	"	"	"
Wikipedia pageviews					
Ecnomiohyla rabborum	E	54 (3.7) [46, 61]	19 594 (1326.1) [17 071, 22 291]	152% (27%) [109%, 214%]	**0.00102**
	I	0.42 (0.092) [0.24, 0.6]	102.63 (22.265) [57.33, 145.9]	130% (83%) [42%, 310%]	**0.00101**
Emoia nativitatis	E	0.71 (0.034) [0.64, 0.78]	258.60 (12.497) [233.92, 284.02]	943% (22 087%) [−16 064%, 16 772%]	**0.001**
	I	−0.34 (0.42) [−1.2, 0.47]	−121.69 (153.99) [−429.5, 171.08]	−5.6% (7.7%) [−19%, 10%]	0.21138
Melomys rubicola	E	2.9 (0.27) [2.5, 3.4]	1034.5 (95.88) [862.2, 1198.7]	151% (35%) [98%, 222%]	**0.01351**
	I	0.23 (0.3) [−0.26, 0.71]	77.33 (99.2) [−87.89, 237.69]	22% (29%) [−14%, 80%]	0.22449
Philydor novaesi	E	0.023 (0.16) [−0.3, 0.35]	5.541 (38.93) [−72.4, 83.49]	2.5% (10%) [−15%, 25%]	0.4382
	I	−0.033 (0.17) [−0.39, 0.34]	−8.282 (44.06) [−97.89, 85.50]	−0.63% (10%) [−19%, 25%]	0.42872
Partula faba	E	21 (0.88) [19, 23]	7727 (323.58) [7088, 8296]	318% (56%) [228%, 436%]	**0.01031**
Chelonoidis abingdonii	E	1.5 (0.015) [1.4, 1.5]	537.6 (5.478) [526.6, 548.3]	9333% (182418%) [−69314%, 78891%]	**0.00101**
Achatinella apexfulva	E	50 (2.9) [44, 55]	18 263 (1079.2) [15 982, 20 295]	457% (186%) [239%, 860%]	**0.00287**
Diceros bicornis longipes	E	597 (6.7) [581, 610]	21 8490 (2444.0) [21 2768, 223 347]	1508% (276%) [1038%, 2252%]	**0.00862**
	I	"	"	"	"

Note: Bolded *P*-values indicate statistical significance at the 0.05 level, highlighting instances where the change in online interest is unlikely due to random variation.

'human activity', can reveal patterns, relationships and associations between words, aiding in the extraction of contextual information. We did this separately for tweets and retweets.

We performed sentiment analysis on Twitter data, including both tweets and retweets, for individual species to gauge the public's sentiment and attitudes (Kouloumpis, Wilson, & Moore, 2011). This analysis was conducted using the *tidytext* package (Silge & Robinson, 2016). We classified emotions in tweets, assigning them to specific sentiment categories (anger, fear, anticipation, trust, surprise, sadness, joy and disgust) which were determined by the presence of words tied to these emotions. We did not include the general sentiments positive and negative. Each tweet was categorised into one or more sentiment groups based on the words it contained as defined by the NRC Word-Emotion Association Lexicon, accessed through the *tidytext* package (Silge & Robinson, 2016). Note this dictionary was developed for English words so tweets in other languages were not included in this sentiment analysis. We aggregated tweet counts for each sentiment category within each species, separately for both original tweets and retweets (Table S1). We then focused on the top five sentiment categories linked with each species and tweet type to visualise the main emotion types (Fig. S2).

User influence

To gauge the influence of individual users, users were ranked based on the total number of retweets their tweets gained. We then plotted rank abundance curves for each species (Fig. 5) and combined (Fig. S2), showcasing the hierarchy of retweet frequency from the most to the least retweeted users. Additionally, we computed proportions of retweets for the top 1, 5 and 10% of users within each species group, to see engagement among top users.

We created a table of top users for each species. We set the threshold for users collectively accounted for more than 90% of the retweets within each species group. This approach focused on identifying the top users who generated the majority of retweets for each species. We then categorised the top users (N = 1002) by their profile description. First, we categorised each Twitter account as either an individual or an organisation. Then, we classified the accounts based on their activities and focus areas, with an emphasis on whether the account was related to conservation activities. For individual accounts, the categories included activism (activism related to conservation or non-conservation issues such as human rights or political advocacy; e.g., use of hashtags or descriptions such as #AnimalWelfare #WorkersRights), environmental/conservation professionals (individuals engaged in professions related to ecology, conservation and environmental science, such as ecologists, conservationists and animal rescuers), news and media (individuals dedicated to journalism, reporting or media sharing), research and education (students, professors, academics and scientists focused on general research) and general (personal accounts that did not fall into the other categories and are considered general public). For organisational accounts, the categories included activism (organisations involved in advocacy and activism), environmental/conservation organisation (e.g. IUCN, Helping Rhinos and London Zoo), non-profit conservation (non-profit organisations dedicated to conservation), news and media (organisations involved in journalism and media such as BBC News or National Geographic), general (organisations that did not fall into the other specific groups, such as those involved in government, education or business activities) and research and education (institutions focused on scientific and academic research, as well as zoos and museums). Accounts with no description were not categorised (N = 23).

To visualise the distribution and categories of these top users, we created alluvial plots from 'ggplot2' using R (Fig. 6). The alluvial plots show the breakdown of top users per species and further categorise them by the type of account (individual or organisation), the category of activity and the continent from which they originate. To further illustrate the impact of certain tweets, we have included a table (see Table 4) showcasing the top three most retweeted tweets for each species. This table serves to highlight the tweets that resonated most with the public and contributed significantly to the online discourse surrounding each species' extinction.

Results

Online interest

During the 16-year period assessed in this study, 95 780 tweets and retweets were made from 80 946 user accounts about the eight species combined. The Western black rhinoceros (*D. bicornis longipes*) was the most frequently tweeted about species in our analysis (n = 21 407 tweets), representing 63.4% of all tweets, with Alagoas foliage-gleaner (*P. novaesi*) receiving the least number of tweets (N = 150; less than 1%) in our analysis followed by *M. rubicola* (18%) and *Chelonidis abingdonii* (13%). However, in terms of retweets, *M. rubicola* garnered the most attention (43.7% of retweets), followed by *D. bicornis longipes* (35.7%) *and C. abingdonii* (7.7%). On average, there were nine times more tweets and retweets with vernacular names than scientific names; only 9.6% were retrieved with the scientific name only, while the remaining 89 000 tweets and retweets used the vernacular name. When retweets were removed, there were 33 821 tweets in total. Although the use of vernacular names led to significantly higher engagement for some species, they were in proportion with scientific names.

In terms of Wikipedia, *D. bicornis longipes* had a large amount of interest with 2.15 million pageviews, 15 times more than the next species, *E. rabborum* (Table 2). We found that there were disparities between online interest on Wikipedia and Twitter in that interest on one platform was not transferable to another, except for *D. bicornis longipes*. For example, *E. rabborum* had the second most read article page on Wikipedia but garnered little attention on Twitter. In contrast, *C. abingdonii* and *M. rubicola* were among the most retweeted, while tweeted species had far fewer Wikipedia pageviews in comparison with other species (Table 2).

