



Research

From habitats to hashtags: examining online discussions about invasive species

Susan Canavan¹ , Pavel Pipek^{2,3} , Kim Canavan^{4,5} , Ivan Jarić^{6,7} , Kevin Healy¹ , Deah Lieurance⁸ , Zarah Pattison⁹ , Petr Pyšek^{2,3} , Emily A. Stevenson¹⁰ , and Ana Novoa^{2,11} 

ABSTRACT. Public awareness is critical for societal support for conservation efforts, including management of biological invasions. However, traditional methods for assessing public awareness are limited, and its role as a key factor in alien species invasions remains largely unknown. The rise of participatory web and social media platforms, such as Twitter (rebranded as X), has provided opportunities to gain insight into societal perceptions through user-generated content. In this study, we assessed public discourse about invasive species on social media by analyzing over 500,000 tweets containing the term “invasive species” posted between 2006 and 2021. Our aim was to identify the most frequently mentioned taxa and habitats, prevailing topics, and subject matters that generated high engagement in discussions on biological invasions. We found that mammals, specifically domesticated and urban pests, were the most frequently mentioned, while aquatic habitats and those interfacing with aquatic habitats dominated the top 15 mentioned habitat types. Additionally, the use of location-based hashtags, such as the Great Lakes and Florida, suggests that people tend to be more engaged with invasive species issues in specific areas. We also observed that a relatively small subset of users contributed a disproportionately large share of retweeted content, highlighting the influence of a few key accounts. This study shows the potential of digital data for identifying prominent taxa, habitats, regions, and influential voices in invasive species discussions. Such information can help refine communication strategies, tailor policy interventions, and foster more effective public engagement in efforts to manage and mitigate the impacts of biological invasions.

Key Words: *biological invasions; engagement metrics; invasive species; public engagement; social media analysis; text mining; topic modeling; Twitter (X)*

INTRODUCTION

Public awareness plays a key role in the management of alien species, as it influences whether people support or oppose management efforts (Novoa et al. 2018). Biological invasions are a significant global issue, with outcomes shaped by the interplay of ecological and human-related factors (Pyšek et al. 2020, Novoa et al. 2025). Although research on public perceptions of invasions has grown in recent years (Shackleton et al. 2019), studies on public perceptions across large scales are still lacking and attempts to quantify them are especially rare because obtaining such data is typically challenging. Yet accessing and building knowledge of societal perceptions has never been easier with an increasingly networked society engaging in participatory web and social media platforms (Chew and Eysenbach 2010). Such user-generated content provides a continuous stream of information that can serve as “human sensors” to specific topics or issues (Becken et al. 2017, Jarić et al. 2021, de Oliveira Caetano et al. 2023). Understanding and synthesizing digital data can be achieved using culturomics tools, which analyze a wide array of digital data types, such as text, images, videos, sounds, metadata, network connections, pageviews, and search volumes, to gain insights into human culture and behavior (Correia et al. 2021, Jarić et al. 2021).

One of the major sources of digital data on social interactions over the last two decades has been the online platform Twitter (now renamed X). Twitter is the most popular social media microblogging platform with an estimated 330 million monthly active users worldwide as of 2019, producing billions of posts (tweets) daily (Daume 2016, Kabakuş and Şimşek 2019). Twitter has been a valuable tool in culturomics as it has many users and is populated with textual content. Up until Twitter was acquired by Elon Musk in 2022, the platform offered free access to publicly available information through the Application Programming Interface (API) for academics (Daume 2016) and was widely adopted by a number of disciplines including mental health service providers (Shepherd et al. 2015), physicians (Choo et al. 2015), and urban planners and managers (Milusheva et al. 2021). However, practical applications within environmental sciences have so far been sparse. Jarić et al. (2020a) advocated for wider use of such digital data and explored the potential of culturomics and iEcology (i.e., the study of ecological patterns and processes using data generated for other purposes and stored digitally) in conservation and management. The expansion into the field of biological invasions has not yet been fully realized despite this discipline’s close links with human-mediated activities, including the spread and control of invasive alien species. Many aspects of

¹School of Natural Sciences, Zoology Department, Ollscoil na Gaillimhe—University of Galway, Galway, Ireland, ²Department of Invasion Ecology, Institute of Botany, Czech Academy of Sciences, Průhonice, Czech Republic, ³Department of Ecology, Faculty of Science, Charles University, Prague, Czech Republic, ⁴Centre for Biological Control, Department of Zoology and Entomology, Rhodes University, Makhanda, South Africa, ⁵Department of Plant Sciences and Afromontane Research Unit, University of the Free State, Phuthaditjhaba, South Africa, ⁶Université Paris-Saclay, CNRS, AgroParisTech, Ecologie Société Evolution, Gif-sur-Yvette, France, ⁷Biology Centre of the Czech Academy of Sciences, Institute of Hydrobiology, České Budějovice, Czech Republic, ⁸Department of Ecosystem Science and Management, The Pennsylvania State University, ⁹Biological and Environmental Sciences, University of Stirling, Stirling, UK, ¹⁰Modelling, Evidence and Policy Group, School of Natural and Environmental Sciences, Newcastle University, Newcastle Upon Tyne, UK, ¹¹Estación Experimental de Zonas Áridas, Consejo Superior de Investigaciones Científicas (EEZA-CSIC), Almería, Spain

invasion science could benefit from gaining insight into public interest and engagement with relevant species, and this information can be accessed through culturomics studies on social media platforms (Jarić et al. 2021).

Twitter has been a valuable tool for specifically understanding aspects of social engagement, public perceptions, and emerging threats related to invasions, as well as aiding in the development of effective conservation strategies (Roberge 2014, Kidd et al. 2018, Shan et al. 2022, Acerbi et al. 2023, Evans et al. 2023, Canavan et al. 2025). By analyzing tweets, researchers can identify trends and patterns in public opinions and reactions to certain issues related to a species (Acerbi et al. 2023). Moreover, Twitter could be used to identify stakeholder conflicts of interest in the conservation and management of species (Evans et al. 2023). Twitter can also provide insights into biological phenomena and help researchers identify charismatic species that receive the most attention from the public (Jarić et al. 2020b).

In this study, we aimed to analyze public discourse surrounding invasive species on Twitter. We quantified (1) the most frequently mentioned taxa and habitats, (2) prevailing topics, and (3) subject matters that became “viral” and were heavily engaged with. We then contextualized the drivers of public interest. Lastly, we identified the most influential users and discussed how understanding the influence of social media on research and management of biological invasions can be applied to mitigate the impacts of invasive species.

METHODS

Data extraction

To conduct our analysis, we created a corpus by retrieving all tweets containing the exact term “invasive species” (in English) between 2 October 2006, and 1 October 2021. These dates are prior to Twitter’s takeover by Elon Musk and the subsequent closing of free data access for researchers (Novoa et al. 2022). Access was obtained when the data were still freely accessible through Twitter’s API for academic research and pulled tweets were downloaded using the R package *academictwitteR* with the function “get_all_tweets” (Barrie and Ho 2021). The data only included publicly available tweets. User data, except for a few prominent influencers and media outlets that we specifically name in the results (e.g., public figures, major news organizations, and accounts with large followings discussed in our analysis), were anonymized.

Data cleaning

Before proceeding with analysis of the tweets, we cleaned and simplified the text corpus using R. First, standard retweets (i.e., tweets beginning with “RT @”) were excluded from the corpus of original tweets; however, their counts were retained and combined with quote tweet counts as a composite measure of user engagement. Using the original Tweets corpus, the *stringr* package was consequently used to convert all text to lowercase (function “str_to_lower”), remove leading, lagging, and double spaces, and convert tabs or new lines to spaces (function “str_squish”), and remove hashtags, tags, html characters, punctuation, numbers, and hyperlinks (function “str_replace_all” with pattern replacement; Wickham 2022). Using the *textclean* package, we replaced symbols with word equivalents (e.g., \$ becomes dollar; function “replace_symbol”), removed kern

spaces (function “replace_kern”), and replaced contractions with long forms (e.g., “isn’t” becomes “is not”; function “replace_contraction”; Rinker 2018a). Using the *textstem* package, we lemmatized words or grouped together inflected or variant forms of the same word (e.g., “runs,” “running,” “ran” all become “run”; function “lemmatize_strings” with Mechura’s (2016) English lemmatization dictionary; Rinker 2018b). Using *quanteda* and *quanteda.dictionaries* packages, we standardized spelling by converting U.S. spelling to UK spelling (e.g., “color” becomes “colour”; function “tokens_lookup”; Benoit et al. 2018).

