



Biagio Bartalini's Herbarium: an insight into the flora of Siena and its surroundings (Italy) during the eighteenth century

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Abstract

Studying historical herbaria is invaluable for botanical research. This work analysed Biagio Bartalini's Herbarium, a late eighteenth-century multi-taxon collection from Siena and its surroundings (central Italy). We revised taxonomic identifications, updated nomenclature, digitised associated information, created a high-resolution photographic database, and uploaded the dataset on the Global Biodiversity Information Facility (GBIF) portal. The Herbarium includes 676 specimens of 588 species and infraspecific taxa: 567 vascular plants (474 taxa), 77 bryophytes (70 taxa), 29 lichens (27 taxa), one alga, and one fungus. Most of Bartalini's identifications were confirmed. Originally following Tournefort's nomenclature, Linnean names were also included in a catalogue. The past flora features many species of conservation concern, such as freshwater, segetal, and red-listed taxa, with few non-native species compared to current floras. Specimens were largely collected in urban and agricultural areas, within the city walls or in their surroundings. The analysis of the collection sites suggests significant environmental changes in the study area across the centuries, particularly habitat loss due to urbanisation. The Herbarium is among the earliest collections documenting regional biodiversity rather than focusing on medicinal plants. This study provides a comprehensive understanding of Bartalini's Herbarium, making it accessible to modern researchers, with the data now available online and freely accessible through the GBIF portal, and laying the groundwork for future multitemporal floristic studies.

Keywords Biodiversity · Bryophyte · Historical herbarium · Lichen · Multi-taxon · Vascular plant

1 Introduction

Historical herbaria are sources of crucial information for modern scientific research, since they can store knowledge about the taxonomy, past distribution, ecology, nomenclature, and uses of plants (Stefanaki et al. 2018; Marín-Rodulfo et al. 2024). Such data can be used for many purposes, such as reconstructing past vegetation and climate and detecting shifts in species phenology and distribution range (Willis et al. 2017). This can allow monitoring biodiversity changes across time, so that the information taken from historical herbaria has been increasingly used for scientific studies in recent years (Büttner et al. 2022; Sennikov 2024). The earliest known herbaria date back to the sixteenth century, and many of them come from Italy (Cristofolini et al. 1993; Cristofolini 2024).

Biagio Ignazio Bartalini was an important scholar and lecturer who worked in Tuscany (central Italy). His primary interests were natural history, botany, and

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palaeontology, as he wrote about himself (Bartalini 1776). His botanical studies have been a reference for several important local botanists like Bertoloni (1833), Caruel (1860), Tassi (1905), and Nannizzi (1940). He was born in Torrita di Siena, a small village southeast of Siena (Tuscany, Italy), on February 3rd, 1750. He graduated in Philosophy and Medicine at the University of Siena in 1772 and then worked for Santa Maria della Scala Hospital. In 1780, he succeeded his teacher Giuseppe Baldassarri as a professor of botany and natural history at the University of Siena. In 1778, he became a member of the Accademia dei Fisiocritici, the main scientific institute of Siena, becoming its President in 1815. He was also the Director of the Giardino dei Semplici, the first botanical garden of the University of Siena. He died in Siena on June 10th 1822 (Tassi 1905; Ferri and Miraldi 1993, 1999; Manganelli et al. 2011).

In 1776, Biagio Bartalini published his famous work “Catalogo delle piante che nascono spontaneamente intorno alla città di Siena”, which is considered the first flora of Siena and the first floristic work from Tuscany using Linnean binomial nomenclature (Tassi 1862, 1905). In this work, he listed the plants, algae, bryophytes, fungi, and lichens he collected during the previous years in the city of Siena and its surroundings, which he stored in a personal herbarium that is one of the oldest Italian multi-taxon herbaria. In this context, he also worked on plant systematics, elevating to the specific rank two Linnean varieties of *Medicago*: *M. orbicularis* (L.) Bartal. and *M. coronata* (L.) Bartal. (Ferri and Miraldi 1993). At the end of the Catalogue, he added another one about the marine fossils he found in the same area, called “Catalogo dei corpi marini fossili che si trovano intorno a Siena” (Manganelli et al. 2011). After being published, the botanical Catalogue had an anonymous negative review on the “Giornale Letterario di Siena” (Ferri and Miraldi 1999). Thus, in 1779, Bartalini reworked the botanical Catalogue in an unpublished manuscript titled “D.ni Blasii Bartalini Catalogus Plantarum circa Senam sponte nascentium, in sua genera, secundum sistema sexuale Linneanum, digestus” (Tassi 1905; Ferri and Miraldi 1993). After that, Bartalini abandoned field studies to focus on applied botany. His investigations into the properties of many cultivated or wild plants with medical or manufacturing uses were highly appreciated by the Grand Duke of Tuscany Pietro Leopoldo, who supported his experiments (Ferri and Miraldi 1993).

In 1780, Biagio Bartalini donated his Herbarium collection to the Accademia dei Fisiocritici of Siena (Bartalini s.d.), where it is currently preserved (Herbarium SIAC – code according to Thiers 2025). The collection of the samples included in the Herbarium probably started around 1770, when Bartalini was a student, and ended in 1780 after he started to dedicate to other botanical disciplines (Ferri and Miraldi 1993).

Bartalini’s Herbarium was partially studied by Attilio Tassi, who in 1860 disinfected the Herbarium with mercury and revised or provided a first identification for some specimens (Tassi 1899a). Caruel (1860) consulted the Herbarium as well and reported some of the there-included data in his work “Prodromo della Flora Toscana”. In 1862, the Herbarium was presented at the Botany class of the Congress of Italian Scientists, as noted in “Atti del decimo Congresso degli scienziati italiani” (V.V.A.A. 1864). The revision work of the Herbarium was continued, but not finished, in the following years by Flaminio Tassi, Attilio’s son. Between 1899 and 1906, he published most of the species of Bartalini’s Herbarium in the “Bullettino del Laboratorio ed Orto Botanico dell’Università di Siena” and in the “Atti dell’Accademia dei Fisiocritici” (Tassi 1899a, b, c, 1900a, b, 1901, 1902, 1905, 1906), providing a revised identification for 558 specimens. Further 31 specimens revised by Flaminio Tassi were found and published later by Ferri and Miraldi (1993). Ferri and Miraldi (1993) also provided a revision of the taxonomic identification of the family Boraginaceae and a total count of the species present in the whole collection (583).

