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New records and conservation insights for *Breutelia chrysocoma* (Hedw.) Lindb. in Spain, aided by a citizen science platform

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ABSTRACT

Introduction. *Breutelia chrysocoma* (Hedw.) Lindb., the only *Breutelia* species in continental Europe, was previously considered nearly extinct in Asturias (Spain) after the loss or non-confirmation of most historical localities. Given that bryophytes are taxonomically challenging and specialists are scarce, crowdsourced biodiversity portals may provide a useful complementary source of records to support monitoring and conservation assessments. **Methods.** Casual observations submitted to iNaturalist were used to guide fieldwork, leading to the discovery and documentation of additional localities. This collaboration enabled the implementation of a census for population monitoring of the taxon, using a standardised methodology that also provides population size estimates for bryophytes and the re-evaluation of its conservation status following IUCN standards.

Key results and conclusions. New localities substantially increase the known population of *Breutelia chrysocoma* in Asturias. The resulting data allow for a more accurate assessment of the species' conservation status in Spain and offer further justification for its classification as a Critically Endangered species. These findings underscore the potential benefits of using crowdsourced biodiversity portals to enhance monitoring and conservation.

KEYWORDS

Bartramiaceae; census; extinction risk assessment; iNaturalist; IUCN

Introduction

Plant identification is a complex skill that requires deep knowledge, extensive expertise, and years of training (Alberdi et al. 2000; Stagg and Donkin 2013; Kirchoff et al. 2014). Accurate species identification is essential for biodiversity assessment and conservation efforts (Ely et al. 2017); however, the availability of expert botanists is often a limiting factor. The volume of biodiversity data that needs to be processed far exceeds the capacity of specialists to handle it, limiting the effective monitoring of species distributions, and the detection of rare, endangered, or invasive taxa (GBIF Secretariat 2020; Engel et al. 2021; Páll-Gergely et al. 2024). This challenge is particularly pronounced for organisms that are inherently difficult to identify, such as bryophytes, whose accurate determination often requires microscopic examination. The lack of specialists and adequate funding, coupled with the technical difficulties of identification, has led to significant gaps in biodiversity knowledge for these groups (Troutet et al. 2017).

In this context, the emergence of automated plant identification algorithms has provided both opportunities and challenges for biodiversity research. Platforms such as iNaturalist (<https://www.inaturalist.org>) and Pl@ntNet (<https://identify.plantnet.org>) have

democratised species documentation by crowdsourcing biodiversity observations from a global community of users (Campbell et al. 2023). These platforms integrate automated species identification algorithms based on deep-learning models trained on large community-created datasets of labelled plant images. The models extract key visual features from uploaded images and compare them against a reference database, ranking potential species matches based on similarity scores. Importantly, these platforms incorporate community validation, where users (including many experts) refine identifications and contribute to improving dataset accuracy over time (López-Guillén et al. 2024).

As scientific tools, these platforms have significantly contributed to the improvement of species distribution knowledge and have ignited collaboration between professional scientists and amateur naturalists through citizen science initiatives (e.g. White et al. 2023; Pernat et al. 2024). Their contribution to educating the public about biodiversity has also been emphasised (Schmidt et al. 2022). However, they also present limitations. The accuracy of identification algorithms is highly dependent on the quality and representativeness of the training dataset; misidentifications are common when reference data are incomplete or biased. Additionally, the taxonomic

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coverage of these platforms is uneven. Cryptogams, including bryophytes, are notably under-represented, and accurate identifications for these groups are less frequent than for vascular plants (Cerrejón et al. 2025). Despite these limitations, the ability of thousands of users to continuously upload observations represents a valuable opportunity for biodiversity research. Specialists can use these datasets to detect overlooked populations and refine conservation assessments.

Breutelia (Bruch & Schimp.) Schimp. (Bartramiaceae) is a genus of mosses currently comprising 87 accepted species worldwide (Brinda and Atwood 2025), of which only *Breutelia chrysocoma* (Hedw.) Lindb. occurs in continental Europe.