Analyzing word frequency and collocation

For analyzing word frequency, the text was further processed to identify the most frequently mentioned taxa and habitats. We tokenized the corpus by splitting the text into individual words using the *tidytext* package. To remove commonly used words that carry little meaning (e.g., “a,” “the,” “is”), we applied the *anti_join* function from *dplyr* and *tidytext* using a predefined list of English stop words (*get_stopwords* function; Silge and Robinson 2016, Wickham et al. 2022). We summed how many times each word was used. To consider common names that consist of multiple words (e.g., “red squirrel”), we extracted the most common *n*-grams, or consecutive sequences of words, up to four words and summed their frequency. To correct for typos or variations of words (e.g., “crazi ant” to “crazy ant”) we used text similarity in the *quanteda* package to identify those words that differed from other words or *n*-grams by only a single letter, and corrected where applicable. The above process of summing was rerun to include these corrections. We manually inspected the top 2000 words and *n*-grams, then annotated if they were habitats and if so, the habitat type (e.g., forest) or if they were specific taxa at the species or genus level (note that most taxa were referred to by common or colloquial names and not scientific names). The taxa at broader taxonomic levels such as “insects” or “plants” were disregarded because we were interested in mentions of lower-level taxa such as genera or species. We related the words with their respective tweet engagement metrics and plotted the proportion of the top 10 taxa and habitats mentioned in tweets and those that are replied to, liked, and retweeted. Additionally, we plotted a bigram network graph to visualize the connection between commonly used words using the R package *igraph* (Csárdi et al. 2025).

Topic modeling

We performed topic modeling to examine the prevailing topics surrounding the discourse on “invasive species.” Topic modeling uses unsupervised learning techniques to detect how patterns in words and phrases within documents are clustered. Given that tweets are short texts that were limited to 280 characters (till 2017 just 140 characters) means that more common topic model techniques are less effective. We therefore opted to use the Biterm Topic Model (BTM) technique, which is developed specifically for short texts (Cheng et al. 2014). This model uses co-occurrence patterns (i.e., biterns) in the whole corpus, which has the benefit of more accurately predicting short texts. By aggregating these patterns to learn about topics it solves the issue of infrequent word pairings within individual documents (Fig. 1). To determine the optimum number of topics, we calculated the coherence score of 1 to 100 topics. The coherence score calculates if the words in the same topic make sense when combined. Higher scores indicate that topics have more related words. Each tweet was assigned to the topic with the highest predicted proportion, indicative of the

Table 1. Examples of anomalies in tweet counts and engagement with taxon-specific discussions on Twitter (see Fig. 2). The table includes the taxa discussed, an original or verbatim example tweet, and the contextual information of the topic. The metrics reflect the summarized tweets and retweets for the anomaly day, not the specific event. The recorded number of followers was documented on 12 December 2022. The anomaly (Anom) number corresponds to the anomaly numbers shown in Figure 2. Note that some tweets include URL links, which may no longer be functional.

Anom	Taxa	Tweet	Driver of interest	Context	Metrics	Year
1	Lionfish; Carp	Answer for Invasive Species: Put It on a Plate and Eat It	News source	Proposed novel solution: article by New York Times on managing aquatic invasions off the coast of the United States by promoting them as edible substitutes to other overfished species.	98 tweets	2011
2	Lionfish; Carp; Feral hogs	Can U.S. Eliminate Invasive Species by Eating Them?	News source	Proposed novel solution: article by CBS news on managing aquatic invaders as well as feral hogs by consuming them.	168 tweets	2014
3	200 aquatic hitchhikers including knifejaws and Mediterranean blue mussels	Displaced Japanese dock is “alien mother ship” of invasive species (shorturl.at/psuRT)	News source	Invasion alert: published pictures by National Geographic on a washed up dock on the West Coast of the United States that was debris from the Japanese Tsunami five years prior. The debris was described as “Teeming with invasive life-forms” and a “dirty needle that just got stuck into our ecological arm.”	130 tweets; 154 retweets; 54 likes	2012
4	Aquatic invasives	It’s National Invasive Species Awareness Week. Check out our ocean fact on invasive species (shorturl.at/brsV2)	Other	Awareness post: post made by NOAA’s Ocean Services to create awareness around aquatic invasions.	176 retweets	2014
5	Multiple taxa	EU must take urgent action on invasive species, experts urge	Other	Changes to legislation: the Members of the European Parliament (MEP) voted in favor of new legislation to prevent invasive alien species from entering the EU, including the adoption of a “blacklist” of species, which led to a surge of tweets about the proposal.	139 tweets	2014
6	Hippo	After Pablo Escobar’s death, the four hippos he kept as pets have begun to breed and become an invasive species in Colombia	Charisma	Charismatic species: Tweet made by @Facts, a Twitter account that posts general facts and information with a considerable following (3.4 million).	91 likes	2014
7	Lionfish	Fighting one of the most destructive invasive species in the Western Hemisphere—the lionfish	Charisma	Charismatic species: article by National Geographic	484 retweets; 487 likes	2015
8		Went spear fishing for the Lion Fish today, an invasive species here in Belize. Saving the ocean with @Oceana _____	Social media influencer/ Public figure	Social media influencer: post made by influencer Logan Paul (6.7 million followers)	2466 likes; 305 retweets	2016
9	Carp	Asian carp are an invasive species that endanger Great Lakes—incl. our own Lake Superior. We need a plan in place to address this threat.	Social media influencer/ Public figure	Political figure: post made by former U.S. Senator Al Franken (400.4K followers)	342 replies; 2349 likes	2017
10	Multiple taxa	A new bill would roll back Clean Water Act protections and allow ships to dump dirty water with harmful invasive species and chemicals. Take action against this bill to #ProtectCleanWater for birds & other wildlife.	Other	Changes to legislation: post by the Audubon Society, an American non-profit environmental organization, warning of new bill changing U.S. Environmental Protection Agency’s (EPA) Clean Water Rule.	655 retweets; 170 replies	2018
11	Elephant; Human	If you’re shocked by this video, you need to know that this happens almost every other day somewhere in India. This is what endless growth based development looks like. We can’t keep building infrastructure everywhere. Humans are earth’s greatest pathogen, worst invasive species.	Charisma	Charismatic species: a video of an injured elephant after being hit by a train in India.	61,634 retweets; 3063 replies	2019
12	Goldfish	Don’t ever do this. Gold Fish are an invasive species, they decimate local ecosystems. This isn’t funny or cute, this is awful. If you really want to help these fish just be a good pet owner.	Charisma	Pet trade pathway: a response to a viral video on releasing goldfish	98,102 likes	2020
13	Feral pig	-	Charisma	Charismatic species/ Conflicts of interest: a surge of tweets in response to a post condemning hunting of pigs. With tweets in support and in opposition of the management and hunting of invasive feral pigs.	542 tweets	2020
14	Mystery seeds	Do NOT Plant The Mystery Seeds: People Across The US Receive Unsolicited Seed Packs From China; Americans across the country are receiving packages of mysterious seeds in the mail, mostly from China. Agricultural officials have advised anyone who receives one of these packages to avoid touching the contents and to not to plant the seeds.	Other	Biosecurity threat: thousands of unsolicited mailings with seed packages were received from China all over the world. This led to a surge of tweets on these “mystery seeds.”	376 tweets	2020
15	Moss ball; zebra mussel	If you purchased a Marimo moss ball after February of 2021 you could be unintentionally releasing one of the most devastating invasive species into your local waterways. USFWS has outlined what you can do to properly dispose of the moss balls to hopefully avoid further damage	Other	Invasion alert: Zebra mussels (<i>Dreissena polymorpha</i>) were found in Marimo moss balls sold in pet stores across the U.S. and Canada, prompting urgent warnings from USFWS and CFIA.	14,705 retweets	2021

platform's growth in popularity up until 2022 (Fig. 2; Dean 2022, blog, <https://backlinko.com/twitter-users#daily-active-users>). There was, however, considerably more variation in the average number of tweets per day in the last three years of the dataset (Fig. 2).