Despite the studies described above, the information contained in Bartalini’s Herbarium is still far from being exhaustively known and made easily accessible. Thus, in this study we thoroughly analysed the whole Herbarium using modern tools. Our main aim was to enhance the accessibility and scientific usability of this historical collection, providing a methodological framework for the organization and digitization of historical botanical data. To this end, we revised the taxonomic identification of all specimens, digitized the information contained in the Herbarium and its associated Catalogue into an open-access GBIF dataset, and created an open-access, high-resolution photographic archive of the entire collection. Furthermore, our study serves as a model for the taxonomic updating of historical collections and lays the groundwork for future multi-temporal analyses of floristic diversity and conservation trends over time, which are also useful for analyses on environmental changes (Caneva et al. 2005; Celesti-Grapow and Ricotta 2021). Additionally, we examined the methods used in botanical research during Bartalini’s time, the botanical knowledge of the region at the time, and the collected flora from the perspective of species rarity and conservation value.

2 Materials and methods

2.1 Herbarium structure and organisation

As reported by Bartalini himself, his Herbarium consisted of ‘ventidue grossi volumi d’un bello erbario secco’ (22 large volumes of a beautiful dry herbarium) (Bartalini s.d.). Of such volumes, only 9 have survived to the present day, plus

one package containing uncertainly identified or unidentified specimens, described as ‘Piante facenti parte dell’Erbario Bartalini non ben determinate a causa del loro deterioramento’ (Plants being part of Bartalini’s Herbarium not well identified due to their deterioration) (Ferri and Miraldi 1993). The current Herbarium consists of specimens of vascular plants, bryophytes, fungi, algae, and lichens preserved in 9 volume folders of approximately 23 × 34 cm size. They are divided in 2 groups: 7 volumes containing phanerogams and 2 volumes containing cryptogams (back then, also including algae and fungi). The volume folders have two external labels. The first, larger one is located on the front of the folder and it bears the writing “Exsiccata Bartalini 1776”. The second, smaller one is located on the spine, and it reports a writing indicating the content of the folder, i.e., ‘Phanerogamae’ or ‘Cryptogamae’ and the initial letters of the contained families, in alphabetical order. The package with non-well identified plants lacks a folder, and it is simply tied up with a string.

Inside each volume (Fig. 1a), vascular plant specimens are grouped in families. Specimens of the same family are collected in brown folders of approximately 22 × 32 cm size (Fig. 1b). Within each folder, the specimens are positioned in alphabetical order according to the species scientific names. The family name is reported on a blue-edged label on the front page of each family folder. The family folders are ordered in alphabetical order, according to the family name, within the volume folders. Each specimen is enclosed in a grey specimen folder of approximately 21 × 31 cm size (Fig. 1c), sometimes reporting, on the front, the scientific name, probably written later by Attilio Tassi only on the



Fig. 1 Examples of: **a** volume; **b** family folder; **c** species folder; **d** specimen sheet from Bartalini’s Herbarium

specimens he studied (Ferri and Miraldi 1993). Inside the specimen folder, there is a blank sheet of approximately 20 × 28 cm size. Specimens are glued or, sometimes, stapled on such blank sheets, often with a small label reporting the species name after Bartalini’s identification and an ID number (Fig. 1d). Contrarily to modern herbaria, no other information is present on the sheet label, since the authors of pre-Linnean herbaria used to report additional information in separate documents (Buldrini et al. 2023a).

Each specimen of bryophytes, lichens, algae, and fungi is glued on a blank sheet and it is surrounded by a hand-drawn blue frame, except for the bryophytes contained in the tied up package, which are not framed. Moreover, most of the bryophytes, all the lichens, fungi, and algae, are inserted inside a sheet folded in two, which reports the species description occurring in the Catalogue on its front.

2.2 Revision of specimen taxonomic identifications

We analysed all the specimens and provided an identification at the lowest possible taxonomic level. To preserve their integrity, a non-destructive approach was applied, including the observation of each specimen under a stereoscope while avoiding contacts as much as possible and without using chemical reagents. Vascular plants were identified mainly according to Pignatti et al. (2017–2019) and, subordinately, to Tison and De Foucault (2014). Mosses were identified according to Cortini Pedrotti (2001–2005) and Lüth (2019), liverworts were identified according to Smith (2004) and Paton (1999), and lichens were identified according to Nimis (2019). The fungus and the alga were not identified due to the very bad conservation status of the specimens. The taxonomic nomenclature and species classification into families were updated according to the Portal to the Flora of Italy v. 2024.2 (2024) for vascular plants, Hodgetts et al. (2020) for bryophytes, and Nimis (2023) for lichens.

2.3 Specimens and species information

We compiled a database including all the available information about specimens and species. The database is arranged following the alphabetical order of the current species scientific name (“current taxonomic identification” column) (Appendix 1). A second dataset was created structuring it according to the DarwinCore terms, to upload it on the Global Biodiversity Information Facility (GBIF) portal (GBIF.org 2025; Museo di Storia Naturale dell’Accademia dei Fisiocritici 2025).

The following information was extrapolated from the original handwritten data on each specimen: (i) “name reported on the original specimen label”; (ii) “specimen code”, a number reported on the label, whose meaning is not clear, although Ferri and Miraldi (1993) reported it is linked

to field notes; (iii) “name reported on the sheet folder”, probably written by Attilio Tassi.

