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RESEARCH ARTICLE

# Advancing social-ecological restoration through elicitation of cultural ecosystem services and landscape feature perceptions in restored quarries: a Flickr data analysis

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**With increasing urbanization and demand for construction materials, quarries have become central to the recovery of degraded landscapes into spaces that offer ecological, but also social benefits. While ecological restoration has long been investigated, integrated social-ecological restoration of post-quarrying landscapes remains underexplored. The overall aim of this study is to advance social-ecological restoration by assessing how cultural ecosystem services (CES) and landscape features (LF) are represented in social media posts about quarries in Germany, Denmark, and the Czech Republic. We focus on concepts of CES and LF to investigate the interactions between humans and restored ecosystems. Using a mixed-methods approach, we analyzed 1,660 geotagged photographs from 50 quarries across three regions: Berlin, Roskilde, and the Czech Karst. Flickr social media data were analyzed to elicit the richness of CES and LF and to identify popular quarries. Our results indicate that rehabilitated quarries exhibit higher CES richness than abandoned or operational ones, and that accessibility significantly influences public engagement. Our study demonstrates that once primarily industrial sites, quarries can evolve into vibrant social-ecological systems that provide diverse LF and CES. It also points to the potential of social media data for designing restoration efforts from a social-ecological perspective. Such an approach provides insights into public perceptions of restored urban landscapes and may inform future restoration strategies.**

**Key words: cultural services, ecosystem rehabilitation, extractive industry, Flickr, post-mining landscapes, social media**

### Implications for Practice

- Quarrying companies going beyond ecological restoration by actively incorporating community-centered goals will significantly enhance the richness of cultural ecosystem services (CES) at restored sites.
- Leveraging social media data, such as Flickr, offers a cost-effective method to capture public perceptions and CES related to quarry restoration projects.
- Planners should promote and facilitate public accessibility when restoring post-quarry sites, including promoting nearby public transit stops and parking sites. Public access is key to CES, since CES are formed through physical interactions and engagements with the sites. The greater the access for multiple visitor segments, the richer CES can be formed, along with other social benefits.

## Introduction

Global population growth and the demand for employment have driven a mass migration toward urban regions, and approximately 2.5 billion people are anticipated to relocate to urban areas by 2050 (United Nations 2018). While the urbanization process is slower in Europe than in other continents, the demand for construction aggregates, such as gravel and sand, is projected to expand by a total of 4.2% by 2027 in Europe (Insights 2024).

The European aggregates industry produces approximately three billion tons of aggregates annually, valued at over €30 billion. These aggregates are extracted from around 26,000 quarries across Europe, owned by approximately 15,000 companies (McLoughlin 2022).

Aggregates hold a profound economic value intertwined with their geographic location. Different from most other extracted commodities, aggregates are high-bulk, low-unit value commodities

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that derive much of their value from proximity to consumer markets (Bates 1969). Their transport is a significant cost component and a critical parameter for their market prices. Eighty to 90% of aggregate transportation relies on trucks (Bolen 2005; Menegaki & Kaliampakos 2010). As estimated by Kaliampakos and Benardos (1999), delivery to a radius of 15 km from the quarry leads to a 30% price increase. Delivery distances exceeding 40 km are, therefore, uncommon (Drew et al. 2002). As a result, aggregate extraction takes place in the vicinity of urban centers, strategically positioned near the consumption demands. In this article, we focus on quarrying, the open-cast extraction of nonmetallic aggregates such as stone, sand, gravel, limestone, and other minerals for construction and industrial purposes (Coppin & Bradshaw 1982). We distinguish the term "quarrying" from "mining," which refers to the extraction of valuable minerals, metals, or fossil fuels (such as gold, coal, or copper) through surface or subsurface methods.

### Social-Ecological Restoration After Quarrying

Social-ecological systems approaches have been developed since the 1990s to analyze interlinked human and natural systems in new ways. Such approaches try to overcome a separation of people and nature by emphasizing the multiple interactions between social and ecological components (Biggs et al. 2021). The concept of social-ecological systems has led to increased recognition of the dependence of human societies on ecosystems, for instance, in the assessment reports of the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services. Social-ecological systems thinking has also triggered the development of multiple interdisciplinary methods for disentangling human–nature relationships, with ecosystem services assessments (including cultural ecosystem services [CES]) being central (Fischer et al. 2015).

The rise of social-ecological systems thinking has stimulated many new impulses also for ecosystem restoration (Fischer et al. 2021). The targets of ecosystem restoration have evolved over time, shifting from a narrow emphasis on a single or a few ecosystems to a more systems-oriented approach that considers ecological, social, and economic benefits (Wang et al. 2021). Assuming a social-ecological systems perspective, researchers call for restoration goals to not only include ecological criteria of success but also to consider the effects on human values and beliefs (Martin 2017; Wang et al. 2021; Svobodova et al. 2023). If ecological restoration focuses on practical benefits for human well-being as its main motivation, then including social aspects could expand how restoration is understood and practiced around the world.

In this study, social-ecological restoration after quarrying refers to the process of restoring both the ecological and social aspects of an area that has been affected by quarrying activities. This involves restoring diverse social-ecological interactions between people and the sites, including the re-establishment of ecosystems and nonmaterial benefits people derive from these ecosystems. In restoration efforts, the diversity of these ecosystems and their nonmaterial benefits is crucial, as it supports a wide range of species, ecological processes, human needs, and values, thereby enhancing the long-term sustainability of post-quarrying landscapes (Martin & Lyons 2018; Salgueiro et al. 2020).

We work with the concepts of landscape features and CES. Landscape features are distinct, tangible, and spatially identifiable elements of a landscape that arise from the interplay of natural and human processes, such as hills, rivers, forests, urban areas, and cultural elements (Oteros-Rozas et al. 2018; Schirpke et al. 2021). CES are the nonmaterial benefits that people derive from ecosystems, encompassing aesthetic enjoyment, recreational opportunities, cultural identity, spiritual connections, and educational experiences (Millennium Ecosystem Assessment 2005). In social-ecological systems, landscape features and CES mediate the interaction between ecological processes and human well-being (Zoeller et al. 2022). Landscape features support biodiversity, ecological connectivity, and resilience, shape local identities, and provide recreational spaces (Cardinale et al. 2012). At the same time, CES contribute to human well-being by enhancing mental and physical health, fostering a sense of place and social cohesion (Summers et al. 2012). Restoring landscape features and CES helps ensure long-term ecological functionality while revitalizing cultural and community ties to the restored ecosystems (Tambosi et al. 2014).

By eliciting the social dimensions of restoration, as expressed in public perceptions of CES and landscape features of restored quarries, our study contributes to advancing ecological restoration toward a more integrative social-ecological restoration.