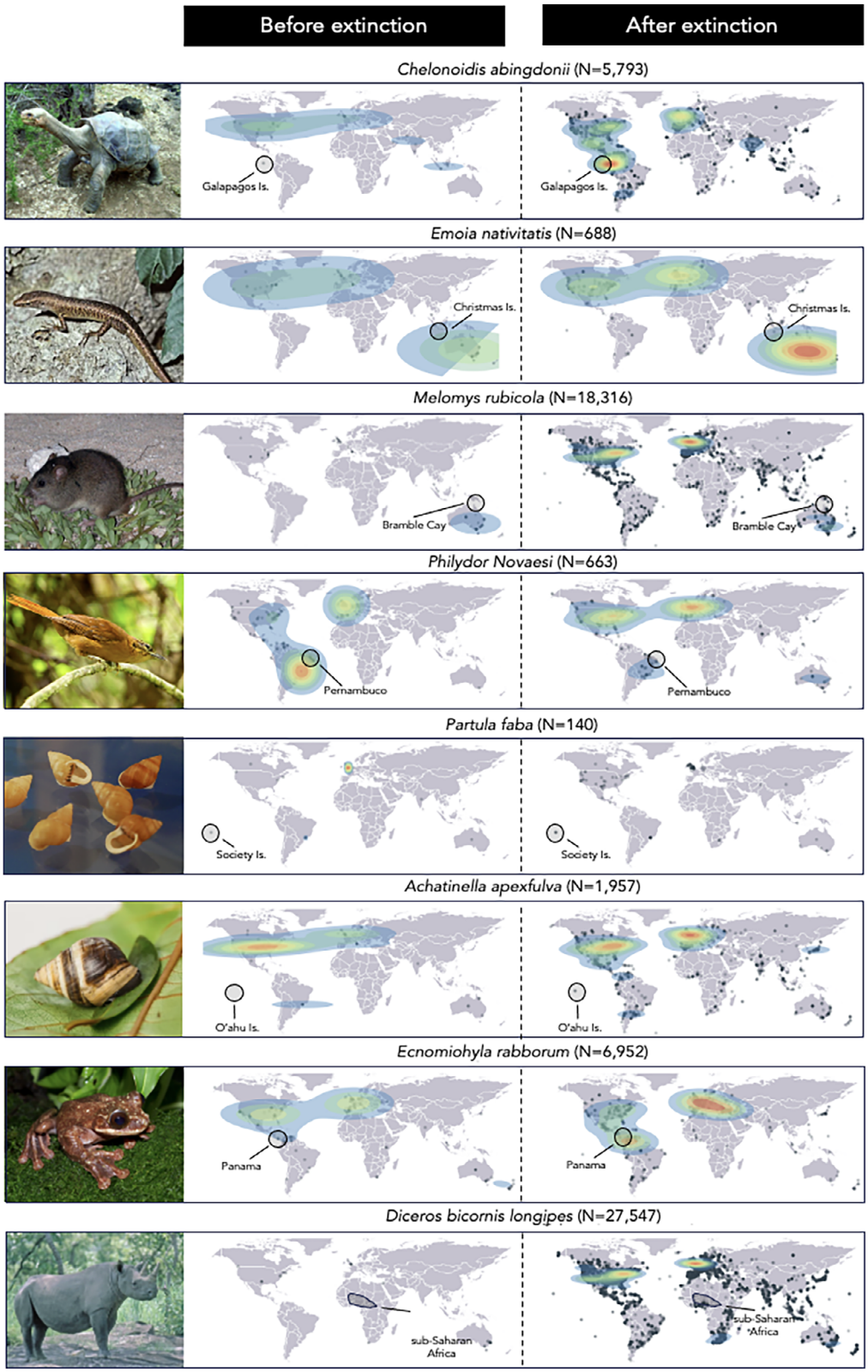

Figure 3 Map of Twitter users with hotspots of activity. Maps on the left represent user locations before the extinction announcement, and the maps on the right depict activity after for each species. Each map showcases a heatmap overlay based on a 2D kernel density estimation of activity hotspots. Besides each species name, the total number of tweets and retweets (*N*) with user location information is displayed. Each point on the map represents a unique Twitter user's location. Data were gathered and geocoded using publicly available Twitter data combined with the Google Maps API. Native ranges are annotated within each corresponding map. Photo credits for *Chelonoidis abingdoni* (David A. Wiedenfeld, CDF), *Emoia nativitatis* (Hal Cogger), *Melomys rubicola* (Bell, I., DES), *Philydor novaesi* (Ciro Albano, eBird S28898963, Macaulay Library ML 26967021), *Partula faba* (Skye McDavid), *Achatinella apexfulva* (Aaron K. Yoshino, Honolulu Magazine), *Ecnomiohyla rabborum* (Brian Gratwicke) and *Diceros bicornis longipes* (Hubert Planton).

Changes in temporal trends

The announcement of a species' extinction had a significant impact on online interest. Interest in a species the year following an extinction event was compared to the previous year for most species on at least one of the platforms tested (Table 3). In terms of Twitter activity, five of the species had a significant positive relative effect indicating increased number of tweets after extinction. For Wikipedia pageviews, the same species had significant changes in pageviews, but all seven species had a positive relative effect including *E. rabborum* and *E. nativitatis*. It is worth noting that estimates for *E. rabborum*, *E. nativitatis*, *P. novaesi* and *A. apexfulva* were associated with a high standard deviation, perhaps reflecting considerable uncertainty due to a smaller sample size, such as fewer tweets and pageviews.

When we tested the release of IUCN reports redesignating five of the species as extinct, we found that only two of the species (*E. nativities* and *D. bicornis longipes*) had attracted a significant change in the number of tweets a year after extinction. In the case of *D. bicornis longipes*, the IUCN date was the same as the extinction date (Figs 1 and 2).

Virality

In terms of anomalies or surges of interests, we found that tweets and retweets spiked either on the extinction date or shortly thereafter (within a few days) for seven species (Fig. 1). Similarly, Wikipedia pageviews exhibited a spike for six species (as illustrated in Fig. 2). *Chelonoidis abingdonii* and *E. nativitatis* had a spike of tweets/retweets at the time of extinction, but there was no spike in Wikipedia pageviews at the same time. Conversely, *M. rubicola* had a spike on Wikipedia pageviews at the time of extinction but a smaller spike that was not significant on Twitter. Significantly, *M. rubicola* had a spike on both Twitter and Wikipedia in 2019 several years after the first announcement of its extinction by the IUCN in 2015 and the Queensland government in 2016. This corresponds with the later official announcement by the Australian government in February 2019.

We found no notable increase in Wikipedia pageviews following the release of IUCN reports, except for *D. bicornis longipes*, which coincided with the extinction date (Fig. 2). On Twitter, however, there was a small but significant spike when *C. abingdonii* was officially declared extinct by the IUCN (Fig. 1a). We also observed some anomalies unrelated to extinction or the IUCN report release (Figs 1a–e and 2a–c,e,h). No species showed anomalies in tweets before their extinction. However, most additional surges on Wikipedia occurred a few years after extinction, with the exceptions of *P. novaesi* and *E. rabborum*.

Global hotspots

We were able to geolocate 75.6% of Twitter users ($N = 61\,156$) finding considerable variation in online interest by users across regions, with a concentration in high-income countries of the global north, that is, North America and Europe (Fig. 3).