When possible, each specimen was linked to a species name reported in Bartalini’s 1776 Catalogue and/or in his 1779 Manuscript (hereafter mentioned as ‘Bartalini’s Works’ – Bartalini 1776, 1779), by looking in such works for the ‘name reported on the original specimen label’ or the ‘name reported on the specimen folder’. From the Catalogue, we collected the following information on the specimens: (i) name reported in the Catalogue or, if missing in the Catalogue, name reported in the Manuscript; (ii) “Linnaeus trivial name”; (iii) the page where the species is described in Linnaeus (1764), indicated as ‘Linn. Spec. Plan.’; (iv) ‘other bibliography’, possible other references from natural history books; (v) ‘Tassi’s species name’, Attilio and Flaminio Tassi’s specimen taxonomic revisions (Tassi 1899a, b, c–1906), when present; (vi) ‘collection site’, the place where the specimen was collected (only available for vascular plants); (vii) ‘Habitat’, grouped in 7 macrohabitats (‘Macrohabitat’ in the database): agroecosystems, forests, harsh environments, meadows, shrublands, urban areas, and wetlands (only available for vascular plants); (viii) ‘Other information’, when applicable.

The current conservation status of the specimens (‘conservation status’ in the database) was assessed using the three categories by Bonari et al. (2017): (a) good, when all the parts of the specimen are well-preserved, (b) medium, when most parts of the specimen are well-preserved, and (c) bad, when few parts of the specimen are well-preserved.

To describe the patterns of rarity and conservation value of the species contained in the Herbarium, we retrieved for each taxon: (i) for vascular plants, distribution data from Peruzzi and Bedini (2015 onwards) at the regional scale; for bryophytes, distribution data from Aleffi et al. (2020) at the national scale; for lichens, distribution data from Nimis (2023) at the national scale; (ii) for vascular plants, protection status and extinction risk at the European (Bilz et al. 2011), Italian (Orsenigo et al. 2021), and regional scale (Sposimo and Castelli 2005); (iii) for vascular plants, their inclusion in the European list of rare and threatened arable plants (Storkey et al. 2012); (iv) for mosses, their protection status and extinction risk at the national (Pedrotti and Aleffi 1992; Puglisi et al. 2023) and global (Hodgetts et al. 2019) scales; (v) for epiphytic lichens, their protection status and extinction risk at the national scale (Nascimbene et al. 2013); (vi) alien vascular plant species from Galasso et al. (2018).

After data mobilisations, each specimen was photographed in high resolution and stored into an open-access database (Museo di Storia Naturale dell’Accademia dei Fisiocritici 2025). Photographs were taken using a Canon EOS 4000D camera which features a 18–55 mm lens and an APS-C sensor with 18 megapixels (resolution of

5184 × 3456 pixels). Specifically, the camera settings used were: iso 100, focal length of 23 mm, time of exposition 1/125 s. and no flash. Each specimen was placed inside a lightbox with a color temperature of 5500 K to calibrate the lights. Photographs were stored as .JPG files.

3 Results

3.1 Revision of specimen taxonomic identifications

At present, the Herbarium contains 676 specimens, relative to 588 specific and infraspecific taxa. Fifty-five duplicate specimens (46 of vascular plants, 7 of bryophytes, and 2 of lichens) and 6 triplicate specimens (only of vascular plants) occur. We also found an individual of the vascular plant *Lysimachia arvensis* glued on the sheet of a *Berteroa incana* specimen, and we identified an overlooked individual of the bryophyte *Jungermannia* sp. on the same sheet of a specimen of *Diplophyllum albicans*.

At present, the Herbarium includes 567 specimens of vascular plants, belonging to 84 families, 323 genera, and 474 species and subspecies. The bryophyte specimens are 77, belonging to 38 families, 57 genera, and 65 species, subspecies, and varieties. Lichen specimens are 29, belonging to 11 families, 15 genera, and 25 species, subspecies, and varieties. There are also one fungus and one alga, which identification was not possible due to the bad conservation status of the specimens.

There is no exact match between the species in Bartalini’s Herbarium and those listed in the Catalogue. In particular, 199 taxa occurring in Bartalini’s Herbarium are not listed in the Catalogue. However, 70 of these species are reported in the manuscripts, while 129 don’t occur in any document.

We could identify most of the specimens to the species and subspecies level. However, 2 species (*Cynoglossum* cfr. *officinale* and *Myosotis* cfr. *nemorosa*) and 1 subspecies (*Sabulina verna* cfr. subsp. *verna*) of vascular plants, 4 species of bryophytes (*Herzogiella* cfr. *seligeri*, *Leucodon* cfr. *sciuroides*, *Platygyrium* cfr. *repens*, and *Ptychostomum* cfr. *imbricatulum*), and 5 species of lichens (*Cladonia* cfr. *cervicornis*, *C.* cfr. *rangiferina*, *Usnea* cfr. *glabrata*, *U.* cfr. *subscabrosa*, and *U.* cfr. *wasmuthii*) were identified with uncertainty. Thirteen vascular plant, 5 bryophyte, and one lichen specimens were identified at the genus level. Two vascular plant specimens were identified at the family level, and one vascular plant specimen only at the class level (Liliopsida). One bryophyte specimen was identified at the class level (Marchantiopsida). Moreover, it was not possible to identify one specimen originally named ‘*Lichen agaricus*’, included among lichens.

For 322 plant, 43 bryophyte, and 10 lichen specimens, we confirmed Bartalini’s original identifications, so that

we only updated species names. By contrast, 245 vascular plants, 34 bryophytes, and 18 lichens were either misidentified or not identified at the lowest taxonomic level by Bartalini, according to our identification. Namely, 104 plant specimens were not correctly identified. For 11 plant specimens we provided a first identification, and for 130 plant specimens we provided an identification at a more detailed taxonomic level. Sixteen bryophyte specimens were non correctly identified, and for 18 specimens we provided a first identification. Moreover, for one specimen identified as “*Jungermannia albicans*” (a name that doesn’t match with any accepted name or synonym) by Bartalini, we could only confirm it is a liverwort. Sixteen lichen specimens were non correctly identified, and one specimen was not a lichen but, probably, a fungus. Moreover, we provided a first identification for two specimens for which Bartalini’s name had no matches in any nomenclatural system (i.e., ‘*Lichen crostaceus*’ and ‘*Lichenoides crostaceum*’): *Lecanora horiza* and *Haematomma ochroleucum* var. *ochroleucum*, respectively. Regarding the specimens revised by Attilio and Flaminio Tassi, their identifications were consistent with ours for 383 plants, 40 bryophytes, and 13 lichens. The rest of the specimens (108) were misidentified by them, though mostly with closely related species.