### Social Media Data to Elicit Social-Ecological Interactions

Geolocated data have been underutilized in mining and quarrying sectors, negatively impacting the industry's reputation and limiting researchers' ability to effectively track potential impacts (Maus & Werner 2024). On a local scale, the acquisition of more detailed socioeconomic and socioecological data is often essential for comprehensive restoration, particularly concerning intangible aspects tied to community livelihoods and people's interactions with the environment (Svobodova et al. 2022). The utilization of social media data holds significant potential to fill this gap. By harnessing the vast amount of user-generated content on platforms like Flickr, Facebook, and Instagram, researchers can gain valuable insights into the perceptions, attitudes, and behaviors of local communities, environmental activists, and other stakeholders (Olafsson et al. 2022). Analyzing social media data in landscapes affected by quarrying could enable researchers to assess the impacts of this industrial activity on local livelihoods, identify emerging concerns and conflicts, and analyze community responses to changes in social-ecological systems. Geissinger et al. (2023) argue that social media data can complement traditional research methods by providing real-time information. However, as Jordan (2018) highlights, researchers must employ rigorous methodologies for data collection, analysis, and interpretation to ensure the validity and reliability of findings derived from social media sources.

Photographs posted on social media platforms offer a visual method for understanding intangible aspects of social-ecological systems, as they can communicate through visual representations and stimuli (Schirpke et al. 2021). Photographs account for historical, cultural, and social ways of seeing the world, and that is why they present data sources as expressions of the ideas themselves (Stedman et al. 2004). In the case of post-quarrying landscapes, social media photographs can help map how people value and use rehabilitated quarries. Photographs and their descriptions can illustrate where people go for scenic views, wildlife encounters, or social gatherings, aiding in the identification of key areas providing CES.

Taking a photograph when being in the landscape is a process of the subjective experience of the landscape with a perceptual and material dimension (Wylie 2007). People photograph a place because it holds value for them. By sharing these images on social media and adding tags or titles, they communicate this value to others. This communicated value can be interpreted through content analysis, a systematic method that includes both visual analysis of the photographs and textual data, as previously done by, for example, Schirpke et al. (2021), Egarter Vigl et al. (2021) and Oteros-Rozas et al. (2018).

### Aim and Objectives of the Study

The aim of the study is to assess CES and landscape features represented in social media posts about 50 quarries across three European capital regions, and provide insights into the relationship between landscape features, CES, and the social-ecological restoration of these sites.

Our three specific objectives are as follows:

(1) To analyze the distribution of Flickr posts across study sites and countries and to quantify the popularity of individual quarries among Flickr users.
(2) To identify the richness of landscape features and CES in each of the quarries, analyze trends and commonalities across the sites and countries.
(3) To elicit how landscape features, the richness of CES, and the popularity of quarry sites among Flickr users are influenced by five groups of quarry characteristics.

## Methods

The study employed a mixed methods approach, as illustrated in Figure 1. Both quantitative and qualitative methods were used concurrently and with equal emphasis on data collection and analysis. This integration of data types was designed to provide a more comprehensive understanding of the complex interactions between natural and human systems (Schoonenboom & Johnson 2017).

### Study Localities

Our study was conducted in three countries—Germany, the Czech Republic, and Denmark. These countries represent a diversity of quarrying practices, traditions of land rehabilitation, and approaches to landscape design. They are densely populated areas with high demands for social and ecological performance in quarry closure and share similar legal frameworks for quarrying. We focused on a total of 73 quarries in three regions near the capitals of the selected countries: the Berlin region in Germany, the Czech Karst near Prague in the Czech Republic, and the Roskilde region near Copenhagen, Denmark (Fig. 2; Table 1).

### Data, Their Collection, and Cleaning

For each of the study quarries identified in the capital regions, we collected data on five groups of characteristics, such as the country of location, quarry closure status, accessibility of the quarry, proximity to urban areas, and public awareness of the site. These characteristics were selected based on the existing literature on drivers of tourist visitation (e.g. Donahue et al. 2018; Stemberk et al. 2018; Svobodova et al. 2019) as well as discussions among the authors. They are described in Table 2.

Social media data related to these quarries were collected from Flickr, an online photograph sharing platform with 240,000 monthly active users in the European Union in recent years. In contrast to more popular, but inaccessible, platforms like Facebook and Instagram, the Flickr platform offers a vast user-generated database accessible through its Application Programming Interface (API). Flickr is especially popular for sharing nature-related content (Toivonen et al. 2019), and hence it has proved effective for analyzing CES in various social-ecological contexts, such as rural landscapes (Oteros-Rozas et al. 2018; Lee et al. 2022), coastal landscapes (Ghermandi et al. 2020; Daymond et al. 2023), and parks (Huai et al. 2022; Lingua et al. 2022).

Data collection was conducted from January 21 to February 6 in 2022, using a Python script, with no restrictions on the dates when the photos were taken. Uniform Resource Locators (URLs) with the specified queries, including radial geo and free text queries, were constructed to retrieve the user-generated content referring to the studied localities. We downloaded the geotagged photograph series by specifying the geographical range around the quarries and retained the photographs within 200-m buffer zones around the delineation of the quarries. The non-georeferenced photographs, of which the title, description, or tags mentioned the studied places, were downloaded with text searching queries specifying the place names. Along with the photographs, coordination details, and attached texts, we also retrieved metadata, including the dates the photographs were taken. In line with the privacy concern recommendations by Di Minin et al. (2021), we managed social media data in a way that prevented potential risks to users involved by minimizing data, anonymizing data, and following a strict data management procedure. Further, to avoid issues of reverse identification, we omitted the use of a specific photo combined with title, description, and tag in this manuscript (Ayers et al. 2018).

We manually inspected the retrieved dataset, consisting of 13,099 data points of photographs accompanied by the textual metadata, and removed unrelated and duplicate photographs, including those of the same objects taken from different angles. Twenty-three quarries were not found on Flickr, either through tag locations or keyword searches. Therefore, only 50 quarries