Breutelia chrysocoma is an acrocarpous, dioicous, robust moss with erect-to-decumbent, irregularly branched, reddish-brown stems, densely tomentose at the base (Cano et al. 2012), and stem leaves with longitudinal folds along the lamina (Cano 2010) (Figure 1). It is distinguished from other species of the genus by its rhomboidal stem leaves arranged in a star-like pattern, strongly plicate, tightly sheathing at the base with sulcate pockets at the shoulders, with alar cells thick-walled but not inflated (I.L., personal observation) and serrulate margins extending from the apex to the lower third. These plants inhabit moist and shady slopes, generally on north-facing heaths and grasslands between 100 and 1300 m in altitude (Cano et al. 2012). They are long-cycle perennials (During 1979, 1992) with an 11- to 25-year generation time (Bergamini et al. 2019). Their reproduction is rarely sexual, mostly relying on the vegetative dispersion of branch and leaf fragments (Cano et al. 2012).

Breutelia chrysocoma is an oceanic species, probably endemic to Europe, that is abundant in the British Isles and southwestern Scandinavia but rare and isolated elsewhere (GBIF Secretariat 2025). It has been reported in nine countries, including Norway (Jorgensen 1972), Denmark (Faroe Islands) (Carlsbergfondet 1908), Switzerland (Frahm and Lüth 2010), the UK (Blockeel et al. 2014), Ireland (Hodgetts and Lockhart 2020), France (Auvergne, Bretagne, Corsica and Pyrenees) (Sotiaux et al. 2007a; Hugonnot et al. 2013, 2016) and Spain (Cantabrian Mountains), but is considered extinct in Belgium (Sotiaux et al. 2007b; Hodgetts 2019) and Germany (Ludwig et al. 1996; Hodgetts 2019). It has also been cited in Azores (Frahm 2011).

In Spain, until 2012, *Breutelia chrysocoma* was restricted to five localities (Table 1) in the Cantabrian Mountains (Cordillera Cantábrica), three in the province of Asturias (Simó 1970; Simó and Vigón 1977; Cano 2010), one in Cantabria (Heras and Infante 1990) and another in Vizcaya (Heras et al. 2000). However, during the last update of the conservation status of this taxon in Spain (Cano et al. 2012), only the one in Vizcaya could be confirmed, consisting of few sterile individuals in a small area and with no apparent threats. However,

this population has not been reviewed since 2010. At two of the other four localities, the species is very likely extinct due to the construction of a parking lot (Covadonga, Asturias) and habitat disturbance (Monte Zalama, Cantabria) (Cano et al. 2012). The populations at these localities were not actually measured, but Simó (1970) estimated that in the Covadonga area the species covered about 50 m². The species was not found at the two remaining Asturian localities (Peña Mayor and Rales) in 2012, but it was not considered extinct, due to the persistence of suitable habitat. Therefore, at least two isolated subpopulations were considered to exist: one in Asturias at two possible localities, and another in the Basque Country at one locality. Later, in 2016, a new population was found in the Purón river (Asturias), being so far the most recently observed (M. Infante, Conservatoire Botanique National des Pyrénées et de Midi-Pyrénées, and P. Heras, Museo de Ciencias de Álava, personal communication, 2025).

The loss of occupancy/presence at four of the six known localities (two clearly extinct and two undetectable) represents, to date, a 66% decline over three generations, considering a generation as 25 years in this case study.

This moss is included in the *IUCN Red List of Threatened Species* (Hodgetts 2019; Hodgetts and Lockhart 2020) under the category of Least Concern (LC) for Europe and the world (considered at risk in France). By contrast, in the *Red List of Threatened Bryophytes of Spain* (Brugués and González Mancebo 2012, 2014) and the *Atlas and Red Book of the Threatened Bryophytes of Spain* (Garilleti and Albertos 2012) it is under the category of Critical Risk (CR) following B2ab(ii, iii, iv) IUCN criteria. This species was already listed in the first *Red List of bryophytes of the Iberian Peninsula* under the category of Vulnerable (Sérgio et al. 2007). The Basque population has been regionally protected since 2013 (BOPV 2013) catalogued as 'Endangered' (EN). However, it is not protected in Cantabria or Asturias, and there is no nationwide legal protection for the species as it is not included in the *Spanish Catalogue of Threatened Species* nor the *List of Wild Species under Special Protection Regime* (BOE 2011).