In general, there was a shift from predominantly local before extinction to global-scale interest of Twitter users after extinction (Fig. 3). For example, the Bramble Cay melomys (*M. rubicola*) had interest mainly localised to Australia before extinction which expands to global interest after extinction (Fig. 4). As expected, species with greater interest overall on Twitter, that is, *D. bicornis longipes*, *C. abingdonii and M. rubicola*, also had the most widespread interest across multiple countries and continents when compared to species with lower engagement, such as *P. faba*, that had a more limited geographic scale of social media impact.

Seven of the species displayed additional hotspots either within the native countries or in regions politically aligned with the native region, either before or after extinction (Fig. 3). For instance, *P. noavesi's* interest was primarily in its native country Brazil before extinction, but shifted significantly towards North America and Europe after extinction. Conversely, *C. abingdonii*, native to the Galapagos islands, only gained attention in Ecuador after extinction. Other species maintained attention in their native countries both before and after extinction, but witnessed more widespread global interest post-extinction, such as *E. rabborum* and *M. rubicola*. *Diceros bicornis longipes* was unique in not receiving attention in its native region, which is likely attributed to limited Twitter usage in that specific area of sub-Saharan Africa. Notably, this species did generate the only hotspot in Africa, specifically Southern Africa, situated on the same continent and within an area known for its significant conservation efforts, particularly concerning rhinos.

Context of tweets

Among bi-terms, we found death-related language was a consistent theme across all species, with terms such as 'die' and 'RIP' frequently appearing (Fig. 4). We also noted that

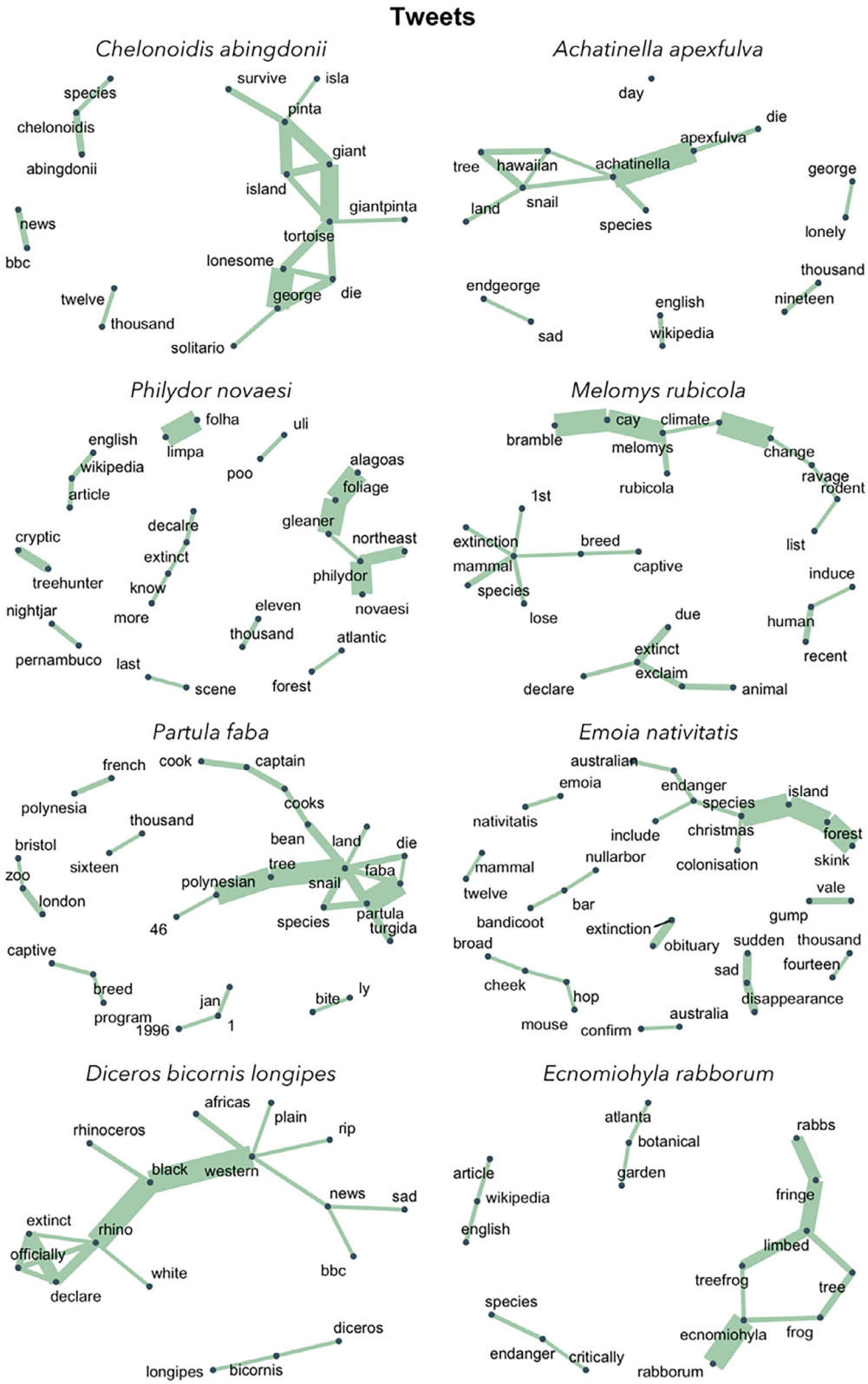

Figure 4 Bi-gram networks. Networks of the most frequently co-occurring words of original tweets associated with each species (See supplementary for bi-gram of retweets). For instance, the network for *Chelonoidis abingdonii* shows co-occurring words in a minimum of $N = 160$ tweets and retweets. The thickness of the connecting green lines between words corresponds to their frequency of use, with thicker lines representing higher numbers of tweets.

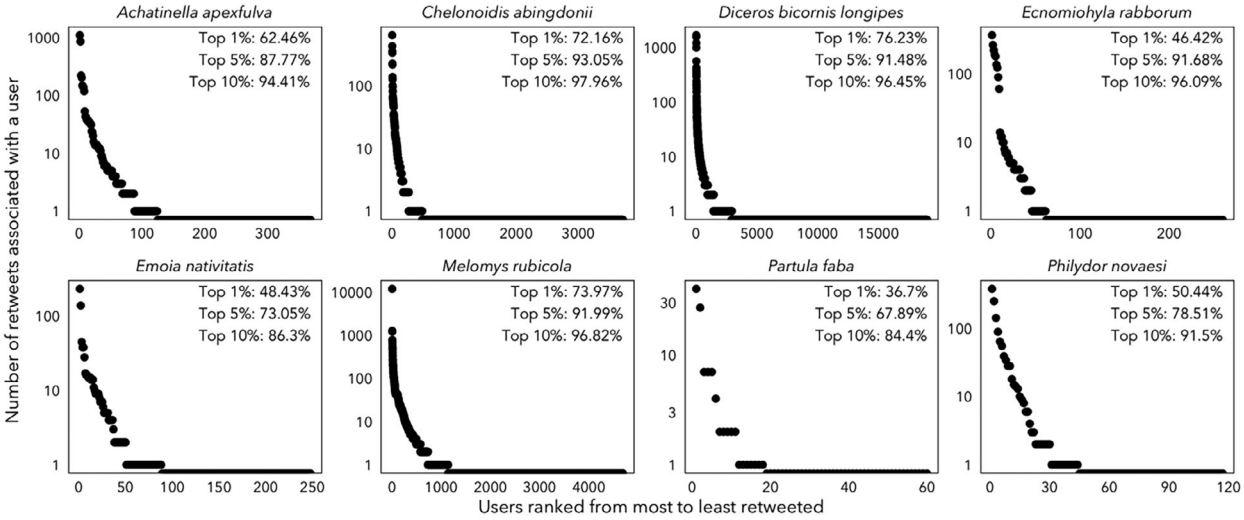

Figure 5 Rank abundance curve of retweets by species. Each point on the curve signifies a user ranked by the number of retweets associated with them, with the *x*-axis indicating the ranking from most to least retweeted. Subplots are organised by species. Additionally, annotations highlight the proportions of retweets contributed by the top 1%, 5% and 10% of users within each species group.