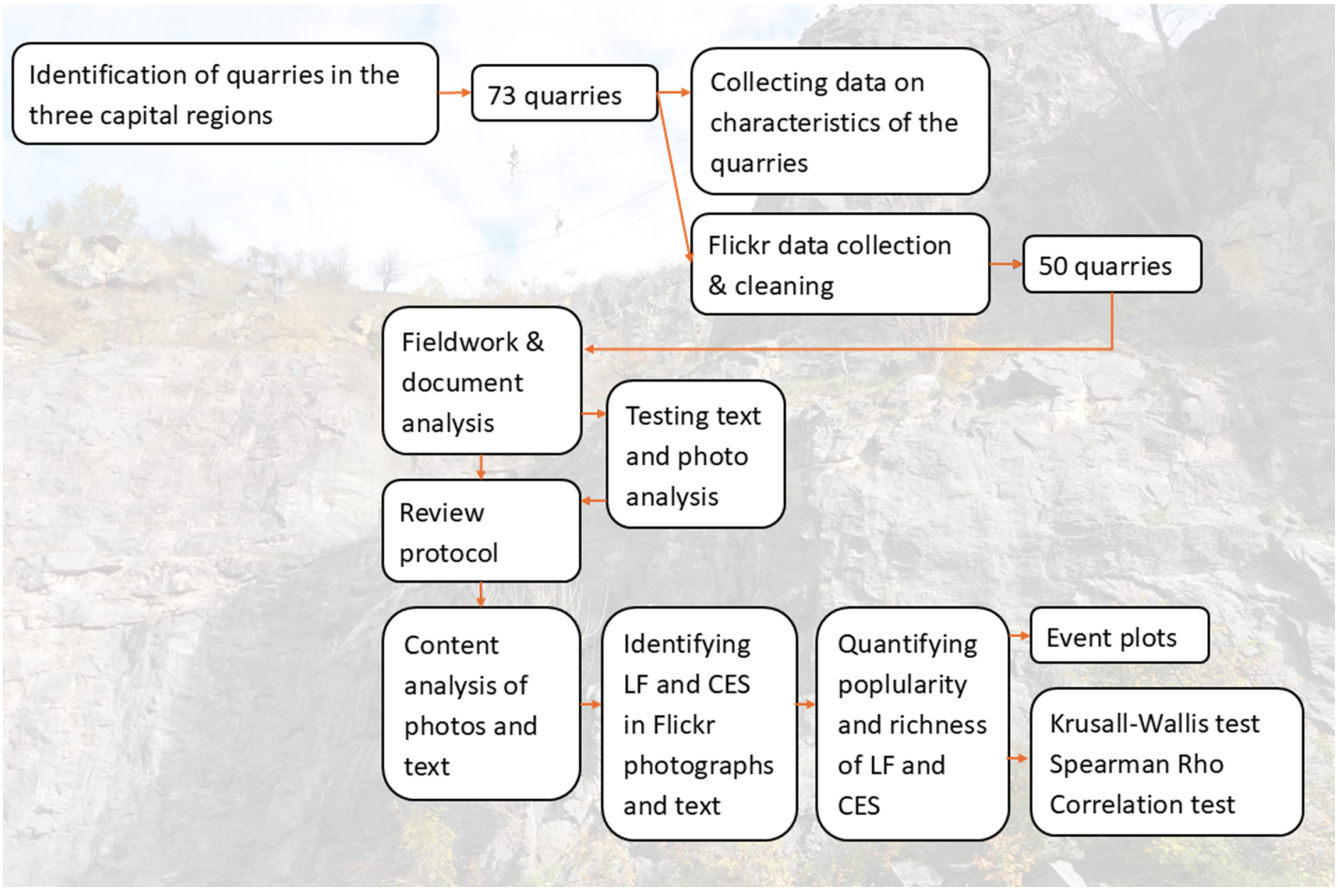


Figure 1. Summary of the methodological approach used in the study (CES, cultural ecosystem services; LF, landscape features).

were part of the final sample and were further analyzed. Sixteen of the 23 missing quarries were located in the Czech Republic, and 7 were in Denmark. All German quarries were included in the final sample of 50 quarries. Detailed characteristics of the study quarries can be found in the data repository (see Acknowledgments).

To counteract bulk uploading, we randomly retained a maximum of five photographs per user per day. The final dataset consisted of 1,660 photographs, with 858 from the Berlin region, 453 from the Czech Karst region, and the remaining 349 taken in the Roskilde region. All the metadata, including the textual data associated with these photographs, were collected in a comma-separated values (CSV) file. We combined the text in the fields of "tags," "title," and "description" and used Google Translation to translate the multilingual text into English. 6,854 unique words with word frequency were identified in the textual data after lemmatization and excluding stop words. The natural language processing tasks were carried out with Python libraries sklearn 1.3.2, nltk 3.8.1. After inspection, we decided to proceed with the textual content analysis for the words that appeared in the dataset more than twice. We further cleaned the dataset by removing the irrelevant items, such as numbers, URLs, brand and personal names, and other unmeaningful items. The final lexicon undergoing categorization consisted of 855 unique words.

### Qualitative Data Analyses

Before conducting the content analysis of the photographs and associated textual data, the first author undertook field trips to the study sites. These visits were essential for gaining a comprehensive understanding of the local context, ensuring the significance of local perspectives, and allowing for the validation of content analysis findings against ground truth data. Based on this fieldwork, we identified 29 landscape features that were consistently observed across the study quarries. Building on the work of Schirpke et al. (2021) and Oteros-Rozas et al. (2018), who associated specific CES with particular landscape features, and drawing on our firsthand observations during field visits to the study sites, we identified 16 CES present across these locations. We developed an initial review protocol that included a list of 29 landscape features and 16 CES to be identified in the photographs and their associated textual data. The protocol is accessible in our data repository (see Acknowledgments).

We further conducted an initial round of textual content analysis to cross-validate the dimensions identified from the photographs and the text. Compared to photographs, which can be

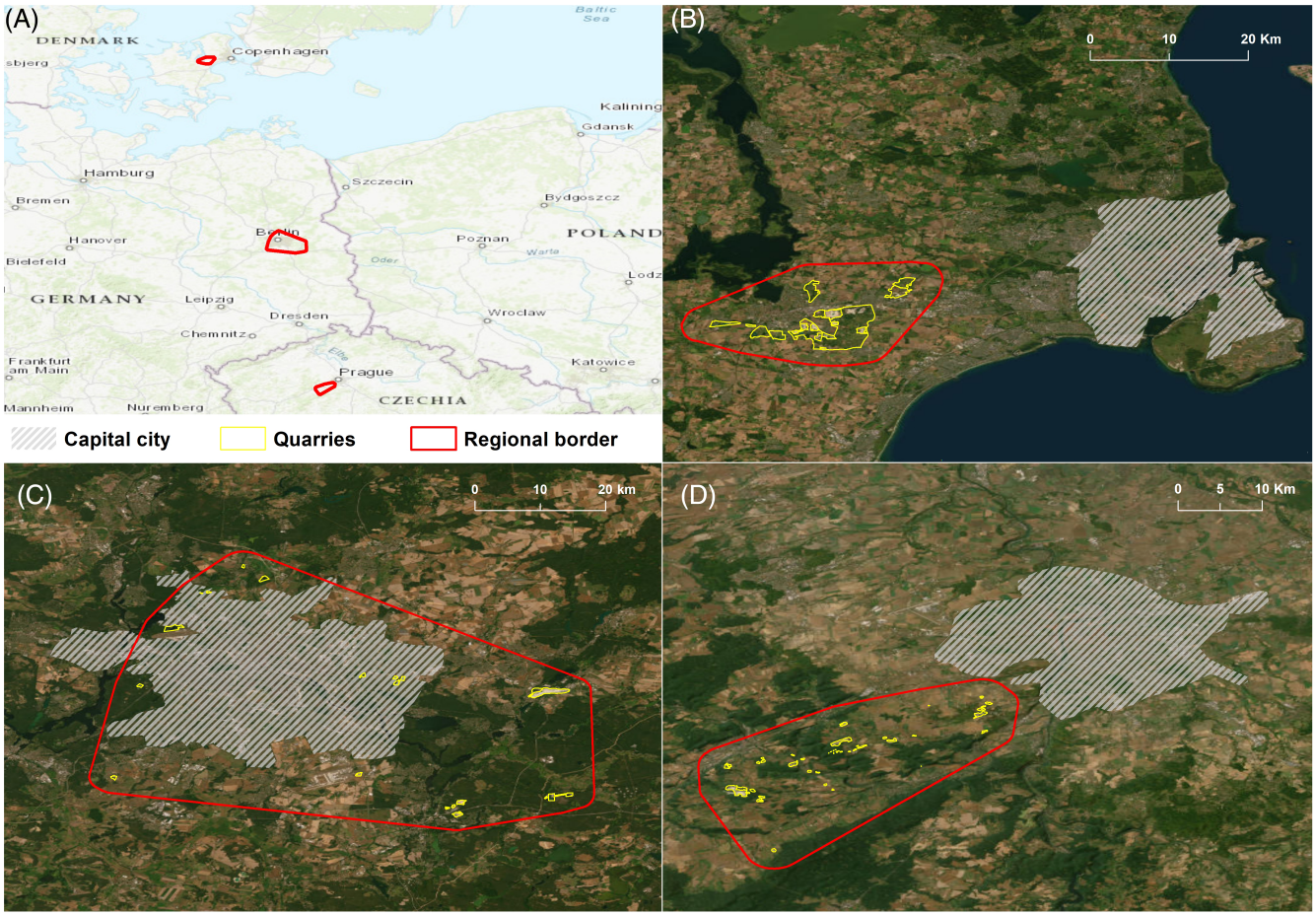


Figure 2. Locations of the study regions and quarries: (A) Overview of all regions, (B) Roskilde region in Denmark, (C) Berlin region in Germany, (D) Czech Karst region in the Czech Republic.

