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OPINION

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iNaturalist projects represent a valuable resource for aggregating plant observations and engaging society: A case study of the Flora of Mongolia project

Shukherdorj Baasanmunkh[1] | Batlai Oyuntsetseg[2] | Zagarjav Tsegmed[1] | Altangerel Undruul[2] | Dariganga Munkhtulga[2] | Magsar Urgamal[3] | Nyamjantsan Nyambayar[4] | Chuluunbat Javzandolgor[3,5,6] | Chuluunbat Bayarmaa[7] | Dashdondog Narangarvuu[2] | Nyambayar Batbayar[7] | Kherlenchimeg Nyamsuren[3] | Tugsuu Namuulin[8] | Oyunbileg Munkhzul[9] | Ganbold Indra[10] | Gansukh Batsugar[11] | Erdenejargal Tsengel[12] | Young Moon Kim[1] | Corey T. Callaghan[13] | Hyeok Jae Choi[1]

[1]Department of Biology and Chemistry, Changwon National University, Changwon, South Korea

[2]Department of Biology, School of Arts and Sciences, National University of Mongolia, Ulaanbaatar, Mongolia

[3]Laboratory of Plant Taxonomy and Phylogenetic, Botanic Garden and Research Institute, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

[4]Laboratory of Vegetation Ecology and Economy, Botanic Garden and Research Institute, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

[5]State Key Laboratory of Systematic and Evolutionary Botany, Institute of Botany, Chinese Academy of Science, Beijing, China

[6]University of Chinese Academy of Science, Beijing, China

[7]Wildlife Science and Conservation Center of Mongolia, Ulaanbaatar, Mongolia

[8]Ikh Zos LLC, Ulaanbaatar, Mongolia

[9]Divisions of Forest Resources and Forest Protection, Institute of Geography and Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

[10]Chuluut Tul NGO, Ulaanbaatar, Mongolia

[11]Ecological Education Center, National University of Mongolia, Ulaanbaatar, Mongolia

[12]Green Nature Land LLC, Ulaanbaatar, Mongolia

[13]Department of Wildlife Ecology and Conservation, Fort Lauderdale Research and Education Center, University of Florida, USA

Correspondence
Corey T. Callaghan, University of Florida, USA.
Email: c.callaghan@ufl.edu
Hyeok Jae Choi, Changwon National University, South Korea.
Email: hjchoi1975@changwon.ac.kr

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Societal Impact Statement

Citizen science – collaboration between scientists and the public – has the potential to advance biodiversity monitoring. Using a case study from Mongolia, called the Flora of Mongolia project in iNaturalist, we illustrate how crowd-sourced biodiversity data fills gaps of plant diversity in Mongolia. Over 52,200 observations covering 2,241 species of vascular plants (ca. 3,050 species) were observed by 665 participants between 2019 and 2023, showcasing the vast potential for rapid

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biodiversity inventories. This case study, from an under-resourced region, illustrates the potential role of citizen science, and iNaturalist, in future biodiversity monitoring efforts.

Summary

At a time of alarming biodiversity loss, biodiversity monitoring is crucial. Yet, funding for such monitoring is difficult to attain, leading to data gaps of baseline biodiversity information in regions of the world that are often the most threatened. In Mongolia, there are limited resources for finding wild photos and distribution points of vascular plant species. Therefore, we established the Flora of Mongolia project in iNaturalist in January 2019 to fill the gap of quantifying the country's plant diversity. Over the course of five years, 665 participants have contributed 52,286 observations belonging to 2,241 species. To date, participants have already observed 69% of the estimated total vascular plant species (ca. 3,050 species) in Mongolia including numerous threatened and endemic species. The total number of observations in iNaturalist is now higher than both herbarium records from GBIF and FloraGREIF for Mongolia, showcasing the potential of crowd-sourcing data. The majority of species and observation numbers were observed in the western and central parts of Mongolia. This iNaturalist project is significantly expanding the capacity for data collection and analysis of vascular plants, highlighting the important role that customized iNaturalist projects can have in biodiversity data generation. As citizen science data collections continue to grow, we can expect them to play a significant role in further improving our knowledge of plant diversity, monitoring invasive species, and quantifying the impacts of climate change on rare and threatened plants.

KEYWORDS

citizen science, community science, flora of Mongolia, iNaturalist, online platform, vascular plants

1 | INTRODUCTION

Biodiversity is essential for maintaining ecological balance, supporting human livelihoods, and ensuring the sustainability of ecosystems. However, biodiversity has been declining more rapidly due to climate change, population growth, land use, resource overexploitation, and environmental pollution (Hochkirch et al., 2023). Such a decline in biodiversity highlights the need for robust biodiversity monitoring, especially in under-sampled regions. Recent efforts have aimed to identify plant diversity "darkspots" — areas predicted to harbor numerous undescribed and unrecorded species (Ondo et al., 2024), showcasing the potential mismatch between where biodiversity is and where we know about biodiversity the most. Additionally, several studies have summarized the conservation status of endemic plants (Gallagher et al., 2023), important plant areas (Kor et al., 2025), and geospatial conservation planning (Cobb et al., 2024) using literature and plant data sources worldwide. However, most of these studies lack information from under-sampled regions, such as Mongolia, due to limited data availability, incomplete georeferencing, and the absence of fully digitalized records.