Analyzing word frequency and collocation

The 15 most frequently mentioned taxa were represented by 14.4% (n = 37,052) of all tweets (Fig. 3a). Half of these taxa were mammals that have been domesticated or considered urban pests including cats (n = 8869), pigs (n = 3751), dogs (n = 2291), squirrels (n = 1804), goats (n = 1,803), rats (1458), and horses (n = 1228). The most frequently mentioned taxa were consistent across tweets, retweets, and engagement intensity in terms of likes and replies (Fig. 3a). However, tweets that were likely to be shared or go viral (e.g., largest ratio of retweets to tweets), on average, contained a different subset of taxa, namely possum (17.3 retweets per tweet on average; 204 tweets), earthworm (9.1; 577 tweets), goat (5.3; 1803 tweets), fern (4; 121 tweets), and boa (3.2; 165 tweets).

In terms of habitat, 5.9% (n = 15,114) of tweets mentioned one of the 15 habitat types (Fig. 3b), with islands (n = 3412) being the most tweeted about. Aquatic habitats and those interfacing with an aquatic system dominated the top habitat types (13 out of 15 habitats; Fig. 3b).

Two of the 20 most used hashtags represented locations in North America (i.e., Great Lakes and Florida; Fig. 4). The remaining hashtags were mostly general subjects related to global change.

Topic modeling

Our results indicated that the optimum division within our corpus was into 40 topics, which we manually assigned into 10 overarching themes (see Appendix 1; Fig. 5). One topic was not in English (Tagalog), likely resulting from tweets that contained the English phrase "invasive species" but were otherwise written in Tagalog. Notably, the topic ("colloquial usage") with the highest number of assigned tweets captured linguistic patterns rather than thematic content, consisting of common action verbs ("get," "kill," "rid," "make") used across all invasive species discussions. Although this is a known artifact of topic modeling of short texts, it reveals the action-oriented, pragmatic language that characterizes public discourse about invasive species on Twitter.

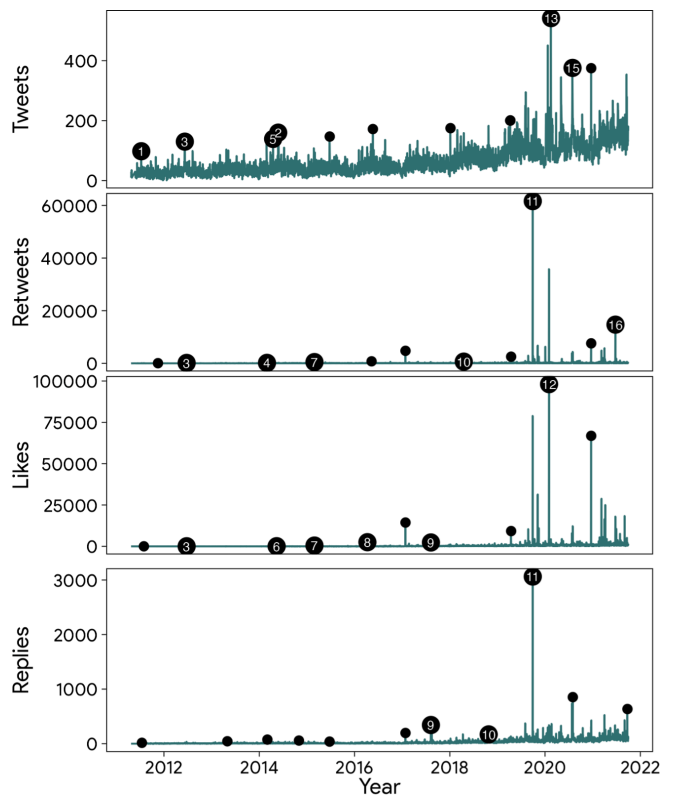
Anomaly detection

Our analysis revealed clear spikes and anomalies in Twitter metrics, as shown in Figure 2. These anomalies represent significant deviations in the number of tweets, retweets, likes, and replies, often coinciding with periods of heightened public interest or significant events related to our topic. Table 1 highlights 15 examples of tweets selected to showcase a range of different taxa and scenarios that led to these anomalies. These examples illustrate the influence of factors such as media coverage, awareness campaigns, charismatic species, legislative changes, and biosecurity threats.

User influence

When analyzing users by their retweet count, we found that just 362 accounts (1% of users) generated 60% of all retweeted content, and the top 5% (n = 181) accounted for 76%. The top 25% (n = 9004) contributed to 90% of retweets (Fig. 6A). Among the top users were the public, news outlets, and journalists, which

Fig. 2. Anomaly detection. Anomalies in twitter engagement over time for tweets, retweets, likes, and replies. This figure shows the temporal trends of Twitter activity across four engagement metrics. The green lines represent the count per day for each metric. The black points indicate days with significant positive anomalies, identified using a periodic detection method with a 30-day period, positive directionality, and a long-term consideration of 365 days. Anomalies were identified by testing whether the number of tweets or user engagement metrics per day experienced a significant spike, with a significance level set at 0.01. The numbers within the black circles correspond to the example anomalies discussed in Table 1.



made up 61% of total users (Fig. 7). Following these were government agencies, conservation organizations, and scientists, all with similar numbers. Additionally, we identified specialized groups such as invasive species organizations, scientific publishers, environment-focused media, and activist groups as significantly active.

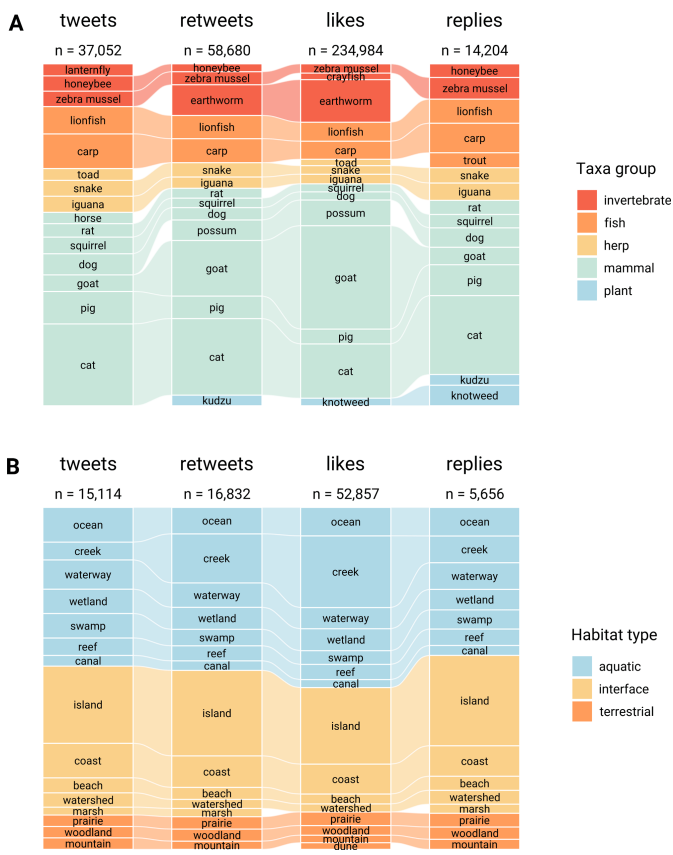
Localities

We were able to geolocate 119,319 users. The majority, 71,850, were from the USA, with nearly all of these users exclusively located within the country (Fig. 8). The UK and Canada followed with 11,362 and 11,160 accounts.