Based on our assessment, 497 specimens (73.8%) are in a good conservation status, 129 specimens (19.2%) are in a medium conservation status, and 47 specimens (7%) are in a bad conservation status.

3.2 Taxonomic data from Bartalini’s Herbarium

Among the 489 vascular plant taxa, 10 are pteridophytes (2% of the total) and 479 are spermatophytes (98%). Of the latter, 477 are Magnoliophyta (99.6%) and 2 are Pinophyta (0.4%). Magnoliophyta include 3 non-eudicot dicots (0.5%), 40 monocots (8%), and 431 eudicots (434; 91%).

Figure 2 reports the number of specimens and their percentage on the total as regards vascular plants, bryophytes, and lichens found in the Herbarium.

3.3 Adopted nomenclatural systems

In the Catalogue, species nomenclature is reported following the “Pinax Theatri Botanici” (C.B.Pin. – Bauhin 1623) for 217 taxa (50% of the total), while it is reported following the “Institutiones Rei Herbariae” (from here on I.R.H. – de Tournefort 1719) for 83 taxa (19%). The remaining 134 taxa (30%) have 22 different references. By contrast, Bartalini states at the beginning of the Catalogue that species nomenclature only follows I.R.H. Moreover, a reference to Linnaeus’ “Species Plantarum” (1764) is provided for all the plant species with the abbreviation “Linn. Spec. Plan.”. Along with the latter, the species description and

the trivial name reported by Linnaeus (1764) are indicated. The nomenclature of 53 bryophytes (69%) and of 22 lichens (76%) follows Linnaeus (1764). For the nomenclature of 18 lichens (62%), a reference to both Dillenius (1741) and Linnaeus (1764) is reported. For the nomenclature of one lichen and 10 bryophytes (13%), only a reference to Dillenius (1741) is present. For the remaining bryophytes (1 taxon) and lichens (3), the nomenclature is according to Vaillant (1723), indicated as “Vaill. Bot. Par.”. Finally, the nomenclature of 5 lichens (17%) follows Micheli (1729).

3.4 Distribution and collection habitats of the species

Based on the information retrieved from Bartalini’s botanical contributions, we could approximately identify the localities (for 125 specimens) and the habitats (for 327 specimens) where the species were collected or reported. For some species, multiple localities and/or habitats were listed. The specimens preserved in the Herbarium were mainly collected in the surroundings of Siena, within the city walls or just outside (Fig. 3). The rest of the specimens were found in the surroundings of the city, including sites in the radius of a few tens kilometres, such as the Crete Senesi or the Chianti hills. However, Bartalini’s Herbarium also contains a few species that only grow in coastal or mountain areas (e.g., *Helichrysum stoechas* subsp. *stoechas*, *Ribes rubrum*, *R. uva-crispa* subsp. *uva-crispa*).

As regards collection habitats, these vary from cultivated fields (e.g., segetal species like *Agrostemma githago* subsp. *githago*, *Delphinium consolida* subsp. *consolida*, *Papaver rhoeas* subsp. *rhoeas*, and *Sulla coronaria*), to forests (*Acer campestre*, *Alnus glutinosa*, *Anemonoides nemorosa*, *Fraxinus ornus* subsp. *ornus*, *Polygonatum multiflorum*), marshes and wetlands (*Mentha aquatica* subsp. *aquatica*, *Nasturtium officinale*, *Potamogeton natans*), and walls or rocky substrates (*Adiantum capillus-veneris*, *Asplenium trichomanes* subsp. *trichomanes*, *A. oopteris*). Urban areas, agroecosystems, and forests were the most visited habitats, while harsh environments were the least visited one (Fig. 4).

As regards bryophytes and lichens, there is no information of their collection habitats. However, there are many bryophyte species typically found in mountainous areas (*Abietinella abietina*, *Ptilium crista-castrensis*, *Myurella julacea*) and in wetlands (*Conocephalum conicum*, *Cratoneuron filicinum*, *Philonotis fontana*) (Cortini Pedrotti 2001–2005). As regards lichens, they include taxa that grow in meadows (*Cladonia* spp., *Peltigera canina*), epiphytic taxa colonising the bark of woody plants (*Evernia prunastri*, *Lobaria pulmonaria*), wetland taxa (*Usnea* spp.), and taxa from rocky habitats (*Xanthoria parietina*, *Xalocoa ocellata*, *Haematomma ochroleucum* var. *ochroleucum*) (Nimis 2023).