Herbaria are valuable sources for understanding the knowledge of botanical diversity and have traditionally been the prominent source of information on the taxonomy of species and distribution (Davis, 2023). However, the value of photographed species as a new-age source of herbaria data is increasingly recognized (Mesaglio et al., 2023). Photographs can complement physical vouchered specimens, allowing for comprehensive documentation of large species (e.g., many tree species), and species that may be difficult to collect or preserve due to toxicity, spines, or stinging hairs (Gómez-Bellver et al., 2019). One of the most globally successful platforms in which photographs of plants are aggregated is iNaturalist (www.inaturalist.org; Seltzer, 2019) — a multitaxa platform whose goal is to encourage public participation in citizen science and promote biodiversity conservation. iNaturalist allows participants to contribute observations of any organism, or traces thereof, along with associated spatiotemporal data. Observations, which are photos of a single organism submitted by a user, are annotated by metadata such as date, time, location, whether the organism is captive/cultivated, taxonomic identification, and other user-defined data fields (Mesaglio & Callaghan, 2021). These data are increasingly used in biodiversity research, including documenting introduced species (Agarwal, 2017), estimating plant phenology (Barve et al., 2020), quantifying bird diversity (Callaghan et al., 2021), understanding the climate impact on flowering phenology (Puchałka et al., 2022), as well as documenting plant global trait patterns (Wolf et al., 2022) and fungal diversity (Filippova et al., 2023; Kherlenchimeg et al., 2024), and as a general measure of biodiversity baselines (Callaghan et al., 2022; Eckert et al., 2024; Kubentayev et al., 2024; López-Guillén et al., 2024; Mesaglio et al., 2023; Pitman et al., 2021; Seregin et al., 2020; Wenk et al., 2024; White et al., 2023).

Despite the increasing use of citizen science data in biodiversity research, it still remains less commonly implemented in low- and middle-income countries than in high-income countries (Requier et al., 2020). As of 2021, for example, Mongolia has hosted approximately 10 distinct citizen science projects (Batsaikhan et al., 2023). Despite the fact, Mongolia has a land area spanning over 1.5 million square kilometers, and stands as one of the largest landlocked countries in the world. In 2022, Mongolia's population was estimated to be around 3.3 million people. The country is divided into 330 soum belonging to 21 provinces. Citizen science is still relatively new in Mongolia and has recently increased, in part due to the activities of nonprofit organizations (NPOs), such as Public Lab Mongolia founded in 2018 (Neve et al., 2017). Very recently, Batsaikhan et al. (2023) revised the online citizen science across Mongolia based on the most available sources. As a result, citizen science projects have increased in recent years. But to better respond to citizen needs and environmental challenges, additional local projects must be developed.

Mongolia is renowned for its diverse landscapes, ranging from the Gobi Desert to mountainous regions, where a variety of plant species have adapted to thrive in different environmental conditions (Gunin et al., 1999). The flora of Mongolia exhibits remarkable adaptability to the harsh climatic conditions of the country, which are characterized by extreme temperatures, aridity, and high altitudes (Hilbig, 1995). To date, approximately 3,050 native vascular species, belonging to 653 genera and 111 families, are known from Mongolia (Baasanmunkh, Urgamal, Oyuntsetseg, Sukhorukov, et al., 2022; Munkhtulga et al., 2025). In addition, approximately 65 non-native vascular plant species belonging to 44 genera have been recognized in Mongolia (Baasanmunkh, Urgamal, Oyuntsetseg, Sukhorukov, et al., 2022; Undruul et al., 2023). Among these, about 100 species and 275 species are endemic and subendemic (the species was previously endemic in Mongolia but also occurs in adjacent countries) respectively (Baasanmunkh, Urgamal, Oyuntsetseg, et al., 2021; Baasanmunkh, Urgamal, Oyuntsetseg, Sukhorukov, et al., 2022). Furthermore, approximately 640 species (representing 21% of the 3,050 native species) of vascular plants have been evaluated using regional red lists in Mongolia (Baasanmunkh et al., 2024; Baasanmunkh, Oyuntsetseg, Efimov, et al., 2021; Nyambayar et al., 2011; Oyuntsetseg et al., 2018; Urgamal et al., 2019, 2024). Among these, 390 and 250 species were classified as threatened with extinction (Critically Endangered, Endangered, and Vulnerable) and non-threatened, respectively.

The recent publication of "Illustrated Flora of Mongolia" (Oyuntsetseg et al., 2022) highlights a significant stride in botanical documentation, yet we suggest that the true potential of photographic records, particularly from citizen science platforms, remains underutilized. We use a case study of a project "Flora of Mongolia" in Mongolia, hosted on the iNaturalist platform, to illustrate our main points. First, we illustrate this point by documenting and quantifying the large percentage of vascular plants, including endemic, subendemic, and threatened that have been photographed, uploaded, and identified in the iNaturalist project. Second, we conducted a detailed analysis of species richness and observation density at the provincial level and protected areas, highlighting a more nuanced view of the plant diversity that defines Mongolia. Third, we discuss how these observations supplement traditional methods, recognizing their role in shaping a more robust future for plant science in Mongolia and beyond.

2 | DEVELOPMENT OF AN INATURALIST PROJECT

On 16 January 2019, the Flora of Mongolia project (https://www.inaturalist.org/projects/flora-of-mongolia) was created on iNaturalist by S. Baasanmunkh who is the first author of this study. This project is focused on the diversity of vascular plants including native and non-native plants based on photo observations in Mongolia. After establishing our project, we introduced the project to Mongolian botanists, amateur botanists, and citizen scientists via the Facebook platform such as the "Flora of Mongolia" Facebook group (https://www.facebook.com/groups/331460460390584). In addition, we added all Mongolian names for all available species to help encourage participation by local participants.

