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Unveiling global narratives of restoration policy: Big data insights into competing framings and implications

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ABSTRACT

Restoration has become a key environmental policy goal of the contemporary era. Yet, what restoration means and how it is pursued remains an object of debate. This study examines the nature of restoration discourses on Twitter – a large, open, and global record of public discussions around contemporary restoration matters. We apply machine learning-powered text analysis of about 350,000 geolocated tweets spanning 2015-2022, focusing on four main restoration terms – landscape restoration; forest and landscape restoration; ecological restoration; and ecosystem restoration. Findings reveal a wide diversity of environmental policies framed through the language of restoration, underscoring its public appeal and use by different institutions from global to national and subnational scales. Restoration discourses foster both ecological and human-centered framings, with the former being more prominent. Other distinct discourses convey promotional efforts, momentum building, political engagement by proponent actors, and what restoration should deliver. Only a few discourses feature quick fixes such as tree planting, potentially implying that contemporary restoration interventions are more diverse than headline-grabbing targets to plant trees. There is little discussion of rural livelihoods, tenure rights, or tradeoffs between environmental objectives and local needs. Although the discourses vary across the restoration terms, we find some shared discourses as well as unique ones. We underscore how restoration discourses carry different worldviews with implications for the purported socio-ecological benefits of restoration. Our work shows how data-driven analysis of social media can shed light on the rhetoric of restoration policy agendas and their nuances among a broad spectrum of social and policy actors.

1. Introduction

Exacerbating interlinked environmental issues of deforestation and land degradation, biodiversity loss, and climate change have led to a rapid increase in forest and landscape restoration initiatives globally, which are now anchored in the UN's 2021–2030 Decade of Ecosystem Restoration (FAO, IUCN CEM, & SER., 2021; Aronson et al., 2020; Young and Schwartz., 2019). Restoring degraded landscapes is considered as a "nature-based" strategy (Cohen-Shacham et al., 2016; 2019) with potentials to deliver integrated climate solutions and socio-ecological benefits (Lamb et al., 2005; Aronson and Alexander 2013; Besseau et al., 2018; Chazdon and Brancalion, 2019). Proponents often describe restoration as a novel policy effort, though restoration ideas seem to draw upon many well-established philosophies of joint conservation and development (Erbaugh, 2022; Atela et al., 2015; Peters, 1998; Gezon, 1997). Restoration is endorsed as strategy in both the sixth climate change assessment report (IPCC AR6) and the post-2020 global biodiversity framework. It is supported by regional flagships that carry considerable country-level commitments to restore several million hectares of degraded landscapes (Fagan et al., 2020). Such restoration flagships include the 20X20 initiative in Latin America, the AFR100 in Africa, the Agadir commitment in the Mediterranean countries, and the ECCA30 in Europe as key examples (Seddon et al., 2021).

Yet although restoration has gained increasing attention with global environmental discourse, just what it means for different scientific, policy and practitioner communities remains less clear. The rhetoric of restoration can influence implementation, including on-the-ground interventions. Conversely, silence around different aspects can also leave

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room for interpretation. For instance, different scientific and policy communities have embraced different definitions for what restoration is and should be. The Society for Ecological Restoration (SER Society for Ecological Restoration, 2004) places emphasis on ecology by defining restoration as "assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed". In contrast, "Forest Landscape Restoration" of the Bonn Challenge explicitly sees restoration as "enhancing the well-being of people" and the UN's "Decade of Ecosystem Restoration" (UNEP United Nations Environment Programme, 2021) as a way to end poverty (among other things) – both of which thus place more emphasis on human's place in ecosystems as well as the environment's contribution to healthy, flourishing lives.

Definitions are central to contemporary debates of what kinds of intervention may "count" as restoration on the ground. Some researchers have cautioned that the word "restoration" is often conflated with reforestation and tree planting (Parr et al., 2024). This is controversial, since it has sometimes resulted in plantation of non-native species and monoculture (Di Sacco et al., 2021; Nunes et al., 2020; Moyano et al., 2024), sometimes in places that may not have had trees previously, such as grasslands (Veldman et al., 2019; Bond et al., 2019, Stevens and Bond, 2023), or locations that are valued for existing biodiverse ecosystems (Fagan et al., 2022). Yet, many scientists and practitioners continue to advocate for tree planting as a pillar of restoration, if done in specific ways (Hawes, 2018; Duguma et al., 2020; Fremout et al., 2022), with some arguing that production forestry could even be an important part of broader restoration strategies (Werden et al., 2024). This illustrates that what restoration means and how it should be pursued remains an object of debate, and this depends greatly on different people's understandings of what "recovery" of an ecosystem is and which ends it should serve despite existing work defining restoration continuum (Gann et al., 2019).

The concerns become even more complicated by the fact that different concepts undergird debates on restoration – and these concepts have changed over time. Therefore, questioning the discourses associated with restoration terms—i.e. concepts used to refer to restoration—and underlying perspectives, values, and priorities is imperative. For instance, extensive work in environmental history and political ecology has explored how historically-defined scientific frameworks, normative ideals, and imaginaries shape responses to environmental challenges (Cronon 1996) – including restoration (Martin 2022). Moreover, in contrast to established fields of restoration science, Indigenous People and local communities have different perspectives of human-nature relationships and different relational values to nature that define their traditionally sustainable land-use practices (Brondizio et al., 2021). Plural and diverse perspectives are often brought to bear on environmental degradation issues, including restoration (Reyes-Garcia et al., 2019) and embracing such pluralism in restoration can provide roads to more inclusion for more equitable and just outcomes (Ramcilovik- Suominen et al., 2024).

Analyzing the diverse discourses associated with restoration can offer insights into different objectives, scientific understandings, and normative ideas that are used to frame restoration policy. It can also shed light on whose interests are served, what kinds of intervention are being prioritized, and what may be overlooked. What do people mean when referring to restoration in the context of contemporary environmental challenges? Is restoration conceptualized and understood differently based on the terms or terminologies in use? What is claimed as restoration by diverse actors? Such understandings can help to preempt potential unintended consequences, for example potential equity and justice dimensions that could affect vulnerable and marginalized groups. This is particularly important given a long history of conservation discourses and subsequent interventions that have often generated negative impacts on rural livelihoods, exacerbated social inequalities, and weakened people's ability to access the critical environmental resources that support their socio-economic and cultural activities (Larrosa et al., 2016; Almudi and Berkes, 2010; Adams and Hutton, 2007; Jones 2006). Often, promoted discursive rhetoric and subsequent legitimized initiatives are incompatible with some local realities and contribute to reinforce processes of marginalization of local communities (Shackleton et al., 2023). For instance, some framings of conservation issues can carry out controversial and contested perspectives and knowledge, thereby wielding some power through those who mobilize them against others (Robbins, 2012). Also, the legacies of common discourses in conservation have made some people invisible and excluded them from decision-making and meaningful participation (Shackleton et al., 2023).

This study sets out to examine the diverse discourse surrounding dominant restoration terms in social media. Despite recognition of various meanings attached to restoration (Reinecke and Blum, 2018), to date there remains limited systematic analysis to draw implications. There is a need for greater understanding of the nature and diversity of restoration discourses and their underlying ideas to establish the implications for the development of fair and just restoration interventions for people and landscapes, linking global goals and local needs. Social media offers a sphere where societal issues are debated and influenced through discursive texts that brings into play various power differences among actors of various backgrounds and views as reflected in language used and social or intellectual classes, creating numerous discourses. Importantly, social media is used instrumentally to shape environmental policy through various tactics, with evidence for climate change (Seberberg, 2017; Boulianne et al., 2018; Mavrodieva et al., 2019; Park, 2020; Dellmuth and Shyrokykh, 2023), education (Sam, 2019, Schuster et al., 2021), and other public policies (Hodges and Stocking, 2016). However, the discourses on restoration in such public digital spheres and their implications for restoration policy have received little attention. Twitter (now known as X), in particular, has become an important social media platform for communication and interactions in modern society, offering a confluent public sphere for interactions among science/academia, policy, and society. Twitter was a popular and important virtual venue for sharing information and engaging in public discourse during the study period from 2015 to 2022. It provides an exceptionally large, open, and global record of public discussions around contemporary restoration agendas, thus offering a basis to explore key framings and discourses across a wide variety of communities and actors.

We explore Twitter communications about restoration, scrutinizing how ideas of restoration have been discussed and their implications for contemporary policy debates. Our main question is: ***What are the nature and the dynamics of restoration discourses on Twitter from 2015 to 2022?*** We aim to examine the broader discursive formations around restoration terms and the nature of popular ones as well as unique ones, including identifying prominent restoration interventions raised in such discourses on Twitter. On this basis, we analyze some of the ways popular restoration discourses may influence policy action as well as possible implications for people and landscapes as restoration is rolled out on the ground. To do this, we apply text mining approaches with machine learning techniques to a collected set of Twitter data. We couple this with content analysis to elicit the topics and rhetoric/language that form restoration discourses. We build upon recent advances that have made this methodological application increasingly vibrant in research (Lesnikowski et al., 2019; Dahal et al., 2019).

Our study reveals how restoration discourses are being used to motivate environmental concerns and the objectives of policy actors. It also uncovers several distinct discursive formations across different restoration terminologies, suggesting key variances in framings that illustrate divergent/competing perspectives, values, and priorities of restoration at play. Overall, we show how Twitter data can help to understand the diversity of ideas behind the contemporary restoration policy and the nuances or contestations that they carry. We draw the implications that discourses—notably their underlying different perspectives and values—can have on restoration's potential socio-ecological benefits for people and the environment.

In Section 2, we expound on the theoretical perspective that guides our analysis and describe our methods, including the data and analysis. We present our findings in Section 3, where we first present an overview of restoration communications on Twitter over the observation period. We then elaborate on the nature and peculiar features of elicited restoration discourses, reconstituted based on the dominant discursive topics identified and the related tweet word clouds for the restoration terms. We discuss these findings in Section 4 before concluding with Section 5.

2. Methods

2.1. Analytical Framework: Environmental Communication and Social Media Discourse Analysis

Social science scholarship in environmental policy, communication, and public sphere has shown that the circulation of ideas and ideologies is rooted in discursive processes, with discourses often shaping which policies are devised and what (the nature of) interventions that are later pursued and in what ways (Adger et al., 2001; Neumann, 2004). Further, the nature and embodiment of interventions, in turn, bring to bear upon specific contexts. Existing research shows that there is a close relationship between the flow of ideas and communication processes (including from disciplinary perspectives), power, policy, and media structures through which they are brought into being. This pattern translates also in several contemporary environmental issues such as deforestation issues (Mempel and Corbera, 2021; Mempel and Bidone, 2023) as well as the realities around restoration of degraded landscapes (Mansourian, 2021; Silveira et al., 2022). This research builds upon this perspective and uses "discourse" as analytical devices to decipher the nature of global restoration policy in Twittersphere and its influence on and implications for local processes.

With a focus on the discourse as well as the power of said discourse, blending perspectives from environmental communication in the public sphere with discourse analysis applied to social media appears a relevant way to explore the discursive constructions of restoration policy in Twitter. Twitter is a social media platform where many, if not most, restoration ideas, initiatives, policy, finance, and actors are featured in one way or another. On one side, environmental communication in the public sphere offers a lens to understanding discursive processes on environmental issues in different spaces, including in media sphere, and how they shape public opinions and perceptions (Park, 2013). This perspective considers environmental problems and their associated policies as the results of claims-making processes using discursive constructions, often time observed in public forums such as in social media as modern public sphere platforms (Mempel and Corbera, 2021). It is therefore a useful lens to explore the discursive processes of claim making, social and political constructions, and even contestations that circulate on Twitter about restoration. On the other side, discourse analyses often undertaken in political ecology studies of environmental governance and policy are primarily applied to examine related discursive framing, including identifying broader discourse formations, their meanings, and their implications (Feindt and Oels, 2005; Waitt, 2005; Koteyko and Atanasova, 2016; Leipold et al., 2019). We draw on such an approach to scrutinize the content of restoration discourses and to demonstrate the importance of considering ideology when analyzing restoration policy on social media (Twitter). Our discourse analysis is to provide a description, explanation, and critical interpretation of the texts (assemblage of words) and language used to foster restoration discourses and their broader social, political, and historical meanings (Koteyko and Atanasova, 2016; Sam, 2019; Bouvier and Manchin, 2020). It is in doing so that we decipher how discourses are used to reinforce (or not) power relations on restoration policy, including the elevation of certain ideas and instrumental interventions, with potential manifestations of discursive inequity from Twitter spaces.

2.2. Data Acquisition and Processing

We utilize Twitter Application Programming Interface (API) for academic research (McCormick et al., 2017) and search the entire Twitter archive from January 1st, 2015 to December 31st, 2022 – an eight-year period before the near close of free download of Twitter data[1] and a period during which we expect to capture major communications in relation to the topic. We focus on tweets featuring communication on restoration in English (see study limitations). We use a set of comprehensive key phrases to capture tweets covering different major terminologies used to refer to restoration, such as *landscape restoration; forest (and) landscape restoration; ecological restoration;* and *ecosystem restoration.* These four key phrases/terminologies are inclusive of the variations in the main concepts or paradigms mostly used in relation to restoration policy, especially focusing on terrestrial ecosystems. These key phrases/terminologies are used by different policy and academic communities. Ecosystem restoration is presently associated with the UN's overarching decade and its broad mandate. Ecological restoration relates to specific groups of people at the intersection of restoration ecology science and policy (e.g. SER). The term "landscape" has been widely in use together with restoration since the emergence of "landscape approaches" (e.g. see Sayer et al., 2013; Freeman et al., 2015; Arts et al., 2017). Lastly, forest landscape restoration emerged as a paradigm with the Bonn Challenge – a 2011global-level call for voluntary (non-binding) efforts to restore 150 million hectares of degraded lands by 2020 and 350 million by 2030. While there is substantial overlap between these terms and the kinds of restoration that they invoke, they are not synonymous. While *rewilding* was another broad term that we considered, it appeared with relatively low tweets, at least in our analysis time frame. Exploring these terminologies individually allows us to capture in greater detail the wide diversity of ideas and framing at play in restoration discourses today among different scientific and/or policy communities. In so doing, it allows us to make stronger statements about both what is included as well as what is not included in different framings. Moving forward in this paper, we will refer to those four main restoration terminologies using related abbreviations: LR = *landscape restoration;* FLR = *forest (and) landscape restoration;* EcolR = *ecological restoration;* and EcosR = *ecosystem restoration.* We conducted the tweet search in January 2023, using the twarc2 program[2] (Summers et al., 2023). Twarc2 is an open-source command-line tool designed for retrieving tweets using the Twitter API. Each retrieved tweet is represented in JSON (JavaScript Object Notation) format. In JSON, the tweet's attributes—such as tweet ID, message, timestamp, and other metadata—are structured as key-value pairs within the JSON object, allowing for efficient data handling and analysis. The search returned a total sample N = 523,730 restoration tweets distributed as follows: LR (101,823); FLR (36,482); EcolR (144,665); EcosR (240,760). The combined dataset, with duplicates removed (i.e., only keeping one tweet if there were the same tweets across the four datasets) returned Nc = 471,572 tweets. We then performed data processing and cleaning for each tweet corpus. We only keep those tweets written in English, which is based on the language field in each tweet. We then extract the timestamp of each tweet and convert it to year-month format. If a tweet is geo-tagged, meaning that the physical location from which the tweet was sent is available as latitude and longitude coordinates, we determine the corresponding country by identifying which geographic boundary the location falls within, otherwise, we use a geocoding library, namely GeoPy (https://geopy.readthedocs.io/en/stable/), to identify the country based on the location names reported in the twitter user's profile. After data processing and cleaning, the number of tweets that were

[1] The period 2015–2022 precedes the turmoil that evolved with Twitter and subsequent name change to 'X' following a private investor purchase of the social media platform.