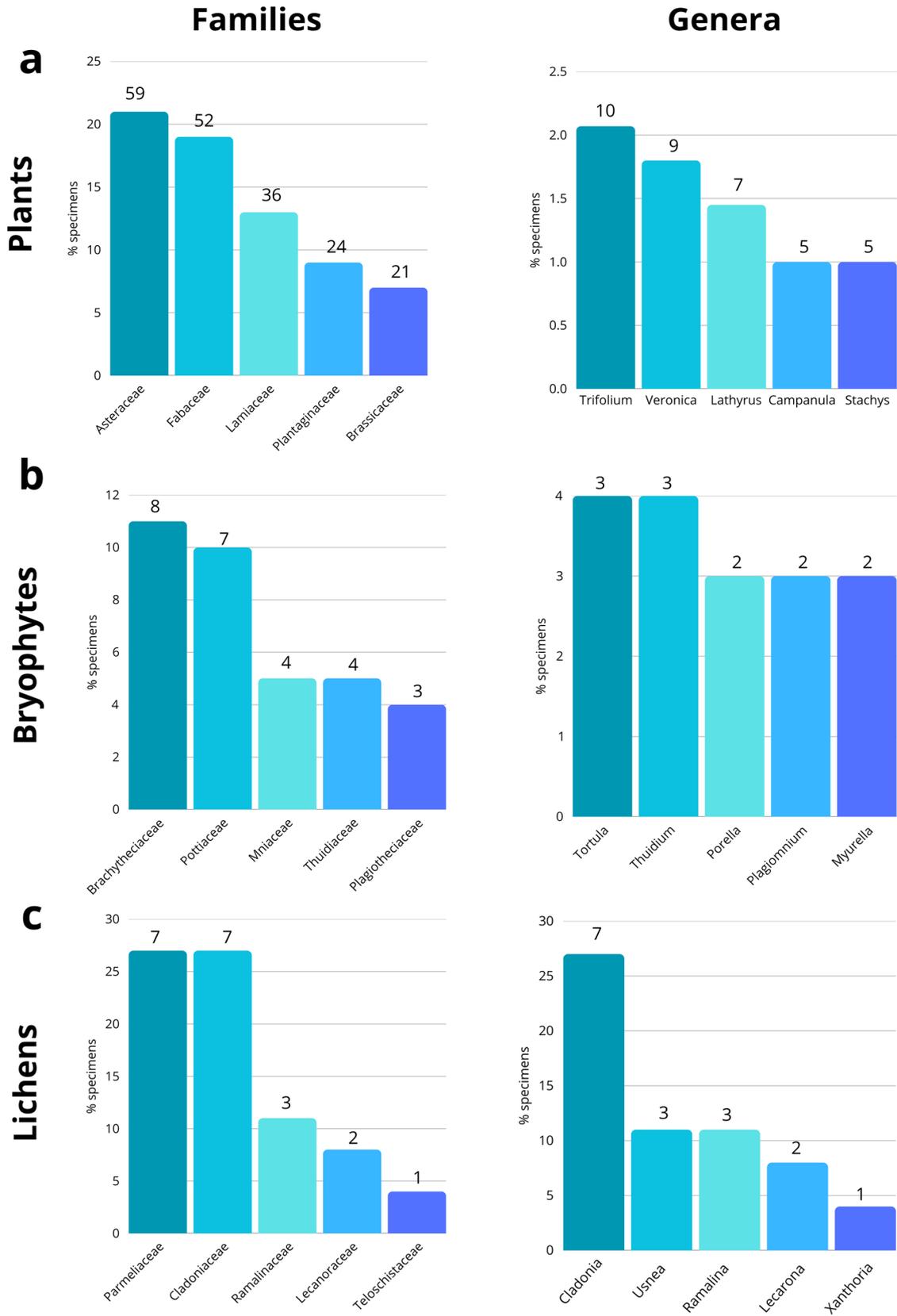


Fig. 2 Number of specimens of **a** vascular plants, **b** bryophytes, and **c** lichens per family and genus (value on each bar) and their percentage on the total of vascular plant, bryophyte, and lichen specimens (y

axis). The first five families and genera including the highest number of specimens are reported

Fig. 3 Approximate distribution of the collected specimens (a) inside the ancient walls of Siena and up to a maximum of 700 m from the walls and (b) between 700 m and 7 km from the walls (Appendix 2)

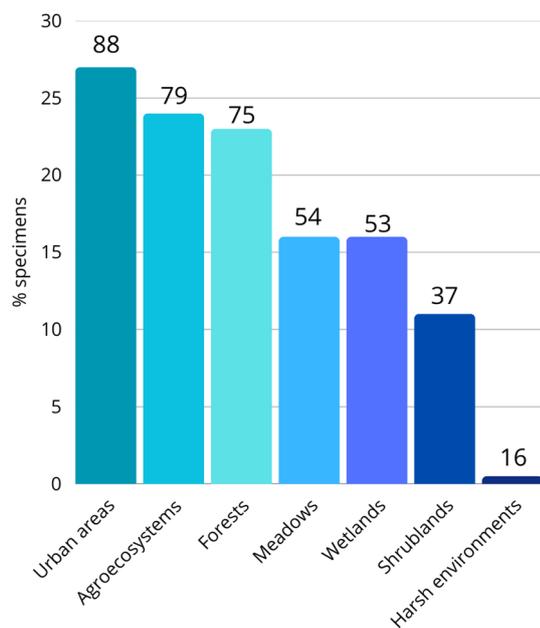
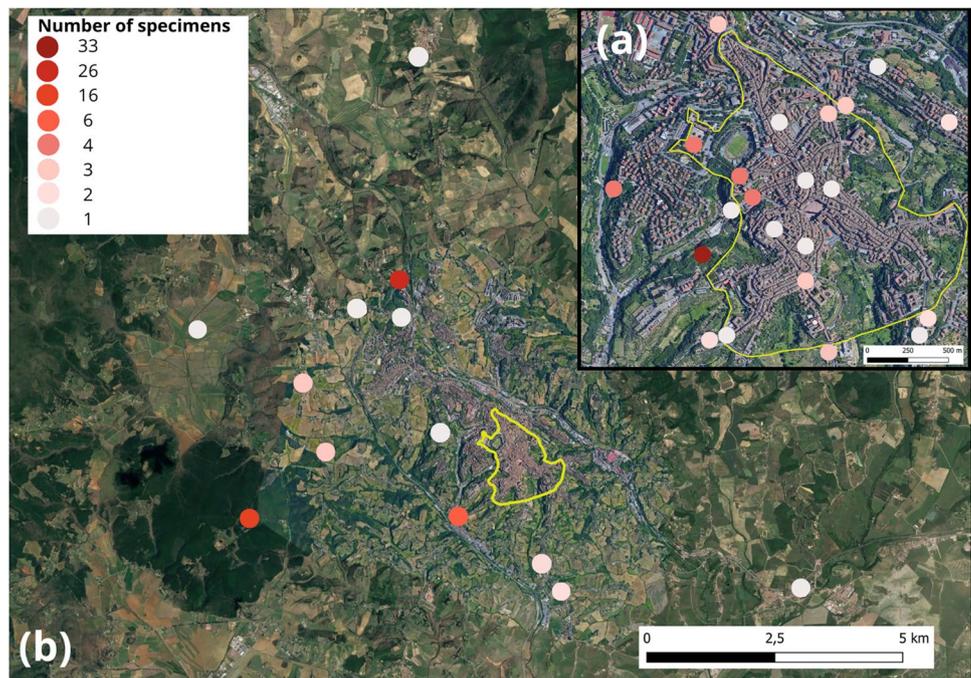


Fig. 4 Number of vascular plant specimens found per each macrohabitat (value on each bar) and their percentage on the total of vascular plant specimens (y axis)

3.5 Noteworthy records and species of conservation value

From a conservation perspective, 38 species of vascular plants are included in European or Italian Red Lists, and/or in the attention list of the Tuscany Region. Moreover, 13 species are present in the List of European threatened arable

plants. Some rare species are also present. These include species that are present in the province of Siena only in one or few localities, which were not found after 1950, or which were never found so far in the province of Siena. Moreover, one endemic subspecies is present (*Helleborus viridis* subsp. *bocconeii*) (Tab. 1).