**Table 1.** Details on quarries in study European capital regions. *The large number of abandoned quarries is due to their location within the protected landscape area (PLA) of the Czech Karst, established in 1972. As part of the PLA management plan, the ecological succession of the abandoned quarries has been prioritized over directed reclamation efforts.

| *Study Region* | *Berlin Region, Germany* | *Roskilde Region, Denmark* | *Czech Karst, Czech Republic* |
|---|---|---|---|
| Number of quarries | 16 | 14 | 43 |
| Stage of quarrying | Rehabilitated (10), operating (5), abandoned (1) | Rehabilitated (6), operating (8), abandoned (0) | Rehabilitated (1), operating (14), abandoned* (28) |
| Commodity extracted | Sand (7), gravel (5), clay (2), limestone (2) | Gravel (14) | Limestone (35), sand (3), clay (2), marble (2), syenite (1) |
| Accessibility | Accessible (11), inaccessible due to ongoing operations (5) | Accessible (6), inaccessible due to ongoing operations (8) | Accessible (28), inaccessible due to ongoing operations or private ownership (15) |

subject to subjective interpretation and are therefore more suited for broader categorization, words provide clearer insights, allowing for the identification of more subtle dimensions expressed by the visitors (Calcagni et al. 2022). As a result, a range of subcategories was initially assigned to the words independently within the review protocol. These were then refined through modifications, including splitting and merging categories and adjusting terminology to align with the review protocol used for the photographs. We ultimately identified the same CES categories from both the photographs and the text. Two unique LF categories ("nature," and "scenery") were identified in the textual content analysis. Categories of "rock," "cave, tunnel," and "mountain/hill" in the photograph content analysis were combined under the "topography" category in the text analysis,

**Table 2.** Quarry characteristics, their explanatory variables, categories, and data sources.

| *Characteristics of the Quarry* | *Explanatory Variable* | *Categories* | *Description; Data Source* |
|---|---|---|---|
| 1. Country | Country | Germany; Czech Republic; Denmark | Countries where the study quarries are located |
| 2. Quarry closure and rehabilitation | Stage of closure | Rehabilitated; abandoned; operating | The specific phase in the lifecycle of a quarry. Fieldwork and document analyses |
| | Age of rehabilitation | 0 (=operating); date 1900–2019 | The start date of progressive rehabilitation, if implemented; document analyses |
| | Commodity color | Darker: gravel, sand clay<br>Lighter: limestone, marvel | Two shades of color, darker and lighter, corresponding to specific commodities; fieldwork |
| 3. Access and facilities | Accessibility | Accessible; inaccessible | Public accessibility of the quarry; fieldwork |
| | Car parking | 0–33 | Number of parking spaces available within a 50-m radius of the quarry site; OpenStreetMap (OpenStreetMap 2024) |
| | Public transports stops and stations | 0–14 | Number of public transports stops and stations available within a 50-m radius of the quarry site; OpenStreetMap (OpenStreetMap 2024) |
| | Path density | 3.7–1,196.7 m/ha | Density of roads and trails within a 50-m radius of the quarry site, measured in meters per hectare (m/ha); OpenStreetMap (OpenStreetMap 2024) |
| 4. Urbanization level | Share of urban areas | 0–55.4% | Percentage of urban areas within a 1-km buffer of the quarry site; Urban Atlas Land Cover/Land Use 2018 (vector), Europe, 6-yearly (Copernicus_Land_Monitoring_Service 2018) |
| 5. Online interest | Google trends 2004–2024 | 100–5,156 | Data on the relative volume of Google searches for user-defined search terms, represented by the total number of web searches per month; Google Trends (Google 2024) |

so as to include additional terms such as "ground," "land," "canyon," "cliff," etc. found in the textual data. "Others" category assigned to photographs was dropped in the text analysis, resulting in 16 categories of CES and 29 categories of LF (see Tables 3 and 4). These categories of CES and LF conveyed through text were identified for each photograph with textual content. The time allocated to the content analysis of each photograph varied from approximately 30–120 seconds, depending on the complexity of the content.

To quantify the richness of landscape features and CES in the quarries, we combined the results of the photographs and text analyses of the Flickr posts from Tables 3 and 4 and calculated the number of unique landscape features and cultural ecosystem categories across the posts related to each of the quarries to measure the richness of LF and CES.

### Quantitative Data Analysis

To measure the richness of LF and CES in the individual quarries, we combined the results of the photograph and text analyses to identify the categories of LF and CES elicited by the Flickr posts. We then calculated the number of unique LF and CES categories across the posts related to each quarry. The categories identified in either photographs, text, or both types of content were visualized by event plots. Event plots commonly used to visualize neuron events in neuroscience have been widely adopted in other fields to illustrate discrete events represented by the presence/absence of dots or lines (Matplotlib 2024). The plots were generated with Matplotlib 3.9.1.

To analyze how the richness of LF and CES, and the popularity of quarry sites among Flickr users are influenced by five groups of quarry characteristics, nonparametric statistical relationship analyses were performed with SPSS version 19.0.2. The Kruskal–Wallis test and Spearman rho correlation were used to analyze the relationship between the quarry characteristics (Table 2) and three dependent variables: Popularity (mean unique Flickr users per year), CES richness (mean), and mean landscape features richness per study site with Flickr data ($n = 50$).