the two species, *E. nativitatis* and *P. novaesi*, were associated with the acronym 'IUCN' indicating that there have been discussions surrounding their conservation status and official assessment. Sentiment analysis indicated that sadness was the predominant emotion, which emerged as the top sentiment for six out of the eight species (Fig. S2). Notably, the term 'extinct' appeared in 45 712 tweets, reflecting that extinction was the central focus of many discussions and significantly driving the sentiment of sadness. When we excluded the term of 'extinct', and variations of, sadness was no longer the dominant sentiment in tweets, although it remained prevalent in retweets. Other terms frequently linked with sadness included 'lonesome', 'lost', 'poaching' and 'victim'. Prominent negative sentiments included fear, disgust and anticipation. On the positive side, sentiments of joy and trust also appeared across several species. Conversely, positive sentiments joy and trust also appeared for multiple species. This was attributed to the words 'calf', 'good', 'humanity', 'kind', 'tree' for joy and 'conservation', 'humanity', 'important' for trust. Generally, tweets and retweets exhibited similar sentiment patterns, with some exceptions (e.g. *P. faba* likely due to a small sample size).

User influence

We found across all species, a small subset of users wielded disproportionately high levels of influence (Fig. 5 and Fig. S3). There were 1002 users (out of 28 473; 3.5%) whose posts accounted for 90% of the tweets that were retweeted for all species. Among the top users, 65% ($N = 633$) were individuals and 35% ($N = 346$) were organisations, excluding 23 accounts that were not classified (Fig. 6). In terms of user categories, the general public represented the largest group, making up 26.3% ($N = 255$) of users. Individual writers, journalists, content creators and bloggers, formed the second-largest group, comprising 17.6% ($N = 171$) of users. They were closely followed news and media organisations, who made up 16.6% ($N = 161$) of users. The remaining users were roughly distributed across research and education (10.6%; $N = 103$), activism (10.5%; $N = 102$), and environmental and conservation professionals and organisations (5.5%; $N = 53$ and 9.3%; $N = 90$, respectively; Fig. 6).

Out of the 90 environmental and conservation organisations the most notable for generating the highest number of retweets were Conservation International, WWF (including WWF Australia, WWF México and WWF España), Helping Rhinos, Richard Dawkins Foundation, Wilderness Society, UN Environment Programme, Save the Rhino International, Programa da ONU para o Meio Ambiente, Animal Defenders International, and the National Wildlife Federation. We also noted there were four museum accounts (Field Museum and California Academy of Sciences, both in the US; NHM Oology, UK; Australian Museum, Australia) and 13 zoo accounts (Colchester Zoo, London Zoo, Newquay Zoo, all in the UK; Kansas City Zoo, Lincoln Park Zoo,

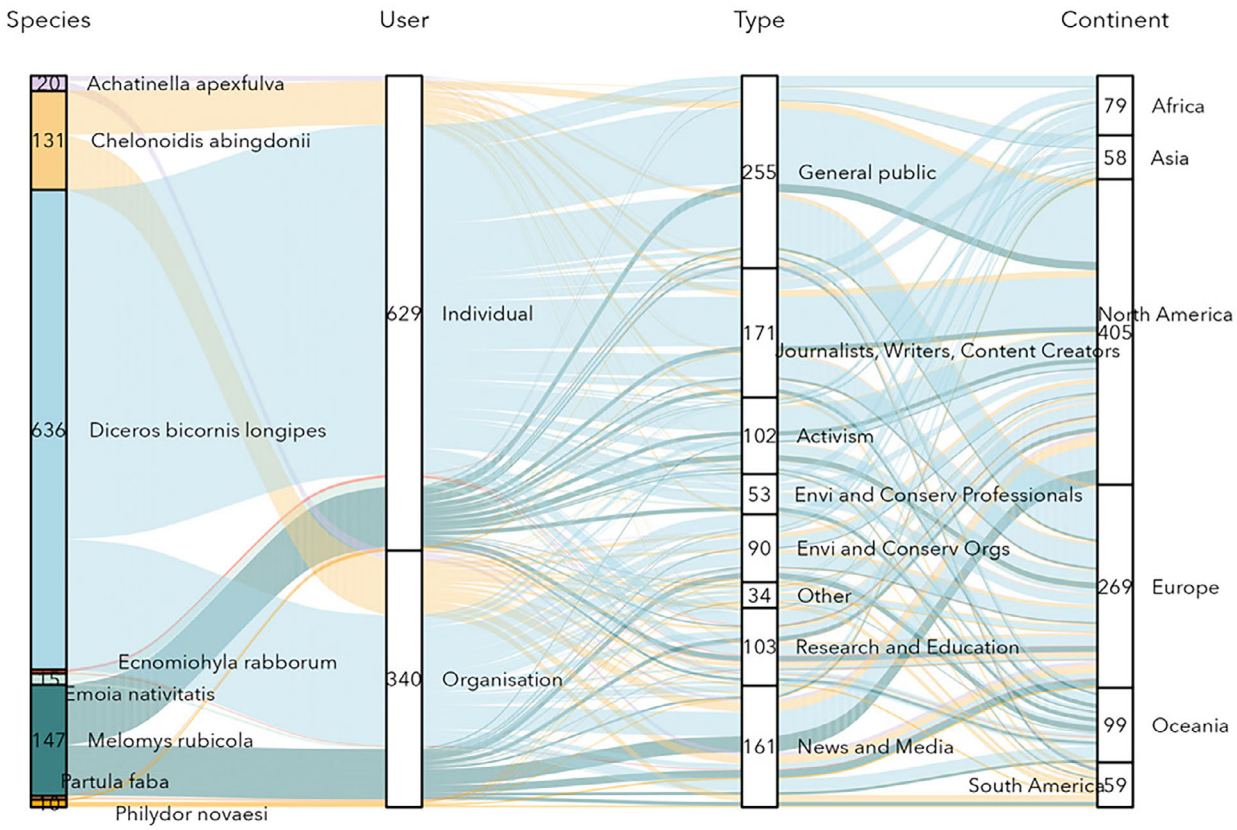

Figure 6 Alluvial plot of top users. Alluvial plot illustrating the top users (*N*) responsible for 90% of tweets that receive retweets. The plot shows the flow between different categories: species tweeted about, user type (individual or organisation), category (e.g. news and media and activist) and continent associated with the user. The colours represent the species that were tweeted about. The thickness of the flows corresponds to the count of users. The categories were unknown in the case of user, type and continent, and they were excluded from the plot ($N = 24$).

North Carolina Zoo, Philadelphia Zoo, San Diego Zoo Safari Park, San Diego Zoo Wildlife Alliance, all in the US; Perth Zoo, Taronga Zoo, both in Australia) in the top users.