[2] https://twarc-project.readthedocs.io/en/latest/twarc2_en_us/.

successfully linked to a country, based on the location reported in Twitter user profiles, is Ng = 342,129 and is distributed as follows: LR (71,414/101,823——70 %); FLR (25,542/36,482——70 %); EcolR (87,307/144,665——60 %); and EcosR (157,866/240,760——66 %). This dataset also serves other analyses (e.g., Djenontin et al., in review). Data (tweet sets) acquisition process, cleaning, pre-processing, and analyses are described in detail below and illustrated in Fig. 1.

2.3. Data Analysis

Discourse analysis can be applied on tweets through not only the messages (actual texts), but also the hashtags attached as well as to what scale the tweet is reaching and referencing. Several techniques are used to operationalize such analysis in accordance with the research objectives and methodological approach adopted (Albert and Salam, 2013). We operationalize our analysis of Twitter restoration discourses with machine learning, deep learning-powered text mining approaches and visualization following recent related works (see Lesnikowski et al., 2019; Dahal et al., 2019). We specifically use topic modeling approaches complemented with word clouds, focusing analyses on tweets and topics word contents. To examine the different discursive formations represented under each restoration term, we paid particular attention to how the combined different topics frame/convey notions of restoration and their implications with respect to 1) *what* should be restored – e.g. what is the understanding of nature, human, and/or human-environment relationships in restoration; 2) *why* restoration is understood as a desirable objective and for what outcomes, e.g. toward what ends should restoration be pursued; 3) *how* restoration is understood to happen, e.g. through what means and/or interventions; and 4) *who* are the actors that are involved, either in driving agenda or in implementation of interventions. We also analyzed how the message is delivered, and the language used to mobilize appeal and/or claim legitimacy as a desirable policy objective.

Topic Modeling. Topic modeling techniques allow us to explore the topics that form restoration discourses and to characterize their nature. We do this separately for each of the four restoration terms. Specifically, we use BERTopic topic modeling tool (Grootendorst, 2022), to capture the common topics discussed in each collection of tweets. BERTopic leverages the combination of BERT (Bidirectional Encoder Representations from Transformers) and Class-based Term Frequency – Inverse Document Frequency (c-TF-IDF – a procedure used to generate features from text documents based on their class) to create dense clusters for interpretable topics (Bauer et al., 2023). BERT is an innovative deep learning technique for natural language processing (NLP) pre-training, designed to bi-directionally train a language model from unlabeled text, where the generated text features, in the form of word embeddings, can be used to better capture contextual relations between the words as compared to single-direction language models. BERTopic is able to provide continuous topic representations from a given dataset, whereas conventional LDA (Latent Dirichlet Allocation) topic modeling can only provide discrete ones. In BERTopic, each topic is represented as a vector in a high-dimensional space, where the vector's components correspond

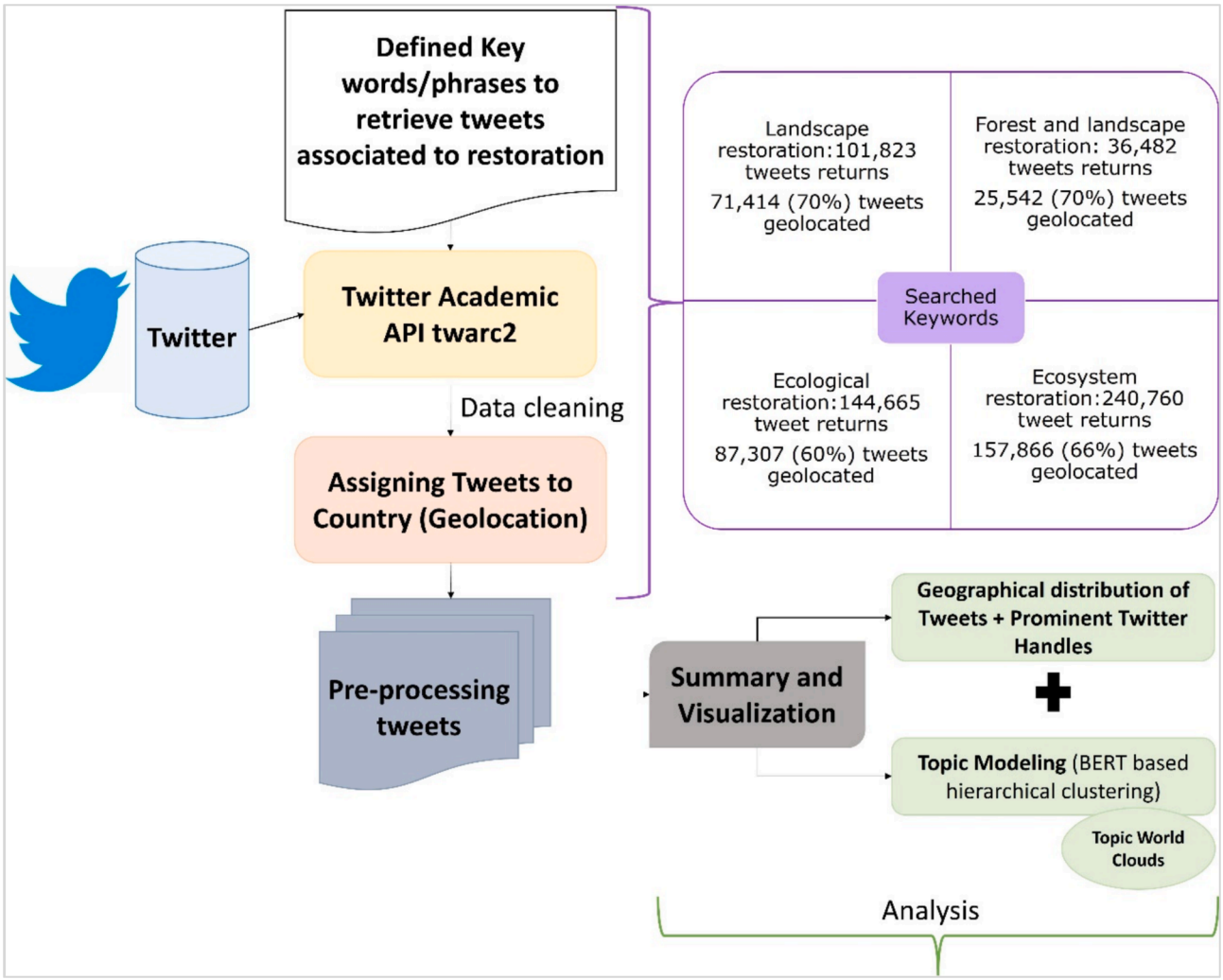

Fig. 1. Overall diagram flow from data acquisition, processing, to analyses.

to semantic features derived from the dataset. We employ hierarchical clustering to group similar topics into clusters based on their cosine similarity or Euclidean distance in this high-dimensional space. The "distance" between two topics is measured by comparing the numerical representations (i.e., vectors) of those topics. More specifically, the distance between two topic vectors quantifies their semantic dissimilarity. Topics that are close in this space are semantically similar and are grouped into the same cluster. Conversely, topics that are farther apart are considered less similar and are placed in different clusters. Therefore, we can merge/group similar topics representations as a larger topic. In this study, we graphically visualize the top 12 merged topics out of 20 specified topics, each displaying 10 salient terms (referred to as topic-terms), sorted by their c-TF-IDF scores. Our choice of 20 topics is guided by both our own heuristic/investigative analysis process and previous similar experimental studies that found that choosing 20 topics for even a larger number of tweet data (compared to our samples) would produce the best topic models that allow capturing enough varieties in the topics (Dahal et al., 2019).

To describe the topics generated, we focus on how different words come together under each topic-term. The relative importance of the key topic-terms that represent a topic are determined by their c-TF-IDF score. The topic-terms help us to identify key words and phrases that are often seen together. Put together under each topic, they display what specific aspects have been emphasized, what the tweet authors found to be particularly important, and reveal the sentiment the tweets sound to convey. In this sensemaking of the topics, the first two co-authors interpreted separately the messages brought together by the topic-terms for each topic and then discussed these interpretations over joint working sessions. Consensus were noted in general across the respective interpretations of the narratives underneath the uncovered topics.

Word Clouds Analyses. We also visualize the word clouds of the tweets that were assigned back to the topics generated. This helps to glean further insights for the discourses that we are teasing out, allowing us to see potentially unique but hidden, and/or prominent but missed words and phrases in the topic model visualization. The text derived from the topic modeling provides simple phrases with their relative importance and the word clouds help us to visualize the frequency of different words within the tweets; we utilize both insights in the interpretation of the topics. The knowledge and engagement with the issue of restoration by the research team was very critical in this sense making process. The resulting snippets of information point toward the various ways in which key words and phrases that "float to the surface" in digital debates illuminate contemporary restoration discussions. The breadth of our analysis–12 topics nested under 4 overarching terms each (= 48 topics in total)–allows us to bring to light how ideas of restoration are framed, including both what is included and what is not.

Our analysis unearths similarities and differences at play in policy and research discussions, presenting a powerful toolkit that allows us to infer general meanings from broad patterns in our data and to study a wide diversity of framings in restoration discourses.

2.4. Study Limitations

We acknowledge that our analysis represents a case study of English-language restoration discourse on Twitter – preventing us from capturing restoration communications in other languages such as French, Spanish, or Portuguese, which may be correlated with the small Twitter users circulating restoration communications in Francophone Africa and Latin America. Moreover, Twitter represents a specific community of users, which is not necessarily representative of the general global public interested in ideas of restoration and sustainability more generally. Twitter has often been used by certain professional communities to advertise and gain attention toward their activities, and by people more broadly engaged in social media discussions. There are of course important omissions – especially those lacking access or interest to engage in social media. Still, as an open and very prominent venue for public discussions, Twitter provides a broad look at global discussions that would not be possible if the analyses were restricted, for example to other media (e.g. journalists) or policy documents. While recognizing these limitations, our dataset of N = 342,129 geolocated restoration tweets is still arguably the largest and encompassing analysis of contemporary discussions on restoration.

It is also important to note that Twitter's format of 140–280 characters constrains the scope of discussion, necessarily resulting in the simplification of complex issues and providing limited space to present nuance in descriptions. As a result, our data arguably gives us greater scope to generalize about what is included in discussions, at least in terms of broad framings, rather than what is *not*, since there may be many things that people would say with more space. Nevertheless, our data—comprising 4 key terms with 12 topics each (48 topics in total)—contain wide range of ideas in contemporary restoration discussions, allowing us to see what key words and phrases "float to the surface" among diverse actors and policy communities. In this regard, the tendency of tweets to trend toward different key words is arguably an asset for our analysis since it allows us to "zero in" on key words and phrases that define and frame different parts of the broader discussion. Indeed, the breadth of our analysis, spanning diverse topics, points toward a wide variety of ways in which discussions are framed, and allow us to make broad generalizations about discourses and framings that would not otherwise be possible. We take great care in the interpretation of results to ensure that we capture the overarching content of discussions as accurately as we can.

Finally, because Twitter was a key pillar of social media during the period of the study 2015–2022, our analysis provides insights from an exceptionally large global dataset, and thus exemplifies many broad trends in global discussions happening at the time. It is true that Twitter use has declined in recent years, since it has become 'X', and this may mean that future analyses have more limitations than in the past. Still, our data comes from a period of particularly vibrant usage and is at least generalizable for the time frame it comprises, including up until 2022 (nearly the present).

3. Results

3.1. Overview of restoration communications and top promoters on Twitter from 2015 to 2022

Our analysis reveals a sharp increase of restoration communications on Twitter during our observation period, with 2021 marking a year that gave prominence to tweets on restoration (Fig. 2). The year 2021 is associated with the launch of the UN's 2021–2030 Decade of Ecosystem Restoration (UN-DER). While tweets with references to the restoration terms FLR and LR dominate from 2015 to 2018, tweets with references to the restoration terms EcosR and EcolR rose to prominence in 2021 and 2022. The particular ascendency of the EcosR term in Twitter communications from 2021 may stem from its used as umbrella term for restoration policy under the UN-DER. The rise in the use of the EcolR term, closely following the use of EcosR term, is important to highlight. In 2019 and 2020, EcolR term and FLR term were the most used in Twitter communication, respectively. This is potentially driven by globally important events that associate with each of these restoration terms.