The 2012 expert assessment of *Breutelia chrysocoma* in Spain reported evidence of population loss and an estimated population size much reduced. The authors of the assessment recommended further studies on this species to enable better understanding of its population dynamics (Cano et al. 2012). Identified or potential threats include habitat alteration (such as human constructions and vegetation succession), overgrazing and other livestock-related activities, as well as population fragmentation.

In this context, the objectives of this study were to: (i) document new localities of *Breutelia chrysocoma* in Asturias (northern Spain) arising from iNaturalist observations and update its known regional distribution; (ii)



Figure 1. *Breutelia chrysocoma* in Asturias, Spain. The first row shows the general appearance of the plant in its natural habitat. The second row presents a closer view, highlighting distinctive features such as the antheridial cups on the left and the reddish colouration of the stems. The final row provides close-up details of the plant's characteristic orange rhizoids at the base of the stems and its clasping, strongly plicated leaves. Photographs: Irene Lafuente López.

implement a standardised census for bryophyte population monitoring that also provides population size estimates; and (iii) use these data to refine the assessment of the species' conservation status in Spain.

Material and methods

Detection of new populations

In early 2024, we detected on iNaturalist some observations of *Breutelia chrysocoma* in Asturias uploaded by Miguel Ángel Casado, a retired botanist and very active user of the platform (but with no experience in bryology) who identified preliminarily the bryophyte observations according to the first match produced by the iNaturalist algorithm. While in one case, the algorithm had correctly identified the photograph as a *Breutelia*, in other instances the best match was a moss from a different genus that was later correctly reidentified by other community members with a bryological background. None of these localities had been

previously recorded in the bryological literature, and the first of these records was uploaded during the 2021 I Biomaratón de Flora Española. We contacted M. A. Casado to gather more detail about these localities and designed a field study to characterise and assess them.

During the final stages of writing this article, another observation of *Breutelia chrysocoma* in Galicia (A Coruña, Cedeira) was reported, via iNaturalist, by *george_wildlife*. Although the relevant photograph seems to correspond with the species, it was not possible to find the specimen in the field. The species is not likely to be abundant at the locality, as in the image the moss looks rather scarce and is mixed among grass, not forming a big mat. Therefore, the possibility of extending the census to this locality had to be discarded.

Population census

Identification of individuals is challenging and inefficient in many plant groups, including bryophytes.

Therefore, we used ‘core’ or ‘mat’ as the sampling unit during the census and refer to locality as a site with one or more cores in close proximity to each other and more than 1 km away from other localities. Whenever several mats were found nearby but not strictly continuous, they were considered a single mat with a degree of fragmentation if the distance between them was less than one quadrat of 25 cm × 25 cm. By contrast, if more than one quadrat could be placed between patches, the patches were considered as two separate cores or mats (see Figure 2). The number of cores within each locality and the number of 25 cm × 25 cm quadrats covered by each core were recorded, and the species cover in each quadrat was estimated as a percentage. The actual area occupied in each core and locality was then calculated using the number of quadrats and the cover in each quadrat.

Finally, to evaluate the conservation status of *Breutelia chrysocoma* in Spain according to IUCN criteria (IUCN 2012), we used individual-equivalents of 1 m², as recommended by Bergamini et al. (2019) for terricolous species growing on more-or-less flat surfaces, for the application of criteria C2. Area of occupancy and extent of occurrence were calculated following IUCN criteria (IUCN Standards and Petitions Committee 2024) for the application of criteria A and B. Area of occupancy was based on the occupied 1 km × 1 km Universal Transverse Mercator (UTM) grid cells derived from known localities.

Results

Population census for three new localities

In Asturias, three new localities were recorded for the species *Breutelia chrysocoma*, thereby extending its known range to three new municipalities: El Mazuco, Villa and Riensena. The extension of population was about 0.6 m² in El Mazuco, 4.1 m² in Villa, and 7.6 m² in Riensena.

A total of 15 cores or mats were found, occupying 198 quadrats, which correspond to 16–21 individual-equivalents. Quadrats did not show full cover of the target species, therefore the actual total area occupied at these three localities was estimated to be approximately 5.13 m².