Discussion

Our analysis validates the notion that reported extinction events bring about significant shifts in the online engagement interest of a species, with many cases showing a substantial increase in interest. However, this was not consistent across platforms or species. These platform-specific and species-specific variations underscore intricate dynamics of online interest which may be influenced by factors such as a species' ecological significance, its visibility in the media, the online communities it resonates with and idiosyncratic events such as when someone with a lot of followers happens to share the information.

Influential users

We confirmed that a small subset of users disproportionately influence the content that gets retweeted and shared (Figs 5 and 6, Fig. S3; Table 4). The general public constituted the largest group among these influential users, many of which could be classified as influencers, for example, individuals that significantly influence their audience's perspectives and actions. We noted that users identifying themselves as content creators, writers, bloggers, etc., also represented a significant portion of influential users. This suggests that those individuals dedicated to communication play an important role in online discussions about conservation and extinction related events. As expected, news and media organisations were a significant part of the top users. It has been well established the role of news and media outlets in triggering initial spikes of interest on Twitter. For example, a study by Fink, Hausmann, & Di Minin (2020) established a strong correlation between daily Twitter volume and daily online news volume on rhino conservation topics.

While we expected influencers to dominate content we still found significant influence from users associated with environmental and conservation work, activism or research and education, with this group collectively comprising about a quarter of the most retweeted top users. Additionally, social media accounts of environmental and conservation

Table 4 Top three most retweeted tweets associated with each species. Tweets not in English have been translated using Microsoft Copilot and are shown following the tweet in square brackets

Species	Date	Tweet	Retweet count	User type	Location	Follower count
Achatinella apexfulva	5 January 2019	This is what extinction looks like. George, the last Hawaii land snail, Achatinella apexfulva, has died. There will never be another. Nevermore #Extinction is forever	1099	Biologist and science communicator	US	89 180
	8 January 2019	'George, the last known Achatinella apexfulva, died on New Year's Day 2019. He is survived by none', wrote the head of the Snail Extinction Prevention Program	855	Newspaper [The Times]	UK	15 231
	17 January 2019	El caracol hawaiano (achatinella apexfulva) es la primera especie extinta de 2019 tras la muerte de George, único ejemplar en los últimos 14 años. Los caracoles de los árboles de Hawai se consideran las 'joyas del bosque'. [The Hawaiian snail (Achatinella apexfulva) is the first species to go extinct in 2019 following the death of George, the last specimen for the last 14 years. The tree snails of Hawaii are considered the 'jewels of the forest'.]	222	Science communication/educational account	Spain	2 315 187
Chelonoidis abingdonii	24 June 2012	Muere el #SolitarioGeorge, la última #tortuga gigante de su especie de la isla #Pinta. [**#***SolitaryGeorge* dies, the last **#***gianttortoise* of his species from **#***Pinta* Island.]	358	Newspaper [El Universo: Ecuador]	Ecuador	2 959 562
	24 June 2015	Un día como hoy, en 2012, murió Solitario George. Con él se extinguió la tortuga gigante de Pinta. [On a day like today, in 2012, *Solitary George* died. With him, the *giant tortoise of Pinta* became extinct.]	338	Educational account	Latin America	1 442 828
	9 June 2021	Look at what we have lost The Pinta tortoise was a unique giant tortoise subspecies which went extinct with the passing away of the last male in 2012. The tortoise has been on earth for over 60 million years but this magnificent subspecies was lost due to excessive poaching	646	Social media influencer	India	132 787
Diceros bicornis longipes	24 January 2012	Another one bites the dust … Poachers-you suck!People that pay poachers or use those animal products-you suck too!	1003	Famous actor	US	7 050 496
	21 September 2017	The western black rhino is a subspecies of black rhinoceros that was declared extinct in 2011. Humans hunted it to extinction #WorldRhinoDay	472	Science communication / educational account specific to extinct animals	Global	115 532
	2 November 2021	rauw releasing these two masterpieces only 6 months apart … healed the world, saved the coral reef, returned the western black rhino from extinction	1602	General public user	Mexico	98

Table 4 Continued.

Species	Date	Tweet	Retweet count	User type	Location	Follower count
Ecnomiohyla rabborum	30 September 2016	Saçak bacaklı ağaç kurbağasının kalan son bireyi de öldü. Tür sonsuza değin yok oldu. Ecnomiohyla rabborum. Sensiz dünya bize ıssız. [The last remaining individual of the fringe-legged tree frog has also died. The species is gone forever. Ecnomiohyla rabborum. The world is deserted to us without you.]	261	Visual artist and social media influencer	Turkey	49 368
	4 October 2016	Dünyada artık hiç Ecnomiohyla rabborum (bir ağaç kurbağası türü) kalmadı [There are no more Ecnomiohyla rabborum (a species of tree frog) left in the world] ?	189	Curated content account sharing viral videos and news stories	Turkey	2 524 130
	29 November 2017	Rabb's fringe-limbed treefrog became extinct in September 2016	295	Science communication/educational account specific to extinct animals	Global	115 532
Emoia nativitatis	8 August 2014	The last known Christmas Island forest skink has died. The species is now extinct	73	Science communication/educational account specific to extinct animals	Global	71 214
	1 January 2015	RIP Christmas Island Forest Skink,d.2014. The endling's name was Gump. She never found a mate.	86	Science communication/educational account specific to extinct animals	Global	5292
	1 January 2016	Until the late 1990s, this species was 'common and widespread'. It's now extinct	57	Science communication/educational account specific to extinct animals	Global	71 214
Melomys rubicola	15 June 2016	This Australian rat is the first mammal proven to have gone extinct due to climate change	681	Digital news and advocacy platform	US	1 247 355
	19 February 2019	It's not a big, iconic or 'sexy' species and it won't get much coverage in the media but this is important. The Bramble Cay melomys is now extinct … the first mammal to be declared extinct due to human-caused climate change. Don't let this go unnoticed	11 886	Academic and science communicator	UK	22 189
	20 February 2019	We must not allow this to be overlooked. The Bramble Cay melomys is now extinct. It is the first mammal to be declared extinct due to human-caused climate change. An indicator of something much larger to come… unless we change now	788	Environmentalist and activist	UK	135 170
Partula faba	18 April 2016	Another extinction: the world's last Captain Cook's bean snail Partula faba died in February	8	Biologist	UK	551
	21 February 2017	1ya today, last known Partula faba dies as a captive breeding program sadly fails. Introduced species had driven them #extinct in the wild	40	Science communication / educational account specific to extinct animals	Global	5292

Table 4 Continued.