Our analysis also shows a global spread of restoration communications on Twitter, indicating that restoration policy has earned a wide attention in many realms via their tweeters who are joining the global discussions around restoration policy. However, some peculiar features are worth pointing out along three lines. First, from a regional outlook, our analysis indicates some subtle concentration patterns of the restoration terms used in such digital communications (Fig. 3). Besides the use of EcosR as dominant restoration discursive term across all the regions, tweets from North America and Oceania refer mostly to EcolR

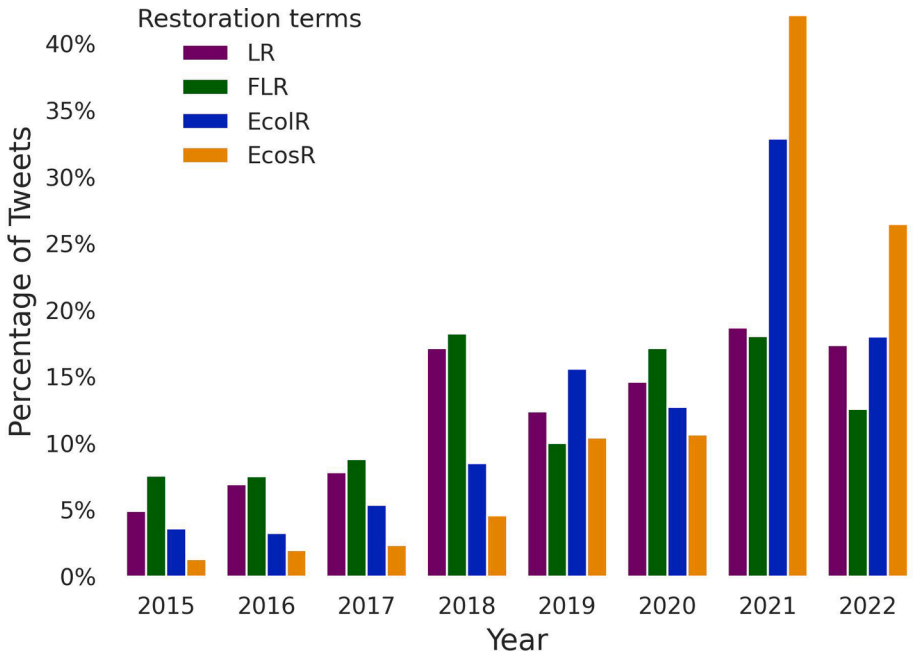

Fig. 2. Percentage of Tweets for each restoration term over 2015–2022 time period. Note: Percentages are normalized by the total number of tweets posted for each year.

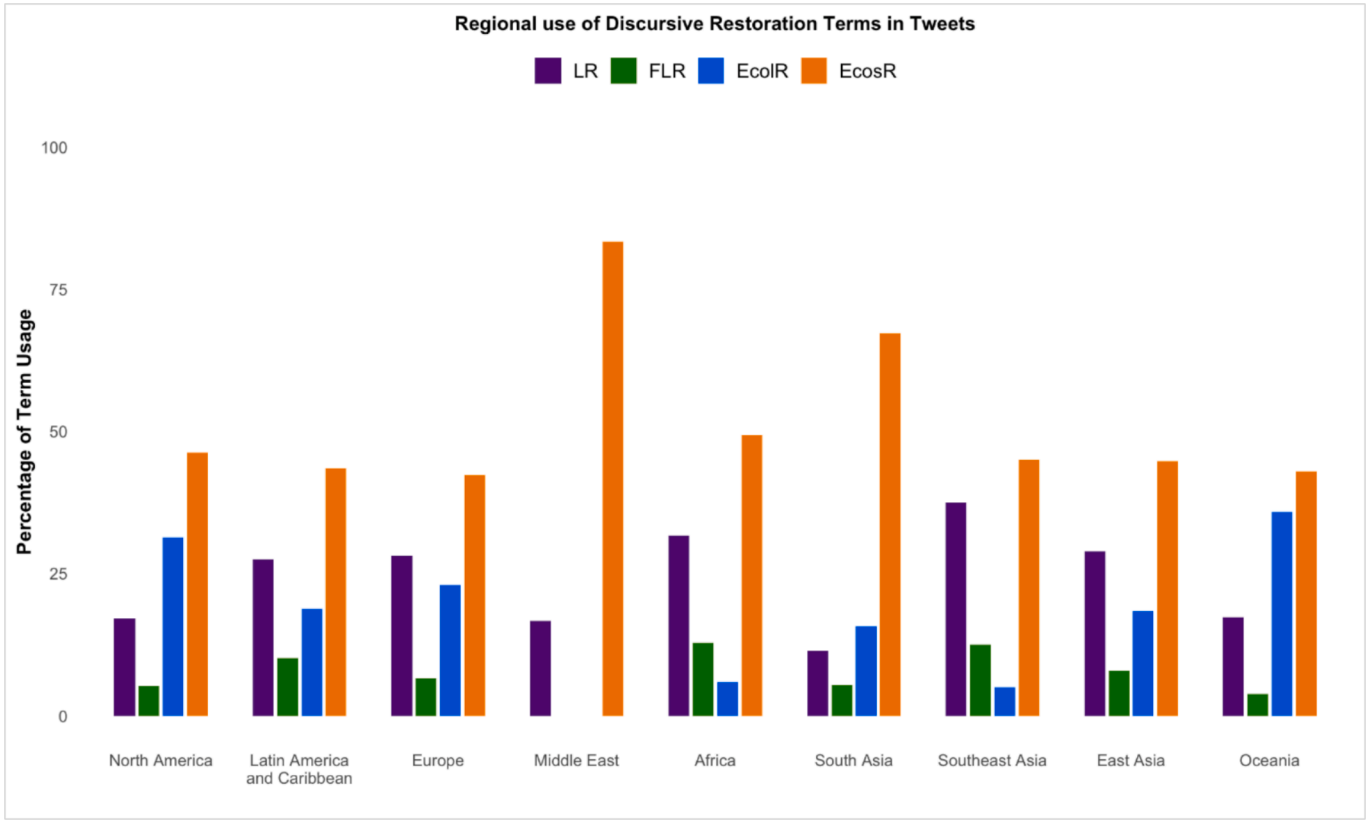

Fig. 3. Regional patterns in the use of restoration terms in Tweets from 2015 to 2022.

term. In contrast, the term LR is the most used restoration discursive term in tweets coming from Europe, Africa, Latin America, and Asia (southeast, south, east). Compared to its used in the Global North (North America, Europe, and Oceania), regions of the Global South, notably Africa, Latin America, and Southeast Asia, employ more the term FLR to foster restoration discourses along their use of LR.

Second, a look at individual country level offers new detailed nuances. Most restoration tweets, irrespective of the restoration term used in the tweets, come from a few numbers of English-speaking countries, mostly from the Global North (North America, Europe, and Oceania), except for two/three Global South countries – India or Pakistan and Kenya or Rwanda (South Asia and Africa, respectively). The US, the UK,

and Canada are consistent Global North countries tweeting about restoration using all four terms. Australia and Germany are also two Global North countries tweeting about restoration but with a stark difference – Australia tweeters use only EcolR and EcosR terms while Germany tweeters use only FLR and LR terms. From the Global South, while India is country tweeting consistently about restoration and using all four terms, Kenya users do not use EcosR term prominently as they do for the other three restoration terms. Rwanda tweeters align behind FLR and LR terms and Pakistan tweeters appear prominently to use EcosR terms. Fig. 4 shows the normalized percentage of restoration-related tweets by country in terms of tweet volume – showing for the top fifty countries for EcosR term (see similar graph for the other three restoration terms in appendix Figures A, B, C). We note that while English-speaking countries are at the top of these digital conversations, reflecting the fact that our data covered only tweet in English, this might also tie to places that use Twitter to a high degree.

Third, focusing on the actual tweeters (Twitter handles), our analysis of the top 50 digital promoters of restoration, distinguished by the terms they use, indicate that a few key institutions and individuals drive the communications around restoration (Fig. 5). While there are some digital actors who employ several of the restoration terms (notably common actors tweeting with both LR and FLR terms or even EcosR), we observe some digital actors who only use specific restoration terms (especially EcolR). In terms of volume, "GlobalLF", known as the Twitter handle of the "Global Landscape Forum" is one prominent institutional actor that has elevated the restoration terms LR, FLR, and EcosR, along with institutions such as ICRAF (for LR), IUCN (for FLR), and the UN CBD (for EcosR). On the other side, "SERestoration", known as the handle for the "Society for Ecological Restoration" is the institution that has lifted the term EcolR, up, along with prominent individual restoration ecologists such as "RestoreCAL" and "restorm" (known also for addressing some economic dimensions of ecological restoration).

3.2. Topic modeling of restoration communications on Twitter from 2015 to 2022

Summary statistics of the topics. Of the 20 topics generated by the model for each restoration term, we focus on the top 12 [0–11] as these represent together at least, and often, more than 75 % of each tweet set, indicating that there is at least 75 % of chance that all the tweets in each tweet set are represented by those 12 topics (See appendix Table A). The importance of the topics in contributing to the broader restoration discourses follows a decreasing order i.e., topic 0 is more prominent compared to topic 5, which in turn is more prominent compared to topic 11. Looking at their temporal dynamics, the top 12 topics show various rises, falls, and consistency, indicating that these topics have changed frequently in prominence over the 8-year period (See appendix Figures D, E, F, G). The temporal trends of the topics reveal how some topics become prominent at some point in time, but the rise can be fleeting as the topics fade out quickly, leaving the spotlight to another topic to dominate the digital conversations.

Meaning/Sense making of the topics. We illustrate in Fig. 6, as an example, the visualization of the top 12 discursive topics for ecosystem restoration tweets (EcosR), including a display of the 10 most salient topic-terms (see appendix Figures H, J, L for the other three restoration terms tweet sets). As noted in the Methods section, the weight of the topic-terms, given their c-TF-IDF score, guides how important they are in determining the nature of the topic. Then, from our meaning/sense

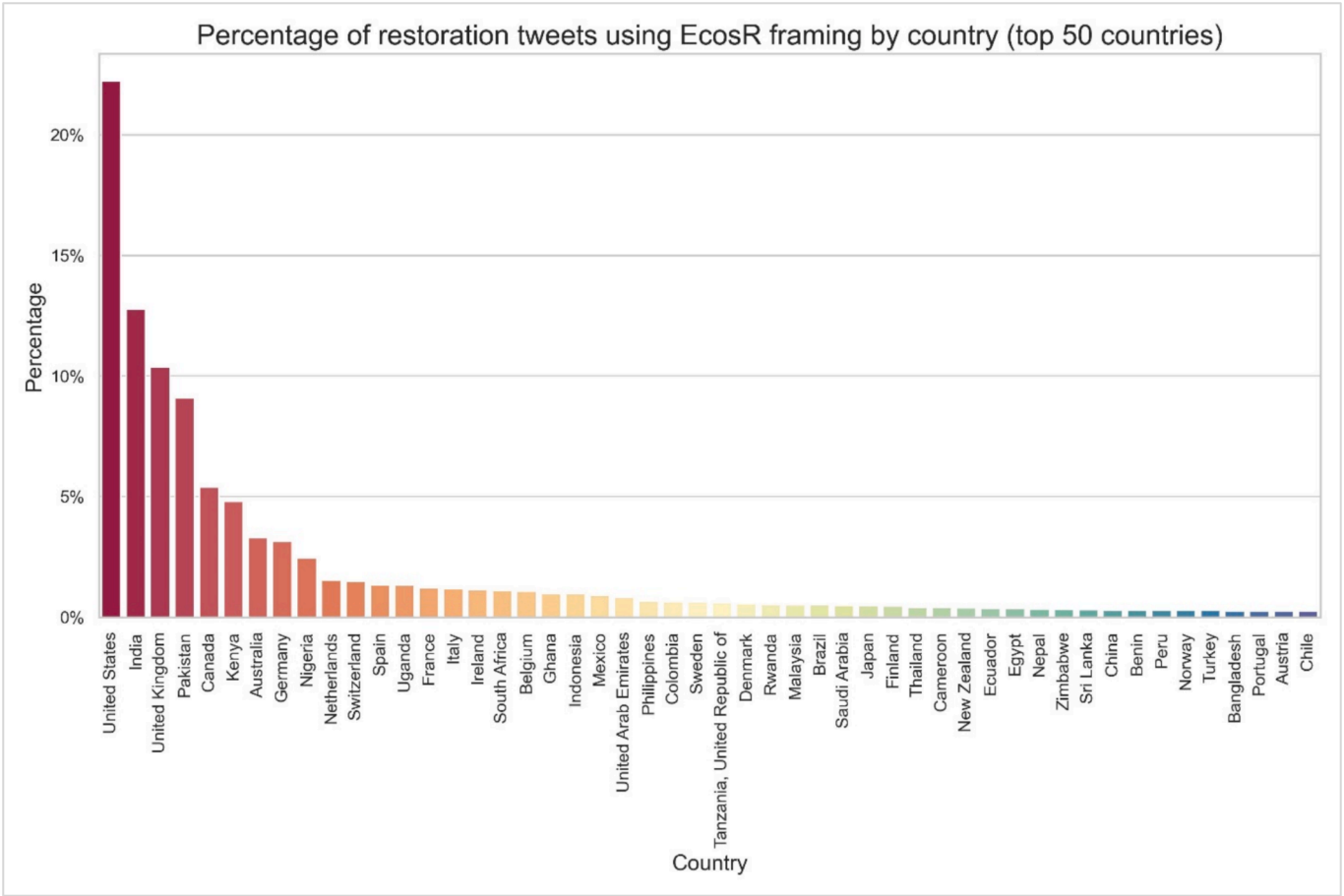

Fig. 4. Normalized percentage of restoration-related tweets using *ecosystem restoration* term by country – showing for the top fifty countries. Note: The percentage of restoration-related tweets—for each restoration term—in a country was normalized by the total number of tweets posted over the 8-year period from that country.