DISCUSSION

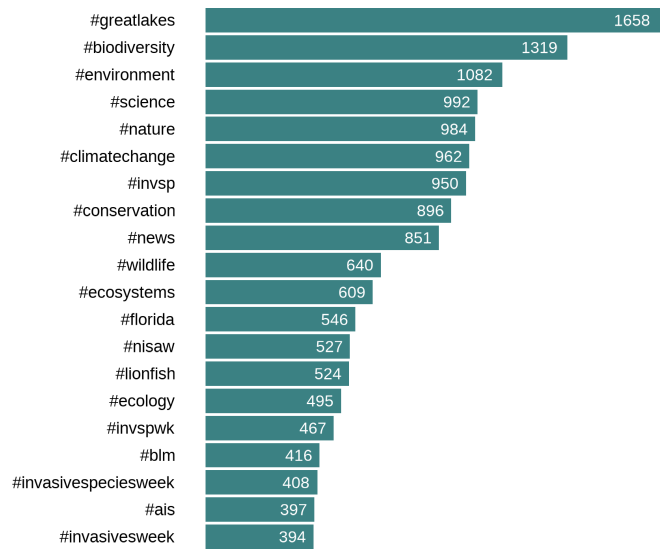
With the ever-growing uptake of user-generated content on social media platforms such as Twitter, how information is generated and understood is changing (Rui and Whinston 2012). In this "information age," outputs from Twitter have been a valuable

Fig. 3. Sankey plot depicting the top 15 taxa (A) and habitats (B) mentioned in the context of invasive species on Twitter, classified by their interactions (tweets, retweets, likes, replies). The top figure (A) shows the specific taxa categorized into taxonomic groups (invertebrate, fish, herptile [herp], mammal, plant) represented by distinct colors. The bottom figure (B) shows the habitat types grouped into aquatic, interface, and terrestrial categories and depicted with different colours. For both figures, the height of each stratum indicates the relative proportion of each interaction type (sum of tweets, retweets, likes, or replies counts), and the values on top of each stratum represent the total number of interactions for each group. Note that these terms have been adjusted from the original tweets to better group similar terms as best as possible, such as consolidating plural and singular forms, unifying variations (e.g., “lantern fly” to “lanternfly”), and incorporating synonyms (e.g., “pig” encompasses the term “swine”).



resource and in many ways have become a major public good (Kupferschmidt 2022). However, such information will only become useful when we have built reliable methods to gather and make sense of this information (Rui and Whinston 2012). In this study, we determined an appropriate way to obtain and synthesize information related to biological invasions and show that the application of culturomics through textual analysis can effectively be applied to user-generated content on biological invasions from Twitter.

Fig. 4. Bar plot showing the top 10 most frequently used hashtags associated with invasive species in tweets. Each hashtag is ranked by its count, with the frequency represented by the bar length. The count value is displayed in white text within each bar. Notably, #invspwk (Invasive Species Week) promotes awareness and prevention, created by Invading Species account (@invspecies). #nisaw is the National Invasive Species Awareness Week and #ais refers to Alien Invasive Species.



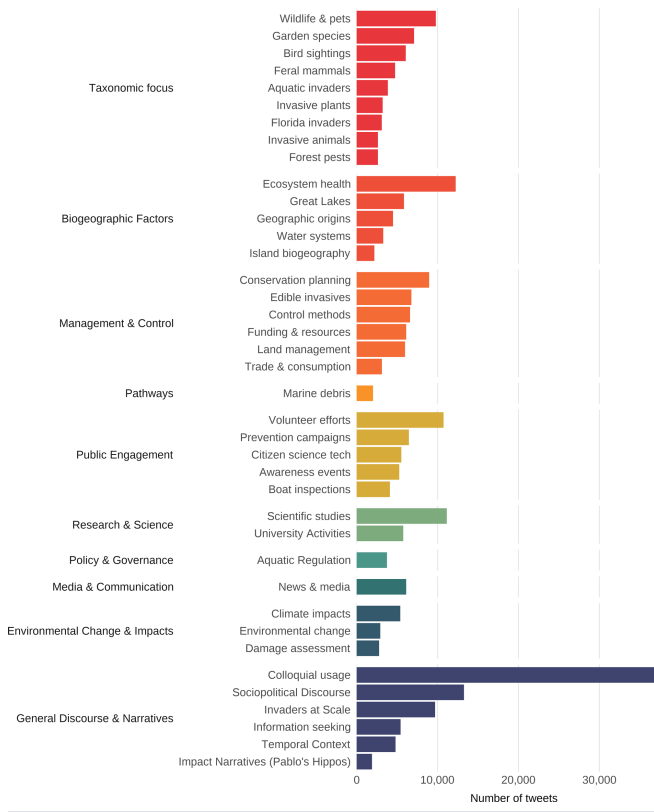
Drivers of virality and social interest

Although viral trends arise from unique situations and species, certain users wield a disproportionate amount of influence as their tweets are more frequently retweeted, particularly those with larger follower counts, leading to increased public engagement on certain topics and taxa (Fig. 6). Most notable are media influencers, public figures and news sources, but we also found that government agencies, conservation organizations, and scientists contribute significantly, along with specialized accounts (Fig. 7). Secondly, the topics and species that draw the most attention are often characterized by charismatic species. Below, we discuss the main drivers of virality and interest for invasive species.

Social media influencers and public figures

We found that the distribution of retweets is not even across all users; rather, certain users are associated with significantly higher levels of retweets (Fig. 6a). As expected, users with higher follower counts (Fig. 6b) are more likely to be in the higher percentiles of users whose tweets are frequently retweeted. Among the top 1% were individual accounts of what we would classify as the general public, or those that did not have a clear connection to professional organizations or specific interest groups specified on their account description. Many of these users may be classified as social media influencers (hereafter, influencers), independent third-party endorsers who shape audience interests through blogs, tweets, and the use of other social media (Freberg et al. 2011). Dubois and Gaffner (2014:1261) define the ability to influence as

Fig. 5. Frequency of tweets belonging to each topic (text left of barplots) determined by Biterm Topic Modeling (BTM). Each tweet was assigned to a topic based on its highest probability to matching that topic. The topics were manually categorized into 10 broader themes (text on the left side of the figure).



“convincing an individual to change his or her opinion, attitude, and/or behaviour.” These users, including public figures, develop a persuasive power within some groups interested in a topic. Although our analysis measures engagement metrics (retweets, likes, replies) rather than actual behavioral change, high engagement suggests these users have the potential to shape discourse around invasive species. Previous studies have demonstrated links between social media influencer content and behavioral changes in other contexts, such as consumer purchasing decisions (Lou and Yuan 2019) and environmental behaviors (Johnstone and Lindh 2018). For example, Johnstone and Lindh (2018) found that influencers perceived as trustworthy significantly increased sustainability awareness among younger consumers, with millennials showing particular responsiveness to influencer messaging about environmental issues. Establishing such causal relationships for invasive species awareness would require further research.

We found two notable examples where social media influencers and public figures generated substantial attention toward invasive species: lionfish (*Pterois* spp.) and lanternflies (*Lycorma delicatula*; anomalies 8 and 9; Fig. 2; Table 1). A post by American media personality Logan Paul (6.7 million followers at the time the metadata was pulled) about spearfishing for invasive lionfish

in Belize garnered 2513 likes and 305 retweets in 2016. Similarly, a tweet from former U.S. Senator Al Franken (400.4K followers) in 2017 about the threats posed by Asian carp in the Great Lakes received 342 replies, 2349 likes and 523 retweets. Despite not being directly involved in invasive species management or scientific research, figures like Logan Paul and Al Franken wield considerable influence, raising awareness on various topics, including environmental issues. However, their influence can be double-edged; although they can disseminate important scientific messages, they also have the potential to spread misinformation. For instance, Wong (2024) showed that media outlets sometimes mislabel unrelated species as invasive red imported fire ants (*Solenopsis invicta*), risking confusion and unwarranted alarm over harmless natives. Therefore, high-profile backing or rebuke from influencers can significantly impact the dissemination of scientific reports and invasive species campaigns (Galetti and Costa-Pereira 2017).