No taxa of bryophytes is included in the Italian or IUCN red lists. Among the lichens, most of the collected species are common, but 8 are currently considered as rather rare (*Peltigera canina*, *Pleurosticta acetabulum*), rare (*Anaptychia ciliaris*, *Lobaria pulmonaria*, *Usnea* cfr. *wasmuthii*), or extremely rare (*Ramalina* cfr. *calicaris*, *Usnea* cfr. *glabrata*, *Usnea* cfr. *subscabrosa*) in Tuscany.

Among vascular plants, 33 alien taxa (6.94% of the total) occur. Most of alien species (19) are archaeophytes, while only 5 (*Amorpha fruticosa*, *Broussonetia papyrifera*, *Erigeron canadensis*, *Prunus laurocerasus*, and *Robinia pseudoacacia*) are classified as invasive neophytes in almost all the Italian territory.

4 Discussion

In this work, we carried out the first thorough revision of Bartalini's Herbarium content, providing a methodological framework to be followed in future similar works. The revision of pre-Linnaean herbaria like Bartalini's Herbarium can offer a comprehensive view of the plant diversity in a specific area during a given period even when containing plant collections from relatively small areas. They also enhance our understanding of historical methods of plant

Table 1 List of species occurring in the European Red List of vascular plants (E.R.L.), Red list of threatened vascular plants in Italy (I.R.L.), Tuscan attention list (T.A.L.) and list of European threatened arable plants (T.E.A.P.L)

Species names	E.R.L	I.R.L	T.A.L	T.E.A.P.L. score	Rare species
<i>Agrostemma githago</i> subsp. <i>githago</i>				1.62	Old records
<i>Ajuga chamaepitys</i>				1.10	
<i>Allium schoenoprasum</i> subsp. <i>schoenoprasum</i>	LC				No records
<i>Asperula arvensis</i>				1.20	Old records
<i>Berteroa incana</i>					No records
<i>Berula erecta</i>	NT				
<i>Campanula latifolia</i>			NT		
<i>Centaurea melitensis</i>					No records
<i>Chenopodium opulifolium</i>					No records
<i>Cirsium monspessulanum</i>					No records
<i>Crepis biennis</i>					No records
<i>Epipactis palustris</i>	LC	NT			
<i>Filago pyramidata</i>				0.87	
<i>Gypsophila vaccaria</i>				1.35	Old records
<i>Himantoglossum hircinum</i>	LC		EN		
<i>Hyosciamus albus</i>					Old records
<i>Holosteum umbellatum</i>					Old records
<i>Kickxia elatine</i>				0.78	
<i>Lathyrus aphaca</i>				0.84	
<i>Legousia speculum-veneris</i>				1.06	
<i>Lepidium latifolium</i>					Old records
<i>Lolium temulentum</i>				1.45	
<i>Malva neglecta</i>					No records
<i>Melampyrum arvense</i>				0.88	
<i>Myosotis nemorosa</i>					No records
<i>Myrrhis odorata</i>			LC		No records
<i>Misopates orontium</i>				0.96	
<i>Oncostema elongatum</i>					No records
<i>Ophioglossum vulgatum</i>					Old records
<i>Ranunculus arvensis</i>				0.82	
<i>Ribes rubrum</i>					No records
<i>Sabulina verna</i>					No records
<i>Salvia sclarea</i>					Old records
<i>Scandix pecten-veneris</i>				1.46	
<i>Sisymbrium polyceratium</i>					Old records
<i>Veronica agrestis</i>					No records

LC = Least Concern, NT = Near Threatened, EN = Endangered, CR = Critically Endangered, VU = vulnerable, T.E.A.P.L. score = threat score in the list of European threatened arable plants (the higher, the more threatened). Old records = reported in the province of Siena through few and old records (before 1950); No records = not reported in the province of Siena according to Wikiplantbase Toscana

preservation, organization, and distribution, which played a role in shaping modern botany (Pulvirenti et al. 2015). Moreover, Bartalini's Herbarium belongs to a series of herbaria, which began to appear at the end of the eighteenth century, where collections were undertaken with scientific purposes rather than with medicinal ones (Ferri and Miraldi 1993). This approach to plant collection, which is in accordance with modern methods, enhances its scientific value. Rather than collecting plants with specific agricultural or medical uses, he aimed at providing a thorough floristic knowledge of

the territory for young botanists (Bartalini 1776). This was uncommon at those times, when botanists considered it useless to record plant collection localities, dates, and habitats. Back then, botany was not an independent science, so that a methodology to carry out floristic studies was not even yet defined. Consistently, 'it was considered a luxury to mark where a plant had been found' and, since botanists were first of all doctors, there was no interest 'in knowing the geographical distribution, but only the name of plants, their shape, and virtues' (Batelli 1886; Buldrini et al. 2023b).

Based on our revision of the taxonomic identifications, the detected taxa are 5 more than those reported in Ferri and Miraldi (1993). Moreover, we found discrepancies between the species in the Herbarium and those listed in the Catalogue, as Tassi (1899a, b, c; 1906) and Ferri and Miraldi (1993) had already observed. Based on this, we can speculate that Bartalini continued to add species to his collection in the years after the creation of Bartalini's Works (Manganelli et al. 2011). Although we could identify most specimens to the species level, the bad conservation status of some specimens led us to have several identification difficulties. Moreover, given the need to preserve the integrity of the samples, we could not apply some traditional identification methods like re-hydration of bryophyte specimens to observe cells, chemical spot tests in lichens, or the observation of microscopic traits by dissecting specimens. Furthermore, most of the specimens were glued to the herbarium sheet, making the observation of diagnostic traits challenging. The relatively high number of corrected identifications from our revision work mostly derives from the addition of subspecies, which were not considered by Bartalini, especially for vascular plants.