3 | DATA ANALYSIS ON AVAILABLE ONLINE SOURCES

We first downloaded all raw data of observations sorted by family, genera, and species level from iNaturalist (accessed on 22 December 2023). A total of 52,286 observations belonging to 2,241 species were downloaded. After removing duplicate records and cultivated observations, we compiled 46,789 observations which were used for species richness and observation intensity analysis in this study.

Second, we checked and downloaded only herbarium data from the Global Biodiversity Information Facility (GBIF), excluding observation records of iNaturalist by filtering for preserved specimens in GBIF. A total of 47,700 herbarium specimens, including many old herbaria collected from Mongolia, are being mobilized in GBIF (https://www.gbif.org/country/MN/summary), mainly from Russia and other countries (Kovtonyuk et al., 2020; Seregin, 2016). We then cleaned the duplicate and ungeoreferenced records of herbarium data of GBIF, with 19,880 records remaining.

Third, we checked the herbarium information from the Virtual Guide to the Flora of Mongolia (FloraGREIF; https://floragreif.uni-greifswald.de/floragreif/). This web project intends to provide an

FIGURE 1 General overview of the Flora of Mongolia project on iNaturalist. (a) Most observed top 10 plants. (b-d) Distribution of selected most common and rare species. (b) *Sanguisrobia officinalis*. (c) *Larix sibirica*. (d) *Potanina mongolica*. (e–k) Selected endemic and rare plants in Mongolia from iNaturalist: (e) *Adonis mongolica* (@oyunaa), (f) *Astragalus sanczirii* (@oyunaa), (g) *Lagopsis darwiniana* (@bayarmaa), (h) *Limonium klementzii* (@munkhtulga), (i) *Tanacetum changaicum* (@baasanmunkh), (j) *Galitzkya macrocarpa* (@baasanmunkh), (k) *Saussurea dorogostaiskii* (@baasanmunkh).

information source of vascular plants for botanists, plant ecologists, and others. Approximately 13,000 herbarium collections were available in the FloraGREIF (Rilke et al., 2013) mainly from herbaria in Germany. We used only the species number and collection information of FloraGREIF (accessed on 22 December 2023) derived from Rilke et al. (2013). In addition, several photos of vascular plants from Mongolia are exported into the Plantarium (https://www.plantarium.ru/lang/en.html), however, we did not include it in this study due to its difficulty in obtaining species and photo observation numbers.

We used geographic information system data of protected areas (downloaded from the World Database on Protected Area (https://protectedplanet.net/, accessed on 22 December 2023) to determine the extent to which species and observations were included in the protected areas. We excluded natural monuments, which are a category of protected areas in Mongolia, as they usually cover small areas and are primarily dedicated to the preservation of historical and cultural heritage.

Finally, we analyzed the species and observations of richness diversity based on both observations and species of iNaturalist in the province and protected areas across Mongolia. In addition, we analyzed the richness of both observations and herbarium specimens of iNaturalist and GBIF using $0.5^\circ \times 0.5^\circ$ grid cell size (approximately 50×50 km^2) in Mongolia, respectively. Because, this grid cell size is more suitable for species occurrence data in the country (Baasanmunkh, Urgamal, Oyuntsetseg, et al., 2021; Kherlenchimeg et al., 2024; Urgamal et al., 2024). We also examined the time periods of herbarium specimens and observation records of GBIF and iNaturalist, respectively.

4 | LEVERAGING CROWD-SOURCED DATA TO EXPAND BIODIVERSITY KNOWLEDGE OF MONGOLIAN FLORA

During the five years that the project has thus far been running, over 630 participants observed 52,286 photo observations of 2,241species on the Flora of Mongolia project in iNaturalist (Figure 1; https://www.inaturalist.org/projects/flora-of-mongolia?tab=observations). Seventy-five percent of all observations were provided with the research grade (RG) score, identified by 921 experts worldwide. The remaining 25% of observations currently need research ID. Furthermore, a total of 19,495 observations from iNaturalist were successfully entered on the GBIF platform (https://www.gbif.org/occurrence/search?basis_of_record=HUMAN_OBSERVATION&country=MN&taxon_key=6; accessed on 14 Sep 2023). All data observations were available under licenses (CC0, CC-BY, CC-BY-NC) and they can be used in various research topics in the future. This high level of engagement demonstrates how citizen science when paired with accessible digital tools, can rapidly fill long-standing biodiversity data gaps in under-resourced regions (Fantaine et al., 2021).

In comparison to the checklist of vascular plants in Mongolian (Baasanmunkh, Urgamal, Oyuntsetseg, Sukhorukov, et al., 2022), the current photo observations of species number share about 69% of the total Mongolian flora. For endemic plants, about 100 species and 275 species are endemic and subendemic to the country, respectively (Baasanmunkh, Urgamal, Oyuntsetseg, et al., 2021; Baasanmunkh, Urgamal, Oyuntsetseg, Sukhorukov, et al., 2022). Among these, 35 (35%) and 133 (48%) species with endemic and subendemic species were photographed in iNaturalist, respectively (Figure 1f–j). For example, some photographs of endemic plants were *Astragalus sanczirii* N.Ulziykh. (Figure 1f; https://www.inaturalist.org/observations?place_id=7347&taxon_id=1226185), *Lagopsis darwiniana* Pjak (Figure 1g; https://www.inaturalist.org/observations?place_id=7347&taxon_id=919523) and *Limonium klementzii* Ikonn.-Gal. (Figure 1h; https://www.inaturalist.org/observations?place_id=7347&taxon_id=1153181).