Species	Date	Tweet	Retweet count	User type	Location	Follower count
Philydor novaesi	10 September 2017	This bird is the alaman foliage-gleaner. It was made extinct by humans in 2011 when its last small piece of forest habitat was turned into sugar cane plantations	85	Science communication / educational account specific to extinct animals	Global	71 214
	15 December 2018	'The study reclassified a further seven birds on the IUCN Red List of threatened species as extinct or deemed highly likely to be extinct. Those never to be seen again are the cryptic treehunter, Alagoas foliage-gleaner and po'ouli.'	85	Science communication/educational account specific to extinct animals	Global	71 214
	9 January 2019	#Biodiversité quelques-unes des espèces qui nous ont quitté en 2018 ? • L'ara de Spix (vu dans « Rio ») • Anabate d'Alagoas • le Cichlocolaptes mazarbarnetti • le poo'uli (un passereau d'Hawaï) • le jaguar oriental • le alamander blanc • la alamander géante chinoise… [#Biodiversity Some of the species we lost in 2018 ?] • The Spix's Macaw (seen in 'Rio') • The Alagoas Foliage-gleaner • The Cryptic Treehunter • The Poo-uli (a Hawaiian honeycreeper) • The Eastern Cougar • The Northern White Rhinoceros • The Chinese Giant Salamander…	89	Science news	France	104 085

organisations, such as WWF and Save the Rhinos, accounted for an additional 10% of the top users. This indicates that these environmentally orientated individuals and organisational accounts have been successful in attracting attention to conservation events, similar to that of influencers and news media accounts. However, these findings also highlight the precarious nature of generating interest through social media platforms as following the acquisition of Twitter in 2022, concerns around increased hate speech, data usage and access, among other reasons, led to a reported mass exodus of this category of users, notably scientists (See Novoa *et al*., 2022; Chang *et al*., 2023). Chang *et al*. (2023) found that nearly 50% of the 380 000 environmentally oriented users on Twitter became inactive 6 months after the takeover. Given our finding that environmentally oriented users are among the top users shaping discourse about conservation issues online, this raises serious concerns about the future awareness of events and the mobilisation of pro-environmental segments of the public.

Our results showing how online interest is generated across users suggests two key points: (1) conservation engagement strategies should prioritise continued engagement with influential individuals and media accounts who shape online conversations, particularly those identified as content creators, writers and bloggers who play a critical role in communicating about conservation and extinction events, and (2) although accounts associated with environmental organisations or individuals have historically had a significant impact on online discourse, the recent mass exodus of these users following the acquisition of Twitter indicates a need to explore and encourage engagement on alternative platforms to ensure continued awareness and mobilisation for conservation issues.

Factors influencing online interest

Several factors may increase the likelihood of news outlets or influencers firstly sharing information and secondly, whether the general public picks up and further disseminates the information, leading to it going viral. Perhaps the most significant of these factors is whether a species is considered charismatic or not, for example, those that have visual appeal, uniqueness or iconic status (Jarić *et al*., 2020). As a result of these innate preferences for charismatic species, online social network users have been found to interact about a highly biased sample of species conservation issues with an uneven level of attention directed to certain taxonomic groups, notably large mammals (Roberge, 2014). This is consistent with our results given that the standout species was the western black rhino (*D. bicornis longipes*). Furthermore, Fink, Hausmann, & Di Minin (2020) specifically looked at the online sentiment towards rhinos and found that tragic events, like the death of the last male northern white rhinoceros, a related species, elicited the strongest reactions. In general, this was true for our study as death-related words were found to be connected to the most frequently used bi-terms in Tweets for all species (Fig. 4). There was also a prevailing sentiment of sadness suggesting that extinction events do resonate with the online users on an emotional level (Fig. S2).

Online preferences for charismatic species carry broader implications for mobilising support and actions in response to imminent conservation threats. There is a direct correlation between the online popularity of a species and the financial resources allocated to its conservation endeavours (Davies *et al*., 2018). Furthermore, Ballouard, Brischoux, and Bonnet (2011) observed a trend that children are strongly influenced by online media about biodiversity. Notably, the knowledge of children and their consideration to protect animals are mainly limited to internet content, represented by a few exotic and charismatic species. Put otherwise, school children display limited recognition of local animals and are more prone to protect 'virtual' (unseen, exotic) rather than local animal species. Such pervasive bias continues to pose a challenge by diverting attention and resources away from thousands of species facing extinction, potentially hindering comprehensive conservation strategies (Davies *et al*., 2018).

How the public engage with species extinction may also have a significant influence on emerging de-extinction efforts. While controversial from a conservation perspective (Bennett *et al*., 2017), de-extinction attempts are increasing, with several projects recently announced (Kenneally, 2023; Vigliotti, 2023). Due to the constraints of de-extinction technology, the candidate species are likely to feature relatively recently extinct species (Lin *et al*., 2022), and funding for these projects is likely to be biased by public enthusiasm for charismatic species (Turner, 2017). Our analysis shows that if de-extinction projects follow trends in public engagement, less globally charismatic species, such as the Polynesian Tree Snail, or species with less global online resonance such as the Alagoas foliage-gleaner, will tend to be overlooked.

Beyond a species' charisma, there are other factors that can influence interest such as symbolic value of a species and those that serve as an indicator of broader environmental issues (Caccone *et al*., 1999). For example, we found that in the case of Lonesome George, the last remaining Pinta Giant Tortoise (*C. abingdonii*) held symbolic value as a flagship species for Galapagos Islands conservation efforts, recognised worldwide. His passing received extensive coverage from local and major international news outlets, including the BBC, and this news was widely shared on Twitter. Viral tweets were also observed in subsequent years on the anniversary of his passing.

In terms of indicator species, the Bramble Cay melomys (*M. rubicola*), a small rodent species exclusively found on Bramble Cay in the Great Barrier Reef, was one of the first species attributed to climate change-related extinction. There was some interest on Wikipedia following the local Queensland government's initial declaration of its extinction. However, it was the Australian government's later confirmation – highlighting the species as likely the first mammalian casualty of anthropogenic climate change –that ignited significant interest on Twitter and global media attention (Hannam, 2019). This highlights the fact that species extinction declarations, when paired with coordinated media coverage,

are more effective in capturing significant public interest compared to standalone announcements. Building on this observation, conservationists can leverage such findings to enhance public awareness strategies. For instance, by aligning announcements with wider environmental narratives and key events such as international summits, the impact of these messages can be amplified. Furthermore, strategic timing could be particularly effective in raising awareness of IUCN reports, including changes to a species status, which our study found to be currently underrepresented in public discourse.

Platform-specific trends

Twitter has been one of the most used online platforms with over 500 million active users and sees at least 500 million tweets per day (Sayce, 2020; Clement, 2022). Given its huge reach, our results indicate that there have been relatively low tweeting rates directly about these species with only 95 780 tweets cumulatively in comparison with other topics that get discussed frequently, such as politics (Sayce, 2020; Clement, 2022). Another aspect about Twitter is that it has served as an immediate catalyst for discussions on the environment and conservation, capturing initial public attention following an extinction event. We found that interest tends to decline rapidly, often within a few days. This affirms Twitter's role as a source of instantaneous, yet ephemeral, discussions. Jarić *et al*. (2023) point out that short-lived online interest poses a challenge for conservation. The phenomenon of 'attention transience' provides a narrow opportunity for conservationists to enhance public awareness and gather support (Jarić *et al*., 2023). This matters because the visibility and duration that an environmental issue holds directly influences its representation in policy-making. The authors suggest that to effectively utilise these short attention spans, it is crucial to employ targeted conservation campaigns, and maintain a continuous spotlight on issues (Jarić *et al*., 2023). Creating sustained public interest in conservation is vital for achieving the objectives of the Kunming-Montreal Global Biodiversity Framework.