## Results

### Popularity of Quarries Among Flickr Users

Analyzing the distribution of Flickr posts across quarries during the studied period reveals notable trends. Within the sample from the Czech Republic, over the years, Velká Amerika Quarry was the most frequently featured, comprising 31% of the posts, followed by Houbův Lom at 10% and Malá Amerika at 9%. In Denmark, Hedeland emerged as the dominant location with

**Table 3.** Landscape features identified in Flickr photograph and text analyses.

| *Codes* | *Text* | *Photograph* |
|---|---|---|
| LF1 | Forest/forest (name) | Forest |
| LF2 | Tree | Solitary tree |
| LF3 | Shrub | Shrub |
| LF4 | Agriculture | Agriculture |
| LF5 | Grassland/heath | Grassland |
| LF6 | Ground | Bare soil/rocky surface |
| LF7 | Water/water (name) | Water body |
| LF8 | Geology | Rock |
| LF9 | Topography | |
| LF10 | | Cave, tunnel |
| LF11 | | Mountain/hill |
| LF12 | | Slope |
| LF13 | Quarry/quarry (name) | Mine |
| LF14 | Livestock | Livestock |
| LF15 | Wild animal | Wild animal |
| LF16 | Plants | Plant |
| LF17 | Bloom | Bloom |
| LF18 | Building | Building |
| LF19 | Industrial artifacts | Industrial feature |
| LF20 | Railway/road | Road, railway |
| LF21 | Vehicle | Vehicle |
| LF22 | Other human infrastructure | Other human infrastructure |
| LF23 | Cultural artifacts | Art |
| LF24 | People | Person |
| LF25 | Sky | Sky |
| LF26 | Phenomena | Weather phenomena |
| LF27 | Nature reserve/nature reserve (name)/artificial nature | |
| LF28 | Scenery | |
| LF29 | | Other |

**Table 4.** Cultural ecosystem services identified in Flickr photographs and text analyses.

| *Codes* | *CES* | *Subcategories of CES* |
|---|---|---|
| CES1 | Aesthetics | Color |
| | | Beauty |
| | | Phenomena |
| | | Scenery |
| | | Topography |
| CES2 | Spiritual and religious | Religious |
| CES3 | Knowledge/education | Education |
| | | Preservation |
| | | Nature |
| | | Geology |
| CES4 | Nature observation | Plants |
| | | Animals |
| CES5 | Social relations | Social relations |
| | | Events |
| CES6 | Recreational photography and art | |
| CES7 | Recreational activities in nature | |
| CES8 | Recreational water activities | |
| CES9 | Recreational sports | |
| CES10 | Recreational activities with animals | |
| CES11 | Other recreation | |
| CES12 | Tourism | |
| CES13 | Cultural heritage/cultural diversity | History/culture |
| | | Heritage |
| | | Industry |
| | | Attraction |
| | | Urban/rural |
| CES14 | Therapeutic/health | Therapeutic/ health |
| CES15 | Inspiration | Inspiration |
| CES16 | Sense of place | Sense of place |
| | | Disservice |

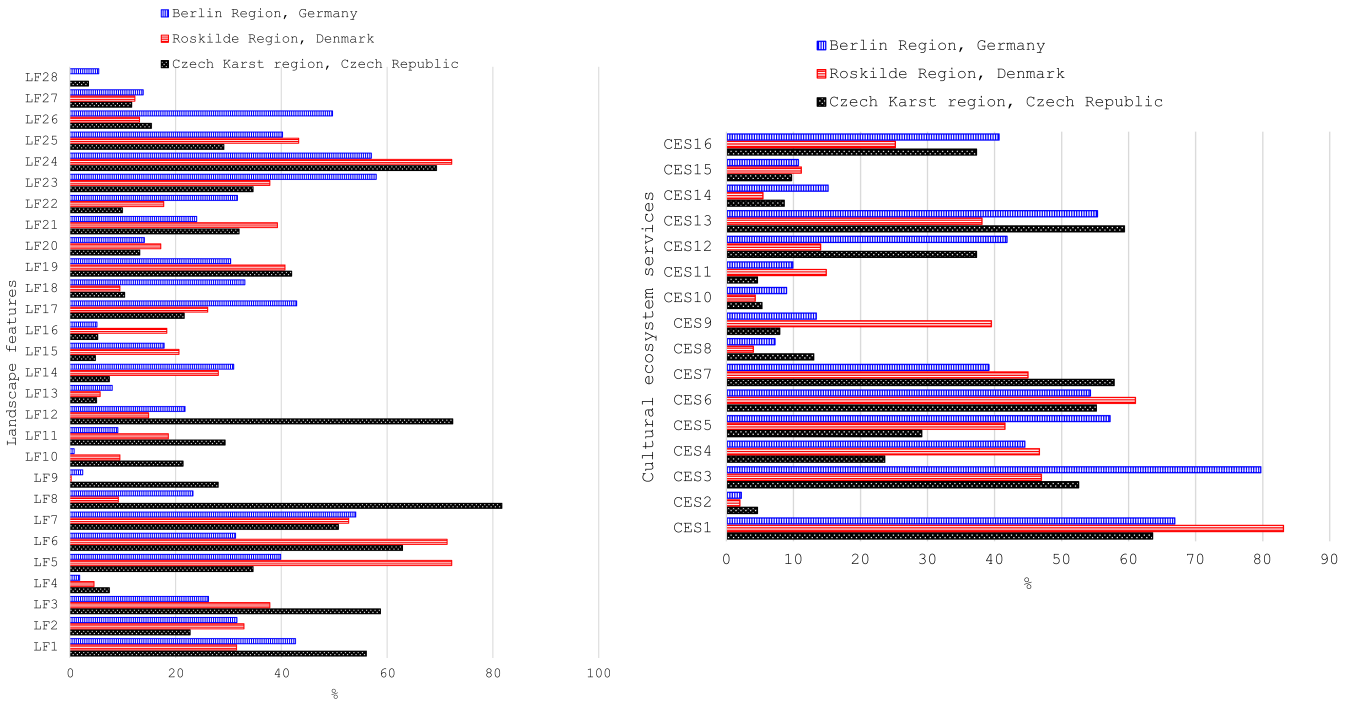


Figure 3. Richness of landscape features (A) and cultural ecosystem services (B) in three study regions.