For non-native plants, approximately 65 non-native vascular plant species belonging to 44 genera have been recognized in Mongolia (Baasanmunkh, Urgamal, Oyuntsetseg, Sukhorukov, et al., 2022; Undruul et al., 2023). Among these, 36 species were photographed in the Flora of Mongolia project. Furthermore, several non-native species were photographed in iNaturalist which were currently not recorded in the country. Therefore, further taxonomic studies are needed on unknown non-native species.

Since 2011, approximately 640 species (representing 21% of the 3,040 native species) of vascular plants have been evaluated using regional red lists in Mongolia (Baasanmunkh, Oyuntsetseg, Oyundari, et al., 2021; Nyambayar et al., 2011; Oyuntsetseg et al., 2018; Shukherdorj et al., 2019; Urgamal et al., 2019). Among these, 390 and 250 species were classified as threatened (critically endangered, endangered, and vulnerable) and non-threatened, respectively. In general, about 235 threatened species were well documented in the Flora of Mongolia project in iNaturalist.

The majority of observations were observed between July and September due to Mongolia's peak plant flowering season (Figure 2a). Furthermore, several observations were observed in the remaining months, but the majority of them were trees and shrubs as participants have been observing the observations of trees and shrubs during winter and spring seasons.

Most species were observed very few times; particularly one to five observations (Figure 2b). Over 100 species, which are widely distributed, observed more than 100 observations in Mongolia (Figure 2b). For instance, 576 observations and 139 herbarium specimens of *L. sibirica* Ledeb (Pinaceae) were found on iNaturalist and GBIF, respectively (Figure 1c). Recently, researchers have not collected herbarium specimens of wide ranged-distribution species (Meyer et al., 2016). Thus photo observations of common species are filling the distribution location.

Most herbarium specimens (over 2000 herbarium specimens) were collected between 1974 and 1980 in GBIF (Figure 3a,b). For iNaturalist, the number of observations has increased dramatically in the last three years (Figure 3a). In 2022, for example, over 14 K observations were uploaded to the Flora of Mongolia project (Figure 3a).

5 | INATURALIST FILLS GAPS COMPARED WITH OTHER TRADITIONAL SOURCES

To date, online sources the information on species' wild photos and occurrence data are relatively low in Mongolia. Researchers have been predominantly using the FloraGREIF platform for various studies such as the taxonomic revision, distribution map, and conservation (Baasanmunkh et al., 2023; Baasanmunkh, Oyuntsetseg, Oyundari, et al., 2021). Unfortunately, the plant records and information have not been updated in FloraGREIF since 2012. In addition, the majority of herbarium specimens in the country were not fully georeferenced, digitalized, and online yet. Because small herbaria are often poorly

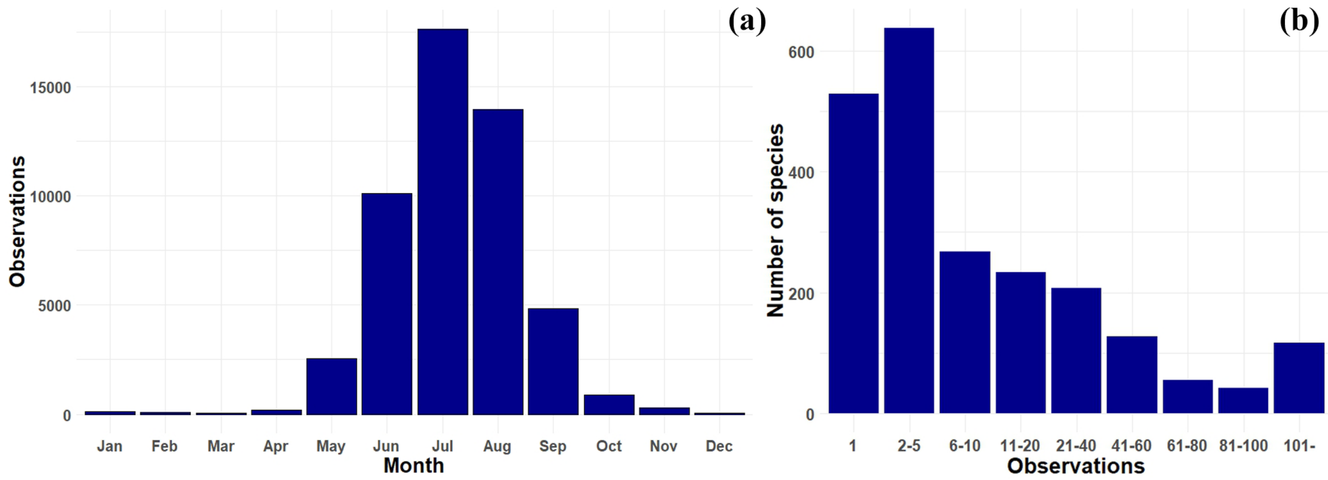

FIGURE 2 Observations records in Flora of Mongolia based on (a) histogram of observations for each species in months and (b) observation records of iNaturalist.