When examining the response on Wikipedia following an extinction event, a different pattern emerged. Unlike Twitter's rapid rise and fall in interest, species' Wikipedia articles displayed a more sustained level of interest over time. The encyclopaedic nature of Wikipedia may be better suited for looking at prolonged engagement curves. Furthermore, Wikipedia's model of open collaboration and its reputation as a reliable source for information on environmental and conservation, including the IUCN conservation status which is featured on listed species' pages. In terms of conservation awareness, this suggests that Wikipedia should be considered a strategic platform for sharing information and maintaining public interest in conservation topics over time. By actively updating and improving Wikipedia entries related to endangered species and conservation efforts, organisations can ensure that accurate and current information is available to the public. Therefore, based on our results, we recommend greater use of Wikipedia as a research resource in conservation, given its open APIs allow for researchers, even those with limited resources, access to data that could be valuable for measuring various facets of public interest.

Conservation status and implications for awareness

Among the five species declared extinct by the IUCN in our dataset, the Pinta Giant Tortoise was the only one that experienced increased interest after the IUCN declaration, and only on Twitter (Fig. 1a). However, in the instance of the black rhino, although interest did surge following the release of the IUCN report, it corresponded with the broader announcement of extinction, implying that the report alone may not solely account for the increased interest observed (Fig. 1h). These findings suggest that the IUCN reclassification influenced public interest differently compared to Van Huynh's (2023) study, which observed direct shifts in Google Trends and Google Ngram activity following the reclassification of mammal species into higher-risk categories. While the pool of extinct species available for our analysis is relatively small, our results nonetheless highlight the need for increased effort and strategic communication of IUCN report updates relating to extinction, ensuring that they generate the desired levels of public awareness and engagement.

Future directions

In terms of methodology queries, we found that the use of vernacular names was far more prevalent than the use of scientific names in Tweets, as would be expected. This observation aligns with the general public's tendency to use familiar vernacular names rather than scientific or Latin names. Although the use of vernacular names was proportional to scientific names, in line with the study by Correia *et al*. (2017), we found that incorporating both types of names allowed for a more comprehensive approach especially for pulling information on less popular species, such as *P. faba*. To enhance the inclusivity of vernacular names, future research could focus on compiling more extensive lists of names from various global regions. For instance, we observed limited tweet activity in Japan and India, despite their high density of Twitter activity, likely due to certain species' names not being fully comprehended in these regions (Statista, 2023). However, one drawback of using vernacular names is the potential presence of names with multiple connotations unrelated to the taxonomic entity. For instance, we had to exclude 'Areho' for *P. fabula*.

Another avenue for consideration revolves around online interest and its efficacy. With the growing accessibility of publicly available cultural data, our understanding is still evolving on how online interest translates to tangible actions in the real world. For example, are momentary bursts of online attention capable of having any substantial impact in terms in conservation? Additionally, in situations where online-driven actions might be too late for species

that have already faced extinction, can we redirect our efforts to support closely related species facing threats or towards de-extinction attempts? As the field of Culturomics grows, these considerations become important for its potential application in conservation management and policy development.

Conclusion

Online platforms play a pivotal role in shaping conservation discourse. Our study examined the impact of species extinction announcements on online interest, focusing on Twitter and Wikipedia. We observed that extinction announcements do trigger an increase in interest for most species, with iconic species unsurprisingly receiving more attention. Spatially, we observed a shift from local to global interest of Twitter users after extinction. IUCN extinction reclassification reports did not consistently drive online activity, with only a few species showing notable increases in interest. On Twitter, a small subset of influential users, including content creators and media organisations, disproportionately shape conservation discussions. Environmentally oriented individuals and organisations also play a significant role, collectively comprising a third of the top retweeted users. However, the 2022 acquisition of Twitter led to a mass exodus of these environmentally oriented users, raising concerns about future conservation awareness on this platform and highlighting the need to explore alternatives. In contrast, Wikipedia demonstrated more sustained interest over time and may be a better suited for studies measuring long-term conservation awareness. We recommend actively updating and improving Wikipedia articles related to endangered species, especially lesser-known ones, to maintain public interest. Moving forward, it is also crucial to determine whether increased online interest translates into tangible conservation actions. Lastly, coordinated media coverage, especially when aligned with broader environmental narratives and key events, can significantly amplify the reach and effectiveness of extinction announcements.

Funding information

This work was funded by the Irish Research Council (COALESCE/2021/117).

Authors' contributions

SC and KH conceived the ideas; SC collected the data; SC analysed the data with help from AK and GN; and SC and KH led the writing of the manuscript with help from DMD, AK, GC. All authors contributed critically to the drafts and gave final approval for publication.

Acknowledgements

We are grateful to the Irish Research Council *COALESCE* Research Fund (2020) for supporting this research.

Conflict of interest

None declared.

Data availability statement

Data to be stored on Zenodo.

References

Adams, W.M., McCorristine, S. & Searle, A. (2023). Conjuring up ghost species: on photography and extinction. In Stark, H. (Ed.), *Extinction and memorial culture: reckoning with species loss in the Anthropocene*: 137–154. London: Routledge.

Ballouard, J.M., Brischoux, F. & Bonnet, X. (2011). Children prioritize virtual exotic biodiversity over local biodiversity. *PLoS One* **6**, e23152.

Barrie, C. & Ho, J.C.T. (2021). academictwitteR: an R package to access the twitter academic research product track v2 API endpoint. *J. Open Source Soft.* **6**, 3272.

Bennett, J., Maloney, R., Steeves, T. et al. (2017). Spending limited resources on de-extinction could lead to net biodiversity loss. *Nat. Ecol. Evol.* **1**, 53.

Betts, J., Young, R.P., Hilton-Taylor, C., Hoffman, M., Rodríguez, J.P., Stuart, S.N. & Milner-Gulland, E.J. (2020). A framework for evaluating the impact of the IUCN red list of threatened species. *Conserv. Biol.* **34**, 632–643.

Brodersen, K.H., Gallusser, F., Koehler, J., Remy, N. & Scott, S.L. (2015). Inferring causal impact using Bayesian structural time-series models. *Ann. Appl. Stat.* **9**, 247–274. https://research.google/pubs/pub41854/

Caccone, A., Gibbs, J.P., Ketmaier, V., Suatoni, E. & Powell, J.R. (1999). Origin and evolutionary relationships of giant Galápagos tortoises. *Proc. Natl. Acad. Sci.* **96**, 13223–13228.

Chang, C.H., Deshmukh, N.R., Armsworth, P.R. & Masuda, Y.J. (2023). Environmental users abandoned twitter after musk takeover. *Trends Ecol. Evol.* **38**, 893–895.

Clement, J. (2022). Most popular social networks worldwide as of January 2023, ranked by number of monthly active users. *Statista* https://www.statista.com/statistics/272014/global-social-networks-ranked-by-number-of-users/ [Accessed 23 August 2023]

Correia, R.A., Jepson, P., Malhado, A.C. & Ladle, R.J. (2017). Internet scientific name frequency as an indicator of cultural salience of biodiversity. *Ecol. Indic.* **78**, 549–555.

Davies, T., Cowley, A., Bennie, J., Leyshon, C., Inger, R., Carter, H., Robinson, B., Duffy, J., Casalegno, S., Lambert, G. & Gaston, K. (2018). Popular interest in vertebrates does not reflect extinction risk and is associated with bias in conservation investment. *PLoS One* **13**(9), e0203694.

Fernández-Bellon, D. & Kane, A. (2020). Natural history films raise species awareness—a big data approach. *Conserv. Lett.* **13**, e12678.