Environmentally orientated accounts

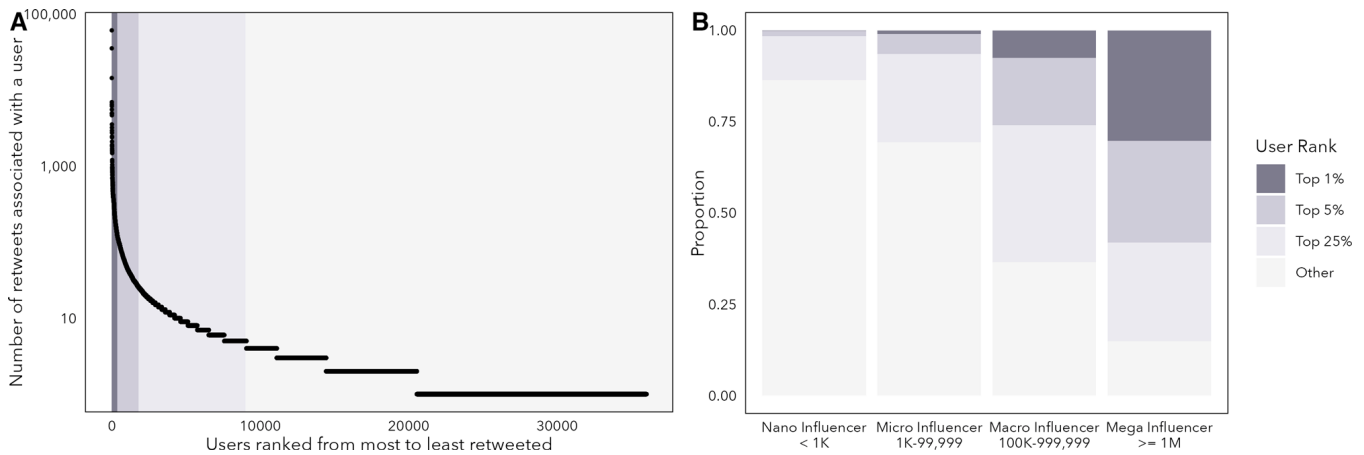
Among the top influential accounts, we found a high representation of environmentally oriented users, encompassing both individuals and organizations (Fig. 7). These included scientists and researchers, invasive-species specific groups, research and education institutions, conservation organizations such as NGOs, and activist and advocacy groups. Notable scientists and researchers that were most retweeted included Helen Roy, Guy Ballard, Bill Sutherland, Anibal Pauchard, and Wayne Dawson, three of whom specialize in invasive species.

Activist accounts also play a crucial role. For example, the Alternative National Park Twitter Account (@NotAltWorld; 993,065 followers) was created in response to the removal of climate change tweets from the official U.S. National Park Service account during Trump’s first presidency, sparking the creation of this rogue account that went viral within 24 hours. It posts about science, climate change, and political content. Another activity account is the Extinction Symbol account (@extinctsymbol; 71,805 followers), which raises awareness of biodiversity loss, specifically focusing on extinctions. Conservation and society accounts such as ZoologiMY (@ZoologiMY; 32,461 followers) raise awareness in Malaysia, and the Entomological Society of America (@EntsocAmerica; 22,794 followers), the largest organization in the world for entomologists, also contributes significantly to retweeted content.

Role of news sources

News media play a crucial agenda-setting role in public discourse by selecting which issues to highlight, thereby influencing the salience of those topics among the public (McCombs and Valenzuela 2020). The framing and language used in news stories can shape public perception, often evoking strong emotional responses that drive engagement. We found that news media indeed have been relevant in what stories about invasive species are shared online. News and media made up the second most influential group of users, with 52 accounts. They also had particularly high numbers of followers (8,329,724 on average). We noted that 9 of the 10 most retweeted media accounts were U.S.-based, including the American Broadcasting Company (ABC), Cable News Network (CNN), CNN Breaking News, NowThis News, Columbia Broadcasting System (CBS), National Public Radio (NPR), The New York Times, and The Economist.

Fig. 6. (A) Rank abundance curve of retweets. 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. Additionally, annotations highlight the proportions of retweets contributed by the top 1%, 5%, and 10% of users within each species group. (B) Stacked bar graph that illustrates the distribution of users across different influencer categories (Nano, Micro, Macro, and Mega), which are defined by the number of followers. These categories are displayed according to their rank (Top 1%, Top 5%, Top 25%, and Other). The user ranks are determined by the number of retweets they have received. Both figures use a purple color scheme to represent user rank, with varying shades indicating different ranks.



Several viral stories or anomalies directly resulted from news sources tweeting stories about invasive species (Table 1; Anomalies 1–3). For example, in 2011, The New York Times published an article exploring the potential of including more invasive species as food sources, which sparked significant interest. The New York Times, with its worldwide readership of about 8.6 million paid digital subscribers, has a vast audience to engage with its articles. Similarly, CBS News published an article proposing the management of invasive species such as lionfish, carp (*Cyprinus carpio*), and feral hogs (*Sus scrofa*) by encouraging their consumption as a food source. National Geographic also had a significant impact with an article and pictures describing a washed-up dock on the West Coast of the United States as debris from the Japanese Tsunami five years prior. Vivid language comparing the debris that was washed up and “teeming with invasive life-forms” with that of a “dirty needle that just got stuck into our ecological arm” likely helped garner attention on the subject and increase the rate the information was shared. The vivid language can create strong imagery and emotional engagement, making the issue more tangible, memorable, and widely discussed.

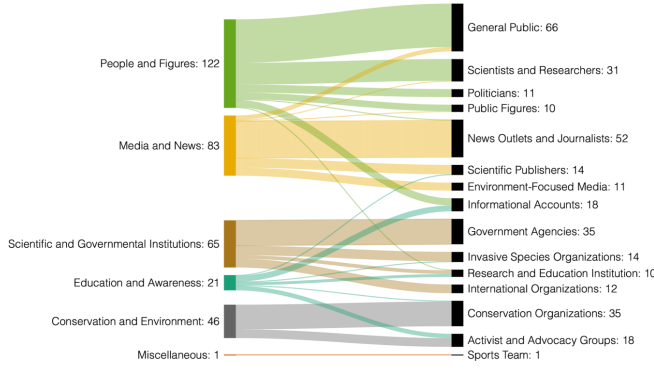
Media coverage is important for bringing these issues to the forefront of public and governmental attention. However, relying on news sources has its limitations. The transient nature of public attention means that the interest in these issues is often short-lived, leading to only temporary spikes in awareness and engagement (Jarić et al. 2023). Sensational stories, particularly those involving charismatic species, are more likely to be published as they attract higher viewership and engagement, amplifying their reach (Jarić et al. 2020b). This focus on sensationalism can skew public perception, as less dramatic but equally important issues may receive less coverage and attention. As a result, conservation efforts might struggle to maintain

sustained interest and support from the public and policy makers. Jarić et al. (2023) recommend that to make the most of these fleeting periods of interest, conservationists must use targeted marketing campaigns and strategic message framing. Regularly refocusing attention on key issues is essential for maintaining public engagement.