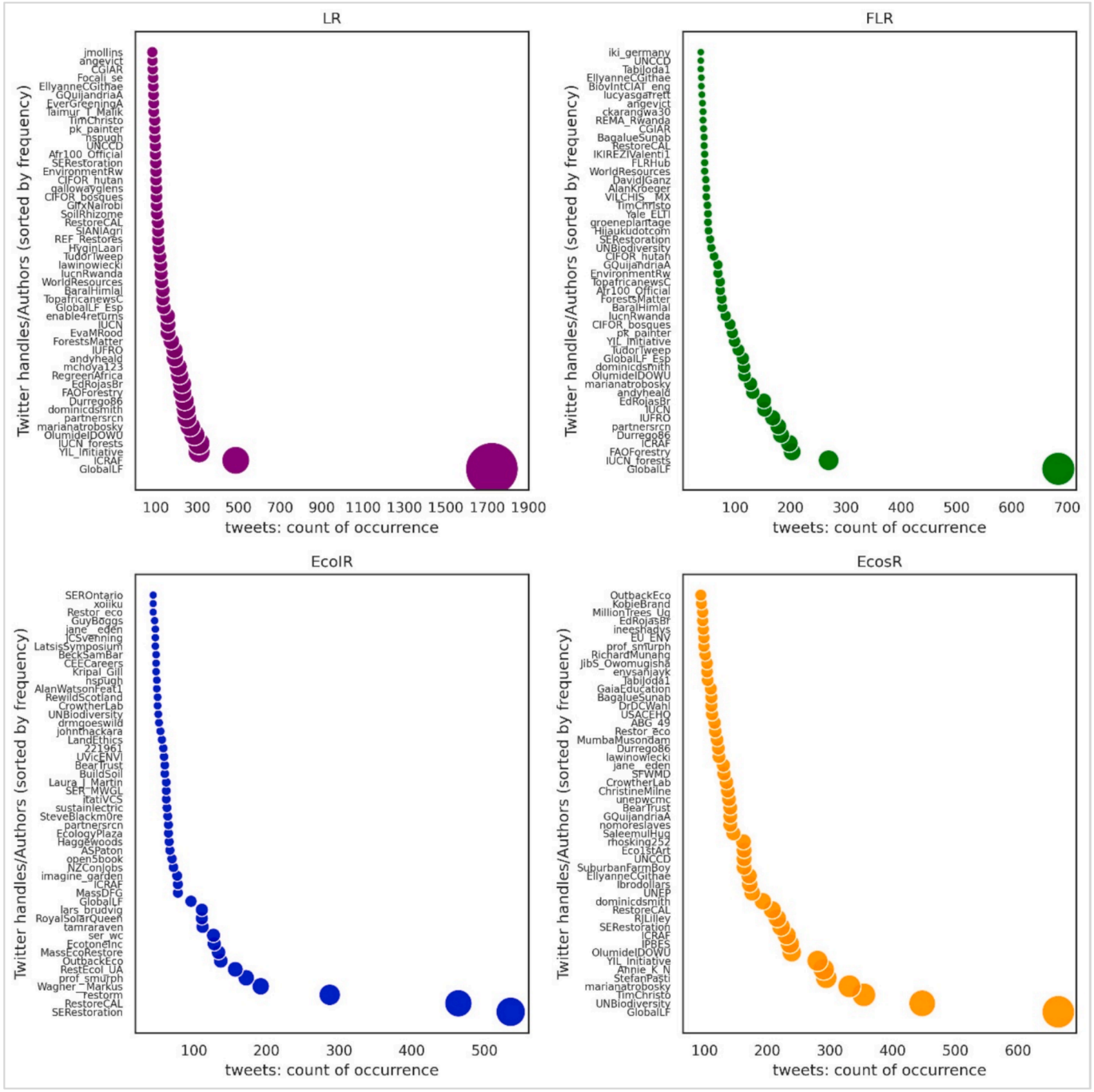

Fig. 5. Top 50 of Tweeters promoting restoration over 2015–2022 time period (distinguished by the main discursive terms used).

making process to understand the discursive language(s) embodied in the tweet sets, we summarize the messages carried out in each of the top 12 topics of each of the four restoration terms (Table 1).

Finally, we illustrate in Fig. 7, as an example, the word clouds of the actual tweets belonging to each of the 12 topics of ecosystem restoration communications (see appendix Figures I, K, M for the other three restoration terms tweet sets). We sought to gather additional insights for the broader discourses. As the tweets were assigned back to each topic as part of the topic modeling approach, the tweets world clouds offer us a chance to grasp potentially unique but hidden, and/or prominent but missed terms in the topic model visualization. Such a process helps to consolidate our sense making of the topics.

3.3. *Diversity of restoration discourses*

The analysis reveals a wide diversity of ideas at play in contemporary restoration discourses. Across each of the terms we find evidence of distinct and often highly divergent framings, with substantial overlap between the four restoration terms.

3.3.1. *Ecosystem Restoration*

For tweets using the term "ecosystem restoration", making the biggest group of the tweet sets, the focus is dominated by the UN Decade of Ecosystem Restoration (UN-DER), which seems to have propelled this term to the center stage (see Figs. 6, 7, and Table 1). Overall, there is an indication that "ecosystem restoration" has become an overarching way of framing global environmental action, with a particular policy-

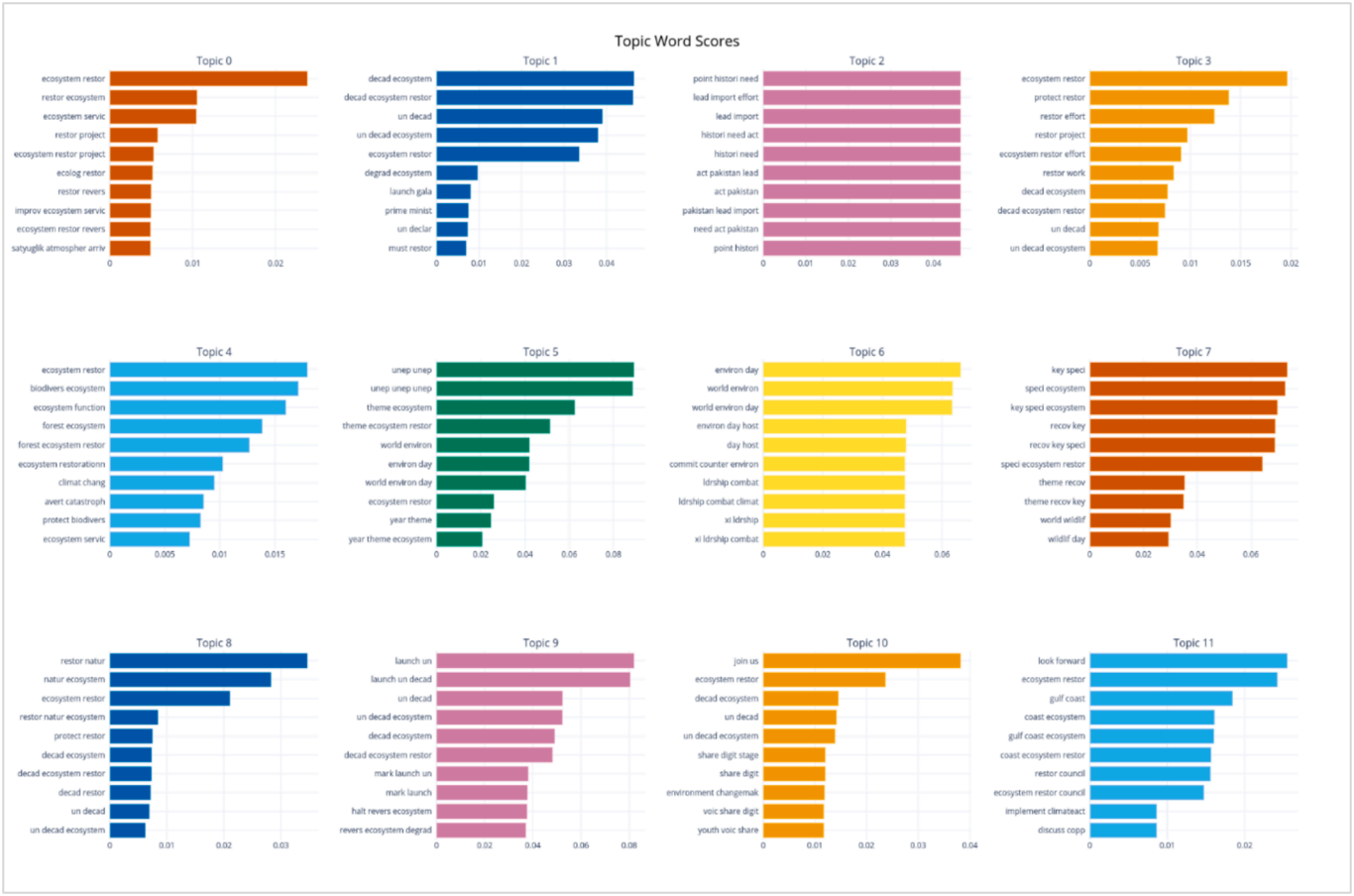

Fig. 6. Top 12 discursive topics forming the discourses for *ecosystem restoration* tweets, with display of the 10-most relevant topic-terms.

oriented focus. Many international agencies/institutions have significantly embraced the term as key to their agenda. Equally significant is that the related tweets and the rhetoric they carry have been extensively retweeted, suggesting that these ideas have resonance to the general public, and have become central to environmental policy discourse at a broad global scale.

More concretely, our analysis shows that many topics have placed "ecosystem restoration" as an overarching signifier to advertise a broad policy agenda and harness political appeal around the UN-DER. Notably, the discourses seem to imply a global focus with political will and engagement, giving a view of ecosystem restoration as an eminently global policy agenda. Aside from its overarching references to the UN-DER, there is a variety of references to popular institutional events used for promotion and momentum building, key global and national actors, and specific examples of restoration implementation. Illustrations include the "launch gala event with Prime Minister" of the UN-DER (topics 1 & 9), the World Wildlife Day (topic 7), World Environmental Day and UNEP (topic 5 & 6), Pakistan as a country showing leadership in action, likely from its Billion Tree Tsunami and restoration of chilgoza pine forests[3] (topic 2), and restoration interventions in the Gulf Coast (topic 11). Moreover, some discourses frequently invoke a sense of urgency, implying a vision of the global policy community to heroically come together to counter and halt environmental degradation. For instance, topic 4 appeals to the public to "avert catastrophe", while topic 2 emphasizes a "historic" dimension and need to act. Despite seemingly targeting a general global public audience, a few discourses appeal specifically to the youth to get involved (topic 10). Besides, while topics under this term tend to be framed around large themes of global interest; the term "ecosystem" is prominent with focus directed toward ecological factors or processes. Topic 0 includes references to "ecosystem services", topic 4 invokes the need to "protect biodiversity" and fight "climate change", topic 7 emphasizes "key species recovery", and topic 8 emphasizes "natural ecosystems".

Yet, our analysis reveals that topics under the term ecosystem restoration give only limited attention to how restoration is to be achieved, and through what means. They frequently reference "projects" (topic 3), suggesting that the current global policy focus has placed emphasis on actionable interventions planned and executed by different actors. Also, except for some individual tweets that emphasize human dimensions, the topics as a whole pay limited attention to potential people-ecosystem interactions or different social dimensions. There is no specific attention to human drivers of degradation, or of broader societal transformations that may be needed to address this degradation before it happens.

3.3.2. *Ecological Restoration*

Discourses stemming from tweets using the term "ecological restoration", the next largest group within our data, appear to mainly frame restoration as an ecological scientific endeavor. Like ecosystem restoration, they pay limited attention to societal drivers of degradation. Yet, the valence of ecological restoration discourses is different. The topics tend to focus less on large global initiatives and emotional appeals for urgent action, and instead tend to emphasize context-specific ecological interventions, particularly in the Global North. Similarly, large global

[3] https://www.iucn.org/news/forests/201708/pakistan%E2%80%99s-billion-tree-tsunami-restores-350000-hectares-forests-and-degraded-land-surpass-bonn-challenge-commitment || https://www.iucn.org/news/restoration-initiative/202111/restoration-initiative-a-pakistan-story.

Table 1
Explanation of the messages carried in the top 12 discursive topics by restoration terms.

Framings Topics #	Ecosystem restoration (EcosR)	Ecological restoration (EcolR)	Landscape restoration (LR)	Forest and landscape restoration (FLR)
0	Improving ecosystem services through restoration projects as restoration benefits	Making the case for "large-scale" ecological restoration as the scope of action	Calls that it is "high time" to make a change, with an emphasis on curbing pollution and change lifestyles	The IUCN as a key actor advocating for FLR; calls that it is "high time" for action
1	The UN Decade of Ecosystem Restoration, launch gala event with prime minister (s) as spurring political will and building political capital	Context-specific project and efforts for ecological restoration: Example of recovering marine biodiversity in Cape Sicié in France.	Example of European landscape restoration project (river restoration)	CIFOR as a key actor, a focus on FLR through "initiatives" and "efforts" to address climate change
2	Historical dimension & urgent need to act; Pakistan – hosting the event and moment of actions being linked to restoration	Making the case for ecological restoration of rainforest Wistman's woodland in Dartmoor England with Neil Burnell photographs	Emphasis on habitat and landscape-scale restoration, habitat restoration, job creation to reduce poverty	Restoration as a key strategy to address deforestation and land degradation
3	Protection and restoration through planned interventions, with a focus on "projects", "work", and "efforts" under the UN Decade	Conference on ecological restoration, Society of Ecological Restoration, Cape Town, South Africa	Rewilding and habitat restoration project in Scotland (Carrifran) as a key example	Calls to restore "millions" of hectares of degraded lands; Africa as a key target of intervention
4	Environmental benefits of restoration with a sense of urgency: to "avert catastrophe" for climate change, biodiversity, and ecosystem services	Ecosystem restoration to restore ecological equilibrium	Objective of LR/FLR: addressing land degradation, broadly speaking, and forests more specifically	FLR as a means to protect against extreme weather events, and to promote sustainable livelihoods
5	Promoting restoration on World Environment Day by UNEP as a key institutional actor	Ecological restoration projects and tree planting; ecological restoration alliance with botanical garden; book "Wild by design"	Achieve climate change mitigation and water-energy-food security with LR/FLR	Landscape scale / large scale restoration / restoration at scale, with a particular focus on forests
6	World Environment Day and emphasis on "leadership" to counter environmental degradation and "combat" climate change	Example of ecological restoration with afforestation projects in Sohra, Meghalaya, India	"Landscape scale" restoration in the UK; focus on wildlife	Worldwide scope of intervention; Point that two billion hectares world-wide could benefit from FLR
7	Emphasis on recovery of key (wildlife) species on World Wildlife Day	Calls to "join" restoration efforts; Pennypack ecological restoration trust; use of isotope analysis in ecological restoration	Landscape art as a means to restore mining landscapes, former open cast coal	Key actor (IUCN) stressing FLR as playing "crucial role" for mitigating climate change and deforestation
8	Calls to protect and restore "natural ecosystems" under the UN Decade	Agroecology practices as restoration intervention to support livelihoods and farmer income generation while fighting climate change	Example of a historic, landmark British LR project as illustration of restoration intervention	FLR as "key" Nature-based solution (NbS); language of health
9	Launch of the UN Decade to halt and reverse ecosystem degradation	Invasive species; Job advertisement in relation to ecological restoration work/research	Calls to advertise a conference on LR in Kenya	FLR intersect with the UNDER/ ecosystem restoration; restoration scientist; knowledge dissemination
10	Calls to "join" efforts through digital media; an invitation to youth as environmental changemakers	Making the case for restoration of eradicated British rainforests and national parks using Neil Burnell photographs	LR/FLR: tree planting as a key restoration activity	Tree planting as a key FLR restoration activity
11	Restoration implementation coastal ecosystems (and the Gulf Coast in particular); a restoration council implementing climate action	A highly publicized paper for prioritizing restoration interventions (Strassburg et al in *Nature*); critique responses that it ignored people in landscapes	Launch of UNDER in Latin America and linking LR and ecological restoration	Reference to restoration case studies that show financial and food security benefits

policy agencies are less prominent, and language of "projects" is far less common – the latter may indicate that restoration is seen as a longer-term process rather than through planned, time-bound interventions (see Table 1 and appendix Figures H & I).