The locality in Villa had the highest core number (9), followed by Riensena (4) and El Mazuco (2). The average core size was 13 quadrats. However, this fluctuated according to the locality: in Riensena, the average was 30, whereas in El Mazuco and Villa, it was 5 and 7, respectively. The largest core or mat was found at the Riensena locality, formed by 64 quadrats representing an actual occupied area of 1.1 m². Overall, the largest mats in the entire census were found at this locality; however, in Villa, two cores measured 17 and 18 quadrats. The average number of individual equivalents per locality is 19, but the average in Riensena is 10, while in Villa and El Mazuco the averages were 8 and 2, respectively.

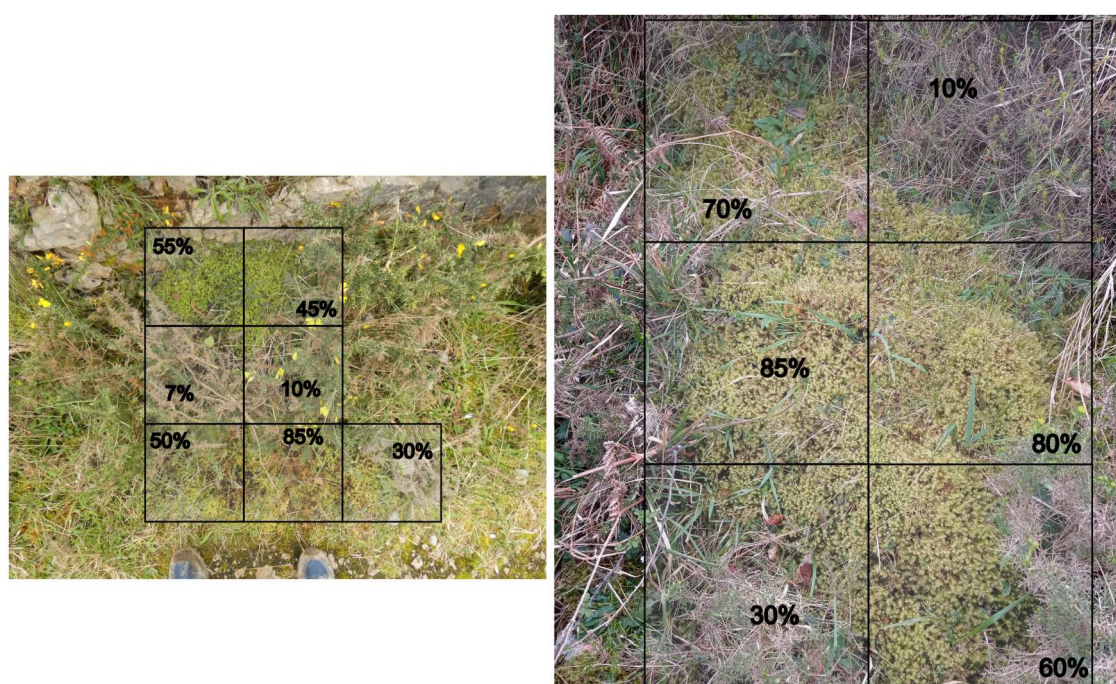


Figure 2. Census methodology. Examples of two different cores, showing the census methodology used. Transparent squares represent the 25 cm × 25 cm quadrats and the percentages of *Breutelia chrysocoma* coverage in each. Photographs: Irene Lafuente López.

We found male plants with reproductive structures (discoidal perigonia) in at least one of the cores at every locality. However, no female reproductive structures or sporophytes were observed in any population.

Current population status

These three new localities in Asturias bring the total number of localities in the province to six (including two that have not been confirmed since 1977 and 2010), the total number of extant localities to eight (with one more from the Basque Country plus the recently found scarce population in Cedeira, Galicia), and the total number of historically known localities where the species has been present to 10 (with the species now considered extinct at two). The occurrences of *Breutelia chrysocoma* at all these localities, which comprise the Spanish population of the species, are summarised in Table 1 and geographically represented in Figure 3.