Charisma

The charisma of an alien species significantly influences its media portrayal and public favour (Lorimer 2007, Jarić et al. 2020b). Those possessing captivating features, such as impressive body size, striking appearances, or unique behaviors, tend to become focal points of public interest and generate more interactions on social media (Roberge 2014). Our findings support this, with large mammals and colorful aquatic animals being frequently tweeted about (Fig. 3), as in the case of Pablo Escobar’s feral hippos (*Hippopotamus amphibius*) in Rio Magdalena, northeastern Colombia (anomaly 6; Fig. 2; Table 1). Pablo Escobar, a drug cartel leader, illegally imported four hippos for his private zoo in the early 1980s (Castelblanco et al. 2021, Subalusky et al. 2023). Following Escobar’s death in 1993 and the forfeiture of his estate, the hippos remained in the area. Despite initial plans for culling, strong public opposition led to the abandonment of these initiatives in 2009. Hippos are considered one of the most charismatic animal species because of their impressive body size and appearance (Albert et al. 2018). They are considered to hold value for local communities as they are believed to attract tourists to the area. Lionfish were also found to be an important charismatic species influenced by their showy appearance with red-and-white zebra stripes with pectoral fins (anomalies 1 and 7; Fig. 2; Table 1). In this case, alternative forms of management have independently arisen and gone viral including fishing and culinary consumption as a means to reduce the population.

Fig. 7. Sankey plot illustrating the categories of the top 1% of users who have been retweeted the most. The left side of the plot represents different account types, and the right side shows the specific user types within these account types. The width of the flow lines and height of the category boxes indicate the number of users belonging to each category, with these numbers also displayed beside each account and user type label.



Interestingly, one anomaly revealed public discourse labeling humans as an “invasive species” (Table 1, anomaly 11). Although humans do not meet the scientific definition of invasive species, this metaphorical use of “invasive species” terminology, though scientifically inaccurate, highlights how the public sometimes co-opts scientific terms to express broader environmental concerns about human-wildlife conflicts and habitat destruction.

Contrasting public awareness and academic research

An important question arises when examining the role of Twitter: does the trending content on the platform accurately reflect the diversity and issues inherent to invasive species, as covered in academic research? This question is particularly relevant in light of the findings by Stevenson et al. (2023), who used a topic modeling (Latent Dirichlet Allocation, LDA) approach to explore the main themes in 10,000 peer-reviewed articles about “invasive non-native species” or “invasive alien species.” These findings provide a benchmark for our analysis, which aims to compare the focus on habitats and regions, the representation of different taxa, and the levels of public engagement and accountability between informal online content on Twitter and formal peer-reviewed literature.

Habitats and regions

Regarding habitats and regions, the literature’s topic model by Stevenson et al. (2023) strongly focused on habitats, dedicating an entire theme to ecosystems and covering diverse habitats. In both their analyses of the literature and our analysis of Twitter, the most mentioned habitats were aquatic and interface habitats, with “marine systems” (including sea, coast, and reef) being most prevalent in the literature and islands receiving more attention on Twitter (Fig. 3b). Terrestrial habitats, though less represented on Twitter, were evenly covered in the literature, with topics like “woodland structure” and “grasslands” being notable. The absence of dunes and mountains on Twitter, as opposed to their presence in the literature, hints at a potential disparity in representation, which may be due to the comparatively lower accessibility of such areas (e.g., for tourism or in urban areas),

possibly driving lower interest. Furthermore, neither platform mentioned polar habitats, despite Chan et al. (2019) highlighting the anticipated risks of invasions in these areas. Lastly, analyzing the countries named both in the literature and online, we identified a significant focus on invasive species in the USA, particularly in Florida. This region was unique in that it was highlighted in both the literature and Twitter models, indicating an exceptional level of attention to this region.

Taxa

In the taxa category, Twitter posts predominantly focused on species. In contrast, Stevenson et al.’s (2023) topic model derived from academic literature had a broader focus, with only two topics dedicated to general groups, such as freshwater fauna and aquatic plants, and a singular topic on a specific taxon, namely crayfish. The taxa emphasized in each model differed markedly; academic discussions primarily concentrated on plant-related topics, including taxonomy, competition, and herbivory. This focus reflects the established taxonomic inclination toward plants within the field of invasion biology, as noted by Pyšek et al. (2008). Conversely, Twitter discussions more frequently mentioned mammals, with plant taxa receiving comparatively less attention (Fig. 3a). The Twitter topic model reveals this discrepancy, within the “Taxonomic focus” theme the topic “Feral mammals” received more tweets compared to “Invasive plants,” for example (Appendix 1; Fig. 5). This pattern is consistent with the phenomenon of “plant blindness,” where plants, despite their extensive coverage in scholarly literature, are less prominent in wider discourse, potentially because of a perceived lack of appeal, as discussed by Jose et al. (2019).

Public engagement and accountability

On Twitter, public engagement was a prevailing theme, with numerous topics reflecting an interest of Twitter users on citizen science (Appendix 1; Fig. 5). In contrast, while the literature model had topics discussing policy and the economic impacts of invasive species there were no topics or themes on public engagement, citizen science, social awareness, perceptions, or non-economic (i.e., social, human well-being) impacts of invasive species. This discrepancy highlights a gap in the peer-reviewed literature’s focus (Shackleton et al. 2019), despite the existence of numerous citizen science programs that contribute vital data for invasive species surveillance, management, and research (Pocock et al. 2024). The disconnect between active public participation in invasive species management and its limited representation in topic models of academic literature suggests a need for better integration of citizen science efforts into scholarly discourse.

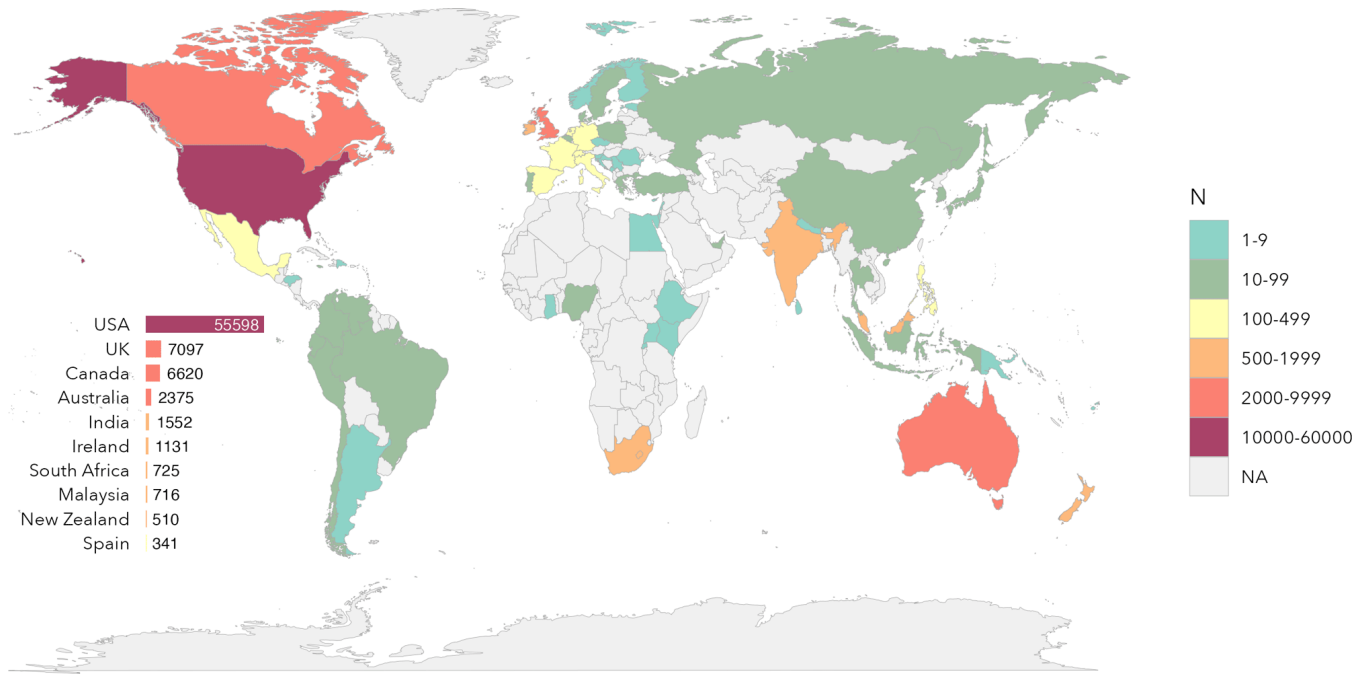
Applications to research and management of biological invasions

Advancements in obtaining and analyzing extensive textual data from online sources have opened new possibilities for utilizing this information in the field of biological invasions. Considering the results from this study, we outline four potential applications to explore the practical implications further.