Specifically, our analysis reveals that the collection of discourses using the term ecological restoration center on the ecological aspects of specific places with particular emphasis on landscapes in European countries and North America. For instance, some discourses very often focus on specific contexts and cases: marine biodiversity in Cape Sicié in France (topic 1), Wistman's woodland in Dartmoor England (topic 2), and projects in Meghalaya, India (topic 6), among others. This indicates that certain cases have gained particular attention as notable examples

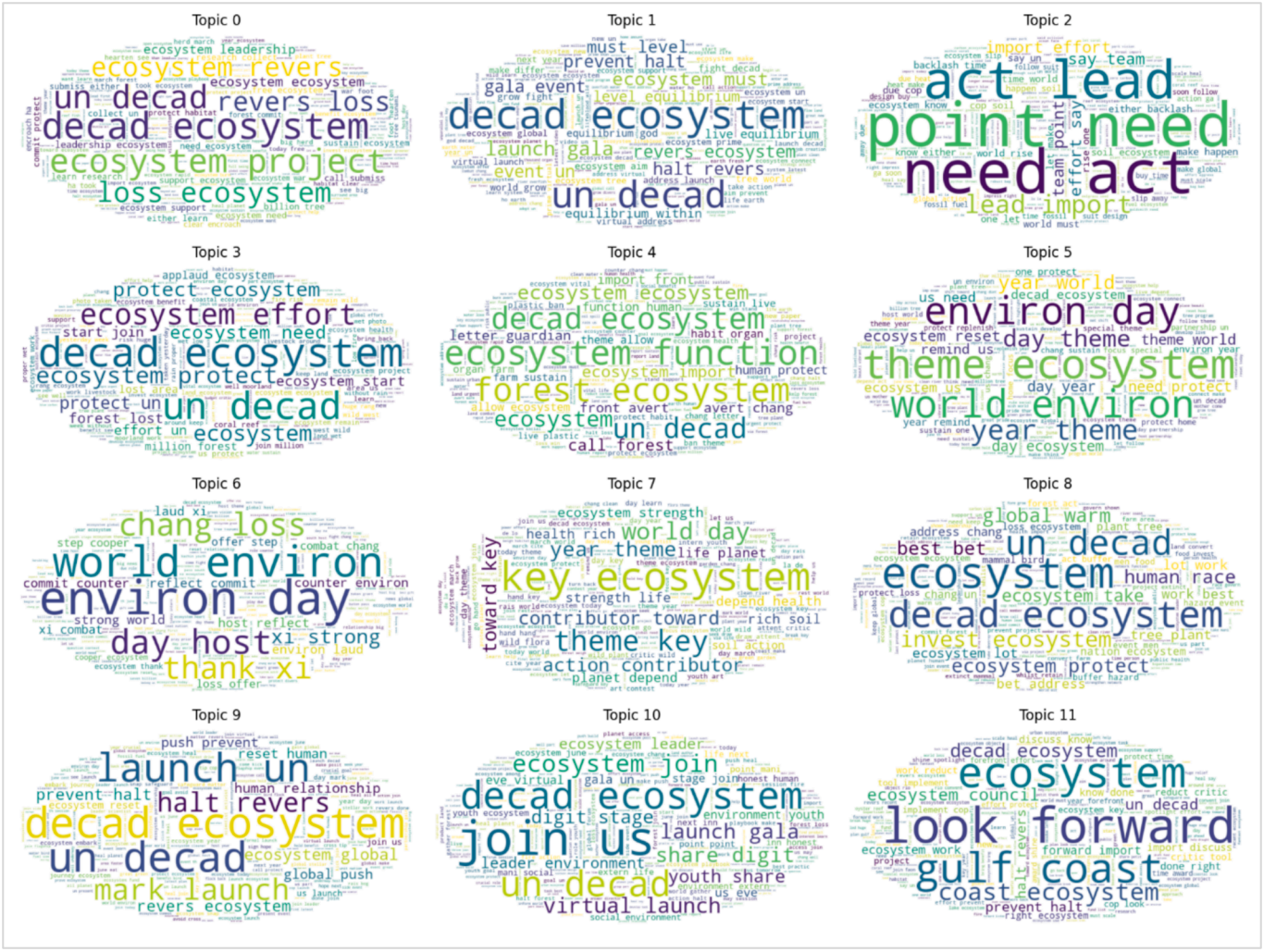

Fig. 7. Tweet word clouds for the top 12 topics of *ecosystem restoration* in Twitter communications.

within the Twittersphere and beside the Indian case, both topics 2 and 10 reference the demonstrative appeal of nature photographs within iconic British landscapes and habitats. In addition, most discourses point toward a vision of restoration that aims to protect the aesthetic value of certain culturally important landscapes from human productive uses. Some topics offer a few clues of what vision of nature is considered as part of restoration, yet without clarity on what scope and types of interventions are envisaged. There are references to "ecological equilibrium" (topic 4), the need to control invasive species (topic 9), and the need for "large-scale" interventions (topic 0). There was also a focus on agroecology, an alternative model for agriculture as restoration intervention (topic 8). Overall, this implies that such discourses envision some alternative human-environment relationships as well as financial and human well-being benefits that may arise in so doing. Furthermore, other discourses highlight particular forms of expertise which are rooted in the ecological sciences, notably emphasizing scientific & practitioner communities with a particular ecological focus. For example, topic 3 references the "Society of Ecological Restoration" (SER) and its conference in South Africa in particular, topic 5 references the Ecological Restoration Alliance, topic 7 references the Pennyback Ecological Restoration Trust in the US, and topics 5 and 9 hint at scientific books and job advertisements. Also highlighting research publications on ecological restoration, topic 11 contains language debating a widely contested scientific paper, pointing to its limited attention of people living in landscapes targeted to be restored. In terms of connection with the other terms, ecosystem restoration is itself mentioned within topic 4, while languages of "projects" and "tree planting" appear in topic 5.

3.3.3. *Landscape Restoration*

Discourses formed around the term "landscape restoration", the third largest in our tweet set, frame restoration in ways that are similar to the previous two terms—ecosystem restoration and ecological restoration—yet distinct in substantial respects. Notably, these discourses present a vision of restoration that emphasizes the need to support both ecological outcomes and human well-being (see Table 1 and appendix Figures J & K). In contrast to ecological restoration discourses, landscape restoration discourses appear to provide a more integrative view of human and environmental processes with greater attention to human needs. They also gesture to human drivers of environmental degradation such as consumption processes. While embracing some of the language of ecosystem restoration, these discourse constructions emphasize diverse needs at the landscape level and focus less on advertising large scale global initiatives.

For example, our analysis uncovers that some discourses emphasize broader landscapes, including their human presence. Notably, topic 0 emphasizes the need for "lifestyle change" and to "curb pollution", remaining the only topic to explicitly address issues of consumption within the broader tweet set. Also, some discourses seem to provide greater attention to human needs by generally referring to overarching terms. For example, there is substantial attention to human dimensions with references to opportunities to address poverty and insecurity (topic 2), to create jobs (also topic 2), and to ensure food production, energy

supply, and water security (topic 5). Besides, other discourses allude to an array of landscape types, often across larger geographic territories (landscape-scale) and/or with an extensive human footprint. This includes, for example, references to interventions to restore "Europe's largest river" (topic 1), "rewilding" and habitat revitalization in Scotland (topic 3), landmark restoration at scale in Herne Bay, Kent (topic 6), and mine reclamation (topic 7). This diversity seems to suggest a framing that moves beyond a focus on specific valued patches of land to a focus on broader landscapes that they are embedded within. Attention is also given to species & their habitats (topics 3 and 6). Despite this diversity, forests remain prominent as an objective of intervention in the topics.

Furthermore, discursive connections to the other terms appear through language references to ecosystem restoration, the UN-DER, ecological restoration, and forest landscape restoration. Some of the topics contain emotional appeals similar to ecosystem restoration, for example calling for action such as "high time for change" (topic 0), invitations to "join us" (topic 9), and emphasizing an "historic" opportunity act (topic 8). While some of the discourses emphasize Global North contexts, especially related to the UK (topics 3, 6, & 8) similar to ecological restoration, these discourses also contain reference to Kenya hosting a related conference (topic 9) and Latin America's launch of the UN-DER (topic 11). Topic 4 hints at addressing degradation drivers as objectives while topic 10 references tree planting. Interestingly, topic 7 emphasizes landscape art as a process to reclaim mines, alluding to opportunities for supporting alternative social and cultural benefits out of previously degraded landscapes.

3.3.4. Forest Landscape Restoration Discourses

Discourses constructed around the term "forest landscape restoration", the smallest in terms of related tweet set, also embrace a framing of restoration similar to the one seen with the term landscape restoration, emphasizing both ecological and human dimensions. The discourses gesture toward human drivers of environmental degradation and broader forested landscapes as a prominent focus, similar to landscape restoration discourses (see Table 1 and appendix Figures L & M). Like ecosystem restoration discourses, forest landscape restoration discourses exhibit a distinct policy-oriented focus, and includes key institutional actors associated with the Bonn Challenge. Yet, in contrast to ecological restoration, the relationship with ecological processes is not well developed.

More concretely, our analysis reveals that some forest landscape restoration discourses appear to define restoration especially in relation to ideas of "degradation", albeit not specifically spelled out (i.e. topics 2 & 3). There is some reference to deforestation reduction as potential environmental outcomes (topic 7). Also, the discourses feature prominent global actors especially IUCN (which hosted the Bonn Challenge, topic 0) and CIFOR (a CGIAR center, topic 1). Yet, unlike ecosystem restoration, these discourses have less of a focus on popular, institutional events and global agencies/institutions. Moreover, other discourses often framed restoration in terms of initiatives/means to address large-scale global challenges, including climate change and other extreme weather events (topics 1 and 4). Indeed, multiple topics invoke claims of large-scale, global action with a frequent focus on aggregate targets, including millions of hectares (topic 3) or even billion hectares as magnitude of opportunities globally (topic 6). There is an allusion to tree planting (topic 10), but otherwise the means through which restoration is to take place are not well developed. However, there is at least some focus on learning and sharing of success (topic 9), denoting that some view restoration less as applying existing science and more as a process of learning how to do it better in practice. Besides, forest landscape restoration discourses do seem to have a regional focus: Africa (topic 3) and broadly the Global South. There is reference to people and their needs (topics 4, 11) and such human needs and benefits are framed in relation to sustainable rural livelihoods (topic 4) and as a means to support financial and food security as social outcomes (topic 11). Topic 8 references both health and economic protection. Thus, in contrast to ecological restoration discourses, which gives emotional appeal to aesthetic and cultural values (especially in the Global North), forest landscape restoration discourses are framed much more as a means to support basic needs among rural populations in the Global South.

Other discursive intersections with the three previous terms analyzed are apparent, including notably with ecosystem restoration and landscape restoration – both of which are referenced in the topics. Similar to landscape restoration, there is a focus on "landscape-scale" as large territories for large scale restoration (topic 5). Like ecosystem restoration, these discourses have a decidedly policy-oriented flavor, with emotional appeals such as "it is high time" to act (topic 0) and the "crucial role" that restoration can play in advancing sustainability objectives of climate change mitigation and deforestation (topic 7). The discourses reference the UN-DER and they also draw upon other terminologies common in restoration debates such as for example Nature-based climate solutions (topic 8).

3.3.5. Commonalities and uniqueness of discourses across the four restoration terminologies

Overall, we find that some discourses are common across the restoration terms, while others are unique (Fig. 8).

On commonalities, all four restoration terminologies share the discourses that articulate the scope and magnitude of actions needed for restoration; in general, restoration is seen as a large-scale endeavor. The use of emotive language to appeal to urgent action is also common. Overall, the terms also tend to frame objectives of restoration as halting and reverting degradation and deforestation in degraded landscapes. The four restoration terms also share a range of discourses that focus on the expected environmental benefits and outcomes of restoration, including mitigation of climate change, biodiversity conservation, and supporting other ecosystem services.

The restoration terminologies FLR, LR, and EcolR share three themes in common: an emphasis on social benefits (sustainable livelihoods, job creation, income generation, and co-benefits for poverty reduction and water-energy-food security); language on forests & tree planting interventions; and advertisements about restoration projects and related efforts. Moreover, EcosR, EcolR, and LR framings share discourses that elevate the expected ecological benefits and outcomes of restoration as well as discourses that tend to articulate the perspectives or views that should shape the implementation of the UN-DER. Besides, EcosR, EcolR, and FLR framing feature common discourses that refer to the institutional actors pushing for each framing – UNEP for EcosR, SER for EcolR, and IUCN and CIFOR for FLR.

We also observe shared discourses between diverse pairs of restoration terminologies, including EcosR and FLR; EcolR and LR; LR and FLR; and EcosR and EcolR. One such shared discourse refers to the geographies that are associated with the uses of the terms. For instance, LR and FLR discourses refer to Africa, EcolR and LR discourses tend to refer to restoration in Europe and the US, EcosR and EcolR discourses are part of discourses coming from Asia although the use of EcosR is global in scope. Another emphasis shared only by LR and EcolR is the one featuring adverts and promotional messages on conferences, research activities, publications, and job positions.

Regarding the unique features, we note for instance two discourses exclusively tied to EcosR and FLR – one that makes appeal to intergenerational dimension, with a focus on the youth, as observed with EcosR discourses only and one that makes strategic positioning statement such as branding restoration as a nature-based solution/natural climate solution (NbS/NCS) as observed in FLR discourses.