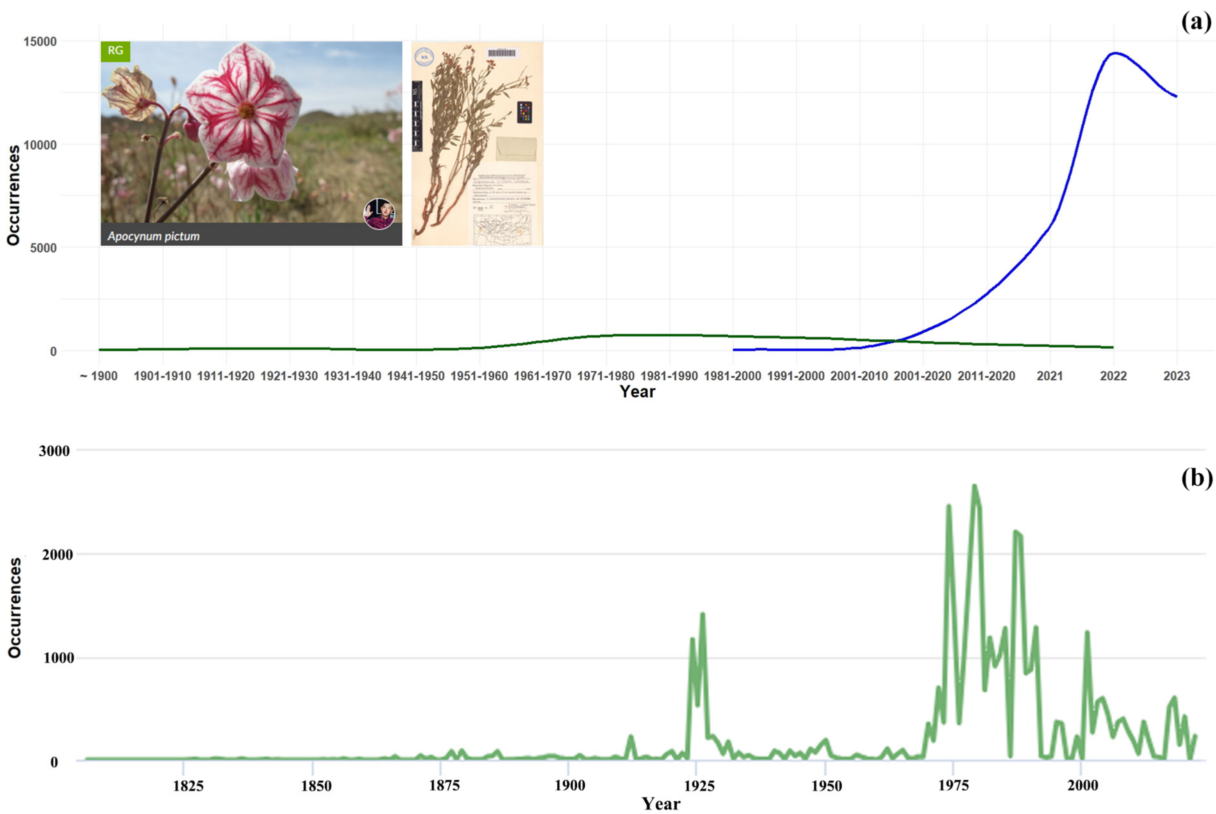

FIGURE 3 Comparison of collection occurrences and time periods between iNaturalist and GBIF. (a) Occurrence records (green lines) and observation records (blue line) from GBIF and iNaturalist, respectively. (b) Enlarged view of GBIF specimen records.

funded, operate with minimal staff, and are predominantly used for education within a limited geographical region (Harris & Marsico, 2017). In Mongolia, for example, herbarium collections (approximately 120,000 specimens) of Mongolian vascular plants have been stored in the three main herbaria of the Mongolian Academy of Science (UBA), National University of Mongolia (UBU) and Khovd University since 1950 (Urgamal, 2018).

In this study, we compared the current number of plant species and observations with two online sources including GBIF and Flora-GREIF (Figure 4). For instance, the vascular plant checklist in Mongolia was gathered from Baasanmunkh, Urgamal, Oyuntsetseg, Sukhorukov, et al. (2022). But the number of observations in iNaturalist is higher than in the two online sources (Figure 4b). While the species number of iNaturalist is relatively less than GBIF but higher than