Identify societal conflicts

The management of invasive alien species often needs to encompass a process to evaluate any potential conflicts that may occur should control of a species take place (Novoa et al. 2018). Gauging public opinion on particular species may be possible by assessing relevant social media content. An example of an anomaly that identified a stakeholder conflict of interest in this

Fig. 8. User locations based on data extracted from Twitter profiles, visualized as a heatmap. The color gradients reflect varying user concentrations across different countries. The top 10 countries with the highest user concentrations, displayed in bottom left inset, indicate the number of associated user accounts.



study was about the control of feral or wild pigs (Table 1, Anom. 13). On 15 February 2020, there was the largest spike with 543 tweets (not including retweets). This was due to a viral post that featured a video of a user shooting a wild pig, sparking backlash from animal rights activists. Wild pigs (i.e., domestic pigs that have gone feral) are an alien species in the U.S. and have major economic and environmental impacts (Jaebker et al. 2021). The most widely used control method across the U.S. has been shooting wild pigs on sight, followed by hunting, trapping, and removing (McKee et al. 2020). The majority of wild pigs are found on private lands and thus there has been a need for public outreach and engagement in their control (Jaebker et al. 2021). Jaebker et al. (2021) assessed the sentiments expressed toward wild pigs by Twitter users, and found that the majority of tweets about wild pigs in the U.S. had negative sentiments, particularly from individuals in academia (Jaebker et al. 2021). Such insights provided an improved understanding to the management of a species that has gained large public interest and led to societal conflicts. However, a majority of the posts were in favor of managing the invasive pigs.

A platform for public awareness

We found a clear representation of tweets about research activities made by researchers (see two topics under the “Research & Science” theme; Appendix 1). This is unsurprising considering the large network colloquially known as “Academic Twitter.” The community grew substantially from a marginal part of outreach and exposure to becoming a central communication infrastructure for academics (Carrigan 2022, blog). Although researchers have played a large part in disseminating information regarding invasive species on Twitter, it remains to be answered

how much of that information is echoed within the community versus being broadcasted and received by a broader public audience. As of early 2025, similar academic communities have emerged on other social media platforms, such as Bluesky and Mastodon, particularly following changes to Twitter’s ownership and policies.

Rally support or opposition to management

Twitter can play a role in both mobilizing support for and expressing opposition to invasive species management. We identified multiple prominent topics on Twitter that specifically focus on aquatic invasive taxa and management, including “Boat inspections,” “Prevention campaigns,” “Water systems,” “Great Lakes,” and “Marine pathways” (Appendix 1 and Fig. 5). These topics highlight how the platform facilitates communication about the risks associated with species transportation between water bodies while providing guidance on proper cleaning and identification techniques. The prevalence of these topics may suggest that Twitter has been an important platform for awareness campaigns, though without longitudinal behavioral data, we cannot determine whether this online engagement translates to actual changes in boater behavior or reduced species spread (Kollmuss and Agyeman 2002). Similar culturomics approaches using YouTube data have revealed complex public attitudes, with recreational fishers simultaneously viewing invasive species as both ecological threats and valued resources (Sbragaglia et al. 2022), suggesting that social media engagement with invasive species management may reflect similarly nuanced perspectives rather than simple support or opposition. Future research could track whether regions with higher Twitter engagement on boat inspection topics show corresponding decreases in new aquatic invasive species detections.

Twitter has also facilitated dissenting voices, with some users expressing opposition to specific management strategies, exemplified by debates surrounding the management of feral pigs in North America (Table 1, Anomaly 13). Twitter's role in the conversation on invasive species management is evident, though the exact impact of advocacy versus critique remains unclear without specific data on the proportion of supportive versus opposing voices.

Expedite changes to legislation

Twitter, and other social media platforms, can be useful tools for the real-time detection of biosecurity threats and the early detection of invasive species. For example, Twitter's role in disseminating information quickly was highlighted during the "mystery seeds" incident (see Anomaly 14; Fig. 2; Table 1), which saw widespread public attention and subsequent investigations. Although it is challenging to attribute policy changes to Twitter's influence directly, the platform's rapid spread of awareness likely contributed to the urgency with which authorities, such as the United States Department of Agriculture - Animal and Plant Health Inspection Service, reviewed and updated biosecurity regulation. In Australia, the government invested in a new X-ray system to enhance seed detection capabilities. Similarly, corporate responses, like Amazon's ban on foreign seed sales in the United States, demonstrate the platform's potential to amplify critical issues and possibly expedite official responses.

Furthermore, the virality of Twitter, along with other social media platforms, has demonstrated potential for mobilizing environmental movements through hashtag activism. Research has shown that environmental hashtags can influence both online discourse and offline behaviors. For instance, Crespo and Cruz (2023) found that exposure to #SaveTheBees content on social media was associated with more positive perceptions of bees and greater engagement in conservation behaviors, suggesting the potential benefits of social media activism for promoting conservation. Similarly, Suitner et al. (2023) documented how #ClimateAction hashtags showed steady increases in usage from 2017 to 2019, with linguistic markers of collective action also increasing over time. Although these studies demonstrate correlations between social media engagement and conservation attitudes, establishing direct causal links between online campaigns and policy changes remains challenging.

Research limitations

There are several limitations and areas for future research identified in this study. First, our initial search to gather the corpus was conducted only in English, which potentially excludes a large portion of the global discussion on invasive species. Including other languages in future searches would likely provide a broader linguistic and cultural context about invasive species. Our decision to search only for "invasive species" likely excluded relevant discourse using synonymous terms such as "alien species," "non-native species," "introduced species," or colloquial terms like "pest species." Different stakeholder groups may prefer different terminology. For example, policy documents might use "invasive alien species" while farmers might refer to "pest plants." These terminological preferences could reveal important differences in how various communities conceptualize and discuss invasive species. Additionally, as observed in our findings, this study

focused solely on Twitter, a platform predominantly used in specific regions, particularly the United States. Meanwhile, countries like China primarily use other social media platforms such as WeChat and Weibo, highlighting a platform-specific bias in our data.

The instability and evolving nature of social media platforms also pose challenges for ongoing research. Although environmentally focused accounts played a significant role in the discourse around invasive species, this dynamic has likely shifted in recent years. Following the acquisition of Twitter by Elon Musk in 2022, concerns about increased hate speech, data usage policies, and access costs led to a mass exodus of users, including scientists. Chang et al. (2023) reported that nearly 50% of the 380,000 environmentally oriented users on Twitter became inactive within six months of the takeover, which occurred after our data collection period. This significant decline in active environmentally oriented accounts raises concerns about the future of awareness and engagement on invasive species issues (Novoa et al. 2022). As these key accounts become inactive, the source of shared information may shift more heavily toward other entities like news outlets, potentially altering the nature of invasive species management and outreach activities. It should be noted that a second large exodus of users occurred following the November 2024 U.S. elections, while the platform Bluesky experienced a significant boost in users, including an influx of academic and environmentally focused accounts (Ittimani 2024).

Nonetheless, this study has provided a unique snapshot of the discussion around invasive species on a widely used and important social media platform. Despite the limitations, the research demonstrates the value of leveraging digital data to understand better the social dimensions of biological invasions, specifically by quantifying taxa and habitats of interest, identifying the role of specific user groups, and exploring the potential of social media as a tool for public awareness and engagement.