5. Discussion

Our findings on restoration discussions in Twitter between 2015 and 2022 point to a few elements, including implications for restoration policy, which are worth discussing following the four main questions

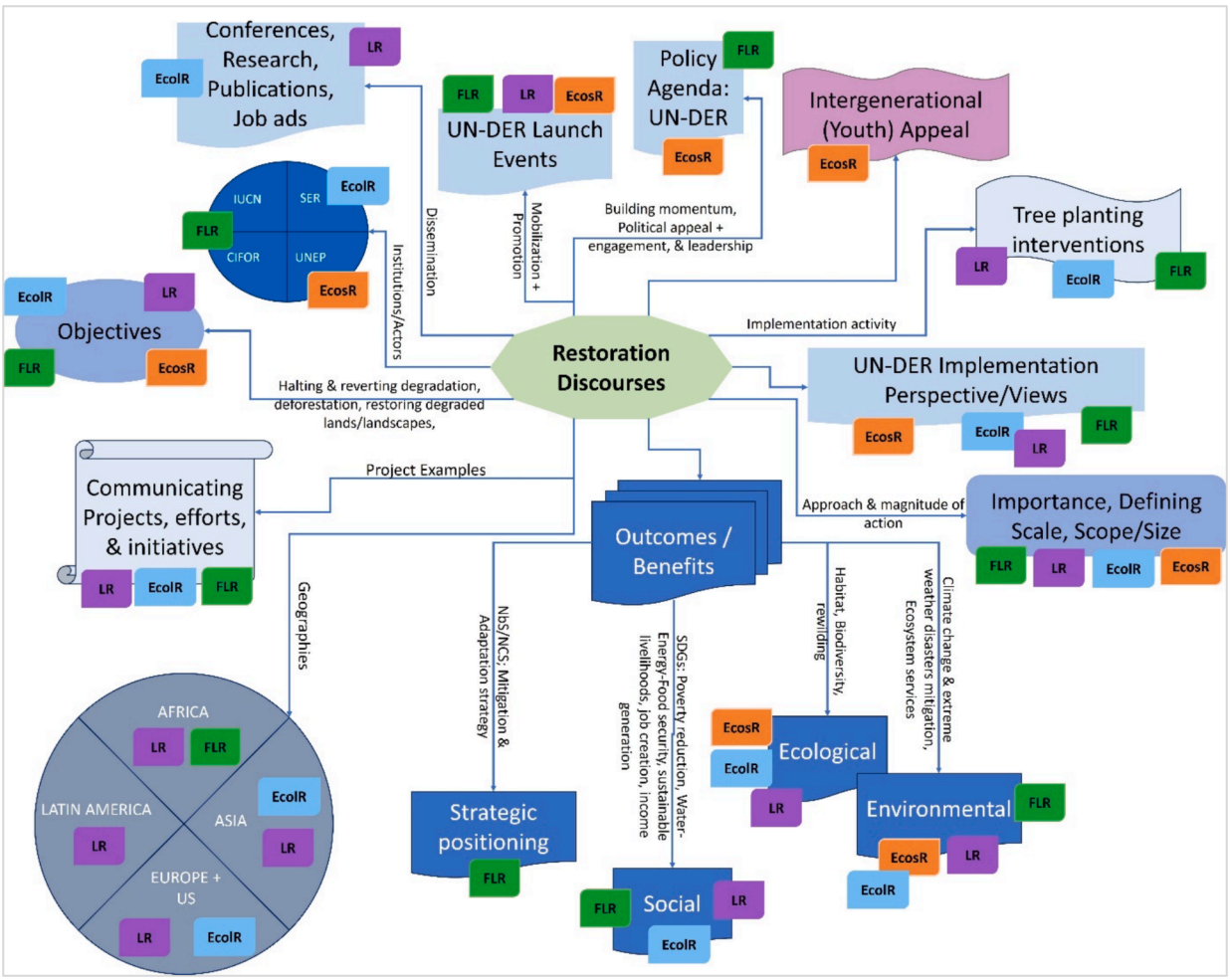

Fig. 8. Themes in restoration discourses in Twitter communications from 2015 to 2022, showing commonalities and differences across the four restoration terms Note: LR = landscape restoration; FLR = forest (and) landscape restoration; EcolR = ecological restoration; and EcosR = ecosystem restoration.

that drive our discourse analysis.

Ecological and human-centered discourses, with overlooked risks. Our findings indicate that restoration discourses focus strongly on ecological outcomes and processes, and they often use ecological concepts to describe objectives – answering our inquiry about the end goals pursed with restoration. Yet, there seems to be some clear divergence in how ecological and environmental dimensions are presented and understood, showing diversified views and values. There are frequent but varying references to climate change, ecosystem functionality, and biodiversity. These emphases also suggest that, from policy, science, to practice, restoration has received more attention from the natural sciences (Di Sacco et al., 2021; ITTO, 2020; Lewis et al., 2019; Bernal et al., 2018; Griscom et al., 2017; Stanturf et al., 2017; Aronson and Alexander, 2013).

The discourses do include some explicit references to human outcomes and well-being. Still, these references are comparatively underdeveloped within the broader tweet sets and are rather specific to some restoration terms. Our findings suggest that discourses around the terms *landscape restoration* and *forest landscape restoration* terms tend to focus more on human outcomes, at least overall, but discourses formed around *ecosystem restoration* and *ecological restoration* tend to emphasize ecological and environmental aspects. This evidence substantiates the suggestion that there is an overall lack of considerations of social dimensions in restoration discussions today, as several scholars have argued (Elias et al., 2021a;Elias et al., 2021b; Löfqvist et al., 2023). This is important to mention for three reasons. First, restoration interventions are presently targeting landscapes globally where millions of rural and indigenous people live (Erbaugh et al., 2020; Fleischman et al., 2022; Schultz et al., 2022). Second, there is a broad consensus that restoration should provide human benefits (Chazdon and Brancalion, 2019; Erbaugh and Oldekop, 2018; Besseau et al., 2018). Third, there is very explicit recognition of the need to protect local and indigenous rights in alike nature/land-based strategies to contemporary environmental challenges (e.g. Woodhouse et al., 2022; Dawson et al., 2021; Besseau et al., 2018; Glasgow Declaration on Forests). A failure to engage with social dimensions of restoration risks overlooking societal processes that may influence both success and failure of ecological outcomes; it also risks overlooking local, rural resource users' needs, potentially coming into conflict with existing resources use practices and livelihoods (Djoudi et al., 2024).

Additional risks are further overlooked as our findings indicate that not a single topic from our analysis acknowledges potential negative outcomes from restoration. This contrasts with academic literature which has drawn attention to the risk of conversion of natural forests to monoculture (Di Sacco et al., 2021; Nunes et al., 2020; Brancalion and Chazdon, 2017), reforestation of grassland ecosystems/biomes (Klaus, 2023; Bond et al., 2019), or debates surrounding (assisted) natural regeneration versus active planting (Lewis et al., 2019; Chazdon and Uriarte, 2016; Chazdon and Guariguata, 2016). Also, extensive work has drawn attention to the risk of injustice such as the undermined ability of rural and indigenous people to access key resources for their livelihoods (Woodhouse et al., 2022, Schultz et al. 2021). There is also far less attention to the diverse actors that may carry out restoration at the local level. There is little attention, for example, to bureaucracies, civil

society, and communities experiencing restoration interventions on the ground. Moreover, there is almost no talk of tradeoffs despite extensive scientific attention to the likelihood of tradeoffs between different ecosystem benefits in many contexts (Fischer et al., 2021; Hua et al., 2022). Furthermore, governance and institutional dimensions have received little attention. There are limited discussions of rights, tenure, or local participation, despite established understandings of the importance of such elements to determine restoration successes (Fischer et al., 2023; Govindarajulu et al., 2023; Rakotonarivo et al., 2023; van Oosten et al., 2014; van Oosten, 2013). Also missing in the discussions are institutional arrangements around issues of scale, power, and sectoral integration to support implementation of landscape-scale restoration (Wiegant et al., 2022a; Wiegant et al., 2022b; Djenontin and Zulu, 2021; Mansourian et al., 2020; Reed et al., 2016; Reed et al., 2020; Djenontin et al., 2018).

Diverse perspectives on restoration. To the question about the understanding of nature, human, and/or human-environment relationships in restoration, our findings point toward a diversity of scientific perspectives at work in contemporary debates, which are rooted in disciplinary background and help to explain the differing objectives of restoration described above. The diversity in perspectives is exemplified especially by the differences between *ecological restoration* and *landscape restoration* (also *forest landscape restoration*). Whereas *ecological restoration* tends to focus especially on ecological restoration of specific "natural" landscapes or ecosystems, *landscape restoration* and *forest landscape restoration* focus on restoration across a diversity of land use types that make up broader landscapes or ecosystems. *Ecological restoration* more often references concepts from the ecological sciences, while *landscape restoration* and *forest landscape restoration* tend to echo ideas often used as a part of a "landscape approach" to environmental governance (Sayer et al., 2013; Reed et al., 2016; Erbaugh and Agrawal, 2017). The difference in policy implications is stark. Whereas *ecological restoration* lends itself toward protection and restoration of specific (intact) landscape patches perceived to be of particular value, *landscape restoration* and *forest landscape restoration* is trained much more to different human processes and needs. These two restoration terms feature discursive topics that explicitly acknowledge drivers of degradation, for example, and reference a range of human needs – poverty, food, energy, and others. Indeed, people often mean very different things when they speak of restoration (Reinecke and Blum, 2018; Chazdon and Laestadius, 2016).

Moreover, our findings suggest that ideals of restoration are being applied to a variety of biomes, with references to forests as dominant terrestrial "landscapes" more broadly, and marine ecosystems to a lesser extent. However, disparate normative views of restoration – and ideas of nature more broadly – are discussed among different actors and policy communities. This suggests that people may think that they all mean the same thing when referring to restoration, but actually they do not. Such a situation risks making restoration policy an "empty signifier" – an idea that can contain almost anything or everything. Still, findings that some discourses are common across certain restoration terms implies some points of unification despite carrying different perspectives – potentially rendering restoration as a boundary concept bridging disparate scientific, policy, and practitioner communities.

Restoration as planned projects and interventions but less quick fixes. Our findings also offer answers to our question of how restoration is understood to happen, suggesting that restoration continues to be a primarily top-down effort, driven by priorities of governments and large institutional actors, rather than an organic upswell of action and initiative of local actors. Indeed, restoration discourses exhibit an overwhelming emphasis on planned policy action. Our findings show that the discourses give a clear picture that restoration is understood and practiced primarily through "projects" and interventions. These discussions imply that many people continue to view restoration as an activity to be done to particular places, rather something to be achieved through transforming the nature of human-environmental systems more broadly. Given the environmental challenges of the present, many topics also invoke a sense of urgency with appeals for quick action. Such appeals may have supported the rise of quick fix interventions as we found in some discourses, notably tree planting, which suggest that this has been elevated as a form of restoration action in some tweets, especially from FLR, LR, and to some extent EcolR terms. This finding confirms arguments that mass-tree planting endeavors have become an appealing restoration intervention given the potential for numerous ecological and social benefits, including climate change mitigation, biodiversity recovery, as well as social, livelihoods benefits (Holl and Brancalion 2020; Martin et al., 2021; Mensah et al., 2024). Both reforestation, understood as planting new trees or regenerating existing trees in formerly degraded forests, and afforestation involving intentional tree planting outside of forest areas are variously advocated for restoration (Brancalion and Holl, 2020; Holl and Brancalion, 2022). However, we note that restoration discussions on tree planting are contained within just a few topics overall, thereby contrasting several leading contemporary tree-planting drives (e.g. Trillion Trees Initiative, Lippke et al., 2021), and related discussions on risks and opportunities (Veldman et al., 2019; Fleischman et al., 2020; Pritchard, 2021; Steven and Bond, 2023). We were surprised that tree planting initiatives were not especially prominent in the tweet sets (although we suspect that some efforts may have involved planting trees in one way or another – see Parr et al., 2024 and subsequent responses). This suggests that, at least in policy discussions, restoration is overall conceived as broader than target-based planting. Restoration discussions seem to be far more diverse than headline-generating tree planting schemes, comprising a diversity of actions in a wide range of land cover types. Comparing evidence on the ground with discourses in digital spheres can be a further research endeavor.

Actors of restoration discourses. To our last analytical question of who are driving the restoration agenda and/or its implementation, our findings suggest frequent references to international institutions. We note that tweets using the terms *ecological restoration* and *forest landscape restoration* identify a wide range of institutions and professional societies that are active in restoration discussions today. These tweets can be viewed as strategies used by these institutional actors to build momentum for restoration agendas. Our findings provide further glimpses into these key institutional actors (e.g. UNEP, SER, IUCN, CIFOR), which are arguably instrumental in shaping restoration agenda and actions, from the global level, regional geographies, and nation states. Yet it is also clear that the institutions mentioned have much to gain through popular recognition and appeal through these references. It is indeed striking that so many institutions use terms associated with restoration to frame their agendas, underscoring its central place in environmental discourses today. Unpacking further those digital actors of restoration and their network associated to each restoration term could offer additional insights into the different powers at stake.

Overall, the research expands our knowledge on the digital construction of discourses on restoration as a contemporary environmental policy, while expanding methodological possibilities for discourse analysis in critical environmental governance studies (Sharp and Richardson, 2001; Neumann, 2004). Mapping out prominent and evolving discourses on restoration has helped to identify different understandings of restoration and what is being pursued under restoration policy. Digital discourses can put forward ideological values and norms of a few powerful actors and institutions, which can then drive and shape the types of actions advanced and research orientations, including the types of knowledge produced and disseminated (Meinherz et al., 2020; Lunstrum, 2014).

6. Conclusion

This study sets out to understand the diversity of restoration digital discourses on social media and their nuances in order to tease out potential implications of restoration policies for people and the environment. We ground the question about the nature of discourses of digital

restoration communications in Twitter spheres in a critical social media discourse analysis approach operationalized with machine-learning powered text analysis techniques coupled with content analyses and visualizations.

We found that restoration thinking has been ascendant and growing, as shown by the number of tweets and their extensive retweets, and has become a defining aspect of environmental policy. Restoration encompasses a variety of ideas and objectives and mobilizes substantial popular attention, with several aspects from policy to science and practice discursively conveyed through social media to also legitimate the objective of policy actors. Our work charts its emergence, growth, and global scope as a critical way to frame contemporary land-based strategies for contemporary sustainability needs and goals.

Moreover, we uncover several distinct discursive formations that emerged around restoration, with different dominant topics in restoration tweets connoting not only momentum building but also specific restoration framings and areas of geographical focus. On one hand, the discourses are predominantly focused on advertising, mobilizing impetus, harnessing political capital, and posing legitimate acts. Big initiatives such as the UN-DER get a lot of attention, and a few notable institutions ride the wave as part of their discourse and to legitimate themselves. Yet our work also shows that these initiatives raise attention and gain salience from the general public. On the other hand, underneath the highly promotional tones, we do find evidence of different ways of framing. Restoration framings are diverse in views and values/ideologies, varying across different policy and scientific communities. While restoration has become a broad boundary concept, unifying lots of people to get on board, it still does not seem to have a coherent meaning as various perspectives emerged. Our work also implies that the circulation of powerful restoration discourses may legitimate certain restoration interventions, notably the ones that carry technocratic fix ideas such as mass tree planting, although only few discourses uplift them.

Overall, this research has helped to understand dominant discourses underlying restoration terms and their potential implications for restoration policy to achieve balanced, equitable, and just social and ecological benefits. Theoretically, the study has contributed to understanding the political nature of restoration policy on social media, while pointing toward some ways that its various framings may influence implementation on the ground, and their implications for people and the environment. Future work should further investigate the diversity of restoration actors and their linkages to the restoration terms and framings, representations of people in evolving and recent restoration discourses, and how different framings are shaping actual restoration practice globally.