Fink, C., Hausmann, A. & Di Minin, E. (2020). Online sentiment towards iconic species. *Biol. Conserv.* **241**, 108289.

Hannam, P. (2019). 'Our little brown rat': first climate change-caused mammal extinction. The Sydney Morning Herald. https://www.smh.com.au/environment/climate-change/our-little-brown-rat-first-climate-change-caused-mammal-extinction-20190219-p50yry.html [Accessed 23 August 2023]

Holmes, B. (2023). The recently extinct plants and animals database. https://recentlyextinctspecies.com/ [Accessed 23 August 2023].

IUCN (International Union for Conservation of Nature). (2022). *The IUCN red list of threatened species (v2022-2)*. Gland, Switzerland: IUCN.

Jarić, I., Correia, R.A., Bonaiuto, M., Brook, B.W., Courchamp, F., Firth, J.A., Gaston, K.J., Heger, T., Jeschke, J.M., Ladle, R.J., Meinard, Y., Roberts, D.L., Sherren, K., Soga, M., Soriano-Redondo, A., Veríssimo, D. & Roll, U. (2023). Transience of public attention in conservation science. *Front. Ecol. Environ.* **21**, 333–340.

Jarić, I., Courchamp, F., Correia, R.A., Crowley, S.L., Essl, F., Fischer, A., González-Moreno, P., Kalinkat, G., Lambin, X., Lenzner, B. & Meinard, Y. (2020). The role of species charisma in biological invasions. *Front. Ecol. Environ.* **18**, 345–353.

Joly, C.A. (2023). The Kunming-Montréal global biodiversity framework. *Biota Neotropica* **22**, e2022e001.

Jorgensen, D. (2017). Endling, the power of the last in an extinction-prone world. *Environ. Phil.* **14**, 119–138.

Kearney, M.W., Heiss, A. & Briatte, F. (2016). Package 'rtweet'. https://cran.r-project.org/web/packages/rtweet/rtweet.pdf [Accessed 19 March 2019].

Kenneally, C. (2023). A 'De-extinction' company wants to bring Back the dodo. *Sci. Am.* https://www.scientificamerican.com/article/tech-company-invests-150m-to-bring-back-the-dodo/:~:text=Most%20de%2Dextinction%20programs%20aim,that%20related%20species%20to%20develop [Accessed 23 August 2023]

Kouloumpis, E., Wilson, T. & Moore, J. (2011). Twitter sentiment analysis: the good the bad and the omg! In Proceedings of the international AAAI conference on web and social media, 5, 99, 538–541.

Ladle, R.J., Jepson, P., Correia, R.A. & Malhado, A.C. (2019). A culturomics approach to quantifying the salience of species on the global internet. *People Nature* **1**, 524–532.

Lin, J., Duchêne, D., Carøe, C., Smith, O., Ciucani, M.M., Niemann, J., Richmond, D., Greenwood, A.D., MacPhee, R., Zhang, G. & Gopalakrishnan, S. (2022). Probing the genomic limits of de-extinction in the Christmas Island rat. *Curr. Biol.* **32**, 1650–1656.

McCallum, M.L. & Bury, G.W. (2013). Google search patterns suggest declining interest in the environment. *Biodivers. Conserv.* **22**, 1355–1367.

Meissner, P. & R Core Team. (2020). Wikipediatrend: public Subject Attention via Wikipedia Page View Statistics. https://CRAN.R-project.org/package=wikipediatrend

Mooney, A., Conde, D.A., Healy, K. & Buckley, Y.M. (2020). A system wide approach to managing zoo collections for visitor attendance and in situ conservation. *Nat. Commun.* **11**, 584.

Munson, E.L., Smith, C.M., Boehmke, B.C. & Freels, J.K. (2019). Sentiment analysis of twitter data (SAOTD). *J. Open Source Soft* **4**, 764.

Novoa, A., Canavan, S., Jarić, I., Pipek, P. & Pyšek, P. (2022). Musk's twitter takeover jeopardizes culturomics. *Nature* **612**, 211.

Okoli, C., Mehdi, M., Mesgari, M., Nielsen, F.Å. & Lanamäki, A. (2014). Wikipedia in the eyes of its beholders: a systematic review of scholarly research on Wikipedia readers and readership. *J. Assoc. Inf. Sci. Technol.* **65**, 2381–2403.

Régnier, C., Fontaine, B. & Bouchet, P. (2009). Not knowing, not recording, not listing: numerous unnoticed mollusk extinctions. *Conserv. Biol.* **23**, 1214–1221.

Rinker, T. (2018*a*). Package 'textstem'. Version 0.1.4. http://github.com/trinker/textstem

Rinker, T. (2018*b*). textclean: text cleaning tools. version 0.9.3. https://CRAN.R-project.org/package=textclean

Roberge, J.M. (2014). Using data from online social networks in conservation science: which species engage people the most on twitter? *Biodivers. Conserv.* **23**, 715–726.

Rodrigues, A.S., Pilgrim, J.D., Lamoreux, J.F., Hoffmann, M. & Brooks, T.M. (2006). The value of the IUCN Red List for conservation. *Trends Ecol Evol.* **21**(2), 71–76.

Roll, U., Mittermeier, J.C., Diaz, G.I., Novosolov, M., Feldman, A., Itescu, Y., Meiri, S. & Grenyer, R. (2016). Using Wikipedia page views to explore the cultural importance of global reptiles. *Biol. Conserv.* **204**(Part A), 42–50.

Sayce, D. (2020). The number of tweets per day in 2020. https://www.dsayce.com/social-media/tweets-day/ [Accessed 23 August 2023]

Silge, J. & Robinson, D. (2016). Tidytext: text mining and analysis using tidy data principles in R. *J. Open Source Soft* **1**, 37.

Statista. (2023). Leading countries based on number of Twitter users as of January 2022. https://www.statista.com/statistics/242606/number-of-active-twitter-users-in-selected-countries/ [Accessed 23 August 2023]

Turner, D.D. (2017). Biases in the selection of candidate species for De-extinction. *Ethics Pol. Environ.* **20**, 21–24.

Valdez, R.X., Kuzma, J., Cummings, C.L. & Nils Peterson, M. (2019). Anticipating risks, governance needs, and public perceptions of de-extinction. *J. Respon. Innov.* **6**, 211–231.

Vallis, O.S., Hochenbaum, J. & Kejariwal. (2019). AnomalyDetection: anomaly detection using seasonal hybrid extreme studentized deviate test. R package version 1. https://rdrr.io/github/twitter/AnomalyDetection/

Van Huynh, A. (2023). Effect of IUCN red list category on public attention to mammals. Conservation biology. *J Soc. Conserv. Biol.* **35**, e14050.

Vigliotti, J. (2023). De-extinction: bringing animal species back from the brink. *CBS News* https://www.cbsnews.com/news/de-extinction-bringing-animal-species-back-from-the-brink/ [Accessed 23 August 2023]

Wickham, H., Chang, W., Henry, L., Pedersen, T.L., Takahashi, K., Woo, K., Yutani, H., Dunnington, D. & Posit, P.B.C. (2023). Package 'ggplot2'. Create elegant data visualisations using the grammar of graphics. version 3.4.3. https://CRAN.R-project.org/package=ggplot2

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1. Sentiment category counts for tweets and retweets across species.

Figure S1. Bi-gram networks.

Figure S2. Sentiment categories.

Figure S3. Rank abundance curve of retweets.