Vascular plants are the great majority of the specimens. However, bryophyte and lichen specimens are approximately 16% of the total, which is a considerably high proportion if compared to earlier herbaria, e.g., from the sixteenth century (Stech et al. 2018). This could be since a deep study of bryophytes and lichens only began in the early eighteenth century (Gilbert 2000), after Dillenius (1741) provided a modern systematic definition of the two groups, which were previously considered as one (Crawford 2019).

As regards the species identified by Bartalini as '*Lichen crostaceus*' and '*Lichenoides crostaceum*', for which we found no matches in any nomenclatural system, there is evidence that the author could not give them a correct identification at his times. This is because the taxa the specimens belong to were either still unknown to science or had just been described. *Lecanora horiza* was only described in 1810 sub. *Lecanora subfusca* var. *horiza* Ach. (Nimis 2023). *Haematomma ochroleucum* var. *ochroleucum* was described as *Lichen ochroleucus* in 1771 (Nimis 2023), so that Bartalini probably did not have access to the information on this species yet. Similarly, many of the 'misidentified' bryophytes and vascular plant species had not been described yet at that time (e.g., *Lonicera etrusca*, *Veronica barrelieri* subsp. *barrelieri*, *Kindbergia praelonga*). Bartalini started his work in a challenging time characterised by major changes in botanical research, for instance soon after the first contributions by Linnaeus. Moreover, identification tools such as microscopes were less effective, and the access to international scientific literature was limited. As regards identification tools, dichotomous keys did not exist yet, so that botanists

had to identify plants through species descriptions and by comparing collected specimens with iconographic sources. The first dichotomous keys were probably provided in the first edition of "Flore Française" by Jean Baptiste Lamarck (Lamarck 1778; Griffing 2011; Buldrini et al. 2023a).

Attilio and Flaminio Tassi misidentified 108 specimens as well during their revision work, though mostly with closely related species. Though carried out decades later, even Attilio and Flaminio Tassi's work was subjected to knowledge and to technological limits. However, they used Linnaeus' binomial nomenclature and referred to Bertoloni (1833) for plant species identification, which were the most modern tools available at those times.

Despite the age of the Herbarium, the specimens are overall in good conservation status, as previously observed by Ferri and Miraldi (1993). This highlights the effectiveness of the past drying and conservation techniques of botanical specimens, as well as of the disinfection carried out in the second half of the nineteenth century by Attilio Tassi (Ferri and Miraldi 1993). Regarding vascular plants, the most well-preserved specimens (with less than 2 specimens in bad conservation status) belong to species of Rosaceae and Caryophyllaceae families. The latter include species being rich in secondary metabolites like saponins, which are toxic to insects and might have contributed to their preservation (Chandra and Rawat 2015; Mamadalieva et al. 2014).

The taxonomic composition of Bartalini's Herbarium content is consistent with the findings from other pre-Linnaean Italian (Bonari et al. 2017; Stefanaki et al. 2018) and eastern-Mediterranean (Ghorbani et al. 2018) herbaria. Moreover, it mirrors the composition of recent floras in areas around Siena (Bonari et al. 2021; Fiaschi et al. 2023). The predominance of plant families such as Fabaceae and Lamiaceae was previously highlighted in historical Tuscan herbaria, probably due to the preferential collection of species belonging to these families due to their practical uses and to their easiness of identification (Amadei et al. 1998; Bonari et al. 2017). By contrast, the small number of Poaceae, with only 7 specimens being present in the current collection, was unexpected. However, 59 Poaceae species are listed in Bartalini's Catalogue. Thus, we can speculate that most Poaceae specimens went lost across the years. As regards the eleven species of Orchidaceae, they are either still very common in the study area (*Anacamptis morio*, *Epipactis helleborine*) or currently being rather rare (*Epipactis palustris*, *Himantoglossum adriaticum*) (Landi et al. 2009; Frignani 2011). In bryophytes, the prevalence of Bryopsida over Marchantiopsida in the collection is consistent with the respective species ratios observed in Italy (Aleffi et al. 2023). The absence of species from the class Anthocerotopsida can be probably due, at least in part, to their rarity. The high representation of lichen species belonging to the genus *Cladonia* is consistent with the findings from other sixteenth-century herbaria

(Stech et al. 2018). Moreover, *Cladonia* is one of the species-richest lichen genera in Italy (Nimis 2023).

Regarding cryptogams, we highlighted how the collection of large, beautiful species of bryophytes and macrolichens, mostly with a fruticose or foliose habitus, was preferred to the collection of small bryophytes and crustose lichens. Therefore, Bartalini's sampling was likely somewhat preferential, in line with the methods typically adopted by the botanists from the sixteenth and seventeenth centuries (Stech et al. 2018). This might also be due to the higher difficulties in collecting and fixing on herbarium sheets such organisms. Probably, this approach led to overlook small bryophytes and crustose lichens.

The adopted species nomenclature, following several sources, is in contrast with what Bartalini states at the beginning of the Catalogue. An explanation to this apparent inconsistency is that, in Bartalini's Catalogue, a reference to I.R.H. is only reported for the 83 species that were described for the first time in Tournefort's work. In the Catalogue, Bartalini (1776) also states to follow Linnaean nomenclature to adapt his work to the needs of modern users, avoiding the long descriptive sentences of older nomenclatural systems. This shows his understanding of the practical usefulness of the Linnaean system, which was a novelty at those times, so that he rearranged most species names according to such a system. This evidence further strengthens the historical value of Bartalini's work, confirming the author as one of the first botanists to use the Linnean nomenclature (Tassi 1899a, b, c; 1906).