Competing interests: The authors declare no competing interests.

Credit authorship contribution statement

Ida N.S. Djenontin: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Formal analysis, Conceptualization. **Harry W. Fischer:** Writing – review & editing, Writing – original draft, Validation, Formal analysis, Conceptualization. **Junjun Yin:** Writing – review & editing, Visualization, Software, Methodology, Formal analysis, Data curation. **Guangqing Chi:** Writing – review & editing, Resources, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

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Table A1
Summary statistics of the topics generated from the topic modeling.

Restoration terms Topics	Ecosystem Restoration		Ecological Restoration		Landscape Restoration		Forest Landscape Restoration	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
−1	24,117	15.31	15,870	18.20	13,004	18.23	3762	14.75
0	35,949	22.82	48,574	55.70	21,380	29.98	13,168	51.63
1	21,443	13.61	7689	8.82	6567	9.21	2781	10.90
2	11,183	7.10	2002	2.30	5725	8.03	787	3.09
3	10,479	6.65	1970	2.26	3868	5.42	738	2.89
4	8163	5.18	1811	2.08	3151	4.42	616	2.42
5	6515	4.14	1567	1.80	3047	4.27	616	2.42
6	5952	3.78	1080	1.24	2515	3.53	370	1.45
7	5529	3.51	840	0.96	2365	3.32	363	1.42
8	3585	2.28	828	0.95	1893	2.65	291	1.14
9	3386	2.15	759	0.87	1552	2.18	274	1.07
10	2805	1.78	715	0.82	1237	1.73	273	1.07
11	2748	1.74	703	0.81	1135	1.59	264	1.04
12	2580	1.64	620	0.71	1090	1.53	263	1.03
13	2441	1.55	589	0.68	872	1.22	202	0.79
14	2382	1.51	581	0.67	797	1.12	188	0.74
15	2309	1.47	348	0.40	677	0.95	177	0.69
16	2156	1.37	252	0.29	193	0.27	170	0.67

(*continued on next page*)

Table A1 (*continued*)

Restoration terms Topics	Ecosystem Restoration		Ecological Restoration		Landscape Restoration		Forest Landscape Restoration	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
17	2083	1.32	241	0.28	164	0.23	151	0.59
18	1727	1.10	168	0.19	91	0.13	51	0.20
Total n —- All 20 topics	157,532		87,207		71,323		25,505	
Total % —- All topics excl. "-1″		84.7		81.8		81.8		85.3
Total % —- Top 12 topics		74.7		78.6		76.3		80.5

Note: The "Count" is the number of tweets that appear as part of the topic i. The topic marked "-1" represents the set of topics that were too scattered in content to cohesively categorize and represent about 15–18 % of each tweet set.

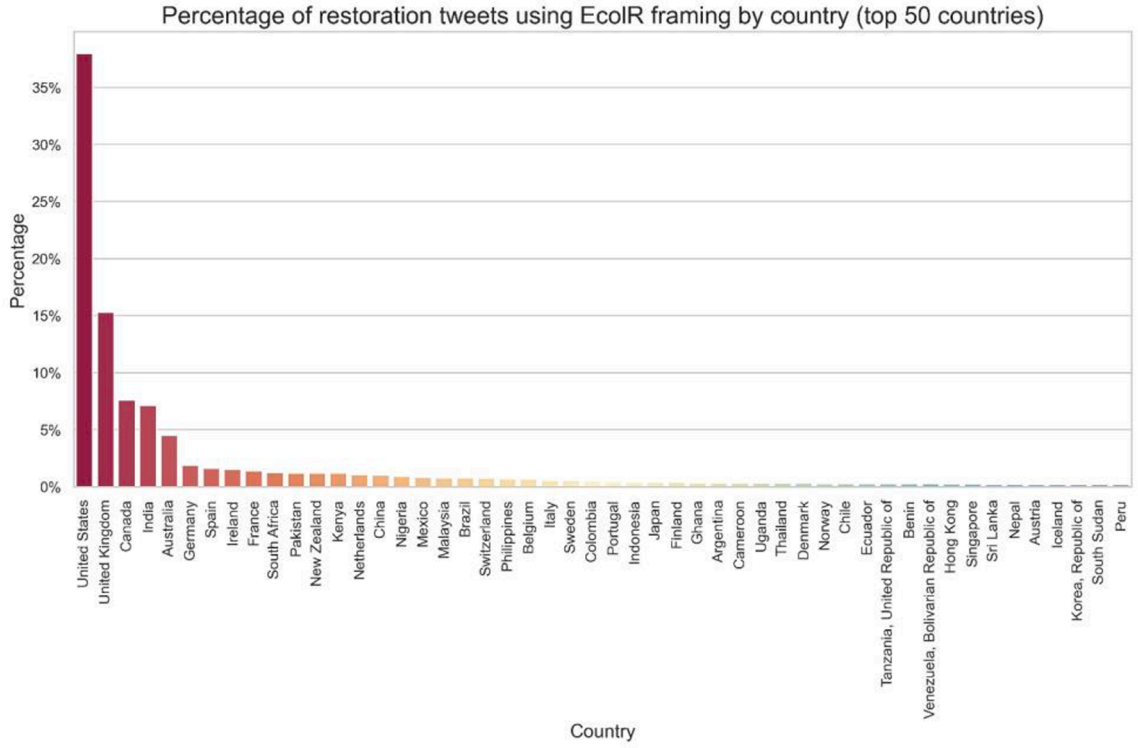

Fig. A. Normalized percentage of restoration-related tweets using *ecological restoration* term by country – showing for the top fifty countries.

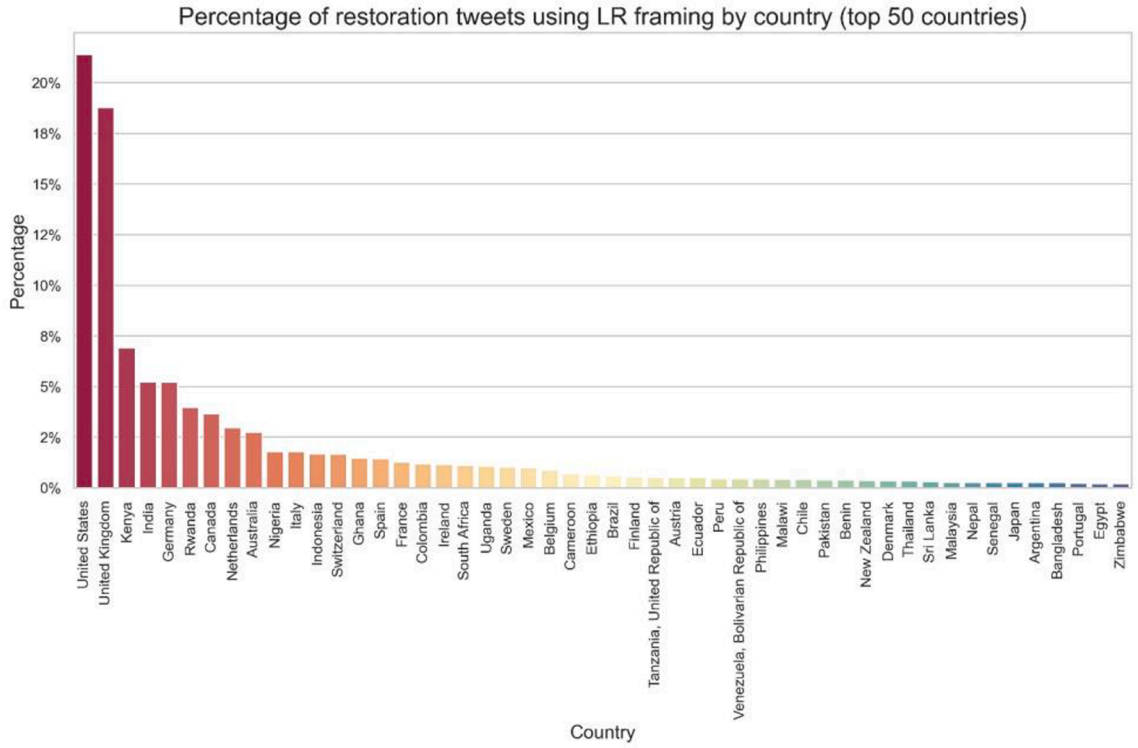

Fig. B. Normalized percentage of restoration-related tweets using *landscape restoration* term by country – showing for the top fifty countries.

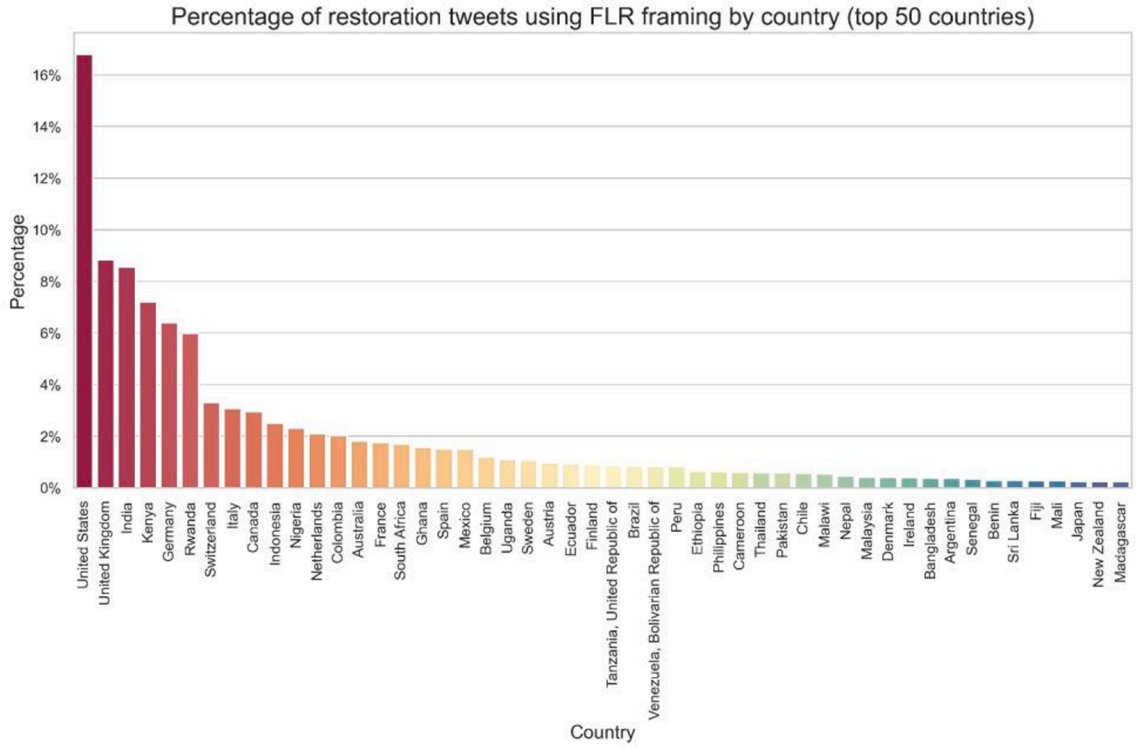

Fig. C. Normalized percentage of restoration-related tweets using *forest landscape restoration* term by country – showing for the top fifty countries.

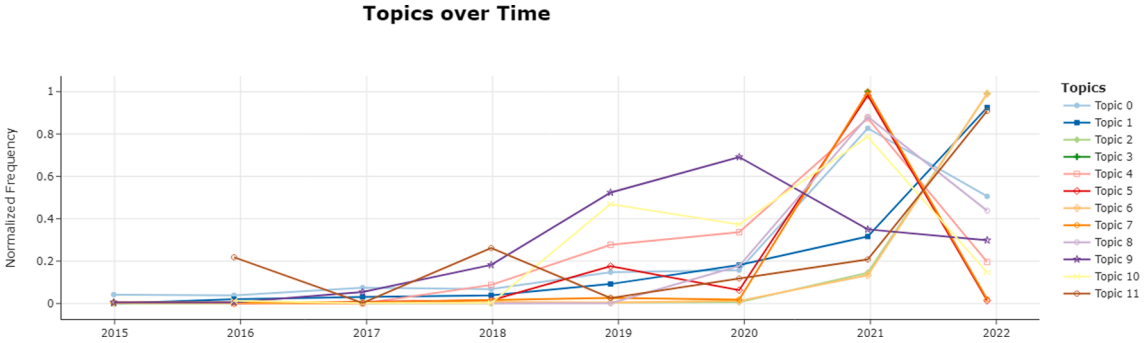

Fig. D. Likelihood of the top 12 discursive topics for *ecosystem restoration* tweets by year Notes: Most of the discursive topics for ecosystem *restoration* tweets were nearly insignificant from 2015 to 2018 (topics 0, 1, 4, 5, and 10), from 2015 to 2019 (topic 8), and from 2015 to 2020 (topics 2, 3, 6, 7) – given their normalized frequency nearing 0. The year 2021 saw a steep rise in prominence of half of the topics (3, 10, 0, 4, 8, 7, 5) with a normalized frequency of 1, which then drop from the spotlight to leave the place to four other topics (2, 6, 1, and 11) to become prominent as well around the year 2022. Topic 9 was the only one with a relative consistency over the 8-year period, rising to the fore with a normalized frequency of 0.7 only around 2020 but decreasing in importance thereafter.

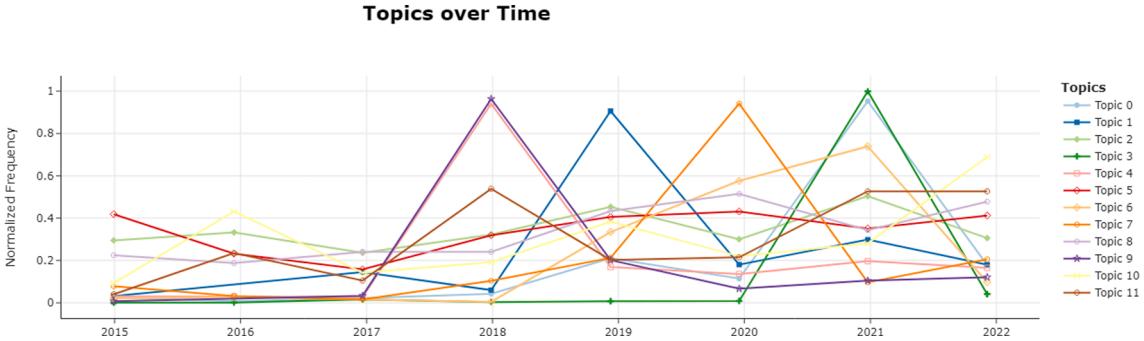

Fig. E. Likelihood of the top 12 discursive topics for *ecological restoration* tweets by year Notes: For *ecological* restoration tweets, a few topics appeared also insignificant in the discourses between 20152017 (topics 0, 4, and 9), between 20152018 (topic 6), and between 20152020 (topic 3). Unlike with ecosystem restoration framing tweets where almost all topics started at 0, many topics were already part of the digital conversations with a normalized frequency of 0.1 (topics 7 and 10) and between 0.20.4 (topics 2, 5, and 8). Each year from 2018 to 2022 exhibits a steep rise in prominence with a normalized frequency of 0.91 followed by a drastic drop with a normalized frequency below 0.2 for specific topics: topics 4 and 9 (2018), topic 1 (2019), topic 7 (2020), topics 0 and 3 (2021). For each of these years, the remaining topics are present in the discussions, albeit with a decreased importance with a normalized frequency between 0.206 in most cases.