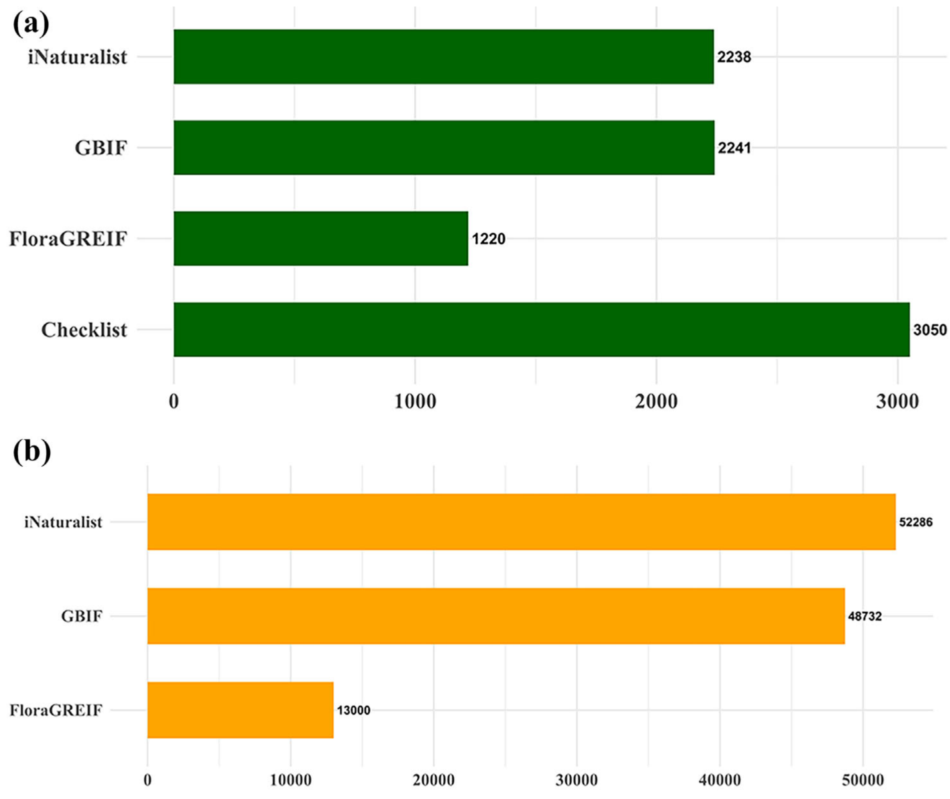

FIGURE 4 Comparison of number of (a) species and (b) observations between online sources from Mongolia.

FloraGREIF (Figure 4a). In contrast, the Flora of Mongolia project, which began in 2019, has more observation when compared to the online sources. This shift in data volume highlights the growing role of community-generated data as a complementary resource to traditional institutional repositories, particularly in regions with limited infrastructure. We feel that it is important to continue to support these digital repositories, such as iNaturalist, which allow for these data gaps to be filled.

6 | PATTERNS OF BIODIVERSITY AND OBSERVATIONS THROUGHOUT MONGOLIA

We removed 27,820 herbarium specimens (a total of 47,700 downloaded herbarium specimens) from GBIF due to inaccurate coordinates or duplicate records. In particular, the majority of removed records (58%) were removed because they did not have coordinates. For observations of iNaturalist, we removed 5,497 observations (a total of 52,286 downloaded observations) which were mostly duplicate records, because most observations were well georeferenced by citizen scientists. The observations of iNaturalist are more evenly distributed across the country (Figure 5a). In particular, four grids have over 5,000 observations which are located around Ulaanbaatar city and Bogd Khan protected areas (Figure 5a). While the herbarium specimens of GBIF data show localized clusters of high-density records, particularly in the west and northeast of Mongolia (Figure 5b). The highest herbarium collections were collected in the central part of Mongolia (Figure 5b). In addition, the majority of herbarium collections were collected in the Altai mountain ranges which is a high-diversity region compared to other regions (Baasanmunkh, Urgamal, Oyuntsetseg, Sukhorukov, et al., 2022).

Both species and observations richness of iNaturalist were unevenly distributed across provinces and protected areas in Mongolia (Figure 5). Generally, the northern and western provinces tend to have higher species richness and observation intensity, while southern desert provinces have lower species richness (Figure 6). We identified, that the three provinces including Tuv, Khuvsgul, and Khovd had a high diversity of species richness (Figure 6a). Similarly, the majority of observations were photographed in Tuv, Khuvsgul, Khovd, and Khentii provinces (Figure 5b). Overall, species richness and observation intensity were greatest around Ulaanbaatar city due to its numerous populations, representing half of human populations living in this city. These spatial patterns likely reflect both biodiversity hotspots and accessibility for participants, but teasing the differences between these two apart can be difficult. Nevertheless, our findings illustrate the potential for targeted campaigns in remote regions to ensure equitable data coverage. One way this can be achieved is through adaptive sampling – where participants are encouraged to sample in specific regions using behavioral nudges (Callaghan et al., 2019, 2023).

In Mongolia, the protected areas have been quite well-established (Farhadinia et al., 2022). The country has protected 20.1% of its