We consider the localities in Asturias to be part of the same subpopulation, as they are less than 50 km apart. This short distance represents a minimal barrier to dispersal, particularly for organisms that propagate via spores. However, the Basque locality situated over 100 km away is sufficiently distant to be considered as a distinct subpopulation within the Spanish population.

Extinction risk assessment for the species in Spain

Our results indicate that *Breutelia chrysocoma* should be considered CR C2a(i, ii)+D in Spain due to: (i) the very low number of individuals, clearly fewer than 250 (estimated as around 30 individual-equivalents);

(ii) the destruction of two of 10 of the known sites; and (iii) the extreme loss of individuals at the other two, where the species is not easily detectable now. The concentration of individuals is highest in the Asturias subpopulation (> 90%), whereas in the Basque Country subpopulation the estimates are fewer than five individual-equivalents.

Despite the lack of historical census, the estimates provided by Simó (1970) for the extinct Covadonga locality show an extensive population of 50 m², much larger than for any other extant locality; Riensena does not reach 8 m², indicating a drastic population reduction of over 50% (perhaps 80%). Therefore, it could also be considered clearly threatened following criterion A2b, although it is not clear if it should be evaluated as EN or CR.

The species extent of occurrence is 4383 km², and the area of occupancy is estimated to be 20 km² (32 km² at most, if the non-detectable Peña Mayor, Rales and Cedeira are considered). A reduction in number of individuals has been detected, as well as severe fragmentation due to the concentration of 90% of the individuals in a single subpopulation in Asturias. This subpopulation is separated by over 100 km from the two-individual Basque subpopulation and the undetectable Galician subpopulation. All together qualify *Breutelia chrysocoma* as Endangered (EN) under criteria B1ab(ii, iii, iv, v) + 2ab(ii, iii, iv, v).

We maintain the most restrictive CR assessment under criterion CR C2a(i, ii)+D.

Discussion

The present article describes a census methodology for population monitoring of *Breutelia chrysocoma* in

Table 1. Summary of all historically known localities for the Spanish populations of *Breutelia chrysocoma*.^a

Locality	Province	Subpopulation	First report	Last reported attempt	Persistence ^b	Abundance ^c	Area of occupancy ^d	Actual area ^e
Monte Udalaiz	Vizcaya	Basque Country	1995	2012	<i>In situ</i>	1 UTM 1 km × 1 km, few mats [<10 25 cm × 25 cm], 1–2 IE	4 km ²	Small
Monte Zalama	Cantabria	Cantabria	1985	2012	Extinct	Unknown	–	–
Covadonga	Asturias	Asturias	1970	2012	Extinct	Unknown	–	–
Peña Mayor	Asturias	Asturias	1977	2012	Not found	Undetectable	–	–
Rales	Asturias	Asturias	2010	2012	Not found	Undetectable	–	–
Río Purón	Asturias	Asturias	2016	2016	<i>In situ</i>	1 UTM 1 km × 1 km, 2 mats [<10 quadrats], 1–2 IE	4 km ²	Small
El Mazuco	Asturias	Asturias	2024	2024	<i>In situ</i>	1 UTM 1 km × 1 km, 2 mats, 10 quadrats, 1–2 IE	4 km ²	0.32 m ²
Villa	Asturias	Asturias	2024	2024	<i>In situ</i>	1 UTM 1 km × 1 km, 9 mats, 66 quadrats, 6–9 IE	4 km ²	1.9 m ²
Riensena	Asturias	Asturias	2024	2024	<i>In situ</i>	1 1 km × 1 km UTM, 4 mats, 122 quadrats, 9–10 IE	4 km ²	2.9 m ²
Cedeira	Galicia	Galicia	2025	2025	Not found	Undetectable	–	–

^aIn all cases, the extent of occurrence, determined in accordance with IUCN (2024), is 4384 km².

^bWhether the population has been detected in the field (*in situ*) or is considered extinct (extinct), or whether its presence at low abundance has not been ruled out (not found).

^cQuantification of the species' presence using different parameters, depending on the study. In the *Atlas de los Briófitos Amenazados de España* (Garilleti and Albertos 2012), number of 1 km × 1 km Universal Transverse Mercator (UTM) grids, and estimates of real individuals (mats), were used. For this census, the number of 25 cm × 25 cm quadrats was added to increase precision, as well as the number of individual-equivalents (IE) for assessment using the IUCN methodology. Reasonable estimates of the abundance values that were not measured in the original study are shown in brackets.