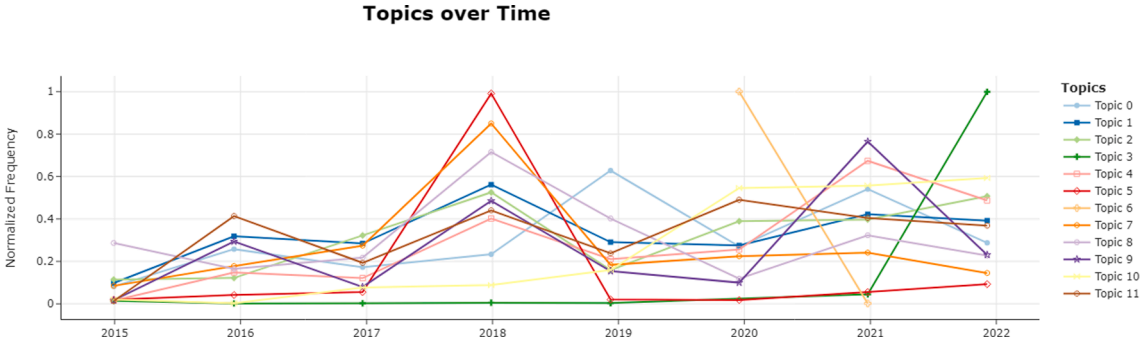

Fig. F. Likelihood of the top 12 discursive topics for *landscape restoration* tweets by year Notes: Most of the discursive topics were significantly apparent in the conversations carried in *landscape restoration* tweets since 2015 with a normalized frequency between 0.10.3, except topics 5 and 10 that were insignificant until 2016, topic 3 that was insignificant until 2020 but rose suddenly in prominence around 2022, and topic 6 that appear suddenly in 2020 with high prominence but followed by a sharp fade out. While almost of the topics exhibit some consistency in the digital conversations throughout the observation period (normalized frequency between 0.10.5), the years 2018 and 2021 saw the rise in prominence of a few topics: topics 5, 7, 8 (2018 with a normalized frequency between 0.71) and topics 4 and 9 (2021 with a normalized frequency between 0.70.8).

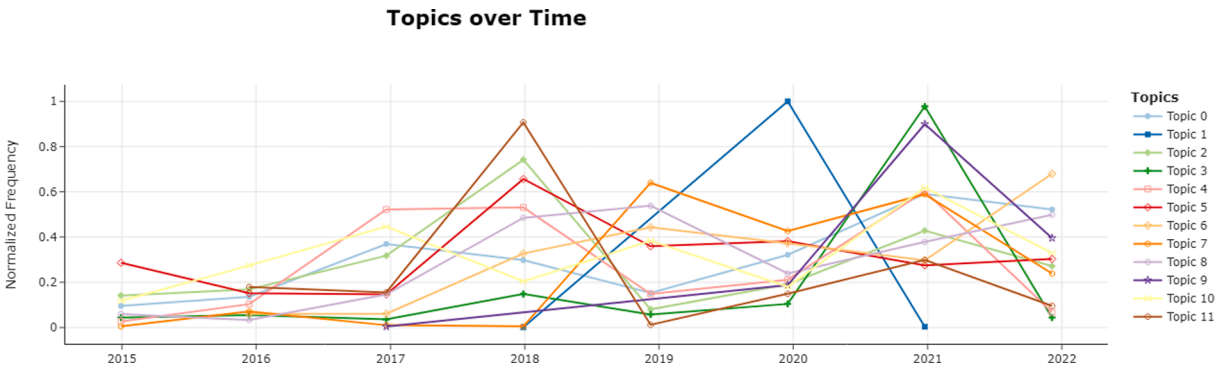

Fig. G. Likelihood of the top 12 discursive topics for *forest landscape restoration* tweets by year Notes: For *forest* landscape *restoration* tweets, the similar temporal dynamics of the discursive topics are observed compared to landscape restoration framing tweets, especially in terms of their consistency throughout the observation period (normalized frequency between 0.10.6). Here also, the years 2018 and 2021 exhibit some sharp rises in prominence for topics 2, 5, and 11 (normalized frequency between 0.70.9) and for topics 3 and 9 (normalized frequency between 0.91), respectively. A specific observation is the rise in full prominence of topic 1 with a normalized frequency of 1 in 2020 followed by a sharp decline nearing 0 in 2021.

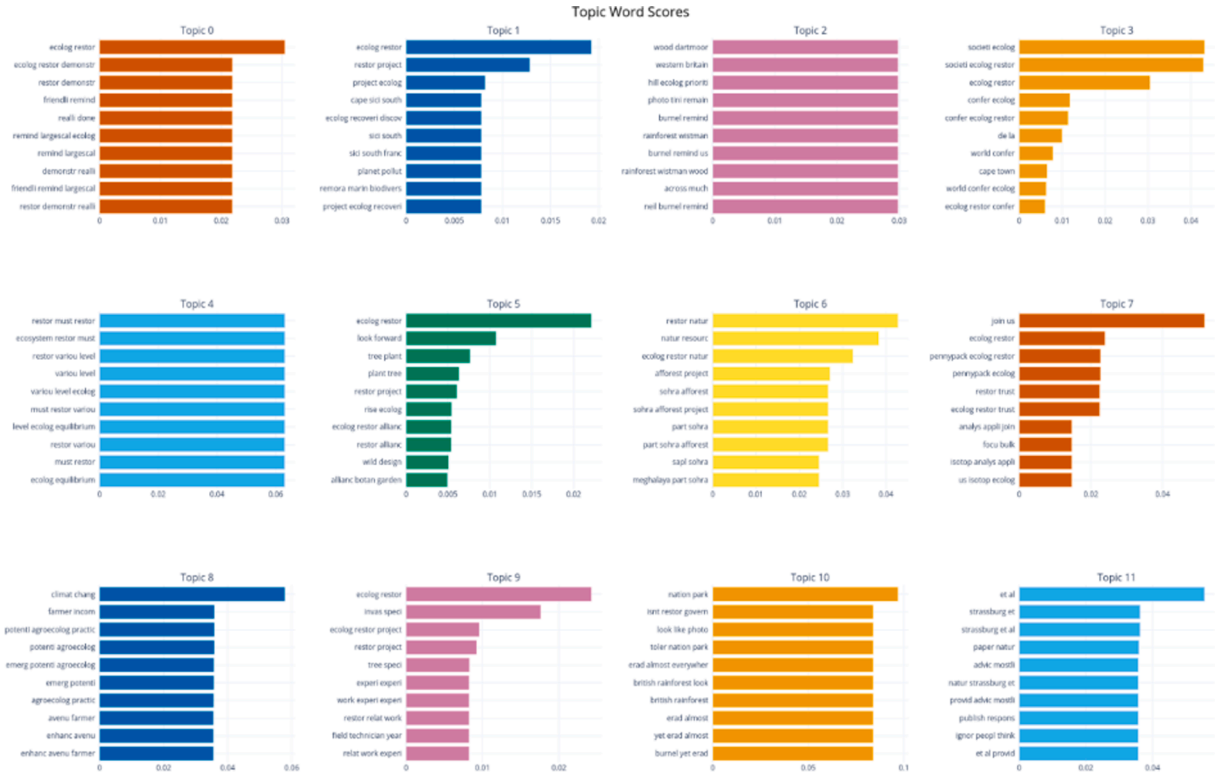

Fig. H. Top 12 discursive topics forming the discourses for *ecological restoration* tweets, with display of the 10-most relevant topic-terms

Fig. I. Tweet word clouds for the top 12 topics of *ecological restoration* in Twitter communications

Fig. J. Top 12 discursive topics forming the discourses for *landscape restoration* tweets, with display of the 10-most relevant topic-terms

Fig. K. Tweet word clouds for the top 12 topics of *landscape restoration* in Twitter communications

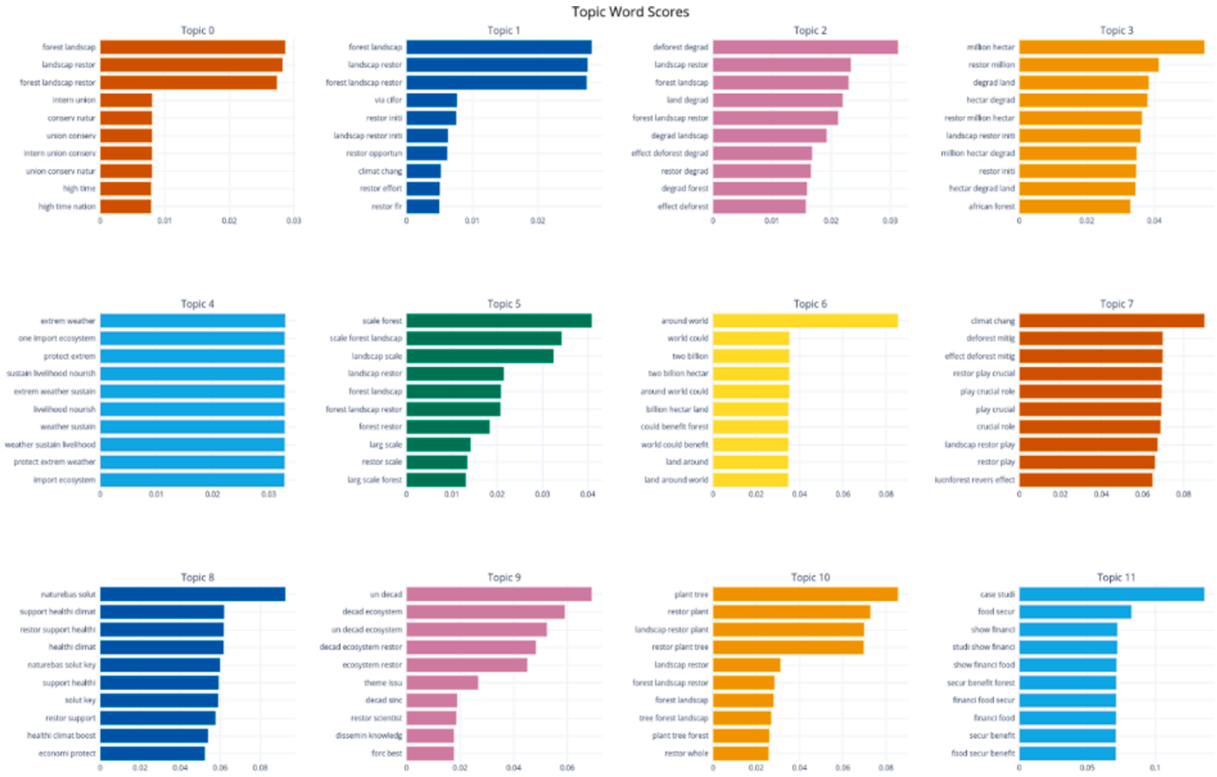

Fig. L. Top 12 discursive topics forming the discourses for *forest landscape restoration* tweets, with display of the 10-most relevant topic-terms

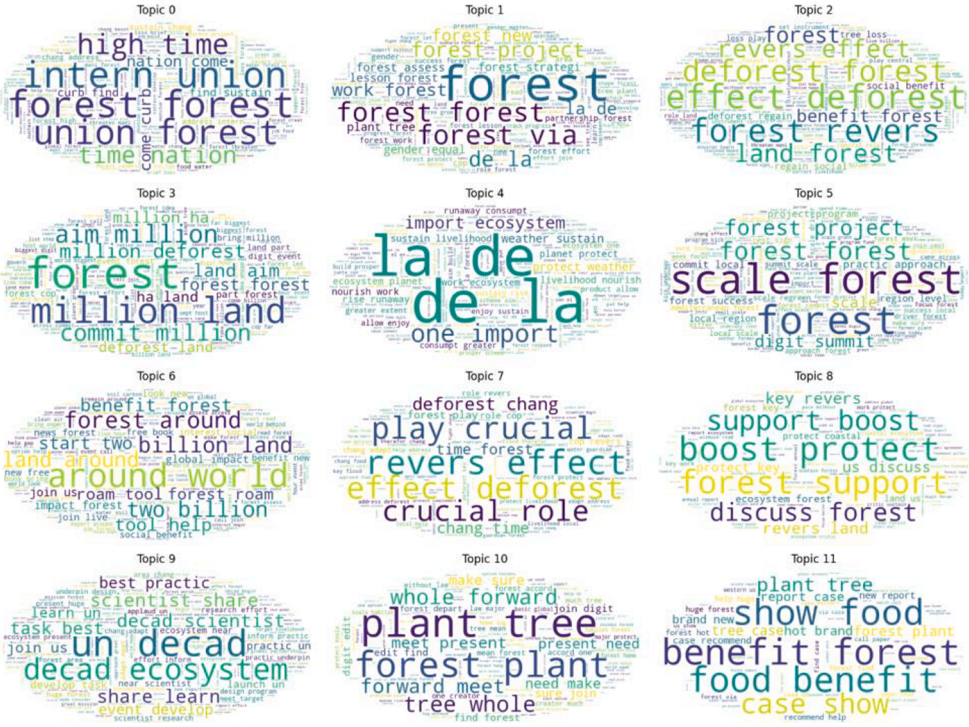

Fig. M. Tweet word clouds for the top 12 topics of *forest landscape restoration* in Twitter communications

Data availability

The Twitter datasets used in this study are not publicly available in accordance with Twitter's data sharing policy. Nevertheless, the tweet IDs analyzed in this research can be provided upon request. The codes for conducting spatial–temporal trend analysis and community network analyses can be accessed at https://github.com/ai4geocomp/LandscapeRestoration_Discourse_SocialMedia.

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