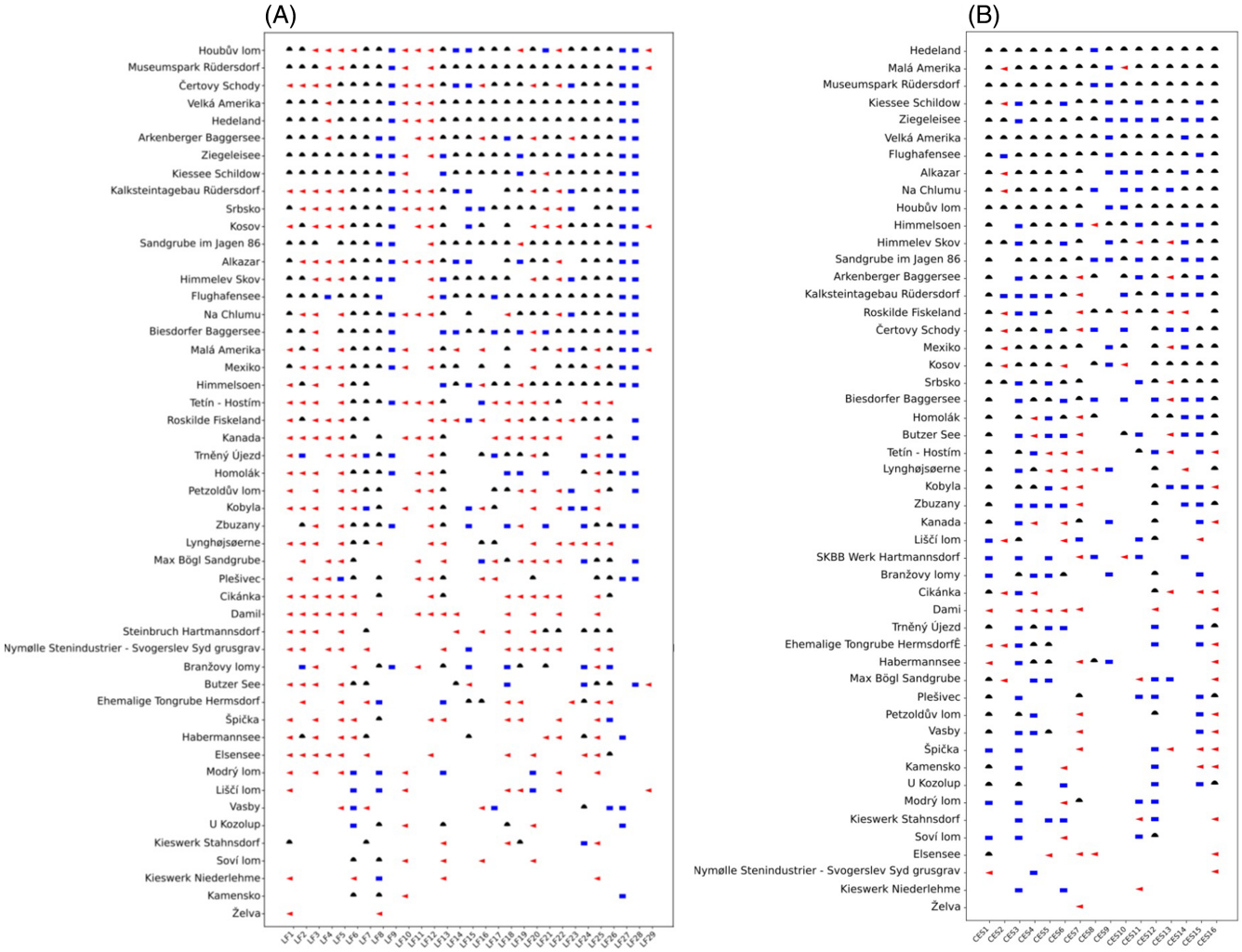


Figure 4. Event plot of unique landscape features (A) and cultural ecosystem services (B) categories identified in the individual quarries (corresponding categories for the shorthand notations are listed in Tables 3 and 4). The red bar marks indicate categories only identified in photographs, blue in text, and black in both.

74% of the posts, while Himmelev Skov and Himmelsøen garnered 9 and 8%, respectively. In Germany, Rüdersdorf Museum Park was the most popular with 24% of the posts, followed by Ziegeleisee at 17%, and Kiessee Schildow and Flughafensee both at 12%.

Considering the mean number of unique Flickr users per year for each quarry, the top 10 sites were Hedeland with 4.2 users per year, Rüdersdorf Museum Park with 3.3, Flughafensee with 2.6, Sandgrube im Jagen 86 with 2.3, Kiessee Schildow with 2.2, Velká Amerika with 2.1, Damil with 2.0, Himmelsøen with 1.4, and Kalksteintagebau Rüdersdorf with 1.4.

### Richness of Landscape Features and Cultural Ecosystem Services

Across all three study regions, the most frequent landscape features in Flickr data were sky (64% of users' posts), water (53%), ground (48%), people (47%), grassland (45%), forest (43%), weather phenomena (38%), shrub (38%), rocks (36%), railway/road (36%), quarry (34%), and buildings (34%). Significant differences emerged between the study regions (Fig. 3A). Excluding the sky, the most prevalent landscape features in the Czech Karst region were rocks (82% of posts), quarries (72%), and ground (63%). In the Danish Roskilde region, grasslands (72%), ground (71%), and water (53%) dominated. In Germany, the key landscape features included people (58% of posts), water (54%), and nature reserves (50%).

Aesthetics (69% of the users' posts) emerged as the most frequently observed category of CES across all three regions, followed by knowledge and education (65%), recreational photography and art (56%), cultural heritage and diversity (53%), social relations (46%), recreational activities in nature (46%), nature observation (39%), sense of place (37%), and tourism (35%). In the Czech Karst region, aesthetics (64%), social relations (59%), and recreational activities with animals (58%) dominated (Fig. 3B). In the Danish

**Table 5.** Explanatory variables, their categories, and their relationship to popularity, CES, and landscape features richness. The *p*-values of significant relationships are marked with *.

| *Explanatory Variable* | *Category* (n) *and test* | *Popularity, That Is, Mean Unique Flickr Users Per Year (Mean)* | *CES Richness (Mean)* | *Landscape Features Richness (Mean)* |
|---|---|---|---|---|
| Country | Germany (15) | 1.34 | 8.22 | 14.44 |
| | Czech (27) | 0.87 | 7.80 | 12.00 |
| | Denmark (7) | 1.50 | 9.07 | 14.00 |
| | Kruskal–Wallis test | $p = 0.153$ ($\times 2$ (2) = 3.748) | $p = 0.865$ ($\times 2$ (2) = 0.291) | $p = 0.512$ ($\times 2$ (2) = 1.337) |
| Commodity | Darker: gravel (12), sand (8), clay (2) | 1.26 | 8.250 | 13.886 |
| | Lighter: limestone (25), marvel (2) | 0.99 | 7.83 | 12.20 |
| | Kruskal–Wallis test | $p = 0.705$ ($\times 2$ (2) = 0.698) | $p = 0.598$ ($\times 2$ (2) = 1.029) | $p = 0.549$ ($\times 2$ (2) = 1.199) |
| Stage of quarry closure | Rehabilitated (16) | 1.46 | 9.91 | 15.88 |
| | Abandoned (20) | 0.96 | 8.50 | 12.55 |
| | Operating (13) | 0.88 | 5.50 | 10.57 |
| | Kruskal–Wallis test | $p = 0.458$ ($\times 2$ (2) = 0.277) | $p = 0.022$* ($\times 2$ (2) = 7.662) | $p = 0.113$ ($\times 2$ (2) = 4.352) |
| Access | Accessible (34) | 1.21 | 9.15 | 13.97 |
| | Inaccessible (15) | 0.87 | 5.91 | 11.13 |
| | Kruskal–Wallis test | $p = 0.599$ ($\times 2$ (1) = 0.277) | $p = 0.017$* ($\times 2$ (1) = 5.686) | $p = 0.219$ ($\times 2$ (1) = 1.508) |
| Path density (mean m/ha) | Spearman's rho (correlation) | Rho = 0.260, $p = 0.071$ | Rho = 0.219, $p = 0.126$ | Rho = 0.055, $p = 0.702$ |
| Car parking (number within a 50 m buffer) | Spearman's rho (correlation) | Rho = 0.553, $p < 0.001$** | Rho = 0.509, $p < 0.001$** | Rho = 0.558, $p < 0.001$** |
| Public transport stops (number within a 50 m buffer) | Spearman's rho (correlation) | Rho = 0.420, $p = 0.003$** | Rho = 0.395, $p = 0.005$** | Rho = 0.431, $p = 0.002$** |
| Share of urban areas (in a 1 km buffer, %) | Spearman's rho (correlation) | Rho = 1.86, $p = 0.200$ | Rho = 0.094, $p = 0.516$ | Rho = 0.178, $p = 0.216$ |
| Google trends 2004–2024 (sum of web search/ month | Spearman's rho (correlation) | Rho = 0.169, $p = 0.247$ | Rho = 0.621, $p < 0.001$** | Rho = 0.586, $p < 0.001$** |
| Age of rehabilitation (years) | Spearman's rho (correlation) | Rho = −0.152, $p = 0.378$ | Rho = 0.040, $p = 0.816$ | Rho = 0.002, $p = 0.989$ |

Roskilde region, aesthetics (83%), recreational sports (61%), and sense of place (47%) were the most frequent CES. Sense of place (80%), aesthetics (67%), and knowledge and education (57%) were the most frequent CES in the Berlin region in Germany.

Quarries with the highest richness of LF and CES were Hedeland in Denmark, Houbův lom and Velká Amerika in the Czech Republic, and Museumpark Rüdersdorf in Germany. The number of unique LF and CES categories across the posts identified for each quarry across all three countries is presented using event plots in Figure 4. Houbův lom in the Czech Republic is the only quarry where all landscape features were identified in Flickr data. Museumpark Rüdersdorf (Germany), Čertovy Schody, Velká Amerika (Czech Republic), and Hedeland (Denmark) were found to contain 26 of the 29 landscape features analyzed. In terms of CES, all 16 analyzed services were identified across 7 quarries. These include four quarries in the Berlin region (Museumpark Rüdersdorf, Kiessee Schildow, Ziegeleisee, and Flughafensee), two in the Czech Karst region (Malá Amerika and Velká Amerika), and one in the Roskilde region (Hedeland).

### Relationship Between Quarry Characteristics and Popularity and CES Richness and Landscape Features Richness

The Kruskal–Wallis test revealed no significant differences between the three countries in terms of mean scores for popularity, CES richness, and landscape feature richness (Table 5). Additionally, the type of commodity had no effect on the reported mean values. However, we found significantly higher CES richness in rehabilitated quarries compared to abandoned and operating quarries ($p = 0.022$), while the age of rehabilitation did not influence the mean values. Mean CES richness was also significantly higher in accessible quarries compared to inaccessible ones ($p = 0.017$).

Spearman's Rho correlation test showed that the number of car parking spaces within 50 m of the quarry sites significantly affected mean values of popularity (Rho = 0.553; $p < 0.001$),

CES richness (Rho = 0.509; $p < 0.001$), and landscape feature richness (Rho = 0.558; $p < 0.001$). The number of public transportation stops within a 50-m buffer of the quarry sites had a significant effect on popularity (Rho = 0.420; $p = 0.003$), CES richness (Rho = 0.395; $p = 0.005$), and landscape feature richness (Rho = 0.431; $p = 0.002$). We also found a significant relationship between Google Trends (used as a proxy indicator of online interest) and mean scores of CES richness (Rho = 0.621; $p < 0.001$) and landscape feature richness (Rho = 0.586; $p < 0.001$) across the quarries.

## Discussion

In our research, we recognize that the ecological and social dimensions of restoration are deeply interconnected. This approach enables us to assess quarry rehabilitation in a more comprehensive manner, extending beyond the purely ecological or aesthetic criteria typically used in studies such as those by Neri and Sánchez (2010), Hendrychová et al. (2020), and Mexia et al. (2020). Using data from Flickr, we examine the extent of social-ecological restoration after quarrying by applying the richness of landscape features and CES as proxies. Our approach aligns with the recommendations for monitoring the social benefits of ecological restoration, as discussed by Martin and Lyons (2018). Our study encompasses 50 quarries at various stages of restoration across three capital regions of the Czech Republic, Germany, and Denmark. In this section, we explore the results of our study, providing insights into social-ecological restoration following quarrying, along with methodological lessons learned from working with social media data throughout the research process.

### Insights Into Social-Ecological Restoration

Our findings allow for understanding the diverse social-ecological interactions between people and quarries in three European capital regions. Through a cross-site comparison, we assess the popularity of quarries among Flickr users and explore the relationship between site characteristics and the richness of landscape features and CES they offer. These insights suggest how the study quarries are utilized by visitors and how their social and ecological benefits of the sites are reflected in user-generated content on Flickr.

Our results emphasize the significance of accessibility and active rehabilitation in maximizing the social and ecological potential of quarries in urban areas. Moreover, the positive influence of online interest on landscape features and CES richness points to the growing role of the internet in shaping the perception and use of restored landscapes, as previously shown by Svobodova et al. (2020) and Kaiser et al. (2021). From a restoration perspective, we suggest that quarries that exhibit a broad range of landscape features and CES are likely to support greater public engagement, enhancing their role as restored multifunctional landscapes.

The results of the Kruskal–Wallis test indicate the significantly higher CES richness observed in rehabilitated quarries compared to abandoned or operating quarries. This supports the idea that active rehabilitation efforts greatly enhance the variety of community benefits these landscapes offer (Martin & Lyons 2018; Kaiser et al. 2021). Similarly, Hernandez-Santin et al. (2024) demonstrated that rehabilitation significantly enhances landscape connectivity from a multi-species perspective, while Wang et al. (2020) showed that progressive rehabilitation positively impacts ecosystem services, particularly carbon sequestration and air quality.

Accessibility also emerges as a critical factor. Quarries with public access exhibit significantly higher CES richness compared to those that are restricted. This is further supported by the strong correlation between the number of car parking spaces and public transportation stops near quarry sites and the mean values for popularity, CES richness, and landscape feature richness. These findings highlight the importance of physical accessibility in fostering public engagement with post-quarrying landscapes. As suggested by Danciu and Radoslav (2015) and Ribot and Peluso (2003), increased accessibility encourages a broader range of stakeholders to engage with the landscape, promoting awareness and stewardship of the restored environment. At the same time, the presence of human activity can support the development of diverse ecosystems and create opportunities for ongoing monitoring, citizen science, and adaptive management strategies (Martin & Lyons 2018). However, easy access and high popularity might also increase harmful effects on biodiversity and wildlife (Larson et al. 2016).

The relationship between Google Trends data and CES and landscape feature richness underscores the role of online interest as an indicator of public awareness and potential use of quarries. In our study, we used Google Search, the most popular search engine, which holds approximately 90% of the global market share over the past decade (Statcounter 2021). Our findings suggest that Google search can be valuable for understanding how CES and landscape features of restored quarries resonate with public interest. Previous research, including studies by Souza et al. (2021) and Cooper et al. (2019), has utilized Google Trends to evaluate public interest in nature, protected areas, and environmental issues. Additionally, Phillips et al. (2022) explored public engagement with diverse natural spaces and activities using the same tool.

The identification of quarries with the highest richness of landscape features and CES shows the importance of certain sites, such as Hedeland (Denmark), Houbův lom, Velká Amerika (Czech Republic), and Museumpark Rüdersdorf (Germany), as examples of sites with a high extent of social-ecological restoration. The presence of nearly all categories of landscape features and CES in these quarries suggests that they provide a broad range of social-ecological benefits and interactions.

Houbův lom in the Czech Republic stands out as the only site where all landscape features were captured through Flickr data, underscoring its unique landscape diversity. Quarries in the Berlin region (Museumpark Rüdersdorf, Kiessee Schildow, Ziegeleisee, and Flughafensee), the Czech Karst region (Malá Amerika and Velká Amerika), and the Roskilde region (Hedeland) offer all 16 analyzed CES, which underscores the amount of social benefits provided for their visitors. Our findings align with previous research (Svobodova et al. 2023), which suggests that individuals

continuously reshape their connections and interactions with landscapes that have undergone long-term disruptions, such as those caused by mining and quarrying.

In terms of richness of landscape features, we showed that sky, water, ground/bare soil, people, grassland, and forests were the most frequently photographed landscape features across all three capital regions. For example, in the Czech Karst region, rocks and quarries appeared in 82 and 72% of posts, respectively. This reflects the location of the quarries within a protected landscape area, where rehabilitation efforts have been minimal, and abandonment, along with natural succession, has driven the recovery process (Novák & Prach 2003). Danish posts predominantly featured grassland and water (72 and 53%, respectively), reflecting the dominant land cover in Denmark (Zhou et al. 2021) and aligning with restoration trends following gravel quarrying. Over the past decades, hundreds of gravel pit lakes have been created in Denmark as part of these restoration trends (Søndergaard et al. 2018). Germany's emphasis on people and nature reserves (58 and 50%) suggests that quarries in the Berlin region have transformed into multifunctional spaces, accommodating both recreational activities and conservation efforts. This finding reflects Germany's societal and policy framework, which prioritizes environmental protection as a key national objective (Zong et al. 2023). In this way, Stone (2003) highlights that Germany's comprehensive environmental policies have deeply influenced all levels of society.

The identified categories of CES reveal variations in how these sites are perceived and used by Flickr users. Aesthetics consistently emerged as the most commonly observed cultural ecosystem service across the three regions (69% of posts). This finding reaffirms that quarries are often appreciated for their scenic beauty, which is consistent with the observations of Svobodova et al. (2023) and Baczyńska et al. (2018). However, significant regional differences in CES point to varied regional interactions with the quarry landscapes. In the Czech Karst region, for instance, social relations and recreational activities with animals were prominent (59 and 58% of posts), while the Danish Roskilde region emphasized spiritual activities and recreational sports (47 and 61%). In Germany, the sense of place was particularly pronounced (80% of posts), suggesting that quarries there are deeply integrated into the people–place relationships.

To the best of our knowledge, no other studies in our study regions have used social media data to evaluate the popularity of locations among social media users. Furthermore, no studies have specifically evaluated the social-ecological restoration of quarries using this type of data. The only notable exception is the study by Gillette and Boyd (2024), which analyzed tourist reviews on Trip.com, a Chinese-language social media platform, to explore Chinese tourists' perceptions of three coal mining heritage parks. To address the gap in research on the social-ecological restoration of quarries, we recommend that future studies explore how quarries compare to other restored social-ecological systems, both more broadly and within the context of our study regions. Expanding the geographic scope to include a variety of urban and peri-urban contexts would further enhance understanding of the role of quarries as rehabilitated landscapes.

Our approach offers a cost-effective and scalable method for assessing the social and ecological benefits of these spaces, making it a valuable tool for informing future restoration projects and management programs. To broaden the implications of our work, we recommend that future research explore the applicability of our findings across a wider array of restored landscapes, such as wetlands, forests, and coastal areas. This is particularly relevant given that, in recent years, only a limited number of studies have utilized geotagged social media data to support the planning, monitoring, and evaluation of social-ecological restoration efforts. For instance, Kaiser et al. (2021) investigated how visitors perceive restored rivers and the CES associated with these spaces. Their study focused on the restored Kishon River in Israel, analyzing social media posts from platforms such as Flickr, VKontakte, and Instagram. While they did not specifically examine landscape features as proxies for the extent of social-ecological restoration, their findings align with ours, demonstrating that secondary habitats created through restoration projects provide a wide range of CES.

### Methodological Insights

Our study responds to the growing demand for detailed data on social-ecological interactions in quarry landscapes (Olafsson et al. 2022; Maus & Werner 2024). With increasing interest in utilizing social media data to explore these interactions, this section presents key methodological insights gained from our research experience.

**Representativeness and Data Bias.** In our study, 23 out of 73 quarries were not found on Flickr, including 10 that are rehabilitated and open to the public. This lack of representation may be influenced by factors such as site accessibility and user participation on Flickr, a challenge previously noted by Daymond et al. (2023) and Martínez Pastur et al. (2016). Sociodemographic data about social media users are generally unavailable due to privacy regulations (Guerrero et al. 2016). However, other studies have reported that Flickr users in Finnish national parks were mostly men (79%) and only 10% of the users were women, who contributed only 4% of the photographs (Väisänen et al. 2021). The same study also reported that 62% of the users were locals and 33% were internationals. Hence, Flickr data may create spatial biases by over-representing men, popular, urban, and tourist locations while under-representing women and rural or less photographed areas.

**Data Quality and Completeness.** Many images on Flickr lack complete metadata, such as precise geotags or timestamps, making it difficult to accurately determine the context or location of the image. Authors such as Oteros-Rozas et al. (2018) and Gliozzo et al. (2016) highlight the frequent mismatch between what the photograph depicts and where it has been geotagged, either due to a poor quality in the location or to the distance

between the observer and the landscape object of the photographs. This presents a challenge in terms of data processing and analysis and requires more time-demanding cleaning and data processing procedures. In addition, Flickr's API and data access policies often restrict the amount of data that can be collected, which could limit the scope of analysis.

**Big Data Challenges.** The large volume of images and metadata can present challenges in terms of data storage, processing, and analysis, often requiring advanced computing resources (Erol et al. 2023). The presence of errors, irrelevant or noninformative images and tags (e.g. duplicates) can complicate analysis. Cleaning and organizing large datasets to remove these images can be time-consuming and technically complex.

**Cross-Disciplinary Challenges.** Research involving social media data often requires collaboration across disciplines (e.g. computer science, sociology, geography) and multidisciplinary expertise. Validating findings against ground truth data or other reliable sources can be difficult, particularly when dealing with user-generated content that lacks standardized formats.

**Behavioral Insights and Ecosystem Services.** Increasing numbers of studies demonstrate that analyzing social media interactions can uncover behavioral trends, such as outdoor recreational activities, wildlife interactions, and consumption patterns (e.g. Ginzarly et al. 2019; Rossi et al. 2020; Olafsson et al. 2021). This data can inform ecosystem management by linking human behaviors with environmental impacts. Social media data can also be used to identify and map ecosystem services valued by the public. Geotagged posts, photographs, and comments can support spatial planning and management by identifying hotspots of ecosystem services (e.g. Oteros-Rozas et al. 2018; Schirpke et al. 2021; Daymond et al. 2023). Although debates persist regarding the representativeness of social media data (Hollingshead et al. 2022), it provides in situ observations from a large, albeit demographically uncharacterized, segment of the population across diverse landscapes—something rarely achievable through traditional data collection methods.

This study demonstrates that restored quarries can evolve into vibrant social-ecological systems that provide diverse landscape features and CES. Once quarries become accessible, social media data become particularly valuable for understanding how and where people interact with these restored sites and what the social and ecological benefits are that they offer. This feedback can support quarry managers in making adaptive changes to site management and maintenance strategies and in reflecting on how visitors interact with these sites. Restoration success, after all, extends beyond initial re-establishment and includes the ongoing delivery and maintenance of both ecological and social benefits over time.

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