^dDetermined in accordance with IUCN (2024).

^eThe surface area occupied by the species, estimated as accurately as possible in a quantitative or qualitative manner.

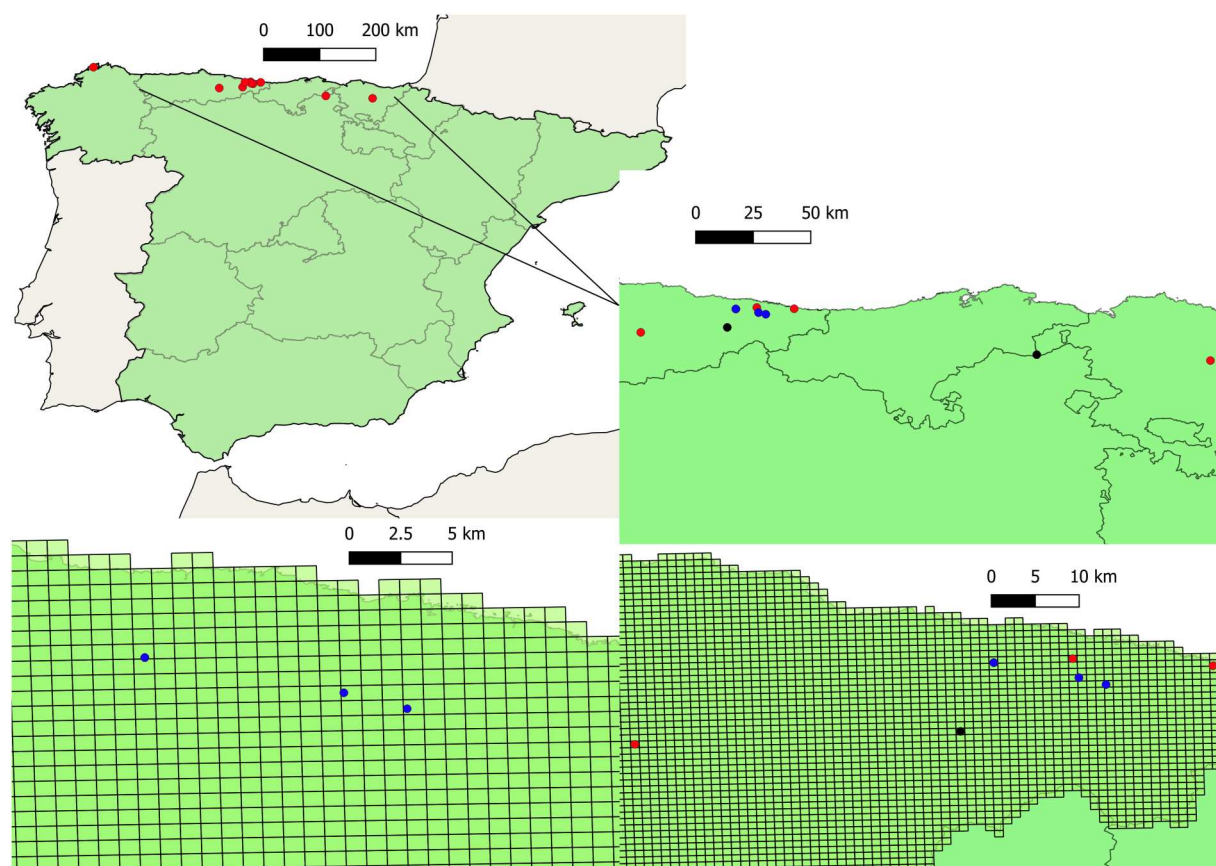


Figure 3. All reported localities for *Breutelia chrysocoma* in Spain. The two upper panels provide a general view of the Iberian Peninsula, showing in red the 10 historically known localities within the administrative boundaries of the autonomous communities and a detailed view of the Cantabrian Mountains; in blue are the new localities with populations monitored in the present study, and in black, the localities where the species is considered extinct. The two lower panels show detailed views displayed on a 1 km × 1 km Universal Transverse Mercator (UTM) grid.