CONCLUSION

This study demonstrated that social media-generated content can be used to detect and synthesize public discourse and opinions surrounding biological invasions. We pinpointed the specific taxa and topics related to invasions that garner greater attention online, as well as the drivers behind heightened engagement. This information can be used by researchers and policy makers to (1) identify disparities between scientific knowledge and public understanding of biological invasions, (2) address public awareness and attitudes on targeted topics with scientific consensus to promote accurate information dissemination, and (3) align their efforts with public concerns and priorities, leading to better-informed policies and collaborative approaches in managing biological invasions. A major advantage of this study, at the time, was the permitted use of Twitter content that was made freely available for academic research. However, since Elon Musk's takeover of Twitter in 2022, there has been a change in both the nature and access to this platform, whereby the company's changes include more restrictions and higher costs to attain any information produced. Such constraints not only disrupt the potential for obtaining longitudinal data but also threaten the repeatability of similar studies. We appeal to social media platforms to maintain accessible data policies for academic

researchers, as the insights gained from such analyses can benefit both conservation efforts and public understanding of environmental issues. As the landscape of social media platforms evolves, it is imperative that researchers remain adaptive to these changes to ensure the continued progress of research and knowledge in our field.

Author Contributions:

SC, PPI, and AN conceived the ideas; SC, PPI, and AN gathered the data. SC and PPI analyzed and visualized the data. SC led the writing of the manuscript with help from PPI, KC, IJ, KH, DL, ZP, PPy, EAS, and AN. All authors contributed critically to the drafts and gave final approval for publication.

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Data Availability:

All relevant data and code underlying the findings described in this manuscript are openly available on Zenodo: <https://doi.org/10.5281/zenodo.17306681>.

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APPENDIX 1

Theme	Topic	Terms
Taxonomic focus	Aquatic invaders	asian, carp, mussel, zebra, hornet, bug, stink, giant, murder, find, invasive, beetle, crab, quagga, know, call, brown, marmorate, species, fish
	Bird sightings	bird, house, see, look, white, little, native, green, love, eat, european, sparrow, know, get, black, cute, call, starling, think, blue
	Feral mammals	cat, feral, wild, pig, hog, dog, keep, outdoor, hunt, horse, kill, animal, domestic, let, boar, indoor, free, consider, pet, much
	Florida invaders	python, squirrel, florida, gray, burmese, lionfish, iguana, red, snake, everglade, swamp, eat, lizard, native, rat, duck, Nile, kill, deer, green
	Forest pests	tree, ash, borer, emerald, beetle, spot, moth, kill, gypsy, pear, maple, pine, fly, oak, fruit, find, hemlock, crop, destroy, bradford
	Garden species	plant, native, species, invasive, tree, animal, bee, remove, grow, garden, much, nonnative, see, many, seed, insect, flower, kill, grass, know
	Invasive animals	giant, snail, red, ant, african, native, frog, ear, land, lizard, crazy, turtle, fire, find, slider, snake, brown, species, worm, black
	Invasive plants	japanese, knotweed, garlic, mustard, himalayan, balsam, plant, flower, wee, common, crayfish, ivy, know, remove, purple, honeysuckle, call, invasive, pull, giant
	Wildlife & pets	animal, kill, pet, bird, hunt, fish, release, population, people, species, wild, native, keep, cat, small, many, wildlife, control, become, eat
Biogeographic Factors	Ecosystem health	native, species, ecosystem, natural, habitat, local, wildlife, destroy, protect, population, environment, threaten, bird, animal, plant, predator, endanger, kill, area, threat
	Geographic origins	state, native, america, north, american, unite, new, introduce, europe, find, much, fish, bring, south, western, northern, consider, species, spread, come
	Great Lakes	lake, great, aquatic, keep, ake, protect, river, find, fish, water, work, new, news, mussel, threat, michigan, tahoe, carp, fight, boat
	Island biogeography	island, global, new, ship, scientist, news, early, arctic, trade, route, warm, study, map, species, detection, lead, open, bear, bring, rapid
	Water systems	water, river, fish, lake, quality, protect, aquatic, bay, find, pollution, clean, ballast, canal, bloom, body, area, system, freshwater, pond, stream
Management & Control	Conservation planning	conservation, management, work, need, take, local, public, land, action, wildlife, protect, much, resource, state, issue, environmental, plan, community, support, help
	Control methods	control, help, management, work, use, good, remove, project, restoration, forest, need, much, habitat, manage, removal, effort, program, fire, plant, restore
	Edible invasives	eat, fish, food, lionfish, good, make, hunt, chef, way, help, use, delicious, new, carp, meat, snakehead, crab, local, dinner, catch
	Funding & resources	dollar, state, fight, county, news, fund, grant, battle, park, aquatic, new, year, official, say, program, award, lake, plan, dnr, help
	Land management	take, tree, area, plant, forest, grow, leave, land, new, space, garden, keep, open, make, live, clear, see, habitat, remove, park
	Trade & consumption	use, plant, water, food, waste, buy, make, seed, local, firewood, plastic, bring, get, see, sell, good, bait, bag, kill, oil

Pathways	Marine debris	sea, tsunami, ocean, debris, ride, dock, plastic, reef, hitch, japanese, pacific, coast, coral, find, wash, marine, float, japan, bring, new
Public Engagement	Awareness events	week, awareness, learn, today, national, free, aquatic, join, event, day, workshop, host, webinar, talk, tomorrow, next, much, register, raise, meet
	Boat inspections	boat, clean, dry, spin, drain, aquatic, check, inspection, water, spread, boater, watercraft, station, prevent, stop, gear, fish, help, equipment, wash
	Citizen science tech	new, report, help, use, app, find, species, news, scientist, track, map, tool, identify, aquatic, invasive, fight, citizen, york, zealand, learn
	Prevention campaigns	spread, help, prevent, aquatic, stop, fight, take, control, protect, keep, way, learn, species, reduce, new, plant, invasive, water, disease, step
	Volunteer efforts	park, remove, help, volunteer, work, nature, day, today, trail, plant, clear, removal, learn, join, national, team, creek, thank, student, pull
Research & Science	Scientific studies	use, species, impact, study, new, research, change, management, control, model, datum, ecological, good, ecology, invasion, aquatic, interest, effect, native, science
	University Activities	student, science, research, work, talk, learn, school, class, project, today, say, environmental, team, thank, study, university, scientist, professor, grade, ecology
Policy & Governance	Aquatic Regulation	water, new, ballast, law, bill, ship, rule, aquatic, regulation, state, act, propose, protect, pass, introduce, lake, legislation, great, protection, prevent
Media & Communication	News & media	new, article, great, read, story, interest, video, talk, good, news, paper, check, today, book, show, write, blog, science, watch, late
Environmental Change & Impacts	Climate impacts	change, climate, habitat, pollution, loss, threat, destruction, biodiversity, human, cause, land, use, disease, include, extinction, impact, species, threaten, development, much
	Damage assessment	cause, damage, ecosystem, impact, disease, much, environment, human, harm, dollar, cost, havoc, ecological, crop, economic, health, environmental, economy, wreak, spread
	Environmental change	increase, fire, high, change, level, water, much, climate, rise, warm, population, reduce, weather, drink, forest, temperature, risk, flood, growth, sea
General Discourse & Narratives	Colloquial usage	get, good, people, make, think, know, way, thing, kill, bad, want, need, say, much, cat, let, see, eat, rid, try
	Impact Narratives (Pablo's Hippos)	threat, problem, big, pose, issue, cause, face, become, escobar, hippo, serious, major, biodiversity, pablo, huge, risk, challenge, species, environmental, solve
	Information seeking	much, see, make, learn, get, info, people, plant, information, find, report, seed, check, want, read, fact, great, fun, share, visit
	Invaders at Scale	much, world, human, species, bad, become, toad, many, introduce, planet, cane, destructive, australia, earth, cat, invasive, consider, part, new, list
	Sociopolitical Discourse	people, human, call, white, think, say, life, trump, much, animal, use, make, nature, take, man, need, come, american, good, see
	Temporal Context	year, time, day, take, last, first, week, see, get, spend, next, work, great, today, come, long, learn, good, new, place