The study of the distribution of Bartalini's Herbarium specimens revealed how Bartalini left us as a legacy an eighteenth-century flora of Siena and its surroundings. As Bartalini himself (1776) wrote, he collected the botanical material in the hills surrounding the city of Siena due to his limited economic resources. However, Bartalini's Herbarium also contains a few species that only grow in coastal or mountain areas (e.g., *Helichrysum stoechas* subsp. *stoechas*, *Ribes rubrum*, *R. uva-crispa* subsp. *uva-crispa*), which were possibly collected during travels, obtained through exchanges, or originated from the local botanical garden.

From the analysis of collection sites and habitats, it can be highlighted how land use changes and urban expansion deeply modified the flora of Siena across the centuries. Many forest and wetland species were collected in areas that are nowadays part of the modern city. Similarly, currently rare segetal species (Fanfarillo et al. 2020a, b) should be much more frequent back then. Such findings are in line with previous evidence provided by historical floristic data elsewhere in Italy (Bagella and Bagella 2023; Buldrini et al. 2023a). Several lichens collected by Bartalini around Siena are currently rare, typical of mountain forests and/or temperate climates. *Anaptychia ciliaris* became much rarer than in the past, though it is still locally abundant in the Apennines (Nimis 2023). *Lobaria*

pulmonaria, which is highly sensitive to atmospheric pollution, was only recently found in the surroundings of Siena (Paoli and Loppi 2001). *Peltigera canina*, growing on terricolous mosses and on bare soil, is a rather rare species in Tuscany, whose presence was only recently reconfirmed in the surroundings of Siena (Munzi et al. 2014). *Pleurosticta acetabulum* is a mainly epiphytic species, which is rather common in the Apennines but rare in other areas of Tuscany (Tretiach and Nimis 1994). *Ramalina calicaris* is mainly found in beech forests, which are not present in the study area (Nimis 2023). *Usnea glabrata* is reported for Tuscany only in the island of Montecristo (Valcuvia Passadore 1978). Among vascular plants, the number of alien taxa in Bartalini's Herbarium is significantly lower than that reported in recent floras of areas near the city (Bonari et al. 2021; Fiaschi et al. 2023). If crop and ornamental species are excluded, this historical Herbarium highlights the presence of an even smaller number of alien taxa. The presence of specimens of some taxa of conservation interest such as endemic, wetland, and segetal taxa, which have now become rare in Tuscany, suggests that they were more widespread in the past. By contrast, alien species increased in frequency and abundance over time, consistently with previous evidence (Sage 2020; Roma-Marzio et al. 2023). Thus, focusing on underrepresented, regionally rare or, on the contrary, alien specimens helps to fill gaps in taxonomic and ecological knowledge of these critical taxa in the past.

Studying historical herbarium specimens, especially when combined with modern geolocation tools, offers a powerful means of deepening our understanding of local biodiversity over the past centuries. Insights from Bartalini's Herbarium, for example, reveal that certain taxa of conservation concern, such as *Ophioglossum vulgatum* and *Agrostemma githago* subsp. *githago*, have been negatively affected by recent environmental changes. These include increased anthropization, land-use changes, pollution, habitat degradation, and climate change, that are patterns consistent with global trends (Orsenigo et al. 2021; Pyšek et al. 2020). At the same time, such conditions appear to facilitate the spread of alien species. This underscores the crucial role that herbarium data, especially when locally detailed and historically rich, can play in understanding biodiversity patterns. High-quality, well-distributed data are essential for accurately predicting species distributions, which is fundamental to developing effective strategies for biodiversity conservation in the face of ongoing and future climate change.

5 Conclusion

With this study, we obtained the first thorough knowledge of Bartalini's Herbarium, providing a useful insight into the eighteenth-century flora of Siena and its surroundings. This

pre-Linnaean herbarium is among the earliest known examples to document, within a single collection, specimens of vascular plants, bryophytes, and lichens. Though limited in geographic scope, its integrative approach to plant diversity is of exceptional scientific value, reflecting an advanced understanding of botanical classification and natural history uncommon for its time and offering a unique window into early botanical knowledge and the integrated study of plant diversity. Moreover, it provided the basis for future comparative multitemporal studies on the bryophytic, lichen, and vascular flora of the study area. Second, like other analyses of Pre-Linnaean herbaria, our study contributed to the knowledge of the past techniques used in botanical research, documenting one of the first examples of the birth of modern botany as a science being distinct from medicine, testified by an herbarium including a relevant number of cryptogams besides vascular plants.

Finally, in an era of fast global changes such as the one we are living, one of the most valuable roles of Pre-Linnaean herbaria lies in uncovering their botanical memory to assess the impact of global change on biodiversity. This potential depends heavily on knowing the time and location of specimen collection. While dates are often available or inferable, precise collection sites are typically vague or missing, limiting spatial analysis. Biagio Bartalini's Herbarium is a rare exception, with many specimens linked to detailed site information from accompanying manuscripts. Its value is further amplified by Bartalini's systematic and taxonomically comprehensive approach aimed at thoroughly documenting the region's flora. Thus, our study represents the first step in using Bartalini's data to understand biodiversity changes across about 250 years covering 4 different centuries, which will be of high importance to plan conservation strategies. As part of our commitment to open science and data sharing, all digitized records were published through the Global Biodiversity Information Facility (GBIF), an international platform for biodiversity data. This choice not only guarantees the long-term preservation and accessibility of the dataset but also allows integration with global biodiversity databases, enabling broader ecological and conservation studies. The availability of Bartalini's Herbarium on GBIF ensures that researchers, conservationists, and institutions worldwide can easily consult, download, and reuse the data. Future resurvey studies will allow to track floristic changes in the study area across such timespan.

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Author contributions TF and CA conceived and designed the study. TF and SC carried out the taxonomic revision of vascular plant specimens and built the databases. DB curated the publication of the dataset

on GBIF and Internet Archive, creating the database structure for the platform and preparing the photographic archive for Internet Archive. SC took photographs of the specimens. IB and TF carried out the taxonomic revision of bryophyte specimens. SL, LG, and SR carried out the taxonomic revision of lichen specimens. GM carried out the historical research on Bartalini's biography and Herbarium. EF, SM, GM, and CA supervised the research. TF, CA, SC, and EF wrote the original draft. All authors critically revised the manuscript.

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Declarations

Competing Interests The authors declare no competing interests.

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