Spain while also providing population size estimates. Additionally, it emphasises the value of citizen science platforms in facilitating collaborations that enhance knowledge of species status and distribution. The first population estimate based on a census for this species in Spain is provided here, offering a more accurate assessment of its conservation status. Although more precise population size estimates and new occurrence records are now available, these data justify maintaining its classification as Critically Endangered, rather than suggesting a reduction in its threat level.

For species in this category, identifying threats to their survival is critical for the design and implementation of effective conservation actions. Based on our observations and available data, we consider habitat degradation, mainly driven by anthropogenic activities such as road and infrastructure development, and shrub encroachment, which increases competition for water, to be the most significant threats. Accordingly, we propose that the main conservation actions focus on preserving habitat integrity and maintaining regimes of extensive livestock grazing or wild herbivory, which is in line with the recommendations of the 2012 expert report (Cano et al. 2012).

The discovery of these new populations of *Breutelia chrysocoma* highlights the crucial role that crowdsourced biodiversity platforms such as iNaturalist can play in bryophyte research and conservation. This finding was possible only due to the collaborative effort between non-specialist naturalists, who uploaded their observations, and members of the bryological community, who verified and followed up on these records. Spain has an extensive record of bryological research in the past decades, and yet significant gaps remain in basic data (such as species distributions), making conservation assessments and monitoring efforts particularly challenging. We believe that crowdsourced biodiversity portals have an unprecedented potential to bridge this sort of gaps, although they are also associated with clear risks that the botanical community needs to face.

Citizen science platforms offer a valuable resource by expanding the reach of biodiversity monitoring beyond the limited workforce of professional botanists, objectively accelerating research (Mason et al. 2025). In a very short time, platforms such as iNaturalist have become instrumental in the improvement of distribution range knowledge (e.g. Dimson et al. 2023),

quantification of biodiversity responses to global change (e.g. Gorta et al. 2023), and the discovery of new species (Mesaglio et al. 2025). These platforms have also become a public forum for interaction and outreach between the public and biodiversity experts (Jansen et al. 2024), filling a space whose absence was criticised for decades prior to the popularisation of the Internet (Bello et al. 1992; Noss 1996; Martens and Segers 2005).

Stepping down from the ivory tower comes, however, with some associated costs. Some major drawbacks related to data quality are often associated with these portals: potential misidentifications, algorithmic bias, or taxonomic subrepresentation (López-Guillén et al. 2024). Some of these challenges are exacerbated in the particular case of bryophytes and other organisms whose identifications require more specific skills (McMullin and Allen 2022).

Most bryophytes require microscopic examination for an accurate species identification, and even macroscopic traits can be difficult to capture in standard field photographs. In our own experience, the vast majority of the bryophyte observations uploaded to iNaturalist cannot be identified at the species level, mostly due to poor image quality (insufficient magnification or focus, absence of microscopic images, or key characters not imaged at all). As a result of these difficulties, bryophyte records (and good-quality records specifically) on crowdsourced biodiversity platforms grow at a slower pace than those for vascular plants, and together with other cryptogams, bryophytes remain strongly under-represented (Cerrejón et al. 2025). However, suboptimal bryophyte images that are now impossible to identify even by experienced bryologists may still be useful in the future given the promising advances in AI-based identifications (Little et al. 2025).

A potential avenue for improving bryophyte representation and quality on these platforms is through targeted outreach efforts, where bryologists could provide guidance on how to photograph bryophytes effectively for identification purposes. Increasing the number of well-documented bryophyte observations on platforms such as iNaturalist would not only enhance species distribution knowledge but also strengthen the foundations for future conservation assessments and management plans. Despite the undeniable challenges associated with the rapid expansion of crowdsourced biodiversity portals, their potential benefits remain clear. It is also important to recognise that an abundance of data, often at the expense of data quality, is a broader feature of the current digital era, not a problem unique to biodiversity platforms. In this context, the ability to critically evaluate data quality has become an essential skill not only for scientists, but for citizens at large.

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Disclosure statement

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