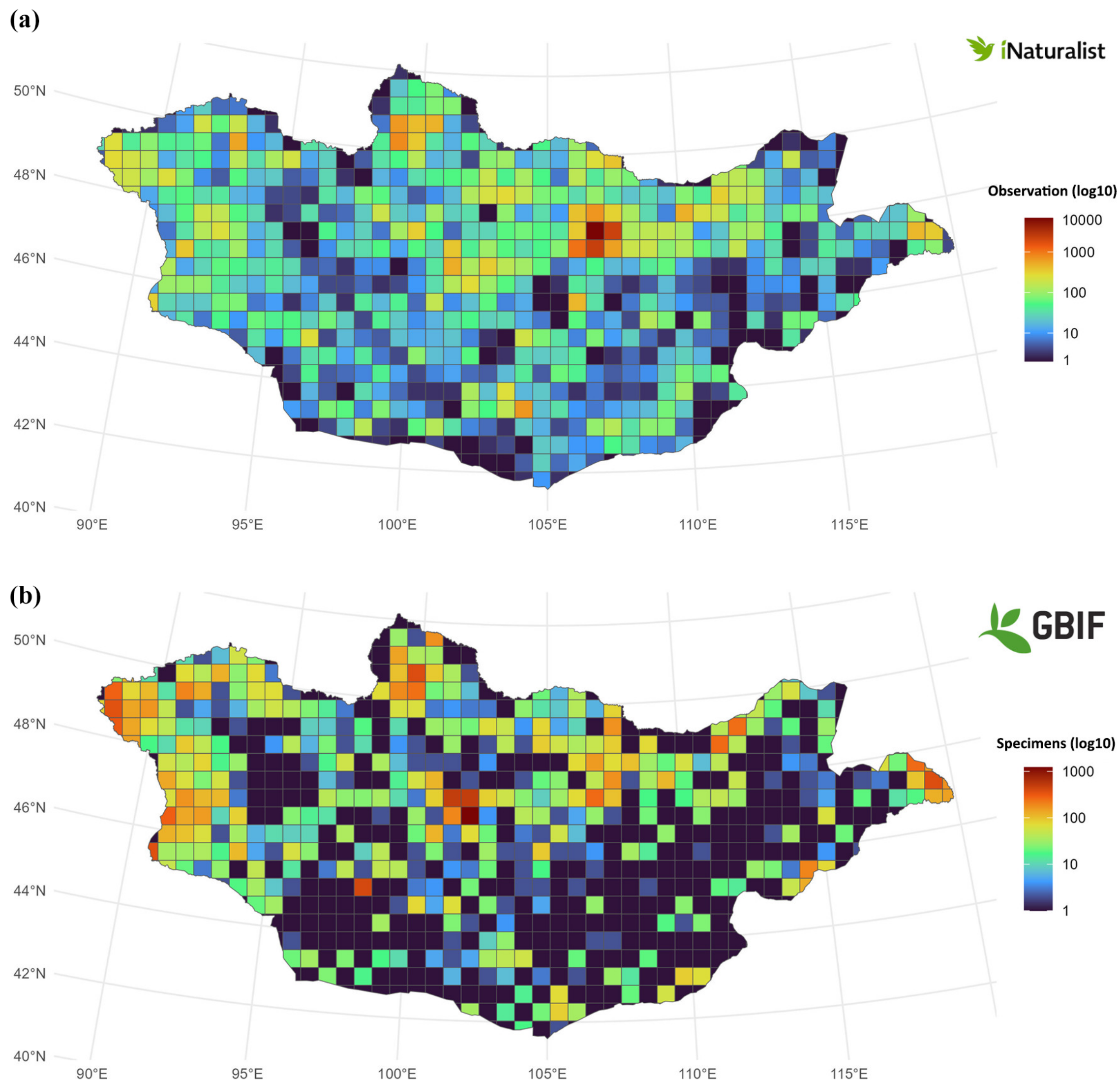

FIGURE 5 Observation and specimen richness of vascular plants in Mongolia. (a) Observation records of iNaturalist. (b) Specimen records of GBIF.

territory (30.27 million ha) under four categories of PAs; strictly protected areas (SPA), national parks (NP), nature reserves (NR), and natural monuments (NM). However, the majority of protected areas are missing information on vascular plant diversity except Great Gobi B SPA (Baasanmunkh, Oyuntsetseg, Oyundari, et al., 2021), Bogd Khan SPA (Bazarragchaa et al., 2022), Hustai NP (Tserendulam et al., 2018) and Sutai NR (Gundegmaa et al., 2022). In this study, we identified five protected areas with a high diversity of both species and observation records of the Flora of Mongolia project in iNaturalist across the country (Figure 6c,d). Among these, the Bogd Khan SPA is the most diverse in both species and observations. In addition, Bogd Khan SPA is a highly diverse area of vascular plants (Bazarragchaa et al., 2022). However, several protected areas exhibited relatively low diversity in both species and observations (Figure 6c,d). This is likely because citizen scientists have limited access to these protected areas, particularly those located near border regions of Mongolia.

7 | EMBRACING DIGITAL RECORDS FOR VASCULAR PLANT RESEARCH

The Flora of Mongolia project, highlights the value of digital records, becoming the most species-rich database for Mongolian flora in a relatively short period of time. In the past two years, research using the digital records of vascular plants has illustrated the potential of this platform and mechanisms for crowd-sourcing biodiversity data (Baasanmunkh, Oyuntsetseg, Tsegmed, Oyundelger, et al., 2022; Baasanmunkh, Oyuntsetseg, Tsegmed, Urgamal, et al., 2022; Baasanmunkh et al., 2023; Kherlenchimeg et al., 2024; Undruul et al., 2023; Urgamal et al., 2024). For example, Urgamal et al. (2024) studied the species pattern analysis on the Apiaceae family which included 3,062 occurrences records from the herbarium (2,015 points) and iNaturalist data (1,047 points), highlighting how data from iNaturalist are filling the gaps for species richness analysis (Urgamal et al., 2024). There have also been about 50 species of previously unknown vascular

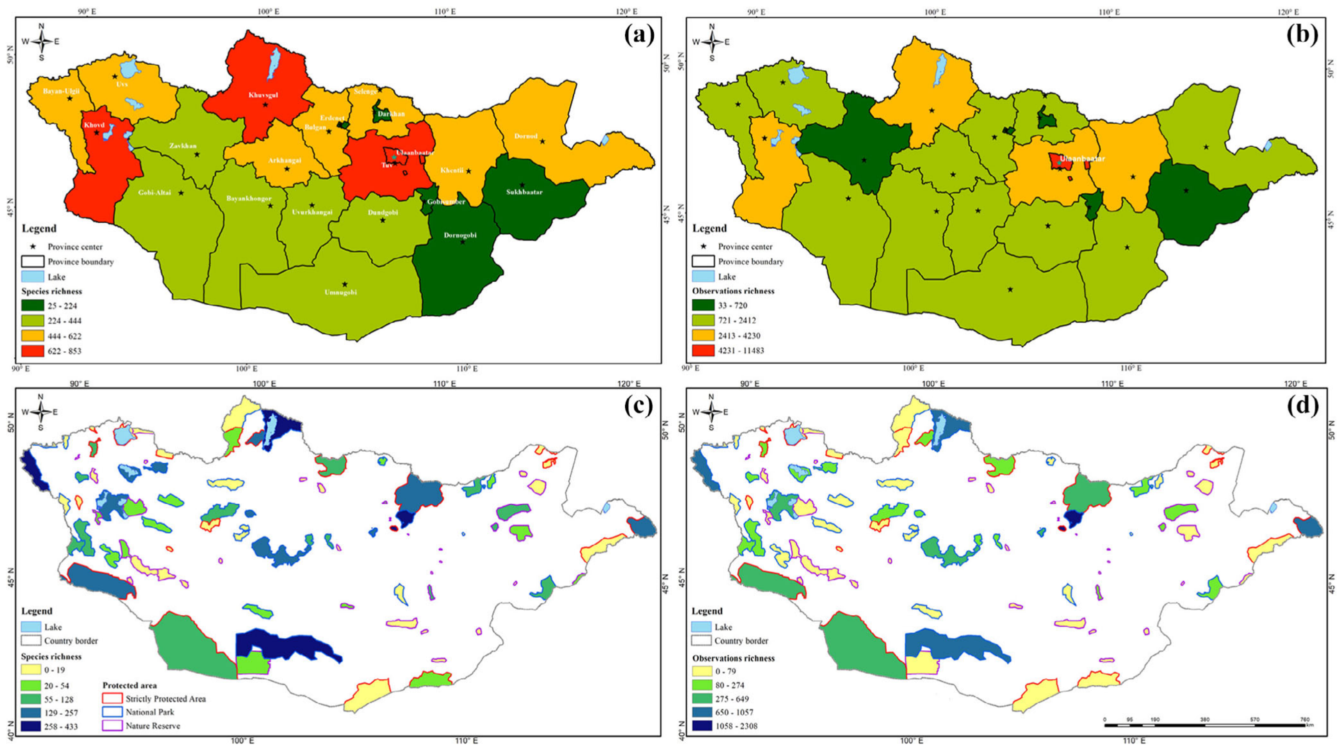

FIGURE 6 The richness of species and observations of the Flora of Mongolia project in iNaturalist across Mongolia. (a) Species richness in the province. (b) Observations richness in the province. (c) Species richness in protected areas. (d) Observations richness in protected areas.

plants which are identified as new records of the Mongolian flora. In particular, *Hordeum jubatum* L., observed since 2017 in the Flora of Mongolia project, was a new alien record in Mongolian flora (Undruul et al., 2023).

8 | CONCLUSIONS

Since 2019, the Flora of Mongolia project has emerged as the most species-rich platform in Mongolia. For instance, the total number of observation records in the Flora of Mongolia project is now higher than two online sources. Moreover, an increasing number of participants, including tourists, amateur botanists, and university students, are joining the Flora of Mongolia project in iNaturalist. Because the project can provide educational resources such as field guides, species descriptions, and tutorials on plant identification, it has created a valuable resource of biodiversity data. These resources help participants develop their botanical knowledge and skills, enhancing their learning experience. Furthermore, participants likely receive feedback on their observations and contributions, which helps them improve their skills and understanding of plant taxonomy and ecology (Mesaglio & Callaghan, 2021). The case study we present here provides a potential model for scaling up biodiversity monitoring in other under-sampled regions, especially where traditional resources like herbaria and formal monitoring programs are limited and securing the necessary funding can be difficult. The success of this project illustrates that citizen science platforms — when combined with targeted outreach, data curation, and regional expertise — can generate valuable biodiversity datasets. The generalizability of iNaturalist to have a global platform, but with localized customizability, has allowed this project to succeed, and we suggest that future efforts in Central Asia and another biodiversity "darkspots" could benefit from adopting similar approaches, customized to local flora, languages, and community structures.

AUTHOR CONTRIBUTIONS

S.B designed the study and wrote the manuscript. S.B. Z.T. and Y.M.K analyzed data. S.B. and C.T.C revised and edited the manuscript. H.J.C supervised and revised the manuscript. B.O., A.U., D.M., M.U., N.N., C.J., C.B., D.N., N.B., K.N., T.N., O.M., G.I., G.B., and E.T data curated and participated in discussion with S.B.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All data available on iNaturalist platfrom (https://www.inaturalist.org/projects/flora-of-mongolia).

ORCID

Shukherdorj Baasanmunkh https://orcid.org/0000-0003-4224-9376
Batlai Oyuntsetseg https://orcid.org/0000-0003-3772-3301
Zagarjav Tsegmed https://orcid.org/0000-0002-6024-4918
Altangerel Undruul https://orcid.org/0000-0002-3804-1161
Dariganga Munkhtulga https://orcid.org/0009-0009-0175-203X
Magsar Urgamal https://orcid.org/0000-0002-8827-8239
Nyamjantsan Nyambayar https://orcid.org/0000-0002-5726-5195
Chuluunbat Javzandolgor https://orcid.org/0000-0003-1158-3291
Chuluunbat Bayarmaa https://orcid.org/0009-0006-4777-1787
Dashdondog Narangarvuu https://orcid.org/0000-0002-5613-4740
Nyambayar Batbayar https://orcid.org/0000-0002-9138-9626
Kherlenchimeg Nyamsuren https://orcid.org/0000-0003-4235-5339
Tugsuu Namuulin https://orcid.org/0000-0002-4796-2085
Oyunbileg Munkhzul https://orcid.org/0000-0002-4399-416X
Ganbold Indra https://orcid.org/0000-0003-0418-9018
Gansukh Batsugar https://orcid.org/0009-0000-5174-6708
Erdenejargal Tsengel https://orcid.org/0009-0000-2168-0947
Young Moon Kim https://orcid.org/0000-0002-5325-603X
Corey T. Callaghan https://orcid.org/0000-0003-0415-2709
Hyeok Jae Choi https://orcid.org/0000-0001-6